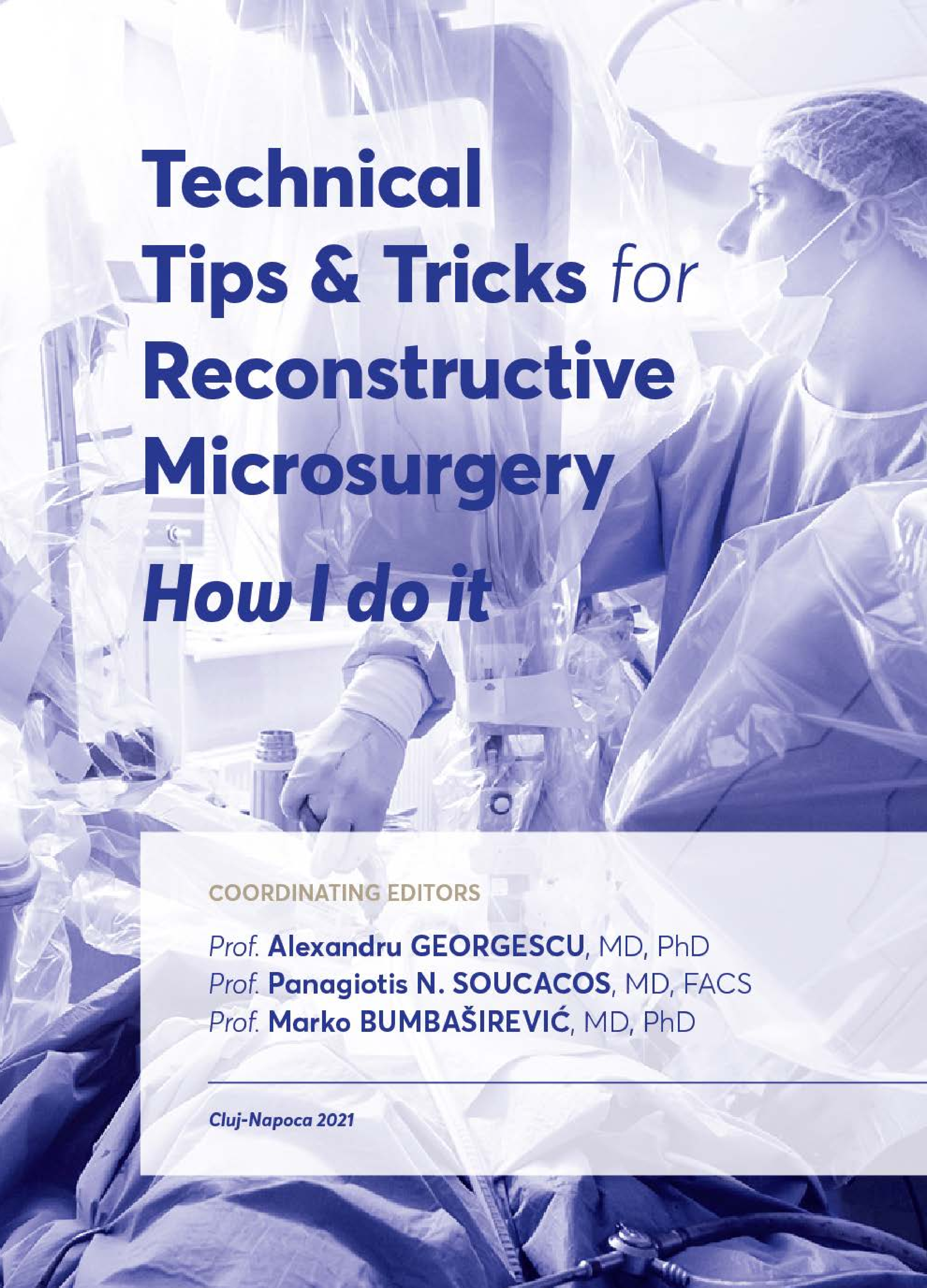

Technical Tips & Tricks *for* Reconstructive Microsurgery

How I do it

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Table of content

I
Head&Neck

1

Supercharging Superficial Temporal Vein Outflow (S.S.T.V.O.)

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Supercharging Superficial Temporal Vein Outflow (S.S.T.V.O.)

Temporal area represents an easily accessible and widely used vascular recipient in reconstructive microsurgery, being a suitable recipient site for microvascular flaps to face and scalp reconstruction (6). Superficial Temporal Artery (STA) and vein are closely approximated in their proximal portion where they exit the parotid gland. The STA is usually constant, stable in both its course and its calibre (about 2 mm) and reliable to perform anastomosis outside the superior border of the parotid gland (1). The artery then divides into two main branches: a parietal and a frontal branch. Each has a mean diameter of 1.6 mm. The bifurcation usually lies 1 - 2 cm preauricularly above a horizontal line from the lateral canthus to the base of the auricular helix, and below a parallel line from the top of the helix (2). In this preauricular area, the STA also gives off a branch that runs posteriorly (the superior auricular artery SAA), which runs within the sulcus between between the temporal bone and the auricular cartilage (1),(11),(7)(Figure1).

The Superficial Temporal Vein (STV) does not have as predictable a course as the artery, and often does not follow the artery except for the most proximal portion (3). Whereas the artery almost always bifurcates into two major branches, the vein may remain as one vessel, or divide into two or three major branches. The bifurcation, if present, lies in the same area as that of the artery, but may be located 1 - 2 cm further caudally. Distances between arterial and venous branches may be considerable (9)(Figure2).

Considering that venous outflow on this vessel is extremely inconstant, both as course and as caliber, we often need to ensure venous discharge by resorting to different possibilities: 1- Extend the dissection further down to reach a broader and larger flow venous collector. This generally involves the use of vein grafts, since that the lower we move, the shorter the pedicle of the donor flap. 2- Prepare a saphenous vein loop, and modify the whole procedure in two surgical stages. In general, the change of plans is not well seen by the patient or parents in children and is interpreted as a complication rather than a disaster prevention. 3- Try to solve the problem using Heparin and Leeches. Only in those cases where the outflow is released within 24/36 hh otherwise redo the venous anastomoses.

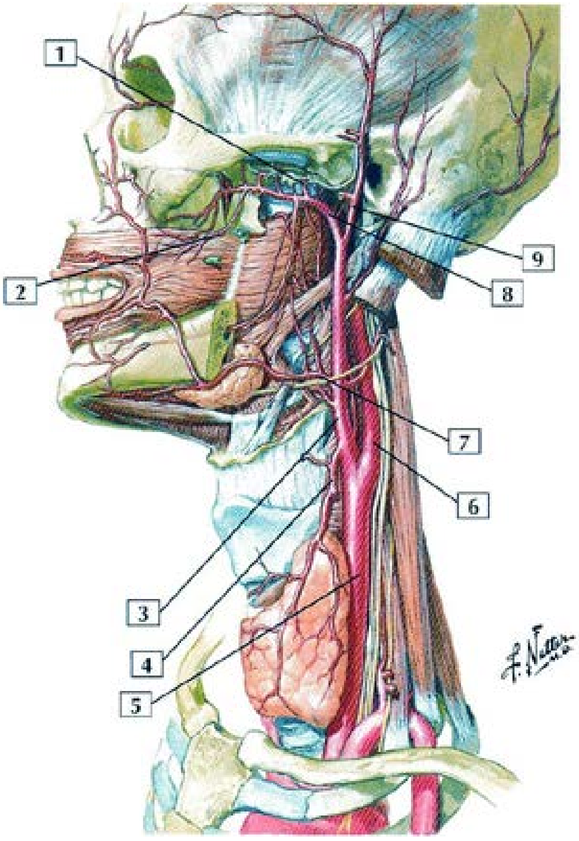


FIGURE 1 - ARTERIES

1-MIDDLE MENINGEAL ARTERY
2-BUCCAL ARTERY
3-EXTERNAL CAROTID ARTERY
4-SUPERIOR TYROID ARTERY
5-COMMON CAROTID ARTERY
6-INTERNAL CAROTYD ARTERY
(REMIND THIS VESSEL GIVES NO BRANCHES)
7-FACIAL ARTERY
8-MAXILLARY ARTERY
9-SUPERFICIAL TEMPORAL ARTERY

*** PAA (POSTERIOR AURICULAR ARTERY)**

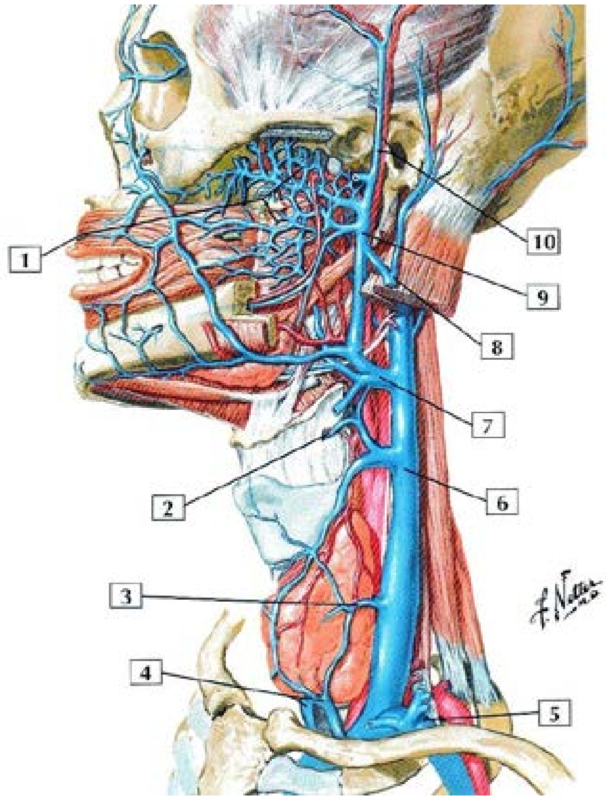


FIGURE 2 - VEINS

1-PTERYGOID PLEXUS
2-SUPERIOR LARYNGEAL VEIN
3-MEDIUM THYROID VEIN
4-INFERIOR TYROID VEINS
5-SUBCLAVIAN VEIN
6-INTERNAL JUGULAR VEIN
7-FACIAL COMMON TRUNK (ANTERIOR FACIAL- RETROMANDIBULAR - LINGUAL)
8-EXTERNAL JUGULAR VEIN (DISSECTED)
9-RETROMANDIBULAR VEIN
10-SUPERFICIAL TEMPORAL ARTERY AND VEIN

*** PAV (POSTERIOR AURICULAR VEIN)**

The Trick of the PAA (Posterior Auricular Artery) Transposed in front of the auricle

In head and neck internal and external venous drainage systems are widely communicating at the level of splanchno and neurocranium also via the transosseous path (5). The two systems must be thought as two dynamic communicating reservoirs, which within defined limits, a share of waste blood mass can deviate from one system to another based on numerous parameters like systemic arterial and venous pressure, blood fluidity, volemia, ortho or clinostatic position, muscle activity, presence of congenital anomalies or anatomical variants, valves, etc. (8) Similarly to other anatomical areas, there are subtle physiological balances that can be modified when needed, between superficial vascular areas and deep layers, internal and external systems, as is also frequent to find anatomical variability between right and left hemisome (concept of Taylor's dynamic angiosomes) (4). The temporal area has extreme variability in size and number of venous vessels, which are however in dynamic equilibrium between about two outflow systems, in front and behind the auricle (preauricular-STV and retroauricular-PAV). Preauricular system consists of the STV which discharges into the Retromandibular Vein (RMV). The latter connects the PAV system through a posterior communicating branch (Pb)(see Figure 3-4). The RMV vein also emits another anterior communicating branch (Ab) connecting this outflow to the anterior facial venous system, which in turn drains into the common facial (CFV) and finally inside internal jugular vein (IJV).

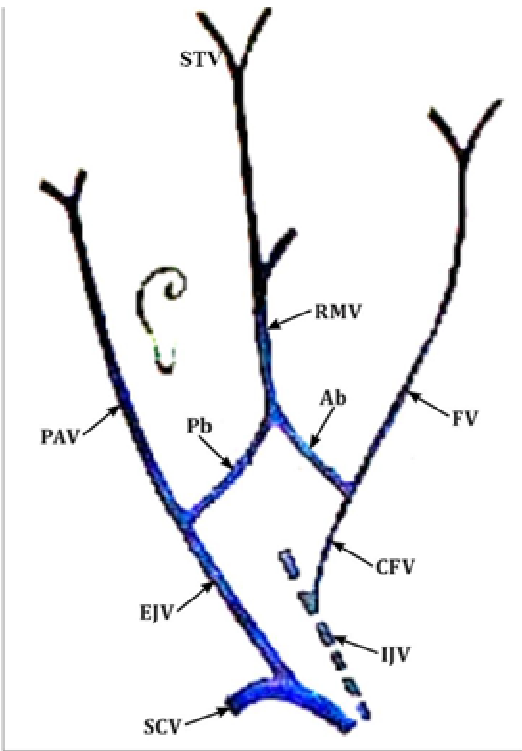
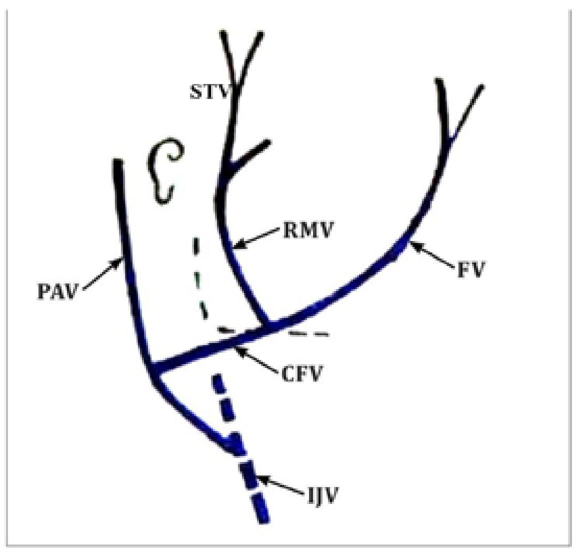


Diagram showing usual formation of external jugular vein and common facial vein. *(**PAV**: posterior auricular vein; **RMV**: retromandibular vein; **Ab**: anterior branch of retromandibular vein; **Pb**: posterior branch of retromandibular vein; **EJV**: external jugular vein; **SCV**: subclavian vein; **FV**: facial vein; **CFV**: common facial vein; **IJV**: internal jugular vein)*

FIGURE 3 - SYSTEMS OF VENOUS OUTFLOW IN THE TEMPORAL AREA
FROM VARIATION OF THE VEINS OF THE HEAD AND NECK - EXTERNAL JUGULAR VEIN AND FACIAL VEIN - BALACH,RA N, PADMALATHA K, PRAKASH BS AND RAMESH BR - INT J ANAT VARIATIONS - 2012 VOL. 5(1)



Line diagram of Figure 3. *(**PAV**: posterior auricular vein; **RMV**: retromandibular vein; **FV**: facial vein; **CFV**: common facial vein; **IJV**: internal jugular vein)*

FIGURE 4 - ANATOMICAL VARIATIONS OF VEIN SYSTEM
FROM VARIATION OF THE VEINS OF THE HEAD AND NECK - EXTERNAL JUGULAR VEIN AND FACIAL VEIN - BALACH,RA N, PADMALATHA K, PRAKASH BS AND RAMESH BR - INT J ANAT VARIATIONS - 2012 VOL. 5(1)

In case of superficial temporal vein anomalies, we expect the system to compensate for the venous drainage of that specific area by rebalancing it. The case shown in the images describes the solution to the problem of critical venous drainage in the temporal area, solved by using the posterior auricular outflow, in addition to the small superficial temporal vein anteriorly. The two systems can be used alone, or both if necessary doing two venous anastomoses, ensuring a supercharged venous outflow.

FIGURE 5 *- Vascular anomaly of left orbit with blindness and huge eyeball proptosys*

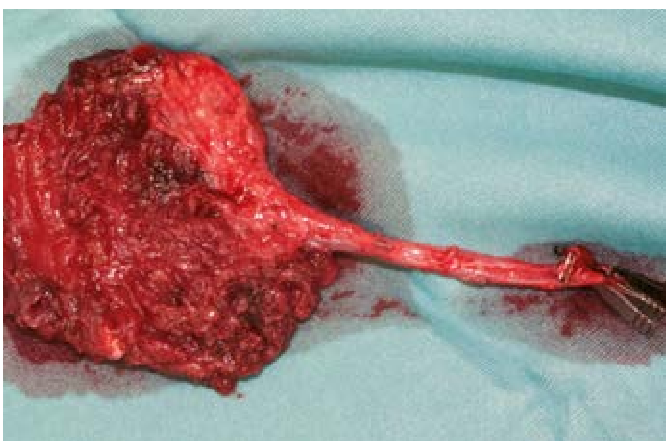


FIGURE 6 *- After surgical enucleation the empty orbit is covered with alt muscular microsurgical flap and skin graft*

FIGURE 7 *- Insetting the flap, arterial and veins anastomosis.*
a-temporal artery anastomosed
b-superficial temporal vein connected with 1 mm coupler
c-posterior auricular vein transposed anteriorly and connected with 2mm coupler

Preauricular incision is prolonged downward by contouring the earlobe to the posterior auricular sulcus as described in the face-lift procedures (10). After the incisions the posterior auricular vein is isolated and transposed by rotating it anteriorly at the earlobe. The procedure is completed by performing the anastomosis with a 2 mm coupler and positioning a non-aspirating retroauricular drainage.

FIGURE 8 *- Follow-up one month postop after positioning an ocular prosthesis*

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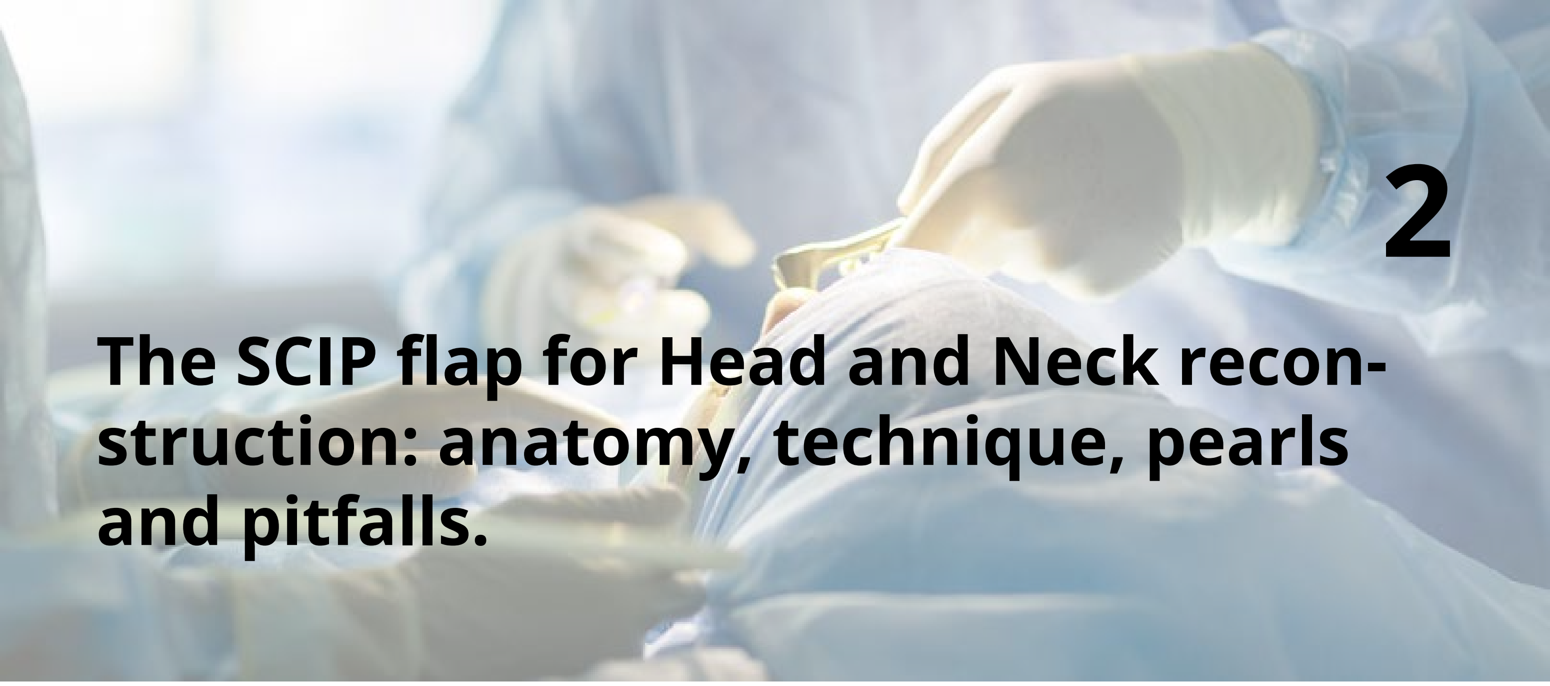

2

The SCIP flap for Head and Neck reconstruction: anatomy, technique, pearls and pitfalls.

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THE SCIP FLAP FOR HEAD AND NECK RECONSTRUCTION: ANATOMY, TECHNIQUE, PEARLS AND PITFALLS.

Introduction

Reconstruction of head and neck defects due to malignancy and / or trauma is nowadays based mainly on microvascular surgery[1]. Free flaps represent the state of the art in head and neck reconstruction and have replaced former workhorse flaps like the pectoral flap-[2]midface (9%. However, free flap choice for head and neck reconstruction is not always straightforward, and with increasing anatomical knowledge and advances in flap design new methods have been developed mainly aiming at reducing donor site morbidity. Especially regarding fasciocutaneous flaps the advent of perforator flaps has dramatically changed the traditional free flap choices. And, while the ALT flap has clearly an established role in head and neck reconstruction the more recently developed superficial circumflex iliac artery perforator flap (SCIP flap) is only sparsely reported as a viable free flap option in head and neck reconstruction[3].

Although the inguinal donor site has been hailed as almost ideal in terms of morbidity, the inguinal flap[4], the first free flap performed clinically[5], has fallen out of favour with the development of new microvascular flaps especially due to the perceived anatomical variations and short pedicle. However, with the landmark works of Koshima[6] and Hong[7]perforator flaps can still be bulky especially to resurface the skin defect. We hypothesized that elevation from the superficial fascial plane can obtain a thin and viable flap.\nMETHOD: In this retrospective study, we report consecutive perforator flaps elevated at the superficial fascial plane from November 2007 to July 2013. Total of 304 flaps which were 196 superficial circumflex iliac perforator (SCIP the superficial iliac artery perforator flap revived the inguinal donor site as the SCIP flap took advantage of perforator dissection techniques and provided thinner flaps with longer pedicles and safer planning regardless of possible anatomical variations. In recent years, the SCIP flaps uses have expanded and mounting experience especially from Asian centers has proven the reliability and versatility of the SCIP flap[3,8,9]a total of 79 cases were performed (age range, 4-80 years. Regarding head and neck reconstruction there is mounting evidence of the use of the SCIP flap, however also especially from Asia[10–12].

We have started using the SCIP flap for head and neck reconstruction in 2018 and have since come to believe that it is a reliable and safe flap with an unmatched low donor site morbidity. However, a clear understanding of the flap's anatomy, careful surgical technique and attention to preoperative workup are absolutely necessary in order to perform a successful SCIP flap reconstruction in the head and neck.

Our aim is to present the anatomical and clinical considerations that have proven essential for the safe use of the SCIP flap in head and neck reconstruction.

Anatomical considerations

In order to address the perceived anatomical variations of the vascularization of the SCIP flap we performed a thorough anatomical cadaveric study which could show the following:

- The superficial circumflex iliac artery (SCIA) consistently emerged from either the common femoral artery or superficial femoral artery.
- A clearly defined deep branch of the SCIA

that runs underneath the deep fascia up to the lateral border of the sartorius muscle could be identified in each specimen.

- The superficial branch and deep branch of the SCIA both give off an average of 3 perforators per branch
- The location of the superficial plane perforators from both branches show a clear medio-lateral division. The superficial branch's main perforators gather around the lateral half of the inguinal ligament while the main perforators from the deep branch can be found in a region latero-inferior to the ASIS and lateral to the lateral border of the sartorius muscle (Figure 1).
- The mean total area of the perfused angiosome is significantly larger for the deep branch compared to the superficial branch.
- The maximal pedicle length measured from the main superficial plane perforator to the origin of the vessel from the femoral artery is significantly longer for the deep branch than the superficial branch
- The superficial raising plane (above the superficial fascia) provides a thinner and significantly more homogeneous flap, a finding underlying the importance of perforator based SCIP flap raising in order to achieve a consistent and thin flap.

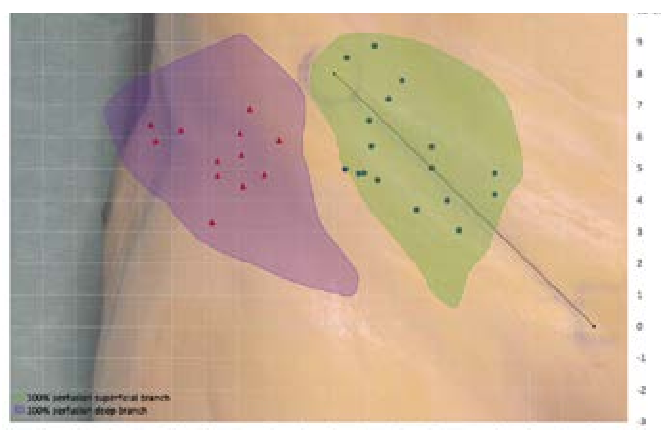

Figure 1. *Distribution of the main branch perforators of the superficial (green dots) and deep (red triangles) branch of the SCIA in relationship to the inguinal ligament (black line). The areas in green and purple represent the areas of the SCIP flap always perfused by the superficial or deep branch.*

In conclusion, our anatomical study revealed that, in contrast to previous experience emphasizing the use of the superficial branch of the SCIA as the preferred flap pedicle[7,8]perforator flaps can still be bulky especially to resurface the skin defect. We hypothesized that elevation from the superficial fascial plane can obtain a thin and viable flap.\nMETHOD: In this retrospective study, we report consecutive perforator flaps elevated at the superficial fascial plane from November 2007 to July 2013. Total of 304 flaps which were 196 superficial circumflex iliac perforator (SCIP, the deep branch of the SCIA provides a larger and thinner flap with a longer pedicle compared to the superficial branch and therefore could be used more frequently as a SCIP pedicle.

Clinical pearls and pitfalls

1. Preoperative considerations

In general, the SCIP flap is a good indication in defects of the soft tissues in the head and neck intraorally or extraorally. Even though the SCIP osteocutaneous flap with vascularized iliac bone has been described and used in head and neck reconstruction[13,14], in our hands the indications for combined soft tissue and bone reconstruction with the SCIP flap are very limited. In general, primary defects of the tongue, floor of the mouth and vestibular mucosa are excellent indications for the free SCIP flap, in these cases the SCIP flap being able to successfully replace the radial forearm free flap (RFFF). We advise caution in using the SCIP flap for palatal defects or secondary defects in preirradiated tissues (shorter pedicle than the ALT or RFFF might prove a disadvantage in these cases)
The clinical assessment of a patient where a

SCIP flap is being considered should include a careful anamnesis regarding previous surgeries in the inguinal region, the presence of scars and/or signs of infections or mycosis.
We perform routinely in each patient a CT-angiography of the pelvis and upper thighs to identify possible variations in the vascular anatomy of the SCIA and therefore choose the best side to harvest the SCIP flap. However, in our experience we find the CT-angiography insufficient to clearly mark the separate perforators of the 2 branches of the SCIA.

2. Markings

The preoperative markings are performed in the afternoon preceding the surgery by marking the following points:

- Tubic pubercle
- ASIS
- A line uniting these points marking the inguinal ligament
- The femoral artery below the inguinal ligament
- A line from a point on the femoral artery 2 cm below the inguinal ligament to the ASIS, which corresponds to the projected course of the SCIA-superficial branch
- If visible, superficial veins are also marked on the skin immediately below the inguinal ligament

With these markings we perform a Color Doppler of the inguinal region identifying the main branches of the SCIA, and perforators passing through the superficial fascia. We especially look for perforators from the deep branch which are located more inferior and lateral to the inguinal ligament. The perforators are marked on the skin and their location also confirmed by hand-held Doppler, which can be thus easily also used intraoperatively (Figure 2).

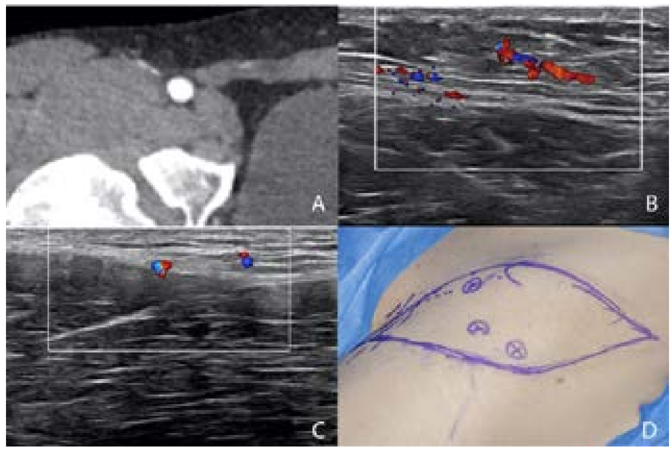

Figure 2. *Preoperative workup and markings of the SCIP flap. A. CT-angiography showing the emergence of the SCIA from the femoral artery. B. Color Doppler image of the superficial and deep branch of the SCIA running in the subcutaneous tissue and underneath the deep fascia respectively. C. 2 Perforators from the deep branch of the SCIA. D. Intraoperative marking prior to flap raising.*

3. Surgical technique

a. Flap raising

With the patient in a supine position the groin, lower abdomen and thigh are disinfected and draped sterile according to usual protocol. The incision starts at the inferior and lateral border of the planned flap and is carried out with a scalpel just until the dermis is incised. Afterwards we prefer to use a cautery to ensure a bloodless field that is essential for identification of the small perforators. The dissection is carried on in a superficial plane (above the superficial fascia) until the marked perforators are identified. Keep in mind that the perforators from the deep branch are located more inferior and lateral. After identifying the perforators, a retrograde dissection is performed carefully freeing up the perforators through the superficial and (in case of the deep branch) deep fascia followed by dissection of the deep and superficial branch all the way up to the main common trunk and its emergence from the femoral artery. As the dissection proceeds cranially usually a superficial vein is identified which proximally runs to the saphenous arch, diverging thus from the main arterial pedicle. Constantly the arterial pedicle is accompanied by one or two commitant veins which usually unite shortly before draining into the femoral vein. We prefer to dissect both branches of the SCIA with 1 or 2 perforators and the whole length of the arterial pedicle up to the femoral artery and venous pedicle up to the saphenous vein. In case a large vein is needed the saphenous vein can be further dissected up to its emergence from the femoral vein. After final determination of the defect size the flap is trimmed accordingly and a choice of pedicle (deep, superficial or both branches) is made depending also on the proximity and quality of the vessels in the neck (Figure 3).

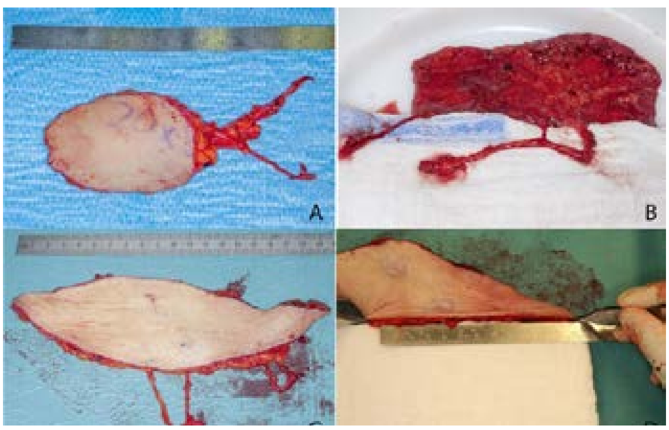

Figure 3. *Details of SCIP flaps used for Head and Neck Reconstruction. A and B. SCIP flaps based of the deep branch of the SCIA. C. SCIP flap based on both the superficial and deep branch of the SCIA. D. Image depicting the thinness of the SCIP flap.*

b. Recipient site

Some considerations are to be made also in the dissection of the recipient site. In general, we find the size of the superior thyroid artery a better match for the SCIA so we preferentially use this recipient artery, the second option being the facial artery. A commitant vein of the thyroid artery can also be used for the venous anastomosis to the commitant vein of the SCIA, while the main venous outflow of the flap, represented by the superficial vein is generally anastomosed to higher caliber venous branches of the internal jugular vein or the external jugular vein.

4. Clinical experience

We have used the SCIP flap from 2018 in 17 head and neck reconstructions, 15 for intraoral and 2 for extraoral reconstructions. All flaps and reconstructions were successful, with one successful revision of a venous thrombosis within 24h postoperatively and one partial necrosis of the flap that was debrided and primarily closed on POD7. We also had one postoperative bleeding of the donor site which required surgical revision. Excellent functional results could be obtained, and the donor site healed inconspicuously in all patients (Figure 4).

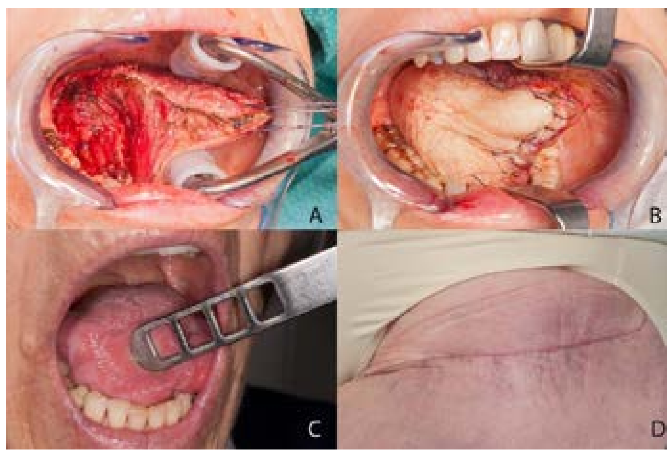

Figure 4. *Example of a clinical case. A. Defect after hemipelviglossectomy for malignant disease. B. SCIP flap sutured in the defect. C. Late result after adjuvant radiotherapy with fully integrated SCIP flap. D. Donor site with healed incision.*

Conclusion

The SCIP flap is a reliable option for head and neck reconstruction especially in primary oncological cases of tongue and floor of the mouth reconstruction as well as extraoral facial skin reconstruction. We prefer to use the flap based on the deep branch as it offers longer pedicles and thinner flaps. The donor site is excellent and the inguinal scar inconspicuous and easily hidden. In our hands the SCIP flap can replace the RFFF in the majority of soft tissue reconstructions of the tongue and floor of the mouth.

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II
Upper Extemity

3

Hand soft tissue reconstruction with Quaba flap

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Introduction

Hand soft tissue defects after trauma injuries or tumor excision are one of the most challenging health problems, physically and mentally, regardless of age, gender or ethnicity. It is important that the reconstruction method chose by the surgeon to restore the hand's full function, mobility and to create the best aesthetic result possible.[1]

Most soft tissue defects in the hand are produced by trauma, tumor excision, relaxation of scar contraction and burns. These cases can be managed by using skin grafts, local flaps, regional flaps and free transfer flaps.[1]

In this new era of microsurgery, the tendency is to protect the principal arteries by using local or free perforator flaps. Maintaining the important vascular supply and still being able to resurface tissue defects is realized by doing as little harm as possible, respecting the reconstruction ladder that is adapting to the newest developments in this permanent changing field.

If it is possible, the preferred method of reconstruction for soft tissue defects of the hand is by using local flaps. There are multiple local flaps that can be used for reconstruction, with the same quality, texture and hairless skin, making a discrete and minimal donor site scar.[1]

This article describes the use of perforator local flaps for resurfacing soft tissue defects with exposure of tendons, nerves, arteries and bones or for a quality reconstruction of the defects that involve the flexion creases.

One of the most elegant methods of reconstruction for soft-tissue defects of MCPJ, web space, proximal phalanx and PIPJ, is the Quaba flap, a perforator fascio-cutaneous local flap with a reliable and relative straightforward anatomy of the pedicle.[2]

Material and Methods

We used the Quaba flap in two cases to show the different type of pathology that can benefit from this method.

The first case is a 43 years old male patient, known with psoriasis, who suffered a home accident with a chainsaw. He presented in our emergency room with a soft tissue defect involving the ulnar border of the proximal phalanx and PIPJ of the 5th finger of the left hand, partially exposing the TFP.

The 2nd case is a 35 years old woman with a round skin tumor, with the diameter of 1.5cm, brown-red, mobile to the underlying flexor tendon, located on the volar surface of the MCPJ. After the tumor excision, the underlying flexor tendons were exposed. (Fig. 1)

Both patients were subjected to detailed medical history and physical examination for scars of the dorsum of the affected hand that can jeopardize the flap viability.

Figure 1 - *case 2: before and after tumor excision.*

Operative Technique

In both cases we used WALANT for patient comfort, a form of extravascular Bier block, without the painful tourniquet. This type of anesthesia facilitates the dissection of the pedicle and has no unwanted side effects that can be associated to the opiates or sedation.[3]

After careful debridement of the injured finger in the first case and the tumor excision with oncological safety margins in the second case, because of the defect's location and the tendons exposure, we considered that it was mandatory the use of flaps for reconstruction. (Fig. 1)

We decided to reconstruct the defects with a one-stage operation, a local perforator flap with a distally based pedicle, the Quaba flap. It can be created from the MCPJ till the distal edge of extensor retinaculum, and the width between 1 and 3.5cm, centered on the intermetacarpal space.[4] It is advised not to skeletonize the pedicle due to possible venous insufficiency.[2,4]

We created the flaps in a similar manner, projected on the 4th intermetacarpal space, with the width of 1.5cm and the length of 4cm. The first incision was made on the radial side, dissecting the flaps superficial to the paratenon and to the fascia of the dorsal interosseous muscle. The next step was raising the flaps from proximal to distal, preserving the sensory dorsal ulnar nerve, until the juncture tendinea because, distal to this, the pedicle can be visualized.[5,6] The distal markings of the flaps were incised at the level of the MCPJ to facilitate the flaps mobilization.[5] (Fig. 2,3)

Figure 2 *- case 1: elevation of the Quaba flap.*

The last step was to incise the skin from the pedicle of the island flap until the defect and we rotated the flap to cover it. The donor site was closed primary, whit an intradermic suture for best aesthetic result.

Figure 3 *- case 2: distally based perforator of the flap*

Figure 4 *- case 1: postoperative aspect of the flap at 2 and 3 weeks*

In the second case, the flap suffered minor distal venous congestion that was treated conservatively with dressings and the wound healed by secondary intention in the distal part of the flap after 20 days. (Fig. 5)

Figure 5 - *case 2: The distal part of the flap suffered minor venous congestion with minimal marginal necrosis that healed at 20 days by secondary intention.*

The donor site healed uneventful in both cases, with minimal, linear scar formation. (Fig. 6)

Figure 6 - *case 2: at 3 weeks postoperatively the donor site healed with a linear scar but the flap has a slight unaesthetic bulkiness.*

Both patients reported a slight bulkiness of the flap, without affecting the functional outcome, preserving full mobility of the fingers. (Fig. 6)

Discussion

The main goal in this type of defects is the successful coverage of the tendons, the reconstruction of the flexion creases and the functional outcome.

We consider that using the Quaba flap, a local perforator flap, with minimal donor site morbidity and easily rising technique is the best choice.[7]

The palmar system and the dorsal metacarpal artery system anastomoses distally. At this level, the anastomoses gives off a branch that supply the skin of the dorsum of the hand.[8,4] This perforator, known as the Quaba perforator, is the pedicle for the flap with the same name, a constant palmar-dorsal perforator from the digital web space.[9] Unlike DMCA flap, the Quaba flap is not sacrificing the dorsal metacarpal artery.[9,5]

Finding the perforator using the vascular Doppler investigation is not necessary because the anatomy is quite constant and reliable for this flap pedicle. Distal to juncture tendinea, at the 2nd, 3rd and 4th interdigital space, at 0.5-1cm proximal to MCPJ is without a doubt the perforator and the accompanying veins that can sustain the Quaba flap.[2,10]

The downside of this flap raising technique is the twisting of the pedicle necessary for flap movement that can lead to venous insufficiency.[11] Unwanted venous congestion can also be obtained by tunneling the flap through the soft tissue. For this reason, it's safer to incise the skin between donor site and the defect.[12]

In the scenario of hand infections with soft-tissue defects, the Quaba flap is contraindicated because of the high risk of total flap loss.[10]

The skin of the dorsum of the hand is similar to the volar one in color, thickness, elasticity and consistency, making this method very suitable for the local defect requirements.

[12,13] Being able to primary close the donor site with best cosmetic result, makes this method well accepted by the patients.[7]

Conclusions

The Quaba flap has the advantage of being a distally based perforator axial flap that can reconstruct soft tissue defects from the volar MCPJ till the PIPJ. It is a safe flap with an easy operative technique, without significant intraoperative or postoperative complications, with minimal donor site morbidity.[13]

Although it is an insensate flap, the only defect that was attributed by the patients was the slight bulkiness that can affect the aesthetics of the hand.

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4

MANAGEMENT OF THE MANGLED UPPER EXTREMITY

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Abstract
The mangled upper extremity is a severe injury of multiple anatomical structures caused by an extremely violent mechanism. Management of such injuries aims not only to limb salvage but also to a satisfactory functional outcome. It requires a team work of high expertise and skills with prioritization of the interventions needed starting of course, from patient's life support.

Introduction
Mangling trauma to the extremities causes definitely multiple tissue injuries and defects and hence it is better to be characterized as the "mangled extremity syndrome". Upper extremity as a precious tool in daily living, is often injured in occupational activities (e.g. machine handling), motor vehicle accidents, gunshots and explosions. Mangled upper extremity is the result of excessive blunt or mutilating trauma mechanism that causes severe injury in at least 3 of 4 tissue types: connective tissue (skin, subcutaneous tissue, tendons, muscles), vascular, nervous, and bones of the arm, forearm or hand[8, 24]. Management of such severe injuries of the upper limb demands high level of expertise and skills by trauma surgeons. Mangling injuries of the extremities were historically associated with high amputation rates. Nowadays, more and more sophisticated microsurgical techniques have increased the prospects not only of limb salvage but also of a functional outcome. Orthopaedic surgeons are usually mostly involved and if there is knowledge of microsurgery, vascular surgeons assistance may be unnecessary especially in cases of injuries distal to the elbow joint.

Management
Initial care
Patients with a mangled upper extremity are often polytrauma patients (with coexisting severe injuries of head, chest, abdomen or pelvis) and they should be initially treated in accordance with Advanced Trauma Life Support (ATLS) guidelines preserving airway, breathing, and circulation (ABC). Meanwhile bleeding in the upper extremity which can be even catastrophic, must be controlled as soon as possible by direct pressure or by the use of tourniquets. Studies have demonstrated low rate of tourniquet-associated complications in prehospital bleeding management but prolonged use or over-tightening may worsen ischaemia. Clamping of bleeding vessels should be avoided because it creates additional trauma to vessel wall and may damage adjacent structures [2, 50]. Completely amputated parts must be wrapped in saline-soaked gauze and put in a plastic container which will be soaked in iced water (4 °C).

As soon as patient is admitted to the emergency department, upper limb must be completely exposed, removing temporary dressing or remaining clothing and foreign bodies. Information about the mechanism, the place and the time of injury is critical [22, 48]. Severity of the injury is thoroughly documented including photographies. Neurological examination of the limb must be carried out if possible, and evaluation of vascular status is crucial in next steps decision making. Capillary refill, presence of palpable peripheral pulses, skin color, temperature and a pulse oximeter are used to recognize an ischaemic upper limb while Doppler ultrasound, computed tomography angiogram (ct-a) and arteriography in the emergency department can be reasonably time-consuming and of limited value at this point [8, 42]. Early diagnosis of compartment syndrome is also important for limb salvage.

Besides the vascular evaluation, wounds are irrigated with saline solution by gravity lavage, dressed and the limb is splinted in an anatomical position. Tetanus prophylaxis is a routine and i.v. antibiotic administration against gram positive and negative micro-organisms must start immediately as various studies have demonstrated increased rate of infection even with a delay of more than 1 hour [34].

Figure 1: *3-level mangling injury of left arm in a 20-year old male (a, b). Due to very contaminated wound and avulsion of vessels (MES score 9), there was no indication for attempting to save the arm (c). Revision amputation was performed at the upper third of the humerus (d).*

Revascularization

After this initial management in the emergency department, patient is carried to the operating room. In case of an ischaemic upper extremity, revascularization must be performed as soon as possible within the warm ischaemia period of 4-6 hours in order infection and tissue necrosis to be prevented and lower the possibility of reperfusion syndrome, though areas with fewer and smaller muscle bellies (e.g. distal to wrist level) can afford longer period of decreased arterial flow prolonging available time for reconstruction up to 24 hours (even up to 94h) [60]. Therefore, time passed from the injury and the time needed for a successful revascularization procedure should be taken into account [3, 8, 57, 58]. Revascularization is performed with removal of intra-arterial thrombus, direct vascular repair, venous grafts, arterial by-pass, or a temporary shunt. At that point, in cases that bone fractures coexist, there is always a consideration about what should be done first: bone fixation for skeletal stability or revascularization surgery? Temporary arterial shunt is a reasonable solution providing the orthopaedic surgeon adequate time for the musculoskeletal reconstruction. Of course, good communication, coordination and co-operation (if different specialties are involved in surgical procedures) are prerequisites for the successful management of a mangled upper limb [13]. Limbs that are ischaemic for more than 4 hours should receive prophylactic fasciotomies anyway [48]. After having restore the arterial inflow, reconstruction of veins can be delayed allowing controlled venous outflow to "wash out" the toxins produced by tissue ischaemia. Of course, venous drainage must be sufficient (2 functional veins are required for each artery). In case of digital amputation, continuous provocative bleeding from the dorsum of the finger using heparinized dressing or even medicinal leeches (Hirudo Medicinalis) can succeed adequate venous drainage [53, 54].

Debridement

Debridement of severely damaged tissues that are obviously nonviable, and nonfunctional must be meticulous but not halting. Necrotized tissues do not contribute to the final function of the extremity and may increase infection rate. Ischaemic or exposed bone should also be removed preserving an adequate length by a spanning osteosynthesis (usually external fixation). Wound excision should take place within the first 24 hours in case of a well-perfused limb that is not treated urgently [25, 37, 43]. The “8-hour window” for an effective debridement does not seem to be confirmed in the literature. However, debridement in the operating room should be repeated as many times as needed to have a clean wound during the next 72 hours. Debridement can be more conservative concerning nerves and major vessels. Copious irrigation is essential in creating a clean wound bed. Studies confirm neither the superiority of various solutions over saline nor different lavage methods over gravity [12, 44, 46]. Culture specimens from wounds, taken during debridement can help in antibiotics selection and even to verify a clean, non-contaminated wound. First generation cephalosporins for at least 5 days with aminoglycosides is a usual scheme while penicillin and metronidazole are preferable in case of anaerobic bacterial infection [30, 37].

Salvage or amputation?

At this point, surgeon has a thorough evaluation of the mangled upper extremity including perfusion and tissue defects (bone and joints, muscles, tendons and nerves) and is mandatory to decide whether the limb must be amputated or begin a salvage procedure. Considering that “the arm is progressively more valuable from shoulder to fingers; the leg, on the contrary, is progressively of less significance” successful salvage procedure of a mangled upper limb can give better functional results than a prosthetic replacement [41]. On the other hand, various attempts to salvage a limb with poor prospectives may lead to a “triumph of technique over reason” with burden for patient and medical system [28]. In an attempt to help surgeons in decision-making, various scoring systems have been proposed (MESS, PSI, NISSSA, LSI, HFS-98). MESS (MESSI) was introduced by Johansen et al. in 1990 [32]. Four factors (skeletal and soft-tissue injury, ischemia, shock and age)create a score that indicates amputation if ≥7. Though this scoring system was proposed for lower limbs, its use was generalized but there is no scientific data supporting its effectiveness for the upper limb. However, there is still a debate over the ability of scoring systems to guide surgeon to the right decision despite the fact that many mangled extremities are borderline cases. Moreover, none of the proposed scoring systems gives the ability of functional outcome prediction. Instead, there are studies demonstrating that functional outcome (measured with the Sickness Impact Profile score-SIP) maybe comparable between salvaged and amputated limbs [5, 6, 17, 18, 33, 38]. The decision to amputate or to salvage a limb must be carefully assessed and in case of an amputation, it should be better based on two qualified surgeons’ agreement. Patient’s age, comorbidities (e.g. diabetes mellitus, atherosclerosis, smoking), and mental status must be taken into consideration [25]. However, in cases that patient can be thoroughly informed over the possibility of a poor functional outcome or the need of further reconstructive procedures, decision should be up to him [40, 55]. As already mentioned, photographic documentation is crucial in any case.

Skeletal stabilization

After securing the perfusion of the limb, orthopaedic surgeon will proceed to skeletal stabilization. Fractures are fixed in a permanent way if doing so is permitted by the general condition of the patient and the condition of the envelope of soft tissues in fracture area.Plate-screw osteosynthesis can be applied almost in every bone of the upper limb and there is a variety of implants available. Intramedullary nailing can be an option mainly for the humerus though plating seems more convenient when fracture site is already exposed. K-wire stabilization is a fast and effective technique for fractures particularly of wrist and hand with minimal additional trauma to the surrounding soft tissues. Internal fixation has the advantage of avoiding secondary surgical exposure nearby an arterial anastomosis or by-pass with the risk of vascular compromising. Permanent fixation can be carried out even in cases of contaminated open fractures without increasing infection rate, if adequatedebridement had been previously performed [61]. However, internal fixation implants (and tendons, vessels and nerves as well) must not be left exposed and if primary coverage is impossible, a negative-pressure dressing has to be applied [15]. As already noticed, spanning external fixation (or spanning plating e.g. in severe comminuted fracture of distal radius) can be a temporary solution particularly when skeletal stabilization is taking place before revascularization in order to create a stable background for vascular surgeon as well as for the cases in which there is a considerable bone defect or an irreparable joint [35]. The application of the external fixator must allow future surgical interventions in the injured area (e.g. flap coverage). External fixation is often exchanged in a permanent internal fixation since the use of external fixation devices as a definite treatment method has considerably high rate of non-union [51]. Restoration of the anatomy should be aimed (especially for intra-articular fractures) but realignment and fixation stability can be enough, even with an amount of bone shortening if needed, as long as it does not prevent muscles and tendons to function properly. Shortening up to 5 cm in the humerus, 4 cm in the forearm, and 1-1.5 cm in metacarpals and phalanges is well tolerated [59]. One-bone forearm can be a reasonable solution in case of severe and compound defects of radius and ulna [47]. However, bone grafts (auto- or allografts, vascularized or not), osteogenesis by bone transport with external fixation devices, and 2-stage induced membrane reconstruction (Masquelet technique) can replace bone defects of various size even during the initial surgical procedure as soon as wound bed and tissue coverage are in the appropriate condition [14, 20, 23]. Intra-articular fractures must be if possible, anatomically reduced and stabilized, aiming to capsule and ligaments healing besides with early joint motion.

Tendon repair

Soft tissue management comes in turn after having a viable and stable upper limb. Tendons must be recognized and evaluated for contamination and possible excessive plastic deformation. Unhealthy parts are excised and primary repair takes place if approximation of two ends does not create excessive tension. Defects that cannot be bridged will be restored by tendon grafts (e.g. palmaris longus, extensor indicis proprius, extensor digiti quinti or flexor digitorum superficialis) using a side-to-side tendon repair or Pulvertaft weave technique.However, primary tendon reconstruction demands sufficient soft tissue coverage [1]. If that is not possible or in case of multiple tendon injury with tendon loss, or loss of muscle mass,two-stage reconstruction by the use of silicon rods, tendon transfer techniques or tenodesis have to be performed as soon as soft tissue oedema has subsided and distal joints are supple (4-6 months after initial injury) or at the time of definite soft tissue coverage [45].

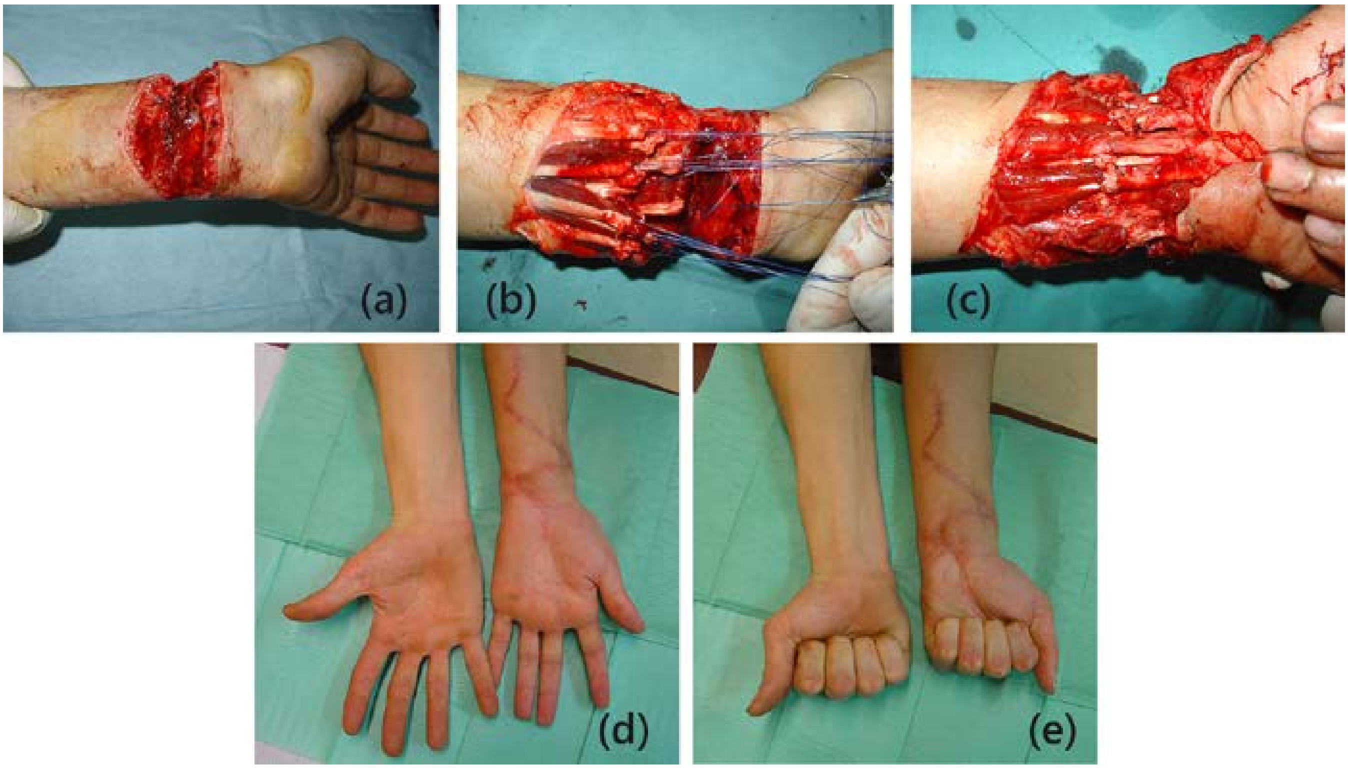

Figure 2: *a 22-year old male sustained this severe injury at his left wrist (a). Radial and ulnar artery, median and ulnar nerve, all flexor tendons and extensor tendons of the 1st extensor compartment were severed (MES score 7) (b). The hand was revascularized by radial and ulnar arteries end-to-end anastomosis, median and ulnar nerves were sutured and all tendons were sutured as well (c). Final outcome: full flexion and extension of wrist and fingers and a functional hand (d, e).*

Nerve repair

Injured nerves must also be recognized and evaluated. Reconstruction of median, ulnar and posterior interosseous nerve is mandatory. Apart from clear-cut injuries, stretching and crushing forces create unhealthy parts at the stumps or even in a seemingly intact nerve. Such injured portions of nerve ends must be excised. Direct repair with end-to-end microsurgical suturing can be performed as long as the stumps of the nerve can be approximated with no tension taking care to avoid mismatching of nerve fascicles. Otherwise, nerve stumps are matched and secondary reconstruction is planned based on the recorded anatomic and functional defect. Nerve autografts is a simple and effective solution. Sensory branches such as sural nerve (mainly), medial and lateral antebrachial cutaneous nerves, posterior interosseous, superficial radial nerve can be sacrificed to repair nerve injuries with motor function loss. A wider recipient nerve can be bridged by multiple thinner nerve grafts in parallel (interfascicular nerve grafting). Nerve conduits supply a protective environment for nerve regeneration up to 3 cm while nerve allografts though gaining popularity are still not widely used [9, 11, 36, 39]. Nerve transfers via an end-to-side repair or with direct muscle neurotization by a healthy nerve, are highly demanding innovative techniques in restoring upper limb functionality. However, tendon transfers can be an effective solution with a faster and good functional outcome [45].

Wound coverage

Coverage of the injured area is the final process in mangled upper extremity management. Excessive swelling and the need of repeated surgical debridement of contaminated and necrotic tissue often do not allow primary closure of such wounds. Secondary closure can be performed after oedema subsides and a healthy, clean wound bed is obtained. Until this stage is reached, exposed bones, tendons, neurovascular structures and implants must not stay uncovered. Negative-pressure wound therapy (NPWT) can provide a temporary coverage, decreasing swelling and promoting granular tissue formation and perfusion of the area. It is also well-documented that NPWT contributes in limiting tissue contamination though studies have shown decreased effectiveness if negative-pressure dressing is maintained for more than 7 days [15, 31, 56]. NPWT can decrease wound dead space that has been created by massive soft tissue loss but it cannot regenerate tissue defects. In case of significant dead space and contaminated environment, negative-pressure dressing can be applied together with antibiotic loaded bone cement spacer or beads (bead-pouch technique). However, dimensions of the upper extremity do not require usually dead space management.

Pure skin defects can be easily covered by skin grafts (of full or split thickness)or artificial skin substitutes (bioengineering products like Integra® and MatriStem®). Soft tissue defects that impede direct closure of wound will obtain flap coverage. Timing of definite coverage of a mangled extremity is controversial. Various studies in the past supported early flap coverage. On the contrary, it has been shown that performing flap coverage within the first 6 days increases the rate of flap failure and infection [19, 21, 27]. Eventually, second and third post-traumatic week seem to be the ideal period for successful flap coverage of upper extremity defects [16]. Regional flaps can be used if possible, as soon as zone of the injury is well defined (usually within 5-7 days). Free pedicle flaps may require far more expertise and microsurgical skills but they can solve both the wound coverage issue for defects up to 30x15cmand the unrepairable loss of valuable structures transferring healthy, well vascularized tissues that promote healing and treat infection [45, 49]. Apart from fasciocutaneous flaps that cover successfully skin defects and permit tendon gliding, musculocutaneous flaps fulfill soft tissue gaps and composite flaps can provide to the injured area, a functional muscle unit (e.g. gracilis, latissimus dorsi), vascularized bone graft (e.g. fibula, osteochondral graft from medial femoral condyle), nerves and vessels [8, 10, 29]. Flaps require close monitoring for 24-48 hours.

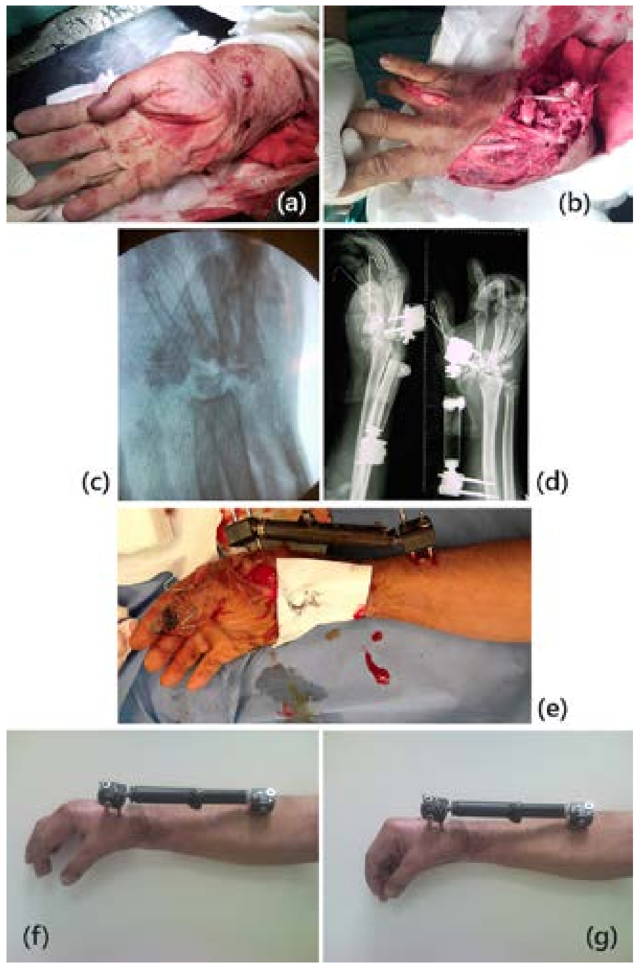

Figure 3: *mangled wrist in a 48-year old male after a motor vehicle accident. Complex carpal fracture-dislocation with bone loss, radial and ulnar artery rupture, nerve avulsion (median, ulnar and superficial branch of radial n.) and skin defects (a, b, c). After wrist stabilization by an external fixator, radial and ulnar arteries were anastomosed and wounds were temporarily covered with Epigard® BIOVISION GmbH (d, e). External fixator remained until complete wound healing (split thickness skin grafts were used) and wrist arthrodesis was performed afterwards (f, g).*

Further interventions

Unfortunately, salvage procedures are not always successful or require multiple operations still with an uncertain result. Surgeon should be aware of the psychological and socio-economic burden of a "hopeless strategy" and the decision of amputation must not be considered as a failure. Furthermore, it is well documented that delayed amputation has higher rates of morbidity and mortality, and double cost than primary amputation [4, 52]. In case amputation is decided, a variety of choices can improve the final outcome. Viable tissues must be preserved as much as possible and tissues of the amputated part of the upper limb can be used as autografts (e.g. fillet soft tissue from amputated fingers as coverage for others). Finger pollicization and toe transfers can restore pinching and grasping ability of the hand. Prosthesis (cosmetic or mechanical) need an adequate stump for proper fitting. Less frequently, and in case of bilateral upper limb amputation, transplantation can be a solution though it will require careful selection of the patient and a specialized transplantation center. Apart from total failure of salvage procedures that will require amputation in a mangled upper extremity (vascular anastomosis failure, congestion or sepsis), there are several complications that can compromise functional outcome. CRPS, deep infection, osteomyelitis, loss of tissue flaps, malunion or non-union of fractures, joint stiffness, post-traumatic osteoarthritis, muscle or tendon adhesions and compression neuropathy will demand further treatment and surgical interventions like additional surgical debridement, new flap transfer, arthrolysis, tenolysis, neurolysis, joint replacement or fusion, and distraction osteogenesis [7, 45].

Patients with a mangled upper extremity will require additional and systematic support for a long post-operative period, including rehabilitation and occupational therapy, chronic pain management and psychological/psychiatric support for post-traumatic stress disorder [43].

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5

How we do it. Tips and tricks for harvesting Posterior Interosseous Flap

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Introduction

The posterior interosseous flap (PIOF) was described by Zancolli and Angrigiani[1] and Penteado et al[2] as an alternative to the radial forearm flap to avoid the sacrifice of a major vessel. The flap is typically harvested as a reverse-flow pedicled flap, based at the wrist on the communications with the anterior interosseous artery on the volar aspect of the forearm. The main indication for this PIOF is coverage of dorsal hand and first web space defects[3].

As an anterograde flap, it is less commonly used to cover more proximal defects, like that ones on the anterior and posterior sides of the elbow.

This flap is not so popular among some surgeons because of its supposed complex and tedious elevation[4]. The authors outline some practical tips that make PIOF dissection linear and consequently easier and safer[5-7].

Surgical Anatomy

The anatomy of the posterior interosseous arterial axis of the forearm is well known and documented in common anatomical textbooks; here will be highlighted only relevant details[8].

The PIOF is vascularized by perforators of the posterior interosseous artery (PIA). This take origins from the common interosseous artery, 1cm after its origin from the ulnar artery.

The posterior interosseous artery emerges at the lower border of the supinator in the lower forearm. It descends on the radial side of the intermuscular septum between the extensor carpi ulnaris and extensor digiti minimi. It is important to highlight that this vascular axis is always clearly visible from the radial side of this intermuscular septum, while it is not visible from the ulnar side. The PIA receives an anastomotic branch from the anterior interosseous artery (AIA) 3 cm proximal to the distal radial ulnar joint.

In the intermuscular septum between the extensor carpi ulnaris and extensors digiti minimi, the PIA gives off four to seven septocutaneous perforators.

Approximately, these perforators are divided in 3 groups[3,7]: proximal, midpoint, and distal. The proximal perforators were considered significant in the originally described technique, even though their tedious dissection. The distal group is relevant only for antegrade free PIOF. The midpoint group is the fulcrum of the distally based PIOF. This is located lightly distal to the center of a longitudinal line drawn from the lateral epicondyle extending to the distal radioulnar joint (DRUJ).

The branches of the posterior antebrachial cutaneous nerve run under the dorsal skin of the forearm and carry a well-developed arterial perineural network with connections with the septal perforators off the interosseous axis, the so-called neurocutaneous circulation.

Its inclusion in the flap optimizes blood supply.

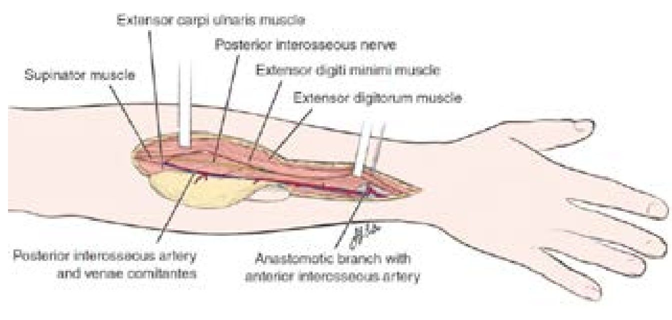

Figure 1: *Surgical anatomy*

Design

With the arm positioned in pronation and the elbow in flexion, a line is drawn from the lateral epicondyle to the distal radioulnar joint(DRUJ). The expected location of the dominant perforator is marked about 2 cm distal to the midpoint of this line.

The skin island is marked over this line, with the dominant perforator in its distal corner (in relation to the pedicle).The pivot point is marked also on this line at around 5 cm proximal to the ulnar styloid, where there is the communication between the posterior and the anterior interosseous artery.
The distance from the pivot point to the nearest part of the defect is measured finally to assess the correct pedicle length.

Surgical Technique

The following simple steps avoid the risk of harvesting the flap out of the axis of the interosseous vessels and consequently cutting of the main perforators:
1) Dissection starts distally to precisely identify the pedicle location, which lies in the septum between the Extensor Digiti Minimi (EDM) and Extensor Carpi Ulnaris (ECU) compartments. An accurate identification of the muscles is more complicated in the fleshy proximal part than in its distal part. A simple maneuver, indeed, can be performed distally to help identify the PIA pedicle, which is often small, and can be damaged: passive movement of the little finger causes the EDM tendon to move under the translucent fascia. After that, the thick ECU tendon is easily identified ulnar to the EDM. This provides the position of the proper septum and consequently the vascular pedicle.
2) Once the septum between ECU/EDM compartments is identified, it is explored from the radial side as vascular axis is always clearly visible from this side: An incision is made on the fascia of EDM. Radial retraction of the EDM exposes the posterior interosseous vessels and the pedicle is identified against the septum. A thin strip of fascia is maintained over the septum and pedicle, which protects the pedicle and simplifies elevation of the POIF. The septum is explored proximally until the dominant cutaneous perforator is identified. The motor nerve branch to the extensor indicis proprius is preserved.
3) The dissection proceeds on the ulnar side. The fascia is incised over the ECU tendon and muscle. Dissection goes radially with an ulnar retraction of ECU: attention shall be given to not to damage the intermuscular septum and the pedicle because the interosseous axis is rarely visible from the ulnar side of this septum.
4) The PIA is dissected only a few millimeters proximal to the midpoint perforator, ligated, and divided. Dissection proceeds dividing the septum deep to the axis. The intermuscular septum is incised on the radial side to always visualize the interosseous vessels during the dissection. The muscles are retracted and the flap is elevated from proximal to distal. This part of the dissection is fast, up to the origin of the connection with the AIO artery. The flap can be safely tunneled to reach the hand defect.

Discussion

Despite positive outcomes for reconstruction of a great range of defects and the added benefits of minimal donor site morbidity with primary closure of the donor site, the PIOF remains a second choice for most reconstructive microsurgeons. Between the factors that have limited the convenience of the PIOF, there are the tedious and time-consuming dissection originally described and the reported venous congestion. Even if this is not a flap for the occasional microsurgeon, with the technical modifications described here it is linear and consequently easier and safer flap, particularly indicated in small and frequent traumas of the hand. The original technique involved dissection of the PIA in the proximal half of the forearm to include the proximal perforators. Recent literature has shown that it is not necessary for flap survival. This is possible owing to the inclusion of the posterior antebrachial cutaneous nerve (PACN) branches[9]. These branches course under the dorsal skin of the forearm and carry a well-developed arterial perineural network with connections with the septal perforators off the interosseous axis, the so-called neurocutaneous circulation. Its inclusion in the flap optimizes blood supply. Furthermore, in the authors' experience, starting the dissection from the radial side to visualize the vascular axis as soon as possible and to keep an eye on the vascular pedicle during the different phase, reduces the risk of injuring the vascular pedicle. As already reported in the literature, the venous congestion of this flap seems to be attributed more to technical errors than to intrinsic problems of the flap.

This flap also has disadvantages: while the scar on the donor site is acceptable if direct closure is possible, the sequelae following a skin graft are much more evident. The back of the forearm is an area frequently not covered by clothing and exposed to people's eyes. The authors recommend the grafting of a dermal substitute before the skin grafting to optimize the aesthetic result and reduce scar adhesions

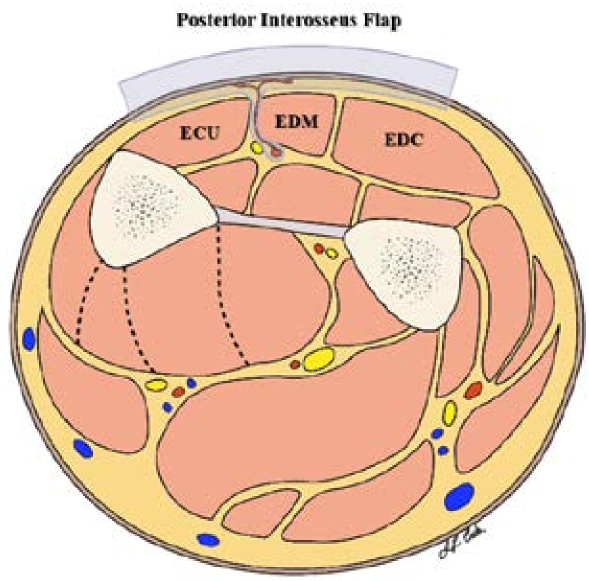

Figure 2: *Flap anatomy*

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6

THE USE OF EXTENSOR INDICIS PROPRIUS IN TENDON TRANSFERS.

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Introduction

The Extensor Indicis Proprius (EIP), arises from the dorsal surface of the ulna and the adjacent surface of the interosseous membrane, distally to the Extensor Pollicis Longus and ulnarly to the Extensor Pollicis Brevis. It passes through the fourth extensor compartment and it continues, to the extensor hood, of the metacarpophalangeal joint of the index finger. It is situated to the ulnar side of the Extensor Digitorum Communis tendon to the index. The EIP tendon, provides independent extension of the index finger. It is also acts as an adductor of the index finger, because it is situated ulnarly to the long axis of the finger. On the other hand, the Extensor Digitorum Communis tendon, acts as an abductor of the index finger.

The EIP provides a graft of sufficient length and has an optimal line of pull to provide advanced mechanical benefit and favorable torque in comparison with other tendon grafts.

Indications

The EIP tendon is used in a few tendon transfers, in an effort to restore the function of the hand, resulting from peripheral nerve damage or due to lacerations of other tendons. The use of this tendon in tendon transfers, gives satisfactory results, without affecting the function of the index finger.

The EIP tendon is used to restore the function of the abductor pollicis brevis and opponens pollicis, resulting from median nerve paralysis [1, 2].

In ulnar nerve palsy, it is performed, the so called, adduction plasty, with EIP tendon transfer, to correct a weakened pinch mechanism [2, 3].

It is also commonly used to restore the function of the thumb, resulting of a rupture of the Extensor Pollicis Longus. This particularly rupture is caused due to a post-traumatic or degenerative change of the tendon. It may happen, in rheumatoid arthritis[4]. In these cases, we transfer the EIP tendon to the Extensor Pollicis Longus.

Another common use of the EIP tendon, is in case of a rupture of the Extensor Digitorum Communis tendon of the middle, ring or small finger in rheumatoid arthritis or as an alternative reconstruction method for the abducted small finger in case of Extensor Digiti Minimi muscle anatomic variations [5].

Graft harvesting - preparation of the graft

Graft harvesting and positioning for restoration of the Extensor Pollicis Longus requires three incisions: a semicircular incision proximal and ulnar to the metacarpophalangeal joint of the index finger to divide the graft, a transverse incision on the distal margin of the forth extensor tendon compartment to redirect the graft and a longitudinal incision over the first metacarpal to interlace the two tendons. A subcutaneous tunnel is used between the second and the third incision for passage of the tendon[6].

In case of low median nerve palsy the tendon is to be traversed around the ulnar side of the wrist and through a palmar subcutaneous tunnel at the radiolateral border of the metacarpophalangeal joint of the thumb. In order to bring the thumb in position of opposition EIP is sutured to Abductor Pollicis Brevis [7, 8].

In low ulnar nerve palsy, EIP transfer is used to correct the abducted small finger. The tendon graft is passed palmar to the superficial transverse metacarpal ligament and dorsal to the deep transverse metacarpal ligament and attached to the normal tendinous insertion of the third Palmar Interosseous muscle. It can also be attached to the distal and radial part of the extensor hood when the muscle is ruptured [5].

Extension of the middle, ring or small finger, when there is a rupture of the Extensor Digitorum Communis (EDC) tendon in rheumatoid arthritis patients, can also be restored by EIP transfer. The combination of end-to-side and EIP transfer seems to give better surgical outcome for triple fingers extension loss [9].

Avoiding surgical trauma to the dorsal aponeurosis and leaving the dorsal hood intact leads to better postoperative function of the index. For this reason, EIP sectioning is to be performed directly proximal to the dorsal hood, avoiding surgical trauma to the dorsal aponeurosis. An established process is to reattach the distal stump of the EIP to the EDC tendon in order to avoid instability of the extensor tendon and extension deficiency of the index finger.

The surgical technique is relatively similar throughout the studies mentioned in the literature, with most authors preferring the Pulvertaft weave suture technique. Even though this is considered the standard technique in tendon transfers and transplants there are studies that have shown that side-to-side repair technique offered superior biomechanical outcomes with comparable repair bulk [10]. Another commonly used method is interlace suture with "fish-mouth" incision that offers the advantage of a more delicate bulging.

Optimal graft placement - tensioning

Correct positioning and tensioning of tendon ends is critical in securing the optimum outcome. In order to maintain normal moment arm some authors propose insertion of the graft through a window in the retinaculum of the fourth dorsal compartment [11].

A great challenge of tendon transfer is the correct setting of the transfer tension. The means for tensioning during tendon transfers are approximate and not very quantifiable. Most authors base their decision on their experience and through intraoperative range of motion check [12]. Standard and over-tensioning in the transfer of EIP to Extensor Pollicis Longus for chronic rupture of the thumb extensor, both seem to provide acceptable functional outcomes. Furthermore, the over-tensioning technique offers significantly better results as far as the range of motion, the elevation deficit, and the strength of the thumb is concerned [13, 14].

To quantify tensioning ultrasound elastography may be useful. Ultrasound acquisitions measured the elasticity modulus of the EIP muscle at different stages: rest, active extension, active extension against resistance, EIP section, distal passive traction of the tendon, after tendon transfer at rest and then during active extension. According to this method the tension applied during the transfer seemed close to the resting tension [15].

It is also of great importance EIP graft and EPL tendon to be connected as far proximally as possible seeing that suturing the tendon too close to the metacarpophalangeal joint can affect the direction of pull and limit the range of motion of the thumb.

Postoperative care

Postoperative treatment regimens range from immobilization for 3 to 5 weeks, to early dynamic extension splinting, to complete free active protocols. For this purpose a thumb and forearm plaster cast or a thumb splint can be applied. Immobilized patients tend to regain their hand function less rapidly, while dynamic and early active protocols seem to provide comparable clinical results [16, 17].

This procedure requires little postoperative re-education. The main goal is to enhance the neural plastic changes at the primary motor cortex level by training the patient to separate movements of the index finger and thumb or the other fingers.

Complications

Complications following Extensor Indicis Proprius tendon transfer are loss of strength, independence and mobility in the index finger in extension. To be more specific, harvesting for tendon transfer leads to decreased independent and dependent strength as well as decreased active extension of the second MCP joint. However, it has minor impact in function and should not compromise the use of the EIP as a tendon transfer [18]. Postoperative complications of index may be avoided if the EIP is sectioned directly proximal to the dorsal hood or reattached to EDC tendon, ensuring minimal surgical trauma to the dorsal aponeurosis [19, 20].

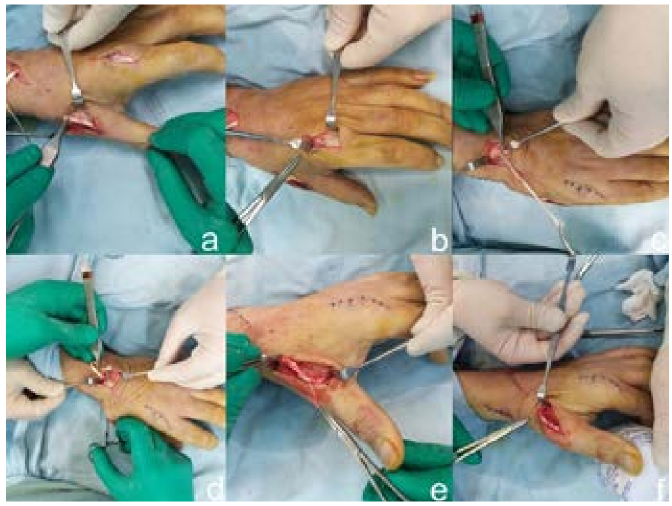

Figure 1: a. *Extensor Indicis Proprius (EIP) graft harvesting for restoration of the Extensor Pollicis Longus (EPL) through three incisions (incision proximal and ulnar to the metacarpophalangeal joint of the index finger to divide the graft, incision on the distal margin of the forth extensor tendon compartment to redirect the graft and incision over the first metacarpal to interlace the two tendons) ,* **b.** *reattachment of dorsal aponeurosis,* **c.** *EIP graft and extensor retinaculum,* **d.** *subcutaneous tunnel, landmarks: palmar of extensor communis digitorum and dorsal of extensor carpi radialis longus and extensor carpi radialis brevis,* **e.** *Pulvertaft weave suture technique (non-absorbable monofilament suture) under tension (wrist: flexion 30^o, metacarpal joint: full extension),* **f.** *final result with intraoperative tensioning test.*

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7

Treatment Plan for Fingers Involving Replantation around the Proximal Phalanx How I do it? – From Initial Treatment to Acquisition of Articular Range of Motion with an External Fixator-

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Introduction

For improving the functions of replanted digits or other injuries, therapeutic strategies focused on reliable initial treatment in consideration of two-stage reconstruction and postoperative rehabilitation is important. Particularly in cases with periarticular injury, not only reliable reconstruction of the articular surface, but also the repair of the soft tissues, such as the flexor and extensor tendons, is important. When range of motion (ROM) exercises are given before bone union, while exerting traction on the joint, to avoid contact with the articular surface, it is appropriate to use a movable external fixator. I would like to introduce my ingenuity to achieve these goals, focusing on specific cases.

Subjects

The subjects were patients with complete or incomplete traumatic amputation (i.e., without blood circulation) near the proximal interphalangeal (PIP) joint, including those with sharp amputations, press injuries and avulsion injuries. This study involved 10 fingers of 8 patients who wore movable external fixators (compass PIP hinge external fixator [CPH]1) or Ilizarov mini external fixator for fingers [IM]2); CPH for 6 fingers and IM for 4 fingers) for joint traction and ROM exercises.

Methods

1) Reduction of the articular surface

If the bone fragment was relatively large and amputation was sharp, criss-cross pinning with Kirschner (K)-wires was used for osteosynthesis, in principle. Soft wiring was added or miniscrew fixation was performed, with the goal of early start of ROM exercises, depending on the size of the bone fragments.

In addition, if there was a bone defect requiring later bone grafting, such as cartilage grafting, a CPH was placed to prevent joint contractures before the second-stage reconstruction. This is also useful for patients who are at a risk of developing infection, as well as in those with bone defects.

I also used a special method in which osteosynthesis was performed using a movable external fixator made by adding original parts to IM; only traction was exerted on the joint without allowing movements at first, and approximately 4 weeks after the surgery, the fixation of the rotation axis was loosened to allow ROM exercises to be performed. This method has the advantages that wires inserted into the phalanx can be used without replacement and that it can be adopted in hospital wards and outpatient clinics.

2) Extensor tendon suture

Kessler and mattress sutures were used, in principle, and in cases with findings such as disarticulation, anchor reinforcement was also used to reconstruct the central slip.

3) Flexor digitorum profundus (FDP) tendon suture

The FDP tendon was sutured. Four-strand suture was used, in principle, and conventional Kessler suture was also used in some cases. The flexor digitorum superficialis (FDS) was sutured in some cases of disarticulation, but only the FDP tendon was sutured in cases of severe soft tissue crush injury.

4) Postoperative fixation position

The mid-wrist position, in which the tendons are naturally balanced, was used, in principle, although depending on the tension during vascular suture. The wrist was held in a resting position, slight dorsiflexion position, in principle, although depending on the tension during vascular suture. If the tension of the blood vessels and nerves allowed, fixation was performed in a somewhat extended position.

If there were no problems with the hemodynamics of the replanted digit, an external fixator was placed 2 to 4 weeks after the surgery.

5) Anticoagulant therapy

Heparin was administered at the dose of 10 000 to 20 000 international units (IU) (activated clotting time [ACT] ≤ 150 seconds) and prostaglandin was administered at the dose of 120 μU (40 μU 3 times a day), in principle.

6) ROM exercises after placing an external fixator

A protocol in which patients were discharged 2 weeks after replantation was used, in principle.

If there was no particular reason, such as skin ulcer or infection, active-assisted ROM exercises were performed for 6 weeks after placing an external fixator and then changed to active ROM exercises (early exercise as per the instructions of the surgeon).

7) Additional surgery

Tenolysis, nerve grafting, bone grafting and other operations were added. For details, see Table 1.

As described above, some patients wore an external fixator to allow space in the defective joint in the initial treatment, and later underwent osteochondral grafting3,4) or other operations. This is useful for detecting signs of infection and serves the purpose of preventing soft tissue contractures, because the external fixator is movable5).

Some patients required flexor tenolysis when sufficient bone support was obtained.

Results

The patients had a mean total active motion (TAM) of 56% and a mean score of 67 on the new functional assessment scale for amputated digits published by the Japanese Society for Surgery of the Hand. The outcomes were good, considering that PIP joint fixation has been selected in many medical institutions. Osteochondral grafting was performed for 3 fingers and autologous bone grafting for 1 finger.

Table 1: Data analyses

B	C	D	E	F	G	H	I	J	K	L	M	N
	Side	Thumb	Index	Middle	Ring	Little	External fixator		Additional surgery1		Additional surgery2	
Case							CPH					
1	Rt		PIP77/91									
2	Lt		PIP49/64				CPH					
3	Rt		MP41/61	MP41/58			CPH*2		Costosteochondral graft*2			
4	Lt					PIP47/64	IM					
5	Lt				PIP56/63	PIP55/62	CPH*2(Ring,Little)		Costosteochondral graft		Tendon graft,Pulley reconstruction	
6	Rt	IP72/71					IM		Extension contracture release			
7	Rt		PIP61/70				*IM(Extension contracture release after15yrs)					
8	Rt		PIP71/82				IM(Tempolary ORIF)		Iliac bone graft, IM(hinge)			
(TAM/JSSH score, Average)			PIP(59.8/73.6)			PIP(51/63)						

Case 2

A 56-year-old male presented with an avulsion amputation injury sustained while he was using a grinder (Fig1a,b).

Fig1 a. *On admission*

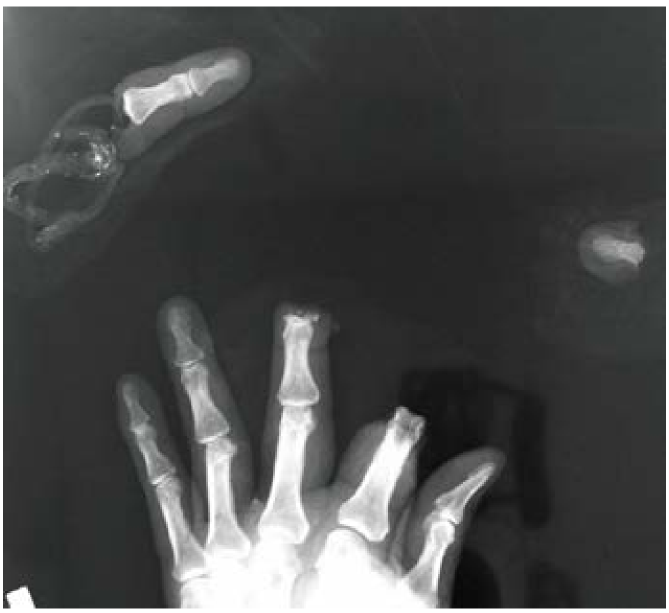

Fig1 b. *On admission XP*

The FDP tendon was retracted to the level of the wrist and sutured using the Kessler method, and suture of the extensor tendon was reinforced with anchors. Three weeks after the replantation, a CPH was placed (Fig1 c,d).

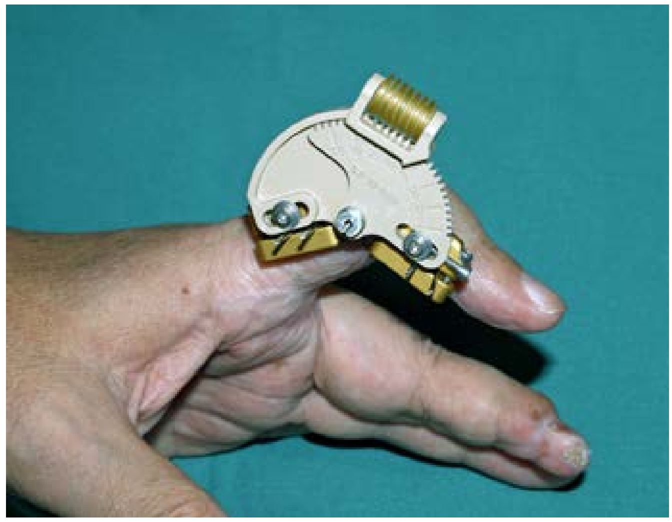

Fig1 c. *CPJH application*

Fig1 d *XP : CPJH application*

At Week 4, active-assisted ROM exercises were started. When rehabilitation exercises were not being performed, the joint was fixed at an angle of -10°. At Week 7, active ROM exercises were started, and at approximately Week 10, passive ROM exercises using a worm gear were started. Ten months after the injury, the TAM was 49% and the mean score on the assessment scale published the Japanese Society for Surgery of the Hand(JSSH score) was 62, indicative of a good outcome(Fig1 e,f). Tenolysis was performed, because priority was given to social rehabilitation.

Fig 1e *Final XP*

Fig1 f . *Final function*

Case 3

A 54-year-old male presented with an incomplete amputation injury of the proximal phalanx of the left little finger sustained while using a press (Fig2 a).

Fig2 a. *On admission XP*

The ulnar digital artery, dorsal digital veins, and digital nerves were reconstructed, and osteosynthesis was performed using IM (with an M3 device) (Fig 2b).

Fig2 b*. Temporary fixation by IM*

An IM made movable using originally created parts (hinge type) was placed (Fig2 c,d). During the initial operation, the moving part was fixed mainly for traction. Four weeks after the surgery, an adjustment was made to allow movement of the moving part, and ROM exercises were started. The patient could return to work in the steel industry in as short as 2 weeks after the injury, and firm fixation of the fracture site proved to be useful for the early return to work. Ten months after the surgery, the TAM was 47% and the outcome was rated as good based on assessment on the assessment scale published by the Japanese Society for Surgery of the Hand(JSSH score)(Fig2,e).

Fig2 c*. IM hinge applied*

Fig 2 d *ROM exercise by IM hinge*

Fig2 *e. Final ROM*

Discussion

Severe finger injuries, such as finger amputation, usually involve not only fractures, but also severe soft tissue injuries, which greatly interfere with the postoperative functional gain. Particularly in cases of injury around the PIP joint, arthrodesis with shortening has been generally performed, because priority is given to engraftment. It goes without saying that the most important goal of replantation is engraftment. However, medical technology has advanced to date, and I think that the goal should be to gain better function.

To achieve this goal, not only excellent microsurgical techniques, but also devices that would serve this purpose are required. As mentioned above, it is essential to balance rigid osteosynthesis with soft tissues in the initial treatment. In addition, in cases with severe periarticular tissue injuries, it is necessary to allow ROM exercises to be performed while appropriate traction is exerted on the joint for preventing joint contractures and ankylosis.

CPH has an innovative design and serves the above purpose. Although it has undergone several improvements, it is not suitable for rigid osteosynthesis due to its material properties. IM has the advantage that the shape can be freely changed by changing the combination of parts, and it is suitable for rigid osteosynthesis. However, pin insertion and assembly are somewhat cumbersome. I changed the IM parts to realize a movable IM. The modified IM is placed on the dorsal side of the fingers and is applicable to a wider range of fingers as compared to CPH, which is applicable only to the index and little fingers, in principle, but requires improvement in many aspects such as weight and X-ray permeability. It is necessary to provide early assistance for anatomical joint motion after performing anatomical reduction, as much as possible, and I would like to conduct further studies.

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8

Thumb reconstruction with the modified Fouche flap based on both the second and the third metacarpal arteries

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The authors have no conflict of interest.

Abstract

The use of a regional vascularized and sensory fasciocutaneous flap harvested from the dorsal aspect of the index finger (the "kite flap") is described as a new modified technique with respect to the vascularization pattern of the flap. The kite flap is probably the most advantageous and adequate flap to cover tissue defects at the dorsal and medial aspect of the thumb. The modification includes a) a wider pedicle that contains two metacarpal arteries (the second and partially the third at its proximal half) and b) at the level of the third metacarpophalangeal joint the third metacarpal artery is divided from the middle finger and harvested together with the flap the ulnar dorsal digital artery which is the right division of the 3rd metacarpal artery. Therefore, the modified flap is based on both dorsal digital arteries of the index finger, in contrast to the original description of the flap's pedicle including the second and the third metacarpal arteries. Using this modification, we have observed complete technical success and viability of the performed microsurgical reconstructions; the functional and aesthetic result was comparable with those using a original flap in all cases. The above flap is also indicted for covering pulp defects in patients with short thumbs or in partial or complete amputation of the thumb because in these circumstances the necessary length of the flap pedicle is shorter than in the normal thumbs length, so the kite flap's length is enough to arrive to the stump. Therefore, when the kite flap is based on both the superficial and deep metacarpal arteries it is absolutely successful, easy to perform, and associated with similar donor site morbidity with the original flap.

Keywords: Thumb defects; Flap; Kite flap; Microsurgical reconstruction.

Introduction

Microsurgical coverage of fingertips' defects is a difficult technical problem in hand surgery and requires adequate planning regarding the choice of flap and the operative technique. Local and regional flaps have been reported to overcome this problem; these include flaps based on a well defined pedicle, free flaps harvested from the toes (wrapped around or free pulp), cross finger flaps or other (submammary and inguinal) flaps.[1-4] Regional vascularized flaps are much more practical and advantageous compared to other flap types. One of these regional flaps is the kite flap introduced by Fouche.[5] This flap a fasciocutaneous vascularized (occasionally reversed) regional flap that is raised from the dorsal aspect of the first phalanx of the index finger and is based on the deep branch of the first metacarpal artery of the first web space.[5-8] Importantly, the kite flap can also be used as a free flap.[9] Its main indication is coverage of the dorsal and medial part of the thumb and reconstruction of the first web space due to contractures as in congenital hand anomalies. The kite flap is also very useful as a local flap for microsurgical coverage of the first web space. It causes less donor site defect compared to the radial artery forearm flap (Chinese flap), it is easier to mobilize and its vascularity is less vulnerable compared to the dorsal interosseous flap.[2-9] However, harvesting of the radial forearm flap must be performed very carefully, because of the danger to injure the radial artery pedicle.

Operative technique

We have used the kite flap in a series of 20 patients with thumb defects (15 patients with acute injuries and five patients with chronic defects). The flap's pedicle was formed originally from both the second and the third metacarpal arteries after a division of the third metacarpal artery at the level of the

Figure 2a. *Thumb pulp defect.*
Figure 2b. *Flap dissection.*

Six patients had a soft tissue defect of the medial or dorsal aspect of the thumb, and four patients had composite hand injuries with bone and soft tissue defects (Figure3A), both groups of patients requiring reconstruction. In all cases, a more wide pedicle was used (Figure 2B)third metacarpal artery. If the pedicle of the flap seemed to be in tension in coverage of the defect, the interphalangeal joint was slightly flexed and immobilized with a Kirschner wire (Figure 2CD). The wider flap pedicle included as many veins as possible towards the flap, a branch of the dorsal sensory radial nerve for the index finger, and the fascia of the first interosseous muscle (Figure 3B). After flap dissection and harvesting (Figure 3C), it was passed through a tunnel under a skin bridge, brought to the medial border of the thumb (Figure 3D), tailored to the defect and sutured carefully without tension.

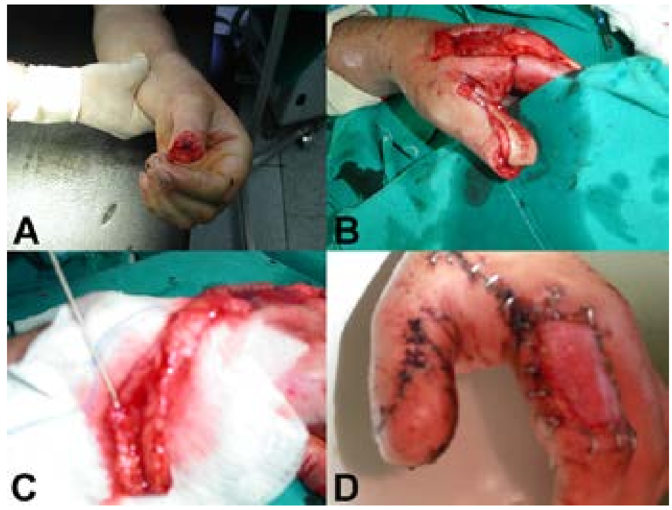

Figure 3a. *Thumb distal phalanx and skin defect.* **Figure 3b**. *Flap harvesting together the interossei aponevrosis.* **Figure 3c**. *Thumb Defect reconstruction.* **Figure 3d**. *Final result.*

Postoperatively, flap blood supply was excellent, without signs of venous insufficiency. At 15 days postoperatively, the sutures were removed and a physical therapy program was initiated, including early progressive mobilization, arriving a full range of motion at 4 weeks postoperatively. At two months postoperatively, the mobility of the thumb was excellent, close to normal. At the last follow-up, all flaps healed successfully at the recipient site without any wound dehiscence or necrosis. The functional, sensory and aesthetic result improved with time in all patients. A satisfactory sensory innervation of the flap was also evident. All patients were reasonably satisfied from the aesthetic result of the microsurgical reconstruction using this flap (Figure 3D).

Discussion

The fasciocutaneous kite flap is well suited for coverage of the medial or dorsal sides of the injured thumb and the pulp defect of a partially amputated thumbs, in the emergency setting or as an elective microsurgical reconstruction technique.[1-4] Compared to other techniques to cover a soft tissue defect of the thumb, the kite flap is superior because it can be applied with safety maintaining at the same time is vascularity and innervation[1,4,5,6,7,8] . Compared to a free flap, the time needed to harvest a regional vascularized flap such as the kite flap is lower, the required anesthesia is less complex, the surgical technique leaves much less stiffness to the fingers than a cross finger flap, and final cosmesis is more acceptable.

The kite flap is based on a true neurovascular bundle but the dorsal metacarpal artery has many anatomical variations.[10-12] In most cases, the artery follows the axis of the second metacarpal and can be located superficial or deep to the aponeurosis of the first dorsal interosseus muscle. There is always an important anastomotic circle at the level of the neck of the second metacarpal with the radial palmar collateral artery of the index and the palmar metacarpal artery. Often two arteries are present, one superficial and the other deep to aponeurosis. Therefore, it is important to include the aponeurosis in the pedicle. Sometimes also, the first intermetacarpal artery could be absent or hypoplastic. The nerve supply to the kite flap' pedicle comes from the sensory branch of the radial nerve.

Modifications has been described for the original kite flap as described by Fouche including the Holevich flap[13] in which the palmar deep branch (perforator) has been used, however with a number of reported flap necroses,[14,15] and modifications with 2 nerves or with nerve repair. In some cases, the flap can be harvested as a reversed flap, or as the TRAM-flap with distal microvascular anastomosis or index pollicisation based on the second dorsal metacarpal artery.[10]

This paper described a modification using a different vascular pattern to enhance the arterial supply as well as the venous return according to avoid vascular insufficiency and possible flap necrosis.

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9

Considerations in replantation at the level of forearm

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Introduction

Total or subtotal amputation at the level of distal third of forearm is usually result of injury caused by the machine/tool equipped with blade. Most commonly it is mechanic saw (crush type injury) or machete (guillotine type injury). In some cases, we encounter avulsion injury when part of the limb is torn away. It happens because hand or something tied around it is pulled abruptly with great force. In that type of injury structures are destroyed at different levels and at some length. This differentiate it from "cut" amputations.

Forearm amputations result in extreme impairment of the limb function. Also, cosmetic defect is very important. Successful replantation and revascularization allow patient to avoid such sequelae. The degree of function return depends on type of injury, skills of the surgeon and cooperation in postoperative period, which includes proper physiotherapy.

Figure 1 *Amputated hand on operating table and 4 weeks after successful replantation*

Most of the cases of distal third forearm amputations are indications for microsurgical treatment. However, when we qualify patient for the treatment, we have to check whether there are any contraindications:

- general health status that disqualify from long surgery
- extensive destruction of the amputated part
- exceeded time of warm or cold ischemia
- lack of microsurgical team or microsurgical equipment (however it seems reasonable that in some cases, replantation at distal forearm level can be performed by orthopedist and vascular surgeon, together)

In literature it is hard to find consistent guidelines concerning tolerable warm and cold ischemia time. Dealing with distal third forearm amputation it is recommended not to cross 8 hours of proper +4 Celsius degree cold ischemia. However, one can encounter indications that prolog this period up to 12 hours. In case of lack of hypothermia – warm ischemia time should never exceed 6 hours. The ischemia time starts at the moment of injury and finishes when circulation is regained, not when the patient is admitted to hospital with microsurgical team ready.

There were 9407 patients treated in 2001,

2004 and 2007 in USA with any amputation. Among them there were 940 amputations at the level of forearm or hand. Only 12% of the last group underwent replantation.
In our material the most of the patients are men and the most common cause is mechanic saw. Usually the non-dominant limb is affected if the accident with saw happens during work.

Technical considerations

The hand replantation scheme at this level does not differ significantly from the typical one and consists of debridement, bone stabilization, tendon repair, anastomosis or reconstruction of vessels and nerves and, finally, wound closure or coverage. An important factor that can change the order of procedures performed is the ischemia time, which is definitely shorter than that of the fingers. For this reason, the priority is to restore circulation by reconstruction of the arteries and veins and only then the remaining structures - tendons and nerves.

Debridement

Debridement is the first stage of replantation and its extent depends on the extent and nature of the injury. This is an extremely important stage and can be underestimated, so it should be carried out by an experienced surgeon. Due to the time of ischemia, the best solution is the parallel work of two teams. It usually starts with the amputated part, the basis is to identify relevant structures and prepare them for repair. Nerves, vessels are shortened to a level where there is no damage, thus healthy tissue. All devitalized or contaminated tissues and foreign bodies should be removed and washed out. Particular attention should be given to tendons and muscles that may have been crushed or avulsed.
Swabs for both aerobic and anaerobic culture should be taken. We carry out multiple washing with saline, in addition, the vessels of the amputated part can be rinsed with heparin solution.

Bone fixation

Because amputation concerns the level of bone shaft, the Kirschner wire stabilization often used in other replantations is usually insufficient, but it is not an error in selected cases. External stabilization, usually monolateral ex-fix, or in some cases plate stabilization should be considered. The external fixator is a safe method of supply, however, in case of difficulty and prolonged bone union after successful replantation, it is uncomfortable for the patient and may require a change to plate fixation. Initially, plating is more convenient because it can be the final solution, but they require more operating time, are significantly more expensive and more susceptible for infection. Shortening forearm bones by approximately 2-3 cm before stabilization is usually necessary. Plates are applied usually from dorsal or volar approach to radius and ulnar, dorsal side for ulna.

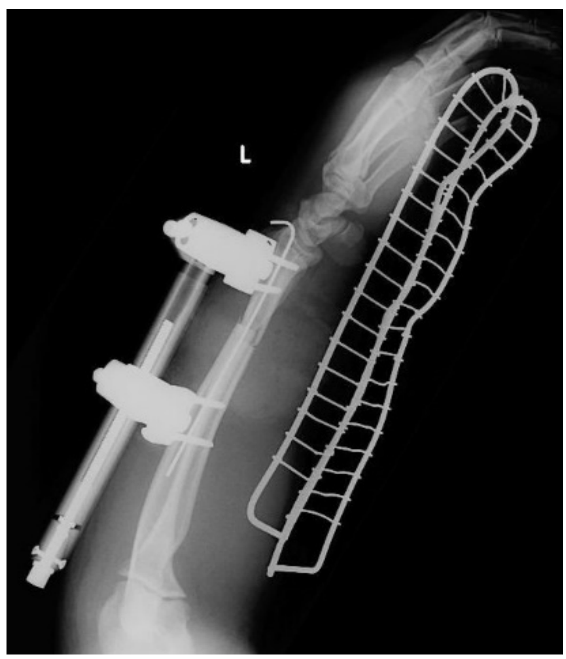

Figure 2 *Forearm fixation with ex-fix for radius and K-wire for ulna*

Tendon repair

In forearm amputation surgeon can meet three types of muscle-tendon injury: tendon, muscle-tendon junction or muscle belly.

In tendon the injury is to the fifth zone of the flexor tendons, the suture technique is not as demanding as in the case of sheath zones. We usually repair all tendons (superficial and deep flexors). You should not miss the wrist flexors and extensors, which provide additional wrist stability. We use a 2 or 4-strand core suture for the finger flexors, in the case of prolonged surgery we can make a 2-thread suture, e.g. according to Kessler. Because in this area the resistance to tendon movement is smaller and we can repair all the tendons, the patient can start active rehabilitation relatively early, after stabilization of the blood supply to the hand and with decreasing pain and swelling.

Extensors are usually joined with U-shaped 2-strand suture. The problem that we may encounter is damage at the level of tendon-muscular junction or muscle belly, then situational sutures should be applied adequate to the condition and mechanical resistance of tissues.

The type of suture used is usually non-absorbable, mono or polyfilament according to the experience of the hand surgery centre or operator, the size used is 2-0, 3-0 adequate to the tendon diameter (flexors / extensors of the wrist or fingers). Polyfilament threads usually are more stable in the tendon, which is important when approaching stumps. In contrast, monofilament threads have a more reliable knot and ease stumps approximation.

Reconstruction of vessels

The order of veins or arteries supply depends mainly on the surgeon's preferences. In simple amputations it is possible to make end to end anastomosis. At this level, we suture the radial and ulnar arteries in microscopic magnification, according to microsurgical technique, using non-absorbable monofilament sutures of size 7-0, 8-0.

Vascular defects are a problem. In some situations (partial amputations) may require temporary bypassing, this significantly increases the possibility of successful replantation by shortening the time of ischemia. In the case of defects, we perform reconstruction using most often the graft from the saphenous vein.

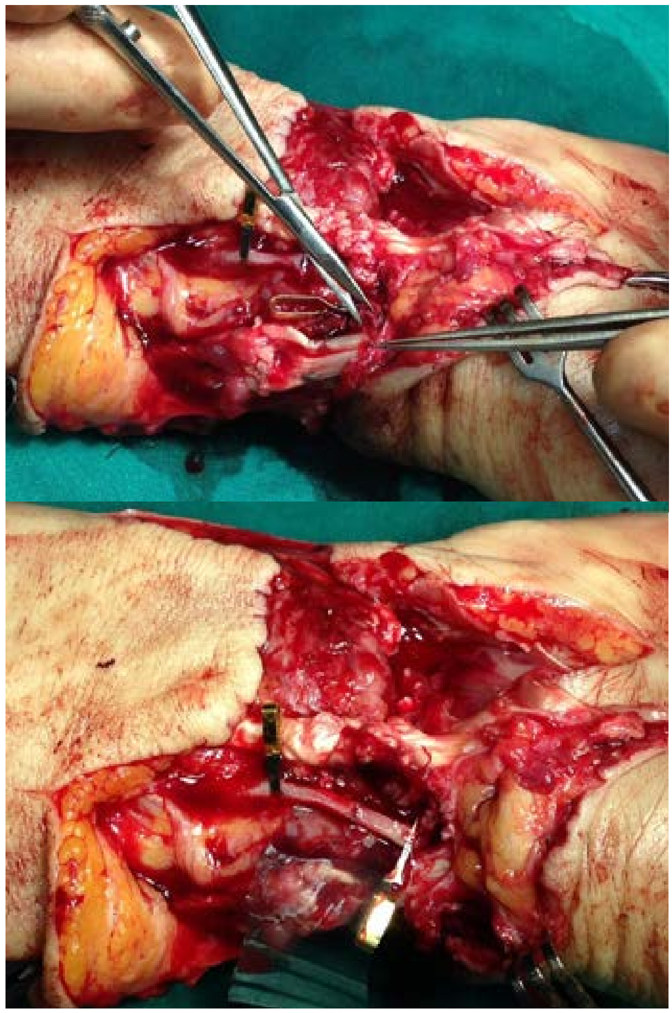

Figure 3 *Preparation of radial artery anastomosis and the result of end-to-end repair*

Nerve repair

In most situations, we perform nerve suture end to end in accordance with the typical microsurgical technique of epineural suture. For anastomosis of nerves at this level, we use monofilament, non-absorbable 6-0 size threads. Reconstruction of the nerve in the event of a defect in traumatic conditions is not recommended due to the difficulty in assessing the defect (extent of the nerve damage, e.g. after crushing), the uncertain condition and the replantation effect makes morbidity of nerve grafting higher than usual. In these situations, it is safer and usually not affecting the result to postpone the treatment of such damage after the local situation has stabilized.

Fasciotomy

Fasciotomy is an indispensable part of replantation at this level and should be routinely performed according to accepted technique.

Early complications

The most common early complications after replantation include venous or arterial insufficiency (ischemia), infection, bleeding and skin necrosis. To properly respond to these adverse situations after replantation, close observation of the state of the hand is required. It is performed regularly by nursing staff and a doctor, which should have experience with these kinds of procedures. The basis is clinical assessment of hand colour and temperature, and vascular play. One can also use appropriate tools such as a dedicated thermometer to measure surface temperature and a pulse oximeter.

Figure 4 Monitoring replanted hand with pulse oximeter

Venous insufficiency

This is a common problem after replantation, especially when venous vessels are inadequately anastomosed. In replantations at the described level, it occurs less often than the fingers because the veins have a larger calibre and the anastomosis is technically easier.

Typical symptoms of venous insufficiency - stasis - are a change in the colour of the hand from pink to darker, blue, lowering the temperature. The vascular game is slowed down and serous blisters may form. An early alarming symptom may be a significant bleeding to the dressing. Since the amputated part is significantly larger than in the case of fingers, the use of medical leeches, cutting the pad or removing the nail is insufficient. In the event of an outflow disorder, urgent venous anastomosis revision or reconstruction of the veins is indicated.

Ischemia

In ischemia, the hand has a pale colour and a reduced temperature. Evaluation of the vascular game is unreliable because there is no adequate inflow. In these cases, urgent revision of the arterial anastomoses, washing the vessels with heparin solution and re-anastomosis are indicated. In some of the cases conversion to vein graft is necessary, mainly in the situation when initial assessment of extent of the injury was inadequate.

Infection

It usually develops in a few days and is mainly caused by bacterial colonization during trauma (various environments) and abnormal circulation in the planted part (it can occur in the inflow or outflow disorders described above). We prophylactically use broad spectrum antibiotic therapy for aerobic and anaerobic bacteria.

Repeatedly, the infection does not undergo treatment and is the reason for reamputation.

Figure 5 *Infection with necrosis of the replanted hand*

Skin necrosis

In the case of hand replantation, circulation may not always be restored in every part of it, resulting in localized, limited necrosis. It requires gradual debridement and secondary adequate coverage after stabilization of the hand status.

Pharmacology

It is impossible to define one consistent and widely accepted protocol of medicines administration during literature search. Usually each microsurgical center has its scheme which is based on own experience and general guidelines. It is always adapted for each individual patient.

In our department we use routinely dextran 40000j 250ml three times per day at the beginning. Then slowly We decrease frequency depending on the status of patient and treated limb.

Physiotheraphy

Physiotherapy is a part of the outmost importance in the treatment process. It is based on good cooperation between patient, hand therapist and doctor. After surgery we immobilize the hand and the forearm in dorsal splint up to the tips of the fingers. Wrist is held in 30 degrees of flexion, metacarpo-phalangeal joints are held in 70 degree of flexion while interphalangeal joints are extended. Physiotherapy is begun just after surgery with edema control. Limb is elevated and patient is allowed to flex and abduct the shoulder – as tolerable. We can start passive exercises of fingers in the range restricted by the splint. After 4 weeks guarded active exercises of the fingers can be stared, under supervision of physiotherapist.

Of course, each protocol is designed for the individual patient. It depends on the extent of the injury and quality of repair. It is very important to check whether patient understands the physiotherapy protocol and wishes to participate in it.

Figure 6 Early assisted active exercises 10 days after replantation – place and hold

Secondary procedures

Even if the replantation is successful usually there are still some problems or injury sequelae that have to be fixed.

Negative pressure wound therapy (NPWT)

This technique applies negative pressure on acute and chronic wounds. It increases perfusion in edges of the wound, stimulate its healing, speeds up granulation and removes physically bacteria. This type of dressing might be useful as a secondary procedure after replantation or revascularization. It can be placed over bare tendons or bone. Swelling or massive exudation are not contraindications. After fasciotomy the wound that cannot be closed primarily can be covered with that dressing. Also, it can cover skin grafts. One has to remember that NPWT is never definite procedure, but rather a step to heal the wound. Although it has many applications, it should not be placed directly over vessels, nerve or necrotic tissue.

Tendons and joints

After successful replantation patient needs a good physiotherapy, under supervision of the hand therapist. If there are no improvement at all during 3 months or they are very slow, we have to find out the cause of such situation. If the range of motion does not get better, we have to examine whether joint contracture or tendon adhesions or both are the reasons. Depending what we have found out we can advise patient to undergo tendon adhesion release (tenolysis) or joint release (arthrolysis) or both. After replantation of distal third forearm usually the problem are adhesions of finger flexors and/or extensors.

Nerves

If during control we do not observe any advancement of nerve regeneration after repair then it should be precisely examined. In everyday practice ultrasound examination is the most easily available. Evaluation should be done by experienced specialist. Adhesions, narrowing or secondary lack of continuity can be found. Also, fascicular structure of the nerve can be checked. If adhesions or narrowing is detected then neurolysis is recommended. If the nerve suture separation is diagnosed then secondary repair or reconstruction should be considered.

Tendon transfers, tenodeses and capsulodeses

After distal third forearm amputation frequently function of intrinsic muscles does not recover. It may restrict daily and occupational activities. In such case we can consider tendon transfers, tenodeses and capsludeses to regain function to some level. Those procedures were design to treat low median and ulnar nerve palsy. When tendon transfers are considered one has to evaluate strength and function of donor muscles because during the complete amputation they were also injured.

Bone

Fracture union after replantation is burdened with similar complications as open fracture. If we diagnose patient with delayed union or non-union, then we have to find a reason for it and start treatment. Details of treatment protocols in such cases exceeds this course book. However, we have to remember that stable bone fixation is necessary for early physiotherapy.

Results

In the majority of studies summarizing the results of replantation, the authors found no significant factors that affect success (age, gender, comorbidities, smoking, alcohol) except for the time of ischemia.

Based on available studies, we can expect 70 to 80% of the global range of motion in relation to the healthy side, sensation on finger tips with a resolution of 8-12 mm. The authors give even better results in replantations in children - movement up to 90% and two-point resolution from 5 to 7mm.

Another issue is the time to recover and obtain the appropriate hand function. In the case of amputation of the hand, this time is longer, many secondary procedures are performed, patients often do not return to work and use a worker's compensation. One should not forget about the psychologist's support in the case of long-term problems, however, according to some reports, in the group of people after hand replantation there are many patients with a good treatment result and a high level of satisfaction.

Figure 7 Fingers ROM half a year after replantation

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10

Radial Artery Reconstruction after RFFF Raising

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The radial forearm free flap (RFFF) has been the most widely used free flap for years in head and neck reconstructive surgery [1]. However, despite excellent results respect to the site of reconstruction, donor site morbidity cannot be neglected [2]. Head and neck reconstructive surgery frequently requires replacement of tissue to provide the most functional and aesthetic result [3]. This flap is also very useful in cleft palate reconstruction, whenever the tissues are made up of scars, or in case of large tissue losses or even in those patients who already undergone reconstructions with traditional techniques that have failed [4]. The fasciocutaneous radial forearm free flap (RFFF) has become the most commonly used free flap in postablative head and neck reconstruction [5,6]. Its advantages include its thinness, versatility, and pliability, the relative hairlessness of volar wrist skin, and the reliability of its long and large diameter pedicle, making it suitable especially for the replacement of the intraoral mucosa but also other application fields such as the reconstruction of complex hand defects [7 8]

Although excellent results of the primary defect can be achieved, a concomitant functional and aesthetic morbidity of the weakened donor site is often observed [3]. Over the last few decades, harvesting modifications have been obtained in an effort to improve these undesirable features, including various types of dissection techniques, autologous or artificial skin grafts, primary closure procedures, or switching to comparable free flaps (Thinned ALT or MSAP)[9,10]. The biggest damage in the donor area is done against the radial artery, which must be sacrificed [11,12]. The rest of the hand keep on vascularized exclusively by the ulnar artery through anastomotic arcades at the level of the palm and wrist, checked in a meticulous way before through a Doppler and an Allen test [13,14]. Additional symptoms, compatible with relatively good use of the hand, may appear after surgery, and include vasoconstriction phenomena, greater sensitivity to cold, paraesthesia, decrease strength and performance perceived by the patient, also related in most cases to psychological aspects [15].

Although the attention of the examined literature focuses specifically on the functional sequelae related to tendon sliding of the volar forearm surface [16], or cosmetic ones, relating to the scar left by skin cover [17], little or no attention is paid to the vascular aspect that arises by the sacrifice of the radial artery [4]. The most common complication described is failure of the skin graft, with exposure of the flexor tendons of the wrist (20%-33%), followed by nerve sensory disturbances (30%) and functional complications such as a reduction of wrist mobility as a result of the damage of parts of the ramus superficialis of the radial nerve [18–22].

After long-term evaluation of the donor site morbidity, it has been demonstrated that the operated arm exhibits a decreased dexterity of the hand, without change in wrist and forearm range of motion, but increasing the range of motion of the little finger. In addition, a decrease in function and an increase in pain have been found [3].

Disadvantages of the RFFF include poor cosmetic scar in the forearm region (in some patients, the donor site scar of the forearm can act as a social stigma) 23, occasional numbness in the first 2 fingers, but mainly the sacrifice of a major artery of the limb 24. We could get less morbidity in these patients, through the radial artery reconstruction during the flap insetting. The procedure does not extend the operating times if a second team is available [25].

Figure1 *- in the middle third of the forearm, the brachioradialis muscle raised by the hook, to make visible the perforating vessels that connect it to the radial pedicle made of one artery and two comitant veins.*

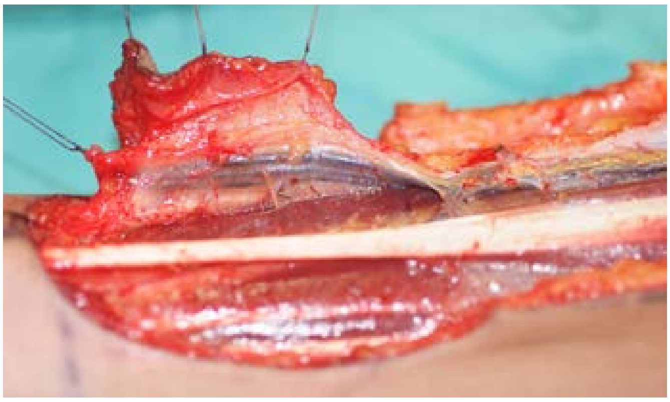

Figure2 *- opposite side view from the previous image. The rising of the skin palette prepared in correspondence of the artery and the two veins begins. The floor of this layer is made up of the flexor pollicis longus of the thumb. The radial artery is tied with a landmark as seen on the left, like its distal stump.*

Figure3 *- the flap fully prepared with its pedicle, proximally up to the bifurcation of the brachial artery.*

Figure4 *- radial artery reconstruction: flow check after proximal and distal anastomosis*

Figure5 *- donor area: tendency to hypertrophic scarring. No sliding problem of the flexor tendons or wrist movements*

Figure6 *- anterior hard palate reconstruction. One month follow-up*

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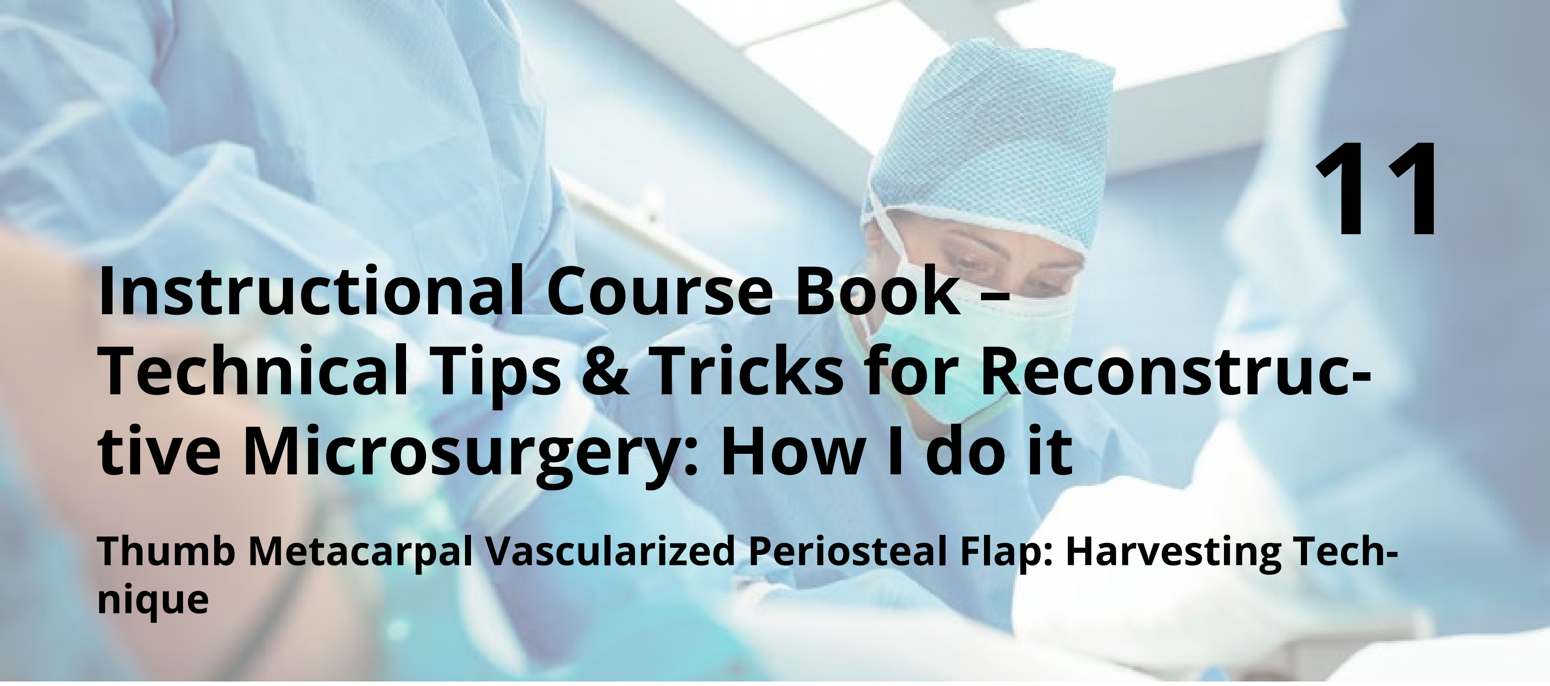

11

Instructional Course Book – Technical Tips & Tricks for Reconstructive Microsurgery: How I do it

Thumb Metacarpal Vascularized Periosteal Flap: Harvesting Technique

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Introduction

This vascularized periosteal flap is obtained from dorsal first metacarpal (VTMPF) based on the first dorsal metacarpal vessels (FDMV) (Figure 1) (Barrera-Ochoa, Mendez-Sanchez, Mir-Bullo, et al. 2019)(Barrera-Ochoa, Mendez-Sanchez, Rodriguez-Baeza, et al. 2019) . It was inspired on thumb metacarpal vascularized bone graft described by Bertelli et al.(Bertelli, Tacca, and Rost 2004).

Currently, we adjunct this flap in any scaphoid nonunion, either in children or adults, associated to bone grafting and fixation . In our series of fifty-two patients older thah 18 years old with scaphoid nonunion and at least one poor prognostic factor (delay in presentation of over 5 years, the presence of avascular necrosis and/or previous nonunion surgery), 96% (50) achieved bone union.

Flap harvesting surgical technique steps

1. A tourniquet is used without Esmarch's band exsanguination.
2. Skin incision. Curved or zig-zag from the dorsal aspect of the thumb metacarpophalangeal joint to a point midway between the extensor pollicis longus and the extensor pollicis brevis (EPB) within the anatomical snuffbox (Figure 1).

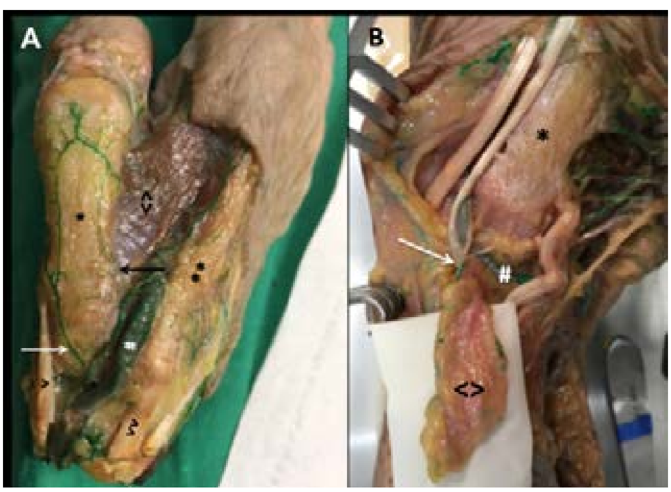

Figure 1. *Anatomy specimen: (A) posterior compartment of thumb metacarpal (TM) (*). FDMA (white arrow) originating in the radial artery (#) between the APL (^) and ECRL (^) muscles run longitudinally over the periosteum of the dorsal aspect of the TM. (**) Second metacarpal. (<>) First dorsal interosseous muscle. (B) VTMPF(<>) harvested from the TM (*), pedicled on FDMA (white arrow) which arises from the radial artery (#).*

3. EPB tendon sheath is opened and retracted in an ulnar direction to expose FDMV.
4. A rectangular periosteal graft is designed in the distal 2/3 of the metacarpal.
5. The distal, ulnar and lateral borders of the flap are incised. In the radial border some overlying abductor pollicis brevis muscle is detached.
6. The periosteal flap is elevated from distal to proximal using a periosteal elevator.
7. Critical point: Incision of proximal border of periosteal flpa from the deep aspect (cambium layer) to superficial aspect and elevation of the flap detaching all soft tissue over the proximal periosteum and trapeziometacarpal joint capsule to avoid injury of the pedicle (i.e. FDMV)
8. Tourniquet might be released to verify periosteal flap vascularization.

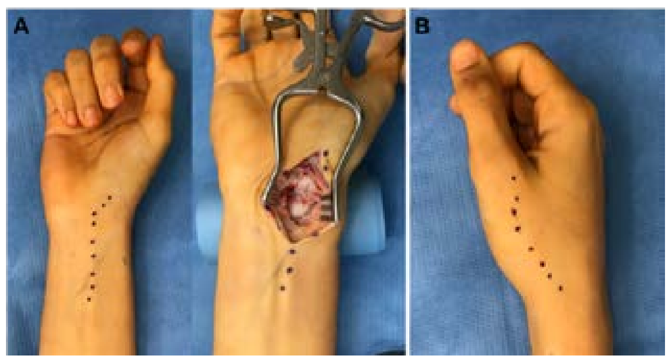

Figure 2. *Incisions. See point 2 in harvesting surgical steps.*

9. A tunnel down to the tendons of the first dorsal compartment is created to reach scaphoid nonunion.

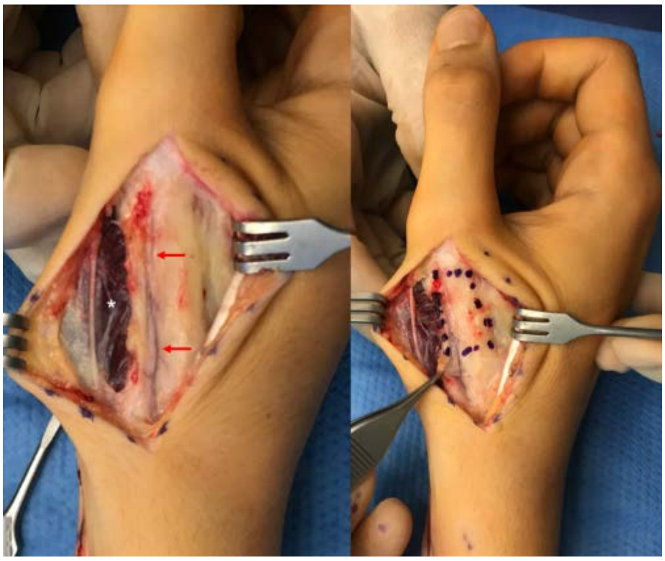

Figure 3. *See point 3 and 4 in harvesting surgical steps. FDMV (red arrows); APB (*).*

10. The VTMPF is placed transversely over the top of the nonunion and sutured to adjacent soft tissues

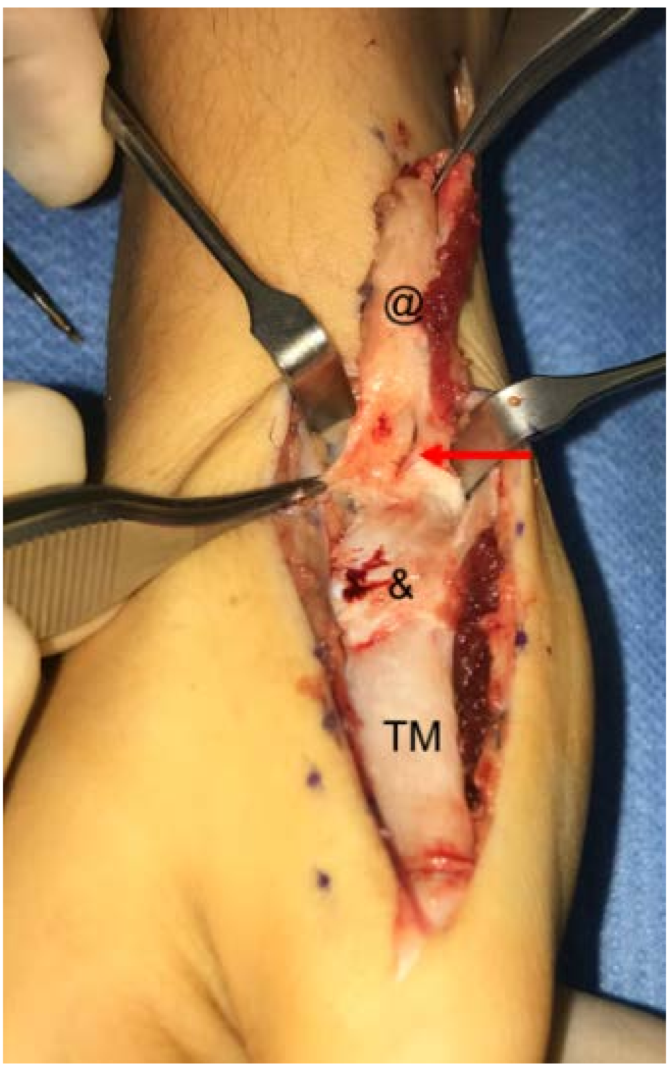

Figure 4. *See point 6 and 7 in harvesting surgical steps. VTMPG is harvested consisting on distal 2/3 of the dorsal thumb periosteum (@) and the FDMV (red arrow) protected and sourrunded by the soft tissue above the proximal dorsal thumb periosteum and dorsal trapeziometacarpal capsule.*

Figure 5. *See point 9 and 10 in harvesting surgical steps. The VTMPG (@) has been tunneled to the scaphoid approach. The nonunion site has been grafted with bone graft obtained from the distal radius (A). The VTMPG is placed covering the nonunion site.*

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12

PROLONGED HEPARINIZED ARTERIAL SHUNTING IN REVASCULARIZATION OF THE UPPER LIMB

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Abstract
Several approaches have been proposed in order to provide an efficient reconstruction and to avoid ischaemic time or related injuries in major traumas of the upper limbs. We herein report on the novel use of a prolonged heparinised arterial shunt by means of a T catheter in a case of a severe arm subamputation: this technique supported a safe and prolonged arterial shunting and allowed an accurate reconstruction of the surrounding bony and soft tissues with an artery-last sequence of repair. Histological analysis confirmed the positive effects of this early revascularization on muscular viability.

Introduction
The appropriate repair strategies and the most efficient sequence of repair still represent a matter of discussion in the management of major traumas of the upper limbs. Although several surgical procedures have been described so far, complications and side effects related to the timing of blood flow restoration remain major concerns. consistently, the importance of prompt blood flow restoration was advocated, since greater morbidity and an higher rate of failures/complications are often incidental to vascular injuries. Hence, despite early revascularization has been largely supported, the implication for constricted skeletal fixation and overall lower quality of repair demand new procedural strategies. Having these issues been considered, the adoption of short temporary arterial shunts supporting an artery-last sequence of repair was described in the early 80's: a favourable reduction of ischemic time and the chance to achieve a more precise reconstruction significantly supported this strategy. [1-8] Moreover, better outcomes with lower incidences of complications have been recently reported with this procedure.[9,10] Nevertheless, major traumas often require lengthy surgical reconstruction: in these cases, adoption of a vascular shunt for a short period of time may not be sufficient to prevent ischemic damage to distal stumps. Consequently, novel procedures and strategies should be investigated to support an artery-last sequence of repair with reduced ischemia time and with proper surgical times for better reconstruction. Histological analysis of actual effects of these procedures on muscular viability may further support their efficacy. We herein report on the use of a prolonged heparinized arterial shunt by means of a T catheter, to support a safe prolonged arterial shunting and to allow an accurate reconstruction of the surrounding bony and soft tissues.

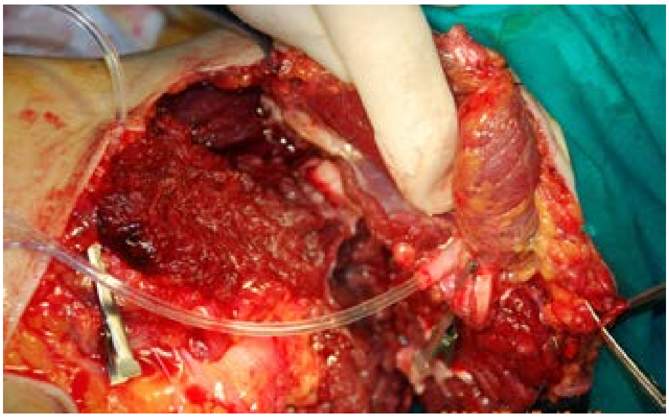
Case report
A 38 year-old-woodsman affected by a sub-amputation above the right elbow in a work-related injury was accepted in our operative room after 2 hours of ischemia of the distal stump. A preliminary medical examination revealed an open humeral fracture and damages of all brachial muscular-tendon structures but a part of the triceps muscle. In addition, a vascular interruption was observed for the humeral artery and for the cephalic and basilica veins. Nervous injuries involved the radial, median and ulnar nerves. (Fig.1). Informed consent was obtained before surgery; procedures were performed with respect of high ethical standards, in accordance and in conformity to the World Medical Association Declaration of Helsinki (June 1964) and subsequent amendments. To prevent ischemic damage and to grant a favourable and accurate repair of the complex skeletal fractures, of multiple muscle and nerve injuries, a prolonged proximal-to-distal brachial artery shunt was performed using a Pruitt-Inahara shunt with an outlying port (LeMaitre Vascular, Inc. Burlington, MA, USA).

This device is commonly used in carotid surgery. Blood loss was favourably controlled by a preserved narrow dorsal skin drainage and the tourniquet-related ischemia was limited to early surgical phases; moreover, the shunt sustained an artery-delayed sequence of repair. The three-way catheter allowed slow infusion of heparinized saline solution (5000/1000 IU /1000ml) and thus ensuring a prolonged permanence of the shunt; furthermore, and a better early arterial infusion of the distal stump was achieved while performing debridement, bone fixation, muscle and nerve repair with end to end suture, and saphenous wrapping for median nerve (Fig.2). The catheter was removed 3 hours after placement, once assessed the complete bone and muscle reconstruction, and a saphenous bypass for brachial artery and vein was safely performed (Fig.3). There was no need for blood transfusion during both early and late postoperative time. Standard post-operative treatment was established. An histological examination of muscular bioptic tissue, obtained from the distal flexor compartment stump after shunt removal, was also performed for a more complete evaluation of the efficacy of the procedure. After surgery there was no need for fasciotomies or hemodynamic support and no major or minor complications developed, including revascularization oedema or signs of ischemia-related injury. Furthermore, the patient displayed an excellent post-operative overall outcome and a positive rehabilitation in the following months. Clinical examination at 2 years of follow-up showed optimal global functional recovery compared to those of the healthy contra-lateral upper limb with regards to total range of motion, fine and gross motion, sensory functions, grip and pinch strength. In addition, a fully satisfying quality of life was achieved and the patient could completely resume his personal habits and working duties. (Fig.3) The histological analysis showed only moderate lymphocytic infiltrate and intercellular oedema: Haematoxylin & Eosin stained cells maintained their orientation with rare intra-cytoplasmic vacuolization, this being the only sign of peripheral ischemia we assessed. In addition, immune-histo-chemistry (desmin/actin) confirmed the good quality of the muscle viability.

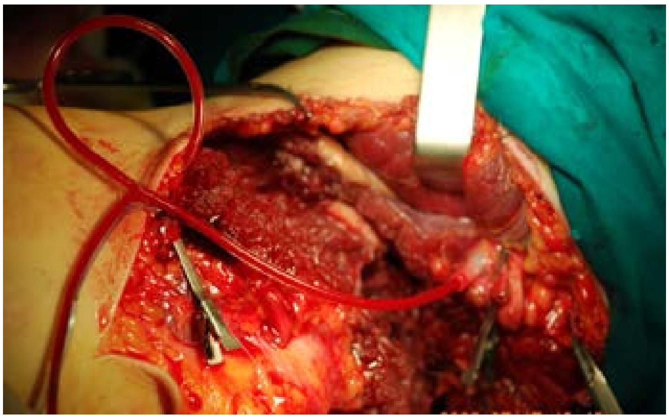
(A)

(B)

Figure 1: *Sub-amputation above the elbow of the right arm with an open humeral fracture (A); particular of the damage of all muscular structures excluding part of the triceps muscle, vascular interruption of humeral artery, cephalic and basilica veins, nervous injuries of the radial, median and ulnar nerves (B).*



(A)



(B)

(C)

Figure 2: *Synopsis of the Pruitt-Inahara shunt with an outlying port (LeMaitre Vascular, Inc. Burlington, MA, USA) adapted for prolonged heparinized arterial shunting. Proximal and distal incannulation in humeral artery after dissection and evaluation of artery gap after radical debridement (A); particular of blood inflow reducing time of warm ischemia (B); overview of the three-way catheter allowed slow infusion of heparinized saline solution*

(A)

(B)

(C)

Figure 3: *The saphenous bypass for brachial artery and vein performed with incannulated shunt, without any time of ischemia (A); particular of bypass and end-to-end sutures for Ulnar, Radial and Median Nerve (B): immediate post-operative result (C).*

Figure 4: *Clinical examination at a two-years follow-up showing optimal functional recovery in the evaluation of the range of motion during flexion (A) and extension (B) of the fingers, oveall view (C).*

Discussion

The constant refinement of reconstructive management in major traumas of the upper limb benefited from several procedural innovations and from the adoption of new devices. The strategy we propose relied on both known procedures (artery-first or artery-last sequence of repair)[9] and acknowledged devices (temporary arterial shunting).[1-10] Previous investigations could rely on large samples of case records, mostly regarding complete amputations of the upper limb (at different distances and with various mechanisms of injury) and, in part, revascularization procedures. On the contrary, our strategy was suggested upon the evaluation of the report of a single case of sub-amputation where the venous drainage was partially preserved and could thus significantly affect the blood loss. Nevertheless, we believe that this strategy may be efficiently and safely applied to a large number of injuries of the upper limb, including complete replantations: in these events a combined venous shunting may contribute to a favourable result. Despite the described limits, our strategy could sustain a prolonged delayed arterial repair, granting an appropriate surgical time for an accurate bone fixation and soft tissues reconstruction. Relevantly, the reported histological findings confirmed the effectiveness of the procedure and the preserved viability of the tissues affected by the trauma. Our results confirmed previous findings reporting the artery-last sequence of repair to be beneficial in decreasing operative time and in allowing correct repair of bony and soft tissues and the temporary arterial shunting to efficiently limit blood loss, the ischemia time, the rate of complications and of fasciotomies.[1-10] In addition, our encouraging results might be applied to a strategy based on a prolonged heparinized arterial shunting for all clinical settings requiring a safely longer reconstructive time. Moreover, we suggest that the histological effects on muscular tissues should be considered as a major outcome in related studies in that it has proved to significantly corroborate the efficacy of the technique.

Conclusions

Thus, the adoption of an artery-delayed sequence sustained by a prolonged heparinized shunt using a three-way catheter may be a novel and original interesting strategy in complete and incomplete amputations of the limbs or whenever a more accurate repair of complex multiple injuries is required. Finally, we thus believe this strategy to be suitable be noteworthy for further investigations aimed at improving the management and outcome of repair in major vascular traumas.

Acknowledgments

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13

Management of Skin Defects about the Elbow

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Elbow joint comprises of anatomical relation of three bones: humerus, ulna and radius. The ulna humeral joint and the radiocapitellar joint allows for flexion and extension of the elbow while the proximal and distal radioulnar joints allow for pronation and supination. With the simplest description, the elbow joint position the hand toward objects then brings them close to the body or the head such as in bringing food to mouth. However, throwing, lifting, pushing and rotational movements of the elbow are important for work or sports demands of the young, and for push off (a chair, walker, or cane) needs of the elderly.

The forces from the hand are transferred to the ulna through the distal and proximal radioulnar joints and then to the humerus through the ulna humeral joint. The proximal and distal radioulnar joints provide for the axial stability of the forearm as well as the interosseous membrane. For a stable elbow, more than half of the olecranon process, the anteromedial facet of the coronoid, and the lateral ulnar collateral ligament of the elbow are necessary. The radial head provides 20 % of the valgus stability while the medial collateral ligament accounts for 80 %.

Triceps and anconeus muscles extend the elbow, brachialis and to a small degree biceps muscles flex the elbow. The brachioradialis muscles balances the forearm when loaded and the common extensor and common flexor origins also contribute slightly to flexion and extension of the elbow. Biceps brachii is the strong supinator of the forearm and the pronator teres is the strong pronator of the forearm, although the supinator and the pronator quadratus muscles contribute to supination and pronation to a degree.

The elbow joint is also a pathway to vital neurovascular structures. Posteromedially the ulnar nerve, laterally the radial nerve and anteriorly the brachial artery and the median nerve cross the elbow joint. Smaller arteries, laterally anterior and posterior descending branches of the superior radial collateral artery, anteriorly the recurrent radial artery and ulnar collateral artery, and posteriorly the superior and inferior ulnar collateral arteries provide local arterial blood supply to the surrounding muscles, bones and nerves, but also allow for collateral circulation anastomosing between major arteries.

Elbow Skin Defects – Evaluation and Management

The skin defects around the elbow joint happen after extensive trauma, infections or tumor excisions. Any of these etiologies may cause skin defects that may range from superficial skin abrasions to complex defects with extensive loss of structures. Even after simple lacerations or incisions around the elbow, skin may be difficult to close after post-traumatic swelling and hardware placement and may require transposition of skin flaps to relieve tension. Skin defects may often proceed severe infections after intravenous drug abuse anteriorly, or infected preolecranon bursitis posteriorly. The involvement of deeper structures such as muscles, joint and bone depend on the extent and duration of the infection.

Mechanisms of traumatic wounds may be avulsion, friction, crush, thermal, or blast injuries but large and deep defects usually happen after a combination of these mechanisms. The road rash to the elbow may range from a contaminated abrasion of the skin to a deeper wound with skin, bone, muscle and neurovascular defects often presenting with different depth of defects at different areas of the wound. (Fig. 1a and 1b)

Fig. 1a: *Road rash injury with a wide defect with different depth of wound.*

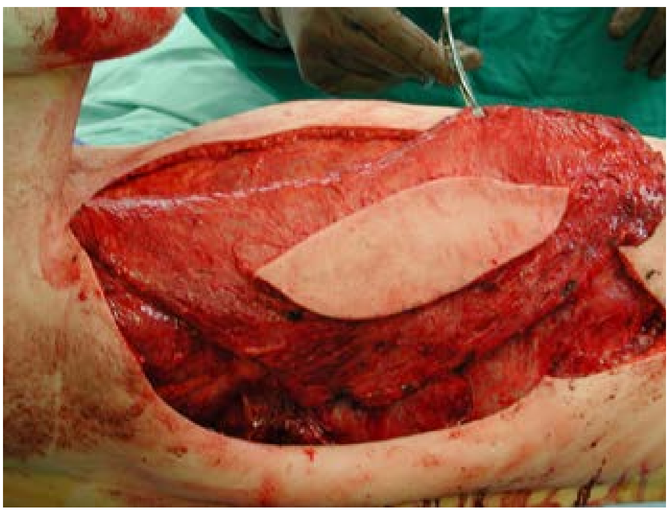

Fig 1b: *Latissimus Dorsi pedicled muscle flap is a reliable option for large and complex skin defects of the elbow.*

Similarly, after getting stuck in a farm machine, friction, compression and avulsion mechanisms would produce very severe injuries with combination of defects, and bone and joint injuries. (Fig.2 and 2b) In a haybaler injuries series it was shown that if three or more tissue components were missing or reconstruction was possible by replacement of three or more tissues, the injury was categorized as 'extensive' and in patients with amputation or devascularization revision amputation was recommended (Ozyurekoglu T, 2007).In contrast, gunshot wounds may present with multiple tissue defects in a confined area. It is important to determine the level and extent of injuries preoperatively and intraoperatively to decide on the appropriate management of these injuries.

Fig 2a*: The extent of damage may be related to the time and friction when a patient is trapped in a machine. This patient was caught in a hay baler and had loss of blood supply to the extremity as well as loss of skin muscle bone and nerve*

Fig 2b*: When devascularization was associated with three or more tissue components missing a revision amputation was performed*

While evaluating the elbow with an open wound, the surgeon should create a plan for treatment only after a careful examination of the joint, and assessment of the amount of contamination and necrotic structures around it. (Fig 3)

Fig 3b: *Necrotizing fasciitis and myositis.*

Elbow defects should be treated after a careful examination of the joint, and assessment of the amount of contamination and necrotic structures around it

Strong radial and ulnar artery pulses showing an intact brachial artery, and finger movements examining the radial, ulnar and median nerves should be checked and recorded before any surgery. Vascular injuries and nerve injuries are often seen in combination with elbow injuries. Compartment syndrome may complicate elbow injuries and the entire upper extremity should be examined proximally and distally. Fractures and dislocations should be assessed, at the very least, with AP, lateral and radiocapitellar view radiography. Ligament injuries and stability of the elbow should be evaluated in flexion and extension.

Abrasions often are contaminated with soil and foreign bodies, hence determining the status of tetanus vaccination of these patients is important. An open wound should be assessed after a through debridement and usually under tourniquet. Radical debridement of a wound removes all necrotic or contaminated structures except for neurovascular structures and achieves a clean wound allowing for early reconstruction. (Scheker LR, 2007) The dead tissues can easily be identified by their darker color, loss of contractility, or lack of bleeding. The SPY-PHI® guided debridement of necrotic tissues may be a helpful way to evaluate tissue perfusion depending on the availability of the device.

Posterior part of the elbow requires special attention as the skin lies immediately over the olecranon. The triceps tendon attaches on the olecranon as well as the posterolateral forearm aponeurosis over the anconeus. The posterolateral insertion can be very helpful to maintain some extension of the elbow even if the long head and medial head insertion on the olecranon is injured. The preolecranon bursa allows for mobility of the posterior skin but can become a compartment accumulating blood or serosanguineous fluid. Simple skin lacerations at the posterior part of the elbow may be repaired primarily however with repeated elbow flexion, the stretch in the posterior skin may cause wound dehiscence and subsequent infections. (Fig 4)

Fig 4: *Preolecranon bursitis can get infected and may end up in a skin defect with exposed bone.*
This is almost the most common reason for infection after total elbow arthroplasty with the incision dehiscing and progressing to an infection. Total elbow arthroplasty can further be complicated by triceps tendon rupture and protrusion of olecranon or the implant through the skin. It is important to keep elbow in full extension after repairs posteriorly until the skin heals in two weeks. A hinged elbow brace can be worn for bringing the elbow into flexion gradually within an additional 4 weeks without any loss of range of motion.

Soft Tissue Coverage options for the Elbow

The laxity of the skin around elbow joint allows for transposition flaps. The posterior skin is loose in extension Medial and lateral skin flaps can be prepared by undermining the skin and advance to the midline to close central defects. Similarly, small medial and lateral skin defects can be closed by advancement of posterior, anterior or both flaps. Anteriorly, antecubital fossa defects can be closed by advancing two flaps to the antecubital crease. A proximal > shaped flap and a distal < shaped flap can meet at the flexion crease with a Z shaped repair. Rotational flaps are rarely needed and must respect the superficial sensory nerves. The remaining defect from the rotational flap can be covered by split thickness skin grafting from the posterior side of the Triceps or from the thigh anterolaterally.

If the defect after debridement is clean and does not expose any bone, tendon, vessels, or nerves, split thickness skin grafting should be the choice as it is a simple and effective method of covering full thickness skin defects. Skin grafting should be considered for burns and defects over the muscles. Split thickness skin graft using a dermatome at 0.010 to 0.015 depth should always be mashed. Vacuum assisted closure may be considered for promoting granulation and delaying the graft shortly, but the coverage should take place within two weeks as longer immobilization may cause stiffness of the joint. Vacuum assisted closure over the applied skin graft is an excellent option to increase the chance of graft take. For posterior defects the skin graft should be applied in flexion and for anterior defects the elbow should be kept in extension. If there is need for circumferential skin grafting such as large area burns, the elbow should be kept in an antideformity position at 30 to 45 degrees of extension.

Brachioradialis Flap

When there is bone exposure over the lateral, medial or posterior parts of the elbow, local muscles can be used to cover the defect especially for its advantage of cushioning. The author prefers the use of brachioradialis muscle pedicled flap over the wrist flexor or extensor muscles described in the literature (Janevicius RV, 1992). Although good functional outcomes were achieved using the Flexor carpi ulnaris turnover flaps, without significant deficits in grip strength or wrist flexion strength were reported (Bayne CO, 2015). Brachioradialis flap functions to balance the forearm against an extension force. The muscle originates from the distal humerus laterally and forms the radial border of the forearm and elbow. It inserts It is supplied by the branches of the recurrent radial artery at the level of the elbow flexion crease. The radial nerve innervates the muscle very proximally, but the superficial radial nerve lies immediately under the muscle and must be protected while raising the flap.

A lazy S incision is made on the lateral border of the forearm extending from the mid-forearm to the elbow flexion crease anteriorly. (Fig 5a)

Fig 5a: *Planning of pedicled brachioradialis muscle flap*

The radial sensory nerve is isolated between the brachioradialis and the extensor carpi radialis longus tendon. The brachioradialis tendon is released distally at the musculotendinous junction and reflected proximally. No circulation beyond 1 cm of the myotendinous junction was observed in a cadaveric injection study. (Leversedge FJ, 2001) The muscle is freed at its belly as there are usually bands fixing it. Then attention is turned to the vessel arising from the recurrent radial artery at the antecubital fossa. (Fig 5b)

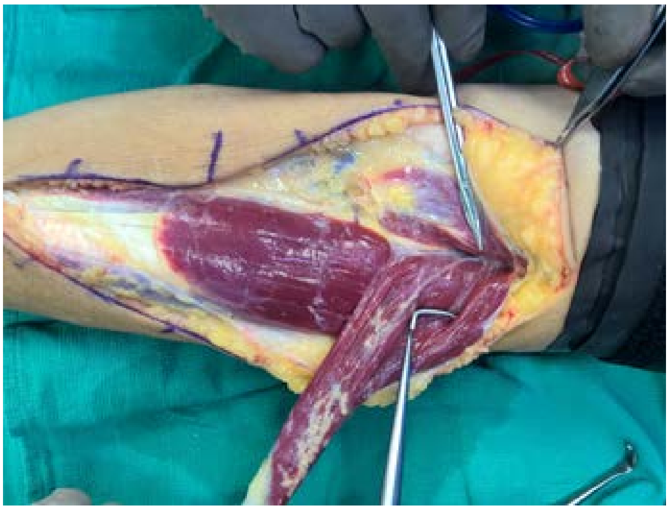

Fig 5b: *The largest perforator arises from the recurrent radial artery at the antecubital fossa*

The distal branches should be sacrificed for mobilization of the muscle. There is usually one large feeder branch at the level of the elbow flexion crease which must be protected. Then the muscle is passed posteriorly by tunneling under the skin and is inset over the olecranon and the defect. It can also be used for anterior or medial defect. The size of the muscle determines the coverage area, but the muscle can be gently folded to cover defect. One of the pitfalls is to overstretch the muscle to increase its width to cover the defect. (Fig 5c) The muscle is usually skin grafted with a split thickness skin graft. (Fig 5d)

Fig 5c: *The brachioradialis muscle is passed posteriorly by tunneling under the skin and is inset over the*

Fig 5d: *Healed defect with split thickness skin graft*

A skin island can also be planned over the brachioradialis muscle flap at the myotendinous junction. Size measurements of the defect and the location of the skin paddle on the muscle belly should be precisely determined. If a skin paddle is desired, one should carefully dissect only one side of the skin paddle at the myotendinous junction initially, then identify the larger perforator at the elbow which is the pivot point of the flap, and finally measure and complete the other border of the skin island. The skin island is a good way of monitoring the flap survival.

Radial Artery Flap

Radial artery flap is successfully used to cover elbow defects either as a pedicled or as a free flap without significant loss of circulation or sensation to the hand . (Jones NF, 2008) The distal forearm skin is thin and mobile and is a reasonable option for coverage of recalcitrant elbow defects. (Meland NB, 1991) After checking the pulses for radial and ulnar artery the radial artery flap is designed axially over the large radial artery that travels on the lateral and volar side of the forearm radial to the flexor carpi radialis tendon. The defect is measured, and the rotation arc is planned. The dissection starts ulnarly and proceeds in a radial direction under the forearm fascia. The deep fascia of the flexor carpi radialis is included in the flap. The dissection starts radially now and the ulnar border of the brachioradialis tendon is identified. The dissection here is usually short and directed under the radial artery. The deep and radial side branches are ligated while the perforators to the skin are protected. A large grouping of perforators was shown at 2 cm proximal to the radial styloid. (Saint-Cyr M, 2010) Then a distal to proximal dissection follows the radial artery. The inclusion of the septum and adipofascial tissues over it helps the venous drainage of the flap through the concomitant veins following the artery. The cephalic vein can be included in the flap. The defect created by the flap is closed using a full thickness skin graft with bolsters.

Posterior Interosseous Flap

The posterior interosseous artery (PIA) is a posterior branch of the radial artery that enters the dorsal compartment at the distal end of the supinator muscle with the posterior interosseous nerve. PIA crosses occasionally under the ECU branch of the radial nerve and a large perforator arises from the interosseous recurrent artery (anconeus branch) making it difficult to raise a posterior interosseous artery flap for the dorsum of the hand. The artery travels in the intermuscular septum between the extensor digiti minimi (EDM) and extensor carpi ulnaris (ECU) and joins the anterior interosseous artery and the dorsal carpal arch proximal to the distal radioulnar joint. In an anatomical study, an average of 3 perforators were isolated at an average of 3 to 7.2 cm (2.7- 9 cm) proximal to the ulna styloid. (Zaidenberg EE, 2018)

The PIA flap can be raised retrograde for defects of the wrist and hand (Zancolli EA, 1988) and antegrade for defects of the elbow. The vascular territory of the flap is about 5 cm in its width. The flap is designed over the line between the lateral epicondyle and the ulna head. The forearm is divided into three and the antegrade flap is oriented over the distal third. The perforators can be identified using a Doppler for better positioning of the flap. The dissection starts radially then ulnarly around the borders of the designed skin island, then the subfascial dissection is carried out down to the septum between the ECU and EDM muscles. The PIA is isolated along this septum and radial and ulnar dissection is carried out in a distal to proximal level isolating the septum. Proximally the branches of the posterior interosseous nerve should be dissected carefully and protected. The PIA is followed proximally down to its origin at the interosseous membrane which is the pivot point of the flap. Once the flap is completely dissected the distal anastomosis with the carpal arch and the deep anastomosis with the AIA are both ligated, the septum containing the PIA is rotated to pass under the tunneled skin bridge laterally to reach the elbow defect posteriorly. The concomitant veins and the adipofascial venous network are normally enough for the venous drainage.

Lateral Arm Flap

The lateral arm flap is one of the workhorse flaps for the upper extremity defects. When this flap is planned for defects around the elbow, particularly if there were past surgeries and lateral incisions, the vascular structures should be evaluated with an angiogram to make sure the vessels supplying the flap are still intact. This type C fasciocutaneous flap is based on the posterior radial collateral artery (PRCA). The deep brachial artery which travels in the spiral groove adjacent to the radial nerve, divides into anterior and posterior branches at the mid-humerus level, one traveling anterior and the other posterior to the lateral intermuscular septum on the humerus. One third width of the humerus can be included in the flap making it an osseo-fasciocutaneous flap. The lateral cutaneous nerve of the forearm passes through the flap but can be protected with some extra dissection; the *lower* lateral cutaneous nerve of the upper arm ends in the flap and can be included in the flap making it a sensate flap. Lateral arm flap can be used as a pedicled flap to cover the elbow anteriorly or posteriorly especially when extended into the forearm or as a free flap. The PRCA diameter is 1 mm to 2 mm and is usually accompanied by two small concomitant veins.

The flap is designed on a line drawn from the lateral epicondyle to the deltoid insertion. A 4 cm incision is added proximally and posteriorly to expose the pedicle further. A tourniquet is applied proximally and can be kept until the radial nerve is identified. A direct closure is possible up to 6 cm, but larger width flaps up to 12 cm can be designed. The largest length of the flap is 10- 12 cm. If needed, the distal forearm fascia can be included to the flap to extend it for another 5 cm.

The dissection starts posteriorly, and the fascia is easily elevated from the underlying triceps muscle. The anterior fascia is similarly incised and carefully separated from the underlying biceps, brachioradialis, and the common extensor muscles to expose the lateral intermuscular septum. The fascia can be sutured to the skin using Vicryl sutures at this point to prevent shearing of the skin. The distal part of the flap can be elevated now. The vessel should always be ligated on both ends. Then a distal to proximal dissection can follow, holding the intermuscular septum and the flap in one hand and dissecting the septum and the anterior and the posterior descending branches off the humerus. The fibers of the lateral head of the triceps are carefully separated from the intermuscular septum on the proximal part of the flap to expose the pedicle. One can usually see the 4-5 fascial perforators within the anterior and the posterior fascia and the lateral cutaneous nerve of the forearm which would lead the surgeon to the pedicle and the radial nerve. The muscular branches can be cauterized or ligated with small clips as dissection proceeds proximally. At the intersection of middle third and distal third of the upper arm, the radial nerve is identified crossing through the intermuscular septum. The PRCA is dissected further proximally into the spiral groove by releasing the aponeurotic bands under the lateral head of triceps and the artery and the concomitant veins. At this point the tourniquet should be released and the flap is allowed circulation and bleeding is controlled.

For free flap application the pedicle can be ligated, and the tissue can be transferred to the recipient vessels. For posterior defects of the elbow a pedicled transposition is a better option. For this purpose, the flap can be advanced posteriorly, medially, and distally. The flap is often positioned distally including the forearm deep fascia. (Fig 6 a,b,c,d)

Fig 6a: *Chronic wound with ruptured triceps tendon and excised olecranon shortly after a failed brachioradialis muscle flap.*

Fig 6b: *The implant and how it cuts through the skin and the failed brachioradialis muscle.*

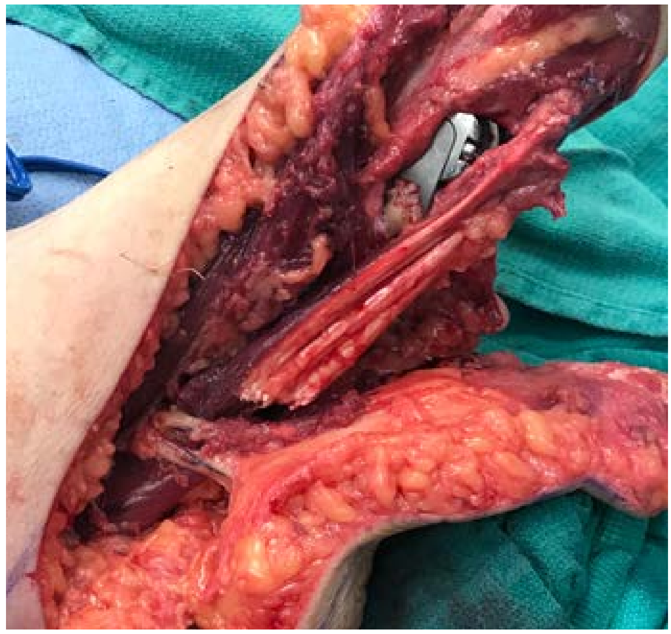

Fig 6c: *Triceps advancement and the elevated pedicle of the lateral arm flap*

Fig 6d: *Well healed flap with restored extension of the elbow.*

The pressure of the olecranon process or the exposed implant may be a challenge for keeping the flap intact. Advancement and reconstruction of the triceps tendon is a viable option. The defect can be closed primarily up to 6 cm width, or skin grafted depending on the size of the defect.

Latissimus Dorsi flap

For large defects of the elbow the latissimus dorsi muscle can be transferred as a pedicled flap to cover defects or as a functioning muscle transfer. Latissimus Dorsi (LD) is a muscle that covers the upper back, originating from the iliac crest spinous processes of 7th to 12th vertebrae, thoracolumbar fascia and the 9th to 12th ribs. It inserts to the intertubercular sulcus on the proximal humerus between the pectoralis major and teres major tendon insertions. (Bartlett SP, 1981 May) LD is a type V muscle flap: the thoracodorsal artery is the dominant blood supply; lumbar and intercostal arteries supply the muscle in different regions secondarily.

The thoracodorsal artery originates from the subscapular artery which arises from the axillary artery. The subscapular trunk divides to circumflex scapular artery and the thoracodorsal artery. The thoracodorsal artery enters in the LD muscle at 8.5 cm distal to the origin of the subscapular artery and about 2.5 cm medial to the lateral border of the muscle, accompanying the thoracodorsal nerve. (Rowsell, 1986) The thoracodorsal artery is about 2 to 3 mm at its origin. The venous drainage parallels the arterial supply. After entering the deep surface of the LD muscle, the thoracodorsal artery divides into a 45 degree transverse branch traveling horizontally following the upper muscle border, and a lateral descending branch along the lateral border of the muscle which allows for perforator flaps. (Spinelli HM, 1996) (Rowsell, 1986) The skin over the muscle is supplied by large musculocutaneous perforators but in the middle part the perforators are smaller. The distal third of the muscle near the iliac crest or the thoracolumbar fascia has perforators that do not anastomose with the main pedicle. This pattern may make the distal part of the muscle not reliable for carrying skin to the elbow.

The surgery begins with patient placed in lateral decubitus position. The skin paddle is planned in a transverse or oblique position over the muscle. (Fig 1b)

For elbow defects muscle flap with skin grafting is preferred over myocutaneous flaps as the distal skin carrying is not always feasible. The axis of the muscle is marked. The dissection starts between the muscle and the skin. Then the perforators are ligated with clips. Then the muscle is elevated and the deep intercostal and the lumbar perforators are ligated. The muscle is incised at the lumbar fascia over the iliac crest and spinal column. The distal and medial border is elevated. The remaining perforators are ligated, and the pedicle is exposed by lifting the muscle. The pedicle is seen at the hilum of the muscle, and the arterial branches to the serratus anterior are revealed with blunt and gentle dissection. These branches are tied, the pedicle is freed to gain mobility. (Fig 1 b) The insertion is left intact and the muscle is transposed from the posterior of the shoulder into the arm and the elbow. For free flap option, the pedicle can be divided with the concomitant veins and the thoracodorsal nerve. Skin grafting follows the inset of the flap.

Pedicled LD flap was reported as a reliable option for large and complex skin defects of the elbow (Hacquebord JH, 2018). However, a high rate of distal necrosis was reported when olecranon area coverage. (Choudry UH, 2007) (Hacquebord JH, 2018) Stevanovic et al recommended not to attempt coverage using LD transposition for defects more than 8 cm distal to the olecranon. (Stevanovic M, 1999) The distal part of the Latissimus dorsi should always be examined for color and blood supply after it is raised completely. If the distal end looks not circulating it should be debrided and LD flap should be advanced distally to cover the olecranon safely. The pedicle and the insertion tendon should be released further to advance the flap distally. Alternatively, the flap can be turned to a free tissue transfer. If the defect is anteriorly, one of the techniques to overcome this problem could be to transpose the LD flap completely anteriorly as an island flap. The insertion is detached and sutured anteriorly to the coracoid process and the distal part of the flap is advanced to cover the proximal forearm.

Several variations of the LD flap are described. The muscle can be split by the arterial branches after intramuscular dissection of the thoracodorsal artery and its two branches. (Tobin GR, 1981) The flap can also be raised with bone from the lateral border of the scapula depending on the circumflex scapular artery or the angular branch to lower scapula of the thoracodorsal artery. To expose these vessels interval between the LD and teres major needs to be developed and the branch to the serratus need to be tied. (Sekiguchi J, 1993)

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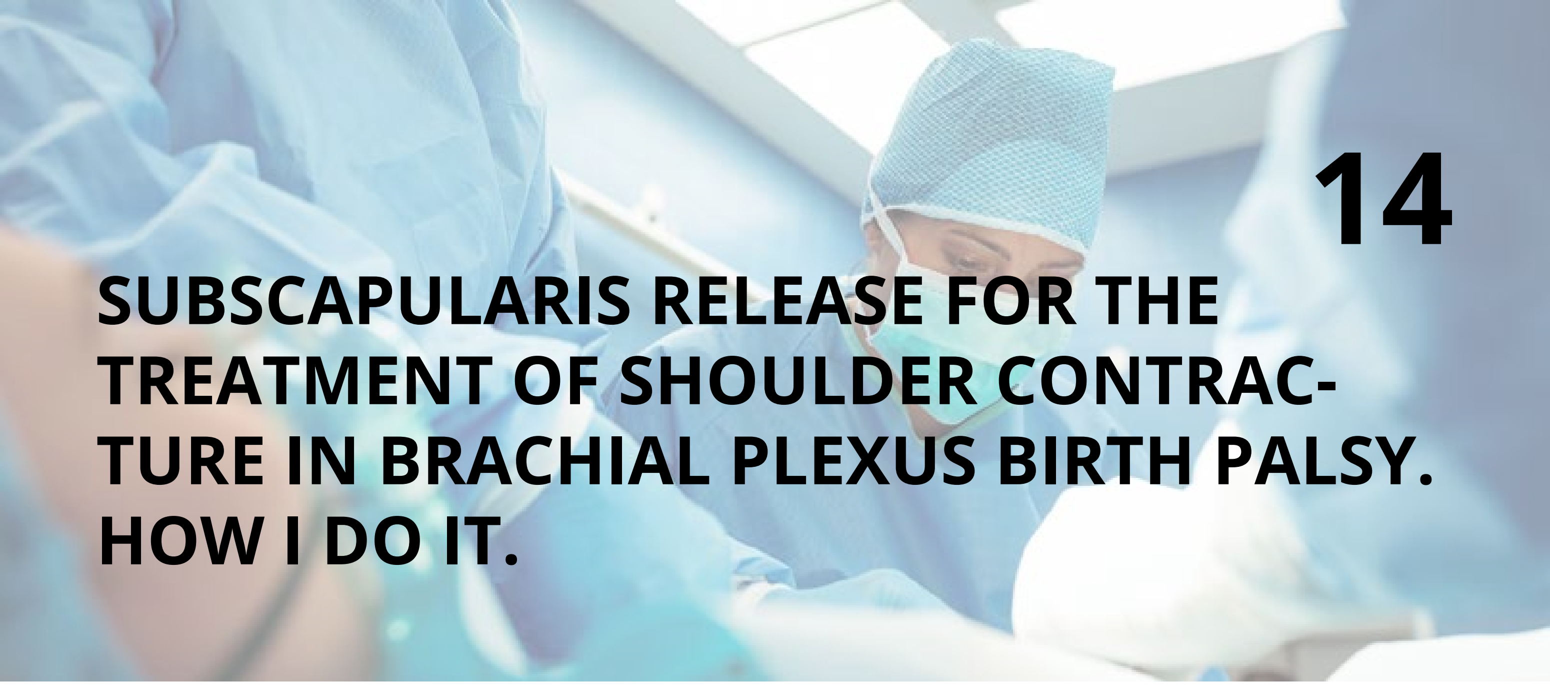

14

SUBSCAPULARIS RELEASE FOR THE TREATMENT OF SHOULDER CONTRACTURE IN BRACHIAL PLEXUS BIRTH PALSY. HOW I DO IT.

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Introduction

Brachial Plexus Birth Palsy (BPBP) is a consequence of excessive stretching of the brachial plexus during labor, and has a reported incidence of 0.1% to 0.4% (1–3). The majority of patients seem to recover spontaneously, but there are rates of failing recovery ranging from 5 to 19%(4).

The most common and mildest form of BPBP involves the C5 and C6 roots (Erb's palsy). The C7 is variably affected and predisposes to a worse prognosis when involved. Pure lower root palsies are rare and global palsies (C5-T1) have the worst prognosis, especially when involved with Horner's syndrome or phrenic nerve palsy (5,6).

Infants with BPBP who do not show signs of recovery in the first 3 months of life have a considerable risk of long-term residual dysfunction (2). Patients with no anti-gravity biceps function by 3-6 months of age should be referred to a specialist for further more aggressive management. In the earliest phase, surgical exploration, neurolysis and operative repair or reconstruction of the brachial plexus may be attempted, mostly between the ages of 3-9 months. Children with incomplete recovery who are seen more than 6 months after birth may present with muscle contractures due to imbalance between antagonist muscles, with a weakness of external rotators and abductors, and associated periarticular tightness secondary to the initial trauma. These patients may benefit from muscle releases, mainly between the ages of 12 and 24 months. In older patients, when the joint is still congruent, tendon transfers may be performed. As the glenohumeral deformity progresses and subluxation or dislocation may occur, osseous procedures may be needed in order to restore the joint congruity (7).

A variety of procedures are performed in order to improve shoulder function for these patients. The first surgical treatments reported date back to 1913, when Fairbank proposed anterior capsulotomy and subscapularis tenotomy, which were followed by a high rate of complications (8). Later in 1927 Sever proposed tenotomy without capsulotomy and in the early 70s, Carlioz and Brahimi introduced the concept of proximal subscapularis release form the scapula (9). More recently, Pearl published his proposal for arthroscopic tenotomy of the subscapularis and anterior capsular release (10,11). In our practice, we also perform arthroscopic release of the anterior glenohumeral ligaments, capsule and upper intra-articular subscapularis tendon, in young children less than 3 years old to improve external rotation of the shoulder (12).

Currently, there are no distinct guidelines on how aggressive surgeons should be, or clear consensus on which procedures offer the most promising results regarding mobility and shoulder function. According to bibliography (13–16) subscapularis muscle release is an appropriate initial surgical approach in patients with an impairing medial rotation and adduction shoulder contracture. Open subscapularis release is the method we prefer for children between ages 3 to 9 years, and therefore we report our surgical technique for children who were treated by this approach.The decision to proceed for surgery was made in those children with a persistent internal rotation contracture (passive external rotation at midline < 30 degrees) associated with active abduction < 90 degrees.

Surgical procedure – How I do it

The child is placed in a supine position with the upper extremity abducted in a hand table. Passive external rotation (with the arm at the side, and at 90 degrees of abduction) and passive abduction of the shoulder are evaluated under general anaesthesia. A deltopectoral incision is made (*figure 1a*) and the coracoid is exposed

Figure 1a. *We present the case of a 8-year old boy with BPBB, treated with subscapularis release by Z-lengthening. We use deltopectoral incision.*

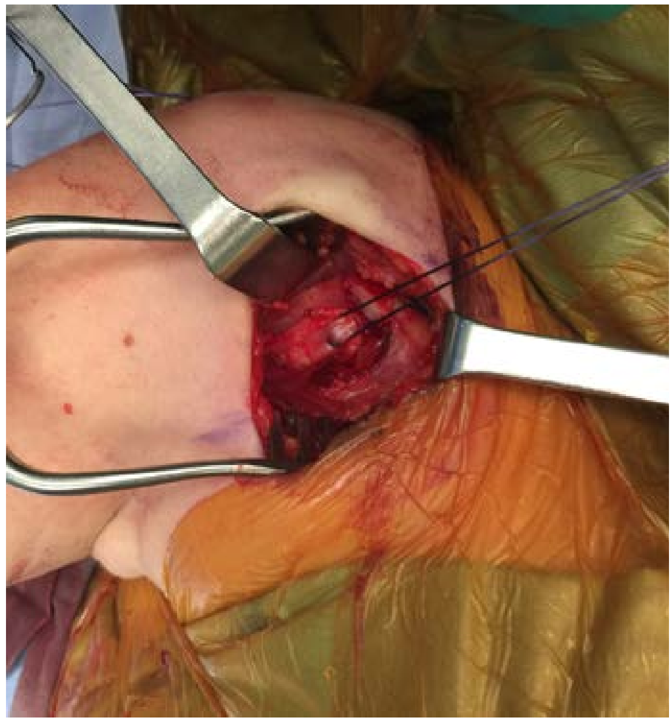
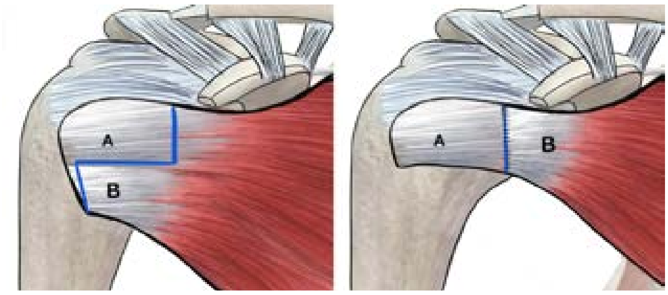


Figure 1b. The tip of the coracoid is excised and a suture to the conjoined tendon is used to secure it later

The tip of the coracoid is excised with the knife and a heavy absorbable suture (Ethicon Vicryl #2 Absorbable Braided Suture) is used to tag the conjoined tendon (*figure 1b*) afterwards. The subscapularis is exposed and with a surgical pen the letter Z is marked on the insertion of the tendon (*figure 1c*).

Figure 1c. The subscapularis is exposed and the letter Z is marked on its insertion.

Then a Z-lengthening of the subscapularis tendon is made, leaving the laterally based flap superiorly (figures 1d & 1e).



Figures 1d and 1e. *Schematic illustration of the procedure: design of the Z lengthening (fig. 1d), and suturing the two flaps A and B together leaving the laterally based flap (A) superiorly (fig. 1e)*

Care is taken to protect the underlying shoulder capsule. In order to inspect the glenohumeral joint a transverse incision is made at the level of the rotator interval, and appropriate congruency of the joint is ensured using external rotation and abduction. At this point, gentle manipulation of the shoulder joint is performed with the arm at the side, and also with the arm at 90° of elevation to obtain almost full passive external rotation and full abduction (*figures 2a & 2b*).

Figures 2a and 2b. *Gentle manipulation of the shoulder joint is performed with the arm at the side, and also with the arm at 90° of elevation to obtain almost full passive external rotation and full abduction*

The two tendon ends are then sutured together with a Vicryl #1 absorbable braided suture with the arm in external rotation and abduction. The conjoined tendon is then secured,with the tag suture,back to the coracoid with a figure of eight stich configuration. After skin closure, the arm is placed in a shoulder spica cast in 90° of abduction and 70° of external rotation for 6 weeks (*Figure 3*).

Figure 3. *After skin closure, the arm is placed in a shoulder spica cast in 90° of abduction and 70° of external rotation for 6 weeks*

Discussion

Brachial plexus birth palsy can be a devastating diagnosis with potential to cause lifelong shoulder problems. Internal rotation contracture is the most frequent sequelae, even in cases where the neurological recovery is complete. It can also lead to early deformation of the glenohumeral joint (dysplasia), which gradually progresses to subluxation and finally posterior dislocation of the humeral head (17–20). Van der Sluijs et al. (19) report that the glenohumeral deformations start at an age as early as 5 months, they progress with age and the internal rotation contracture develops if passive external rotation is not maintained. Early surgical inter-

vention is then more likely to prevent dysplasia,than conventional treatment.
The goals of surgical intervention are to restore functional range of motion and provide a more balanced joint to minimize the progression of glenohumeral joint deformity. Several surgical techniques have been described. There seems to be a trend towards tendon transfers as a first-choice of treatment in children with BPBP, but there are also studies suggesting that a simpler procedure with infrequent complications, such as the isolated subscapularis release, can offer satisfying functional improvement.
Chen et al (15) reported improvement of the Mallet score in 32 of 36 cases, suggesting also that the operative effect is related to the child's age and the recovery extent of the upper trunk of the brachial plexus. Gilbert et al (14) also reported improvement of lateral rotation, with better results maintained long-term for younger patients. Improvement of overall Mallet abduction and external rotation scores is also demonstrated by Naoum et al (21) after proximal subscapularis release in 50 children, with no correlation being found between the child's age or the severity of involvement at surgery and the end result. Less invasive techniques, such as arthroscopic release have also been proposed, with Pearl (10) reporting at least 45 degrees of passive external rotation at surgery at all but 1 of 41 cases, with no other complications being noted.
Although the results are really promising, there seems to be a progressive loss in shoulder mobility over time (16,22,23) possibly because of contractures of the surrounding soft tissues when not complying with physiotherapy. As a result of these findings, it is suggested that the long-term use of regular physiotherapy is needed in order to preserve and even gain upon the improvements in range of motion obtained after surgery.
In conclusion, isolated subscapularis muscle release can offer satisfying results for children with BPBP and residual medial rotation and adduction shoulder contracture. It is a simple procedure with low complication rates that can be used by surgeons as an initial surgical approach aiming to functional improvement and minimization of the joint deformity progression.

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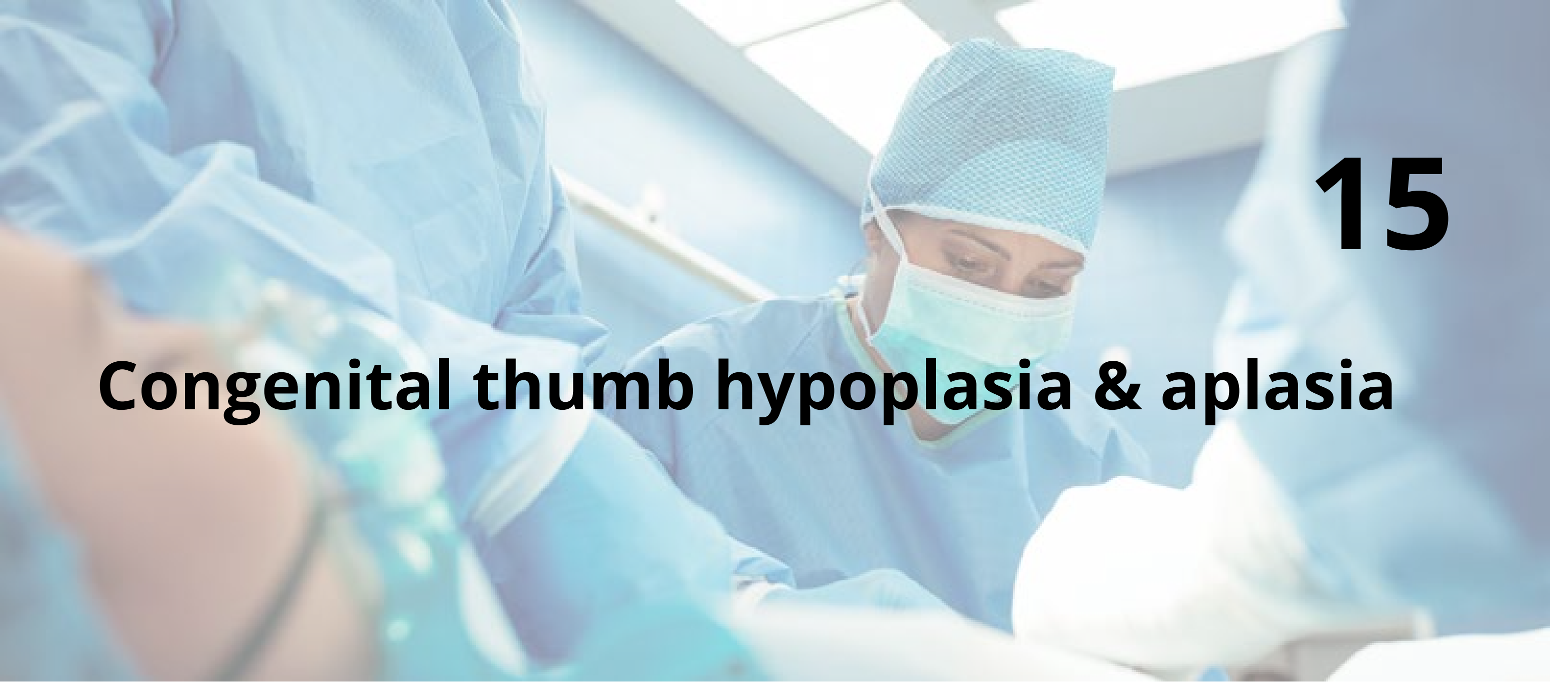

15

Congenital thumb hypoplasia & aplasia

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Introduction

Congenital malformations in the upper extremities, with an overall reported incidence of 21.5/10000 live births [1], may have serious consequences for the individual patient. A variety of such malformations involve the thumb, causing aesthetic and functional problems of varying severity as the thumb is crucial for proper hand function. Among them, thumb hypoplasia/aplasia, with a "non-functioning" thumb represents a surgical challenge and usually requires a pollicization procedure.

Classification

According to Blauth classification, thumb hypoplasia can be categorized into 5 general types or grades [2].

In type I, the thumb is small with mild hypoplasia of most anatomic structures.

A type II hypoplastic thumb has a tight web space between the thumb and index finger, as well as loss of some thenar musculature and instability of the metacarpophalangeal joint.

Type III thumbs show all the characteristics of those seen in type II with additional skeletal hypoplasia (including radial carpal aplasia) as well as loss of some intrinsic and extrinsic musculature [type III-A: stable carpometacarpal (CMC) joint; type III-B: unstable CMC joint].

The type IV thumb (pouce flottant) is small and has rudimentary skeletal elements. It is an unstable digit, connected to the hand by a neurovascular skin bridge. Finally, the type V thumb (aplasia) has loss of all thumb structures and radial carpal bones [3].

Surgical techniques for thumb hypoplasia & aplasia

The classification guides the treatment. Type I hypoplasia usually does not warrant surgical intervention. Type II and IIIA hypoplasia often require surgery to provide stability, improve motion, and enhance function. Blauth types IIIB, IV, and V are indications for index finger pollicization. In type IIIB thumb hypoplasia, the CMC joint is unstable, and although some surgeons have noted success with vascularized metatarsophalangeal joint transfers for this condition, index finger pollicization remains the ideal reconstruction [5-7].

I. Thumb reconstruction

Thumb reconstruction for type II and IIIA hypoplasia requires addressing all the elements that are deficient. The narrowed thumb-index web space, thenar muscle absence, and metacarpoplalangeal (MCP) joint instability, all require treatment.

- Thumb-index web space narrowing is treated with skin rearrangement and soft tissue release. A four-flap Z-plasty lengthens the tight skin and provides a rounded contour to the web space. The deeper soft tissue release includes the fascia around the adductor pollicis. The princeps pollicis artery and its branches must be identified and protected before division of the fascia.
- Thenar absence requires a tendon transfer to provide thumb opposition. Among the various donor muscle-tendon units [flexor digitorum superficialis (FDS) long or ring, abductor digiti minimi, extensor carpi ulnaris, and extensor indicis proprius], the long or ring finger FDS is preferred because of its length, technical ease, power, expendability, and synergism. If the FDS is unavailable, the other donor options are considered [5].
- MCP instability requires stabilization. Unidirectional instability with an incompetent ulnar collateral ligament is the most common finding. Ligament reconstruction can be performed with the residual

length of donor tendon from the opposition transfer. Bidirectional or global instability is more difficult to manage. Reconstruction of both the radial and ulnar collateral ligaments with tendon graft has been described. MCP joint chondrodesis is preferred to achieve firm stability and provide a stable fulcrum for the opposition transfer to function.

II. Pollicization

Pollicization is indicated for type IIIB, IV, and V hypoplasia. The technique is similar with subtle variations depending upon whether a hypoplastic thumb is present or absent.

A. Skin Incision

The skin incision must be planned precisely to allow easy index finger transposition and construction of a sufficient first web space without scar. It consists of two flaps dorsal and palmar, surrounding the index finger to be transferred and the hypoplastic thumb to be removed (Fig 1).

Figure 1 *Skin incision surrounding the index finger to be transferred and the hypoplastic thumb to be removed.*

The palmar skin is incised first. Dissection must be meticulous to avoid injury of underlying neurovascular bundles and veins.

B. Neurovascular Dissection

Under magnification with loupes, the radial neurovascular bundle is isolated. Then, the common digital vessels to the index-long web space are identified and the proper digital artery to the long finger is ligated, allowing tension-free index finger pollicization with vascular supply from the radial digital artery and the common digital artery of the index-long fingers (Fig. 2).

Figure 2 *The pulsating artery of the pollicized digit is depicted.*

The proper digital nerves to the ulnar side of the index and the radial side of the long finger are identified and separated proximally with microdissection.

C. Soft Tissue Dissection

The following structures are released/divided: the A_1 pulley of the index finger (to avoid buckling of the flexor tendons after index finger shortening), the intermetacarpal ligament, and any interconnections of the extensor tendons of the index.

The extensor or flexor tendons are not shortened as these musculotendinous structures adapt over time. The first dorsal and palmar interossei muscles are dissected and released from their distal attachments with a portion of the hood and are then transferred to the lateral bands of the index finger (Fig. 3).

Figure 3 *The first interossei muscles are dissected and released from their distal attachments.*

D. Skeletal Reconstruction

The central part of the 2nd metacarpal (MC_2) is removed. The two cuts are placed at the MC_2 base proximally and at the epiphyseal plate distally so as to ablate the epiphyseal plate and prevent undesirable growth of the index metacarpal [8]. The ideal length of the pollicized digit should be appropriate to reach the middle finger PIP in adduction.

After removal of the central part of the MC_2 the index MCP joint will become CMC joint. During pollicization the fixation is performed with flexion of the MC_2 head and hyperextension of the proximal phalange to overcome the problem of MCP_2 joint hyperextension that is not desirable for a thumb CMC joint that normally does not hyperextend. This is achieved by suturing the MCP_2 joint into hyperextension with two lateral nonabsorbable sutures and stabilizing it to the base of the MC_2 with a Kirschner wire in 45° of abduction, 15° of extension and 100°-120° of pronation [9-11].

E. Skin Closure

The skin is carefully placed around the newly formed structures and any redundant skin is excised. Absorbable sutures are used for skin closure. Suture material and scar within the commissure should be avoided and whenever possible, the first web space suture line must be advanced dorsally. The tourniquet is released and the pollicized digit is observed for several minutes. The arterial circulation usually returns quickly, although vasospasm can result. Time, warm soaks, and patience routinely lead to resolution. Persistent lack of blood inflow requires exploration for arterial kinking or iatrogenic injury. Venous congestion is more common, which can require application of a looser dressing and/or release of any taut sutures. The postoperative dressings are crucial. Adequate fluffy dressings are necessary and a long arm thumb spica is applied with the elbow at 90° flexion and the pollicized digit in 45° of abduction, 15° of extension and 120° of pronation relatively to the palm (Fig. 4,5).

Figure 4 *A long arm thumb spica is applied with the elbow at 90º flexion and the pollicized digit in 45º of abduction, 15º of extension and 120º of pronation relatively to the palm*

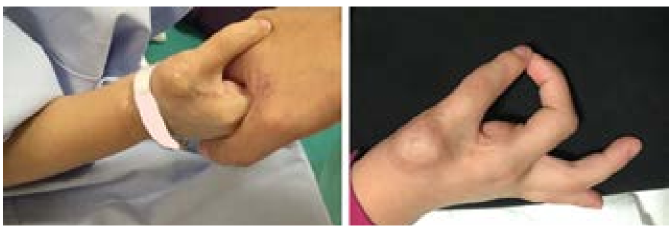

Figure 5 *One and two-years postoperative result.*

Conclusion

The choice of surgical techniques for thumb hypoplasia treatment needs to take into account the degree of underdevelopment of each element of the thumb [12,13]. Numerous surgical options and combinations are available. Approaches vary among surgeons who work in the field of congenital hand surgery and empirical evidence that allows evaluation of the results of techniques is scarce [14]. There is a lack of standardized guidelines and while we continue the search for these, we believe that both the pre-operative assessment and intra-operative findings of all thumb elements – bone, joints, and soft tissues – should be considered in surgical decision-making, as these define the need for reconstruction of each component. The surgeon's preferences and experience, and cultural influences, as well as the patient's age and demands, will further contribute to the final choice of techniques.

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III
Lower Extremity

16

Safe Placement of Tissue Expander for the Anterolateral Thigh Flap Donor Site: How I do It?

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Introduction

Since the first description of a preexpanded free flap by Shenaq in 1987, many donor sites have been used with this technique for various indications [1, 2]. Preexpansion combines the advantage of tissue expansion and free tissue transfer; as in enlarging the area of transferred tissue, possibility of primary closure of the donor site and increasing the vascularity of the transferred tissue. This is especially important in patients with extensive burns, where there is a lack of total healthy tissue and the available donor sites need to be used "economicly". In patients with absolute lack of unburned areas, tissue expansion greatly facilitates economical use of tissue together with primary closure of the donor area.

Recently, free perforator flaps have greatly replaced the musculocutaenous flaps in resurfacing skin only defects with the advantage of sparing functional muscle. Since its first introduction, anterolateral thigh flap has become the work horse of skin free flaps and is regarded as the "universal donor site" by many microsurgery centers [3,4]. However, tissue expanded ALT has not gained popularity and the literature is scarce in its use.

Tsai was the first to use a preexpanded free ALT flap [5]. He used a large vertical incision to gain access and the tissue expander was placed underneath the fascia, as well as dissecting out the perforators to visualize them. Hallock was the second to report tissue expansion of the anterolateral thigh [6,7]. However his aim was to close the donor site with the expanded tissue rather than to create a tissue expanded flap. Our current technique, which was reported in 201,3 was an advent over the prior techniques as an easy, fast and safe technique [8]. We later went onto describe the use of a pedicled tissue expanded ALT flap as well [9]. There have been several other, but few, papers reporting the use of tissue expanded ALT flaps [10-14].

Surgical technique

The patient is placed in the supine position with the legs in neutral position. Anatomical landmarks are marked as if raising an anterolateral thigh flap (i.e. anterior superior iliac spine, super-lateral border of patella, line indicating the inter muscular septum). Using a handheld Doppler ultrasound the vastus lateralis muscle perforators of the descending branch of the lateral circumflex femoral artery (anterolateral thigh flap perforators) are located and clearly marked out [Figure 1].

Figure 1: *Anatomical landmarks are marked as if raising an anterolateral thigh flap*

A 6-8 cm horizontal incision planned at the on the supero-lateral thigh at the inferior border of the tensor fascia lata muscle (The location of the incision can be modified only if the patient already has an existing scar or prior incision) . The location of the tissue expander is planned out to be at least 5 cm away from the horizontal incision and 2 cm lateral to the most lateral perforator [Figure 2].

Figure 2: *Planning the location of the tissue expander*

The horizontal incision is made down to and identifying the shiny surface of the superior border of the fascia lata [Figure 3].

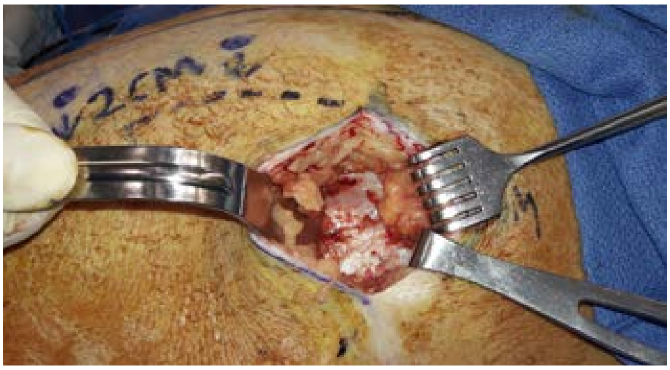

Figure 3*: Skin incision*

The dissection continues in a cephalic to caudal direction right above the fasciae lata at a relatively avascular plane, thus separating the lateral thigh away from he cruris. The dissection is strictly kept 2 cm lateral to the most lateral perforator [Figure 4].

Figure 4: *Dissection above the fascia lata*

The dissection on top of the fascia lata is be made sharply with the semi-open tips of a long Metzenbaum scissors [Figure 5].

Figure 5*: Dissection on top of fascia lata*

The technical maneuver is to push the scissors with open tips tangential to fascia lata (rater than a cutting move), and to move the thigh tissue towards the tip of the scissors via a controlled bimanual motion [Figure 6, 7].

Figure 6 and 7*: Dissection technique with scissors*

The dissection further proceeds bluntly by using a long clamp holding a sponge (sponge stick) [Figure 8, 9].

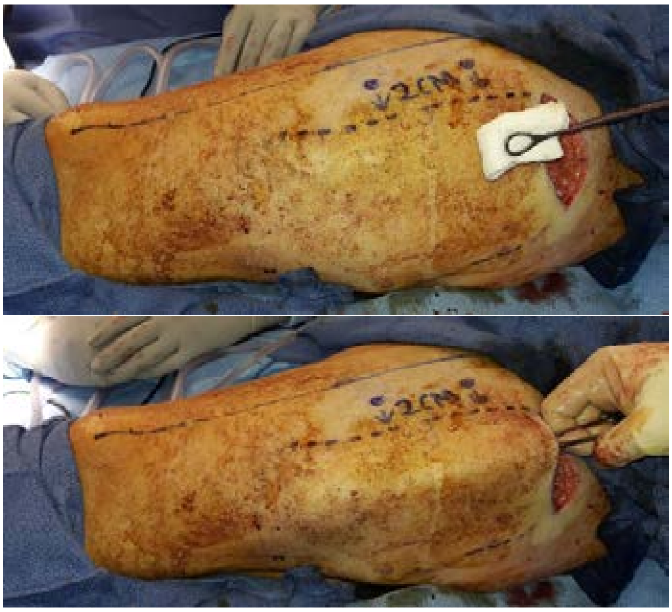

Figure 8 and 9*: Dissection technique with long clamp*

Using this method, any area of potential profuse bleeding can also be identified (although none has been seen in any cases). If any bleeding is encountered, the pocket can always be checked using a lighted retractor and bipolar cauterization can be achieved. Once enough width and length is created to accommodate the base measurement of the tissue expander, the pocket is irrigated copiously first with saline and then with betadine. We prefer to place the largest size expander available. The widest tissue gain is achieved using a rectangular expander, although elliptical implants can also be used [Figure 10].

Figure 10: *Rectangular expander*

The port of the implant is placed above the horizontal incision line a superficial subcutaneous tissue pocket and sutured in an orientation close to the skin surface for easy access with a needle during expansion [Figure 11].

Figure 11: *The implant is placed above the horizontal incision line a superficial subcutaneous tissue pocket*

Before the incision is closed at least 200 cc. of immediate expansion is done, both to see the functionality of the system as well to obliterate the dead space created by the dissection. Slight pressure from the expander also helps to apply pressure to the surrounding tissue, thus decreasing the chance of postoperative bleeding. No drains are required as they can increase the risk of infection. The incision is closed in layers, making sure the cavities for the expander and the port are in completely separated. The expansion can begin anytime when the patient is devoid of surgical pain and pressure, as there are no direct incisions on top of the expander that can potentially breakdown.

After the expansion is completed the perforators are relocated with a handheld doppler and the tissue that needs to be harvested can be determined [Figure 12].

Figure 12*: Expander under the skin*

Advantages of the technique

1. The skin incision is away from the expansion site, which prevents wound breakdown and extrusion of the expander during expansion. In addition, this enables expansion to start early on, rather than waiting for incision to heal completely.
2. The dissection is right above the fascia lata which is an avascular plane during dissection, with minimal bleeding. This also allows a simple and fast dissection without the need for direct visualization.
3. The dissection is at least 2 cm away from the perforators and the perforators need not be visualized during the dissection, making the technique easy and increasing safety.
4. The tough fascia lata acts as a resistant surface which makes the skin expansion more efficient.
5. The skin incision is away from flap area which does not compromise the future incisions making the future flap size and shape planning versatile.
6. Thinning of subcutaneous tissue elements, which is important in surfacing the aesthetic subunits of the face, neck and dorsal hand areas.
7. Total resurfacing of wide aesthetic subunits can be achieved with a single large free flap.
8. The donor area stays under the clothes during the expansion period and is well tolerated by the patient.
9. Potential for primary closure of the donor site.
10. In most cases, 2 teams can work simultaneously during flap harvest and transfer.

Conclusion

This makes the ”universal” donor site also an ”ideal” donor site for pre-expanded free flaps. The technique of tissue expander insertion is easy, fast and safe, and can be quickly learned and adapted by surgeons at all levels.

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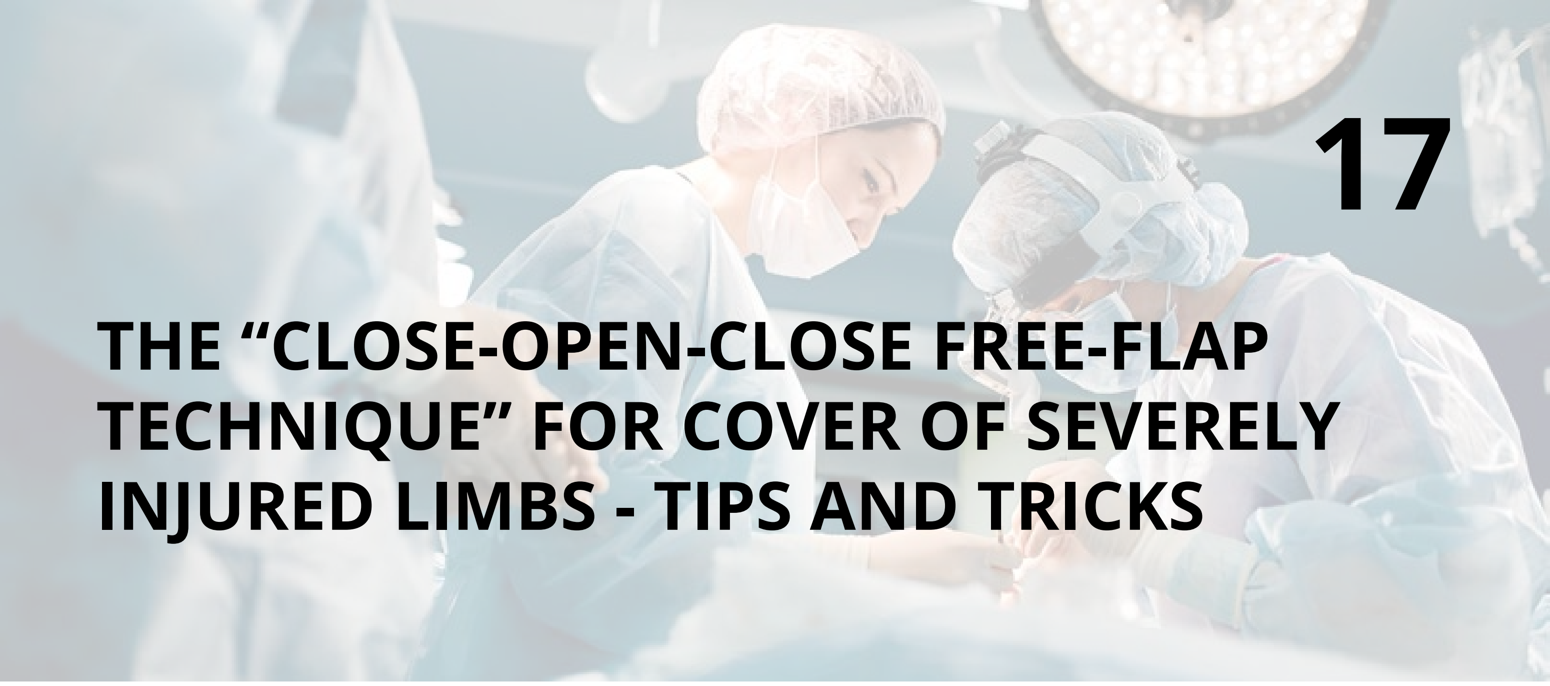

17

THE “CLOSE-OPEN-CLOSE FREE-FLAP TECHNIQUE” FOR COVER OF SEVERELY INJURED LIMBS - TIPS AND TRICKS

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Introduction

Dealing with an increasing number of patients with severe injuries to the lower and upper extremities due to industrialization, traffic accidents, conflicts and wars can be challenging. [1] High-energy traumas, such as blasts [2] or crush injuries that destroy the skin, vital soft tissues, nerves,vessels and bone, cause irreparable damage with consequent tissue ischemia and necrosis. These injuries are usually classified as Grade III open fractures, but they can be characterized descriptively as mangled extremities, mutilating injuries, and incomplete or complete amputations. [3] The lower extremities are always at more of a risk than the upper ones but invalidity and consequences that accompany upper limb injuries are more severe.

Various scoring systems, like the Mangled Extremity Severity Score (MESS), Ganga Hospital Open Injury Score (GHOIS), Injury Severity Score (ISS), Mangled Extremity Syndrome Index (MESI) are supposed to help us in decision-making but in practice it is still a problem to decide about whether to salvage or amputate a limb. [1,4,5,6]

Scores can be very helpful, but many cases teach us that every patient should be assessed individually before the decision is made. [7,8]

Surgical treatment of severe extremity injuries

When dealing with such difficult patients, after the initial assessment, treatment should be directed towards perserving life. According to the ATLS- advanced trauma life support protocol concomitant limb injuries should be neglected at the beginning. [9] A stable patient can then be treated by the usual protocol involving circulatory volume restoration, pain control, tetanus immunization and antibiotics to prevent possible aerobic and anaerobic pathogen infections.

Wound coverage

The severity of a soft tissue injury is the main factor directly related to limb salvage. Soft tissue defects on severely injured extremities are common and one of the best options for limb survival is early coverage. [10-12]

Tissue defects and open fractures with soft tissue trauma are best treated with well vascularized tissue, such as a free flap. According to Godina [10], open fracture wounds should be covered in the first 72 hours to allow revascularisation and recovery of the injured site. He reported low rates of infection and favorable results in general with many other evidence based studies supporting this concept. [12-14] Byrd and coworkers suggested that wounds in open fractures can be covered during the first week, when the biological potential for recovery is still high and before bacterial colonization appears. [15] Due to the lack of specialized microsurgical departments for microsurgical reconstruction and definitive wound cover, patients are often sent late, usually a whole week after being injured. Also, surgical treatment frequently needs to be further postponed due to comorbidity and concomitant life threatening injuries..

As the definite wound cover period from 72 hours to 3 months can lead to potential problems, especially the risk of infection, we have developed a safe, original free-flap technique that prevents infection and covers exposed bones and important structures like blood vessels, nerves and tendons. The technique was named the “Close–Open–Close Free Flap Technique“. It enables wound cover in any biological phase, by combining initial complete free-flap cover, with a possible second look debridements afterwards from one side of the flap after 6-12 hours. This technique works very well for borderline cases including highly contaminated wounds, where even after complete lavage and debridement, dead tissue and even debris still remain in the wound and also in cases in subacute biological phase of the wound declaired by Godina that are initially unsuitable for coverage. [10]

THE STEP BY STEP CLOSE–OPEN–CLOSE FREE FLAP SURGICAL TECHNIQUE

1. The patient is regularly surgically prepared, with a deflated tourniquet placed on the limb, so bleeding can be controlled if necessary. Also, we prepare a donor site with two microsurgical teams ready for simultaneous work; one to prepare the injured limb and the second to harvest the free flap from the donor site.
2. The wound is thoroughly washed and rinsed, preferably with a jet lavage using a large amount of saline and antiseptic solution. [16] Debridement of all the devascularized tissue, including bone and soft tissue, such as skin, fascia, muscles, tendons and blood vessels, is performed. Only nerves in continuity are left untouched, as transected ones are marked for later reconstruction. Also, it is important to remove all foreign bodies that can lead to infection with consequent failure.
3. Stabilization of the fracture is important to enable bone healing, soft tissue healing and to minimize the infection rate. We usually perform external bone fixation, due to the smaller risk of infection, easier manipulation of the limb and clearer visibility into the wound and tissue.
4. In the next act, we try to reconstruct the injured soft tissue as much possible. Reconstruction of the major vessels by direct suture or more often using vein grafts is crucial for limb survival.
5. Muscles and tendons are reconstructed using direct end-to-end repair, but in some cases end-to-side repair or transfer techniques may be more suitable.
6. As mentioned earlier, nerves are reconstructed whenever it is possible in order to provide better functional results. However in some cases, when a defect is present, we marked them for later repair or even in some cases preforme imidiate grafting.
7. As the final step, the defect is covered using a free microvascular flap. (Figure 1) Depending on the injured limb (upper or lower), donor flaps can be various. In our practice the usual workhorse was a free latissimus dorsi flap.

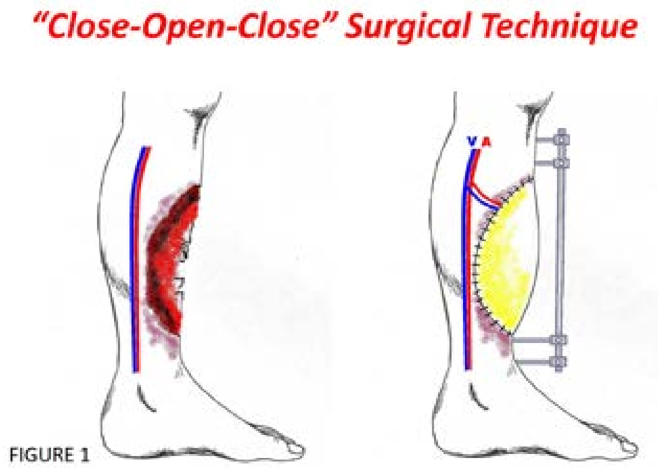

Figure 1 - *After reconstruction of all the possible structures (tendons, muscles, nerves, vessels) the defect is covered using a free microvascular flap*

8. About 12 hours after the initial surgery, and sometimes earlier, when the wound was highly contaminated, skin sutures from the one side of the flap than are removed, distant from microvascular anastomosis and vascular pedicle, and the flap is lifted. With removed stiches we make possibility for second, third and many other debridements if needed. We look for possible tissue necrosis, dead space, any infection sites, formed hematomae or active bleeding. Initial closure under local pressure allows for better hemostasis, but it can compromise vasularization. Arterial and vein anastomosis is checked to

be sure that vascularization is adequate. (Figure 2)

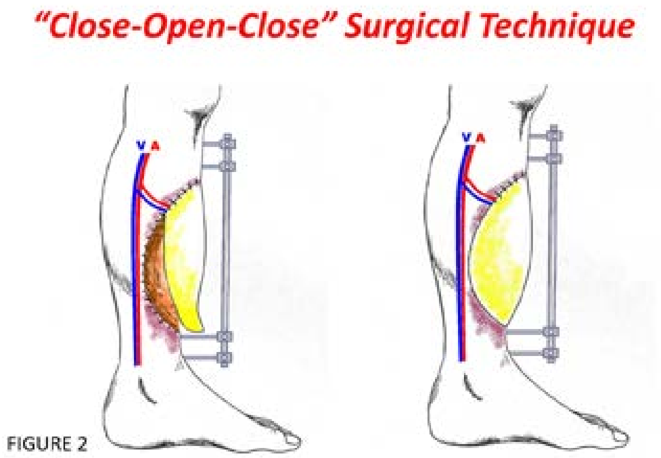

Figure 2 - *Usually 12 hours after the initial surgery, skin sutures on one side of the flap (distant from the vascular pedicle or microvascular anastomosis) are removed and the flap is raised.*

This technique allows us to perform repetitive debridement as many times as is necessary and to clean the wound extensively right up to the moment when no sign of infection or necrotic tissue is present.The wound is then definitively sutured and we proceed with treatment as usual.

Discussion

In cases when a large amount of avascular tissue is present, when a single initial debridement is not sufficient, early flap coverage can be dangerous and potentially risk the patient’s limb and/or life, as occurs with war or agricultural injuries. A secondary amputation of the limb is more likely in the presence of muscle necrosis and extensive soft tissue defects. [12,13]

On the other hand, postponing coverage can lead to complications, with destruction of exposed soft tissues and bony structures. Thus, we have developed a new “close-open-close free flap” technique providing initial cover, while subsequent partial raising of the flap allows prevention of infection, maintenance of wound drainage and secondary surgical procedures. [17]

With potential infection as a serious and important issue opinions still differ about whether to cover the primary defect or to wait for the risk to decrease and make the definitive coverage during the first week.

Our described technique can solve both problems. Namely, we cover the defect early during the first procedure, providing adequate circulation and blood influx for the injured area, and later we are able to access the wound easily to monitor what is going on in the postoperative period and, if necessary, to intervene with further debridement, lavage and even revascularization. [16]

Conclusion

There is a well-established belief that in severe limb injuries, open fracture wounds should not be closed early. However, after the pioneering works of Godina and other surgeons, early wound cover with well-vascularized free flaps became the gold standard. As a definite wound cover period from 1 week to 3 months seems to be hazardous, we have developed a safe, original free flap technique that prevents infection and covers exposed bones, tendons, nerves and vessels. We have named this technique the “Close–Open–Close Free Flap Technique“. It also works very well for emergency borderline cases, where dead tissue still remains in the wound even after complete debridement. Additional debridements, lavages and reconstruction procedures can easily be performed under the flap. When the risk for failure has been minimized, definitive wound closure can be performed.

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18

Pedicled perforator flaps – a modern and reliable reconstructive technique

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The Gent consensus defined the perforator flap as a unit of skin +/- subcutaneous tissue of whose vascularization is supplied by an isolated perforator that transverse through or in between deeper tissue, most often muscle [1,2]. This type of flaps includes advantages as replacement "like for like" as the donor site is in proximity of the defect, reduced donor site morbidity (muscle sparring, complete/partial linear closure of the donor defect), technically less demanding and faster to execute than free tissue transfers [2-6]. Not new, the perforator concept evolved from the concept of conventional flaps. They share similarities with standard random or fasciocutaneous flaps, but the gentle microsurgical dissection principles bring a crucial difference, with no need for microanastomoses [7,8].

Pedicled perforators flaps gained popularity in the recent years due to increased diversity, versatility in the design and composition of flaps. Furthermore, they are no more "flap of choice" for specific anatomical regions due to high number of perforators based flaps that can be transferred in the defect whether pedicled or free [5,7]. The flexibility of selecting individual perforating vessels to skin, for tissue transfer, has revolutionized the way we think about flaps [8].

The theory of aforementioned flap is represented by the perforasome, or the vascular territory supplied by a single perforator. By pedicle skeletonization an increased filling pressure and hyperperfusion of the selected perforator will allow an extensive interperforator flow within direct (suprafascial and adipose tissue layers) and indirect (subdermal plexus) linking vessels. In this way, at least in theory, the conventional rules of length-to-width ratios in flap design no longer apply [2,4,5].

With time passing, gaining maturity and experience, we changed our surgical practice. We are more prone to careful indications, more focus on the patient (safety first, better cosmetics, less morbidity, less anesthesia, rapid recovery – few days, ambulatory surgery, less costs) and less focus on the surgical and academical ego.

As in all reconstructive procedures, healthy young patients are perfect surgical candidates, perforators flaps may also be considered for patients with multiple comorbidities, who are poor candidates for a free tissue transfer. Peripheral vascular disease and insulin dependent diabetes are considered relative contraindications for perforator flaps [2].

Common etiologic factors for pedicled perforators flaps reconstruction within literature include trauma and burn sequalae, post excisional tumor defects, pressure sores, surgical hardware exposure and others as enterocutaneous fistula, postmediastinitis, osteomyelitis, pilonidal sinus disease [5,4,9,10].

The preoperative setting incorporates detection the most suitable perforator. The preferred method across literature, although not perfect, is the handheld doppler. It is inexpensive, can be performed relatively quickly and the patient is not exposed to radiation. Although it is not able to predict the length and the size of the pedicle, it roughly helps in mapping the skin vessels. A strong Doppler signal is not always suggestive for an appropriately sized vessel, for this reason it is advisable to select the perforators after direct intraoperative visualization. Some useful tips for differentiating main vessels from perforators: the main vessel sound is louder and will still be audible when moving the probe proximally and distally (the perforator generates a sound only in one point); putting pressure on perforator will block the flow and the sound will disappear [2,4,6,8,9,11,12,13]. More precise methods for perforators marking are Duplex ultrasound, arteriography, magnetic resonance, high resolutions computed tomography, intravenous fluorescein or near-infrared imaging fluorescent techniques [4,12].

It is advisable to elevate the flap under tourniquet control, for a cleaner dissection and better perforators recognition. The key factor to flap survival, no matter of design (peninsular/insular, propeller, advancement, VY, key-stone, rotation, transposition, bilobed, rhomboid flaps), is the axially based blood source from perforators, which should be chosen adjacent to the defect. After mapping the perforators, an exploratory incision is made, respecting as much as possible the minimal tension lines, old scars, skin laxity and should not interfere with an alternative local flap (the back-up plan) [2,4,13,14]. The most accurate sign of perforator reliability is the pulsation of the pedicle. Another important tip, for gaining more length and to prevent kinking of the vessels (especially for propeller flaps) is to retrograde dissect the pedicle at least 2-3 cm, or down to the origin, although this skeletonization can promote vasospasm [5,11,15]. The orientation of the flap should be transversely in the trunk and longitudinally in the limbs, especially when the surgeons intend to harvest a large flap and the donor area can be closed primarily +/- with skin graft [2,14].

We consider that reserving a skin bridge, although not so elegant for final flap inset, adds further arterial input and venous and lymphatic output compared with a pure island perforator flap [4,16]. The idea is still debatable, other studies highlighted an increased peripheral blood flow by redirecting the blood flow due to releasing the skin bridge [17]. Perfusion of the flap should be enhanced by providing adequate patient hydration and blood pressure, also by avoiding sympathomimetic drugs [5].

Some tips and tricks for avoidance and complications treatment [2,14]:

- Accurate preoperative mapping of all perforators is mandatory, together with having a second-choice flap (back-up plan)
- In case of arterial spasm, the flap should be left in original place approximately 15-20 minutes, until the circulation has settled. Meanwhile irrigating the pedicle with lidocaine 2-4% or papaverine (30 mg/ml) and the flap with warm saline may help. If the perfusion does not improve, the flap will be suture loosely in its native position and wait for 3-5-7 days.
- Venous insufficiency can be prevented by including a good vein into the pedicle and treated with applying local heparinization or leeches.
- Remove some stiches to relieve tension.
- Partial necrosis is often limited to the skin and can be managed by secondary intention healing or skin graft.

Between 2012 and 2018 we treated 28 patients with lower limb (19 – lower third of the leg, 9 – ankle) soft tissue defects with or without surgical hardware, bone and tendon exposure.

All the flaps were integrated, complications were noted in 3 patients: one developed postoperative venous congestion which subsided within three days by conservative means; two patients encountered, at donor site level, partial loss of the skin graft, healed by secondary intention with antibiotic ointment.

The key factor to successful flap transfer and survival is the axially based blood supply from the perforating vessels. Moreover, this fact gives the surgeon freedom in design ("free-style perforator flap), by abandoning the conventional rules of length-to-width ratio for flaps. The major benefit of preserving the axial perforator base is that arterial inflow and venous outflow of the flap are augmented by the perforating vascular bundle.

A second benefit can be provided by preserving an intact skin bridge at the base (adds arterial inflow, venous and lymphatic outflow, prevents partial flap necrosis).
A pure island flap is prone to venous congestion, as the pedicle can be easily kinked, especially when the rotation arc has 180 degrees.
Final remarks:

- Small to moderate sized soft tissue defects around the ankle and lower third of the leg, but not only, can be covered easily and safely using locally available pedicled perforator flaps.
- These flaps have the advantage of relatively rapid dissection, elevation and reliable skin territory.
- In certain patients, with multiple medical issues, pedicle perforator flaps proved to be the best choice in distal lower leg.

Clinical case 1

Clinical case 2

Clinical case 3

Clinical case 4

Clinical case 5

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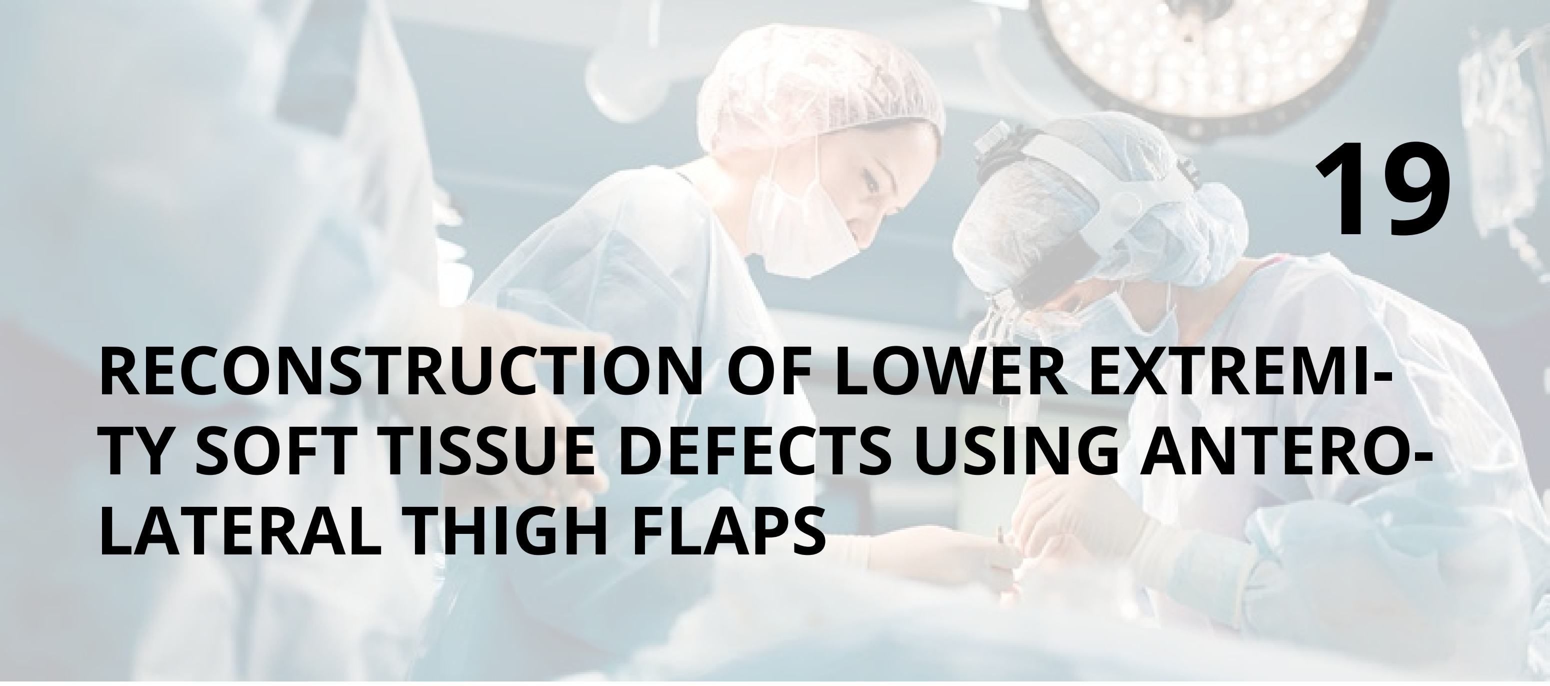

19

RECONSTRUCTION OF LOWER EXTREMITY SOFT TISSUE DEFECTS USING ANTEROLATERAL THIGH FLAPS

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Lower extremity defects are one of the most common injuries resulting in reconstruction using free flaps. The anterolateral thigh flap as a cutaneous, fasciocutaneous, musculocutaneous, chimeric, or flow-through flap was used for oncologic and traumatic reconstruction of the head and neck, lower extremity, upper extremity, and trunk [1]. Having a long pedicle, to reach out of the trauma zone, possibility to have a large skin island and muscle in case if needed, and to be able to close the donor site primarily which can be hidden under trousers are the advantages of anterolateral thigh (ALT) flap. Therefore, ALT flaps are probably the most advantageous flaps in reconstruction of lower extremity flaps.

The descending branch of lateral circumflex femoral artery supplies ALT flap. This pedicle courses between vastus lateralis and rectus femoris muscles. If the pedicle to the flap arises as a septocutaneous perforator the descending branch courses in the septum between vastus lateralis and rectus femoris however, if the flap has a musculocutaneous perforator, the pedicle courses in vastus lateralis muscle giving multiple branches to supply vastus lateralis muscle and then perforates deep fascia to supply overlying skin and subcutaneous tissue. Therefore, the surgeon must be familiar with intramuscular pedicle dissection (Fig. 1) since the pedicle usually courses intramuscularly. The perforators arise within a 3 cm radius circle that was centered between the anterior superior iliac spine and the superolateral corner of the patella [1]. I always skeletonize the pedicle during flap dissection.

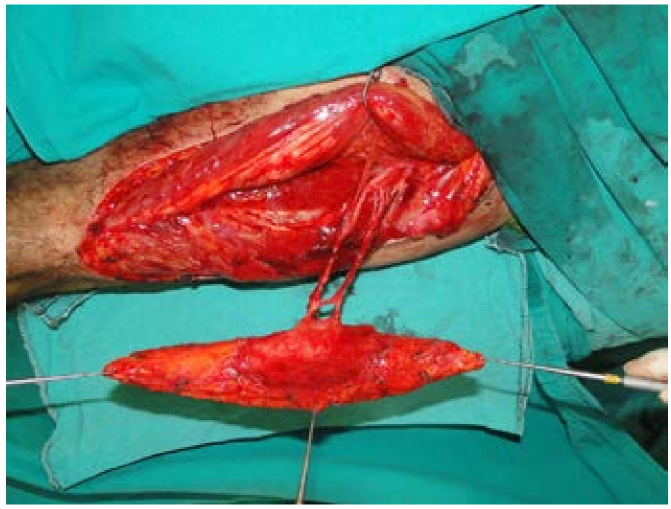

Figure 1: *An ALT flap is seen after intramuscular pedicle dissection is performed and flap is elevated*

Probably, the most important issue in reconstruction of lower extremity defects is deciding the recipient vessel and the level of anastomosis. Once the recipient vessel and the level of anastomosis is decided, the caliber of the recipient vessels and the flap vessels must be well adjusted. Also, pedicle length must be appropriate, not short and not redundant. It must be remembered that the anastomosis must always be performed outside the trauma zone since posttraumatic vessel disease (PTVD) may occur inside the trauma zone. Posttraumatic vessel disease constitute changes that occurs progressively in the vessel and peri vascular tissue after the trauma including loss of normal and easy planes around the vessels, loss of vasa vasorum and increased tendency towards vasospasm, vessel damage when dissection is attempted and lack of thromboresistant properties in which a healthy vessel has [2].

Reliable lower extremity perforators which can be used for anastomosis either arise from peroneal artery or from posterior tibial artery. However these perforators are either usually located in the trauma zone [3] or too far from the defect since lower extremity defects mostly occur in the distal third or middle third of tibia. This is why, perforator to perforator anastomosis can not be usually accomplished.

Anterior Tibial Artery (ATA) and Posterior Tibial Artery (PTA) are the two main pedicles that supply the leg and foot. Sometimes one or both of the main pedicles of the leg may be injured as in Gustillo Type 3c fractures. In these cases anastomosis may be performed either to the injured vessel outside the trauma zone in an end to end fashion if blood flow is pulsatile or to the uninjured vessel in an end to side fashion. The blood flow to the extremity is not effected if the anastomosis is performed onto a perforator, since this prevents steal phenomenon. On the contrary, if the anastomosis is performed onto anterior tibial artery, or onto posterior tibial artery in an end to side fashion the amount of blood that goes distal to the anastomosis will be diminished. This is especially important in the elderly patients who have peripheral arterial disease and in patients who have single intact vessel supplying foot and leg such as in Gustillo Type 3c injuries. However, if anastomosis is performed in an end to side fashion and thrombosis occur in an extremity which is supplied by single artery, extremity perfusion may be threatened distal to anastomosis if thrombosis obliterates main vessel lumen. This is the reason why every attempt must be undertaken to maintain blood flow for the injured vessels in case of Gustillo Type 3c injuries before the reconstructive operation or during the reconstructive operation. It must be remembered that ALT flaps may also be used as flow-through flaps. Especially in cases with Gustillo type 3c fractures, flow-through ALT flaps can be used to bridge the proximal and distal part of the injured artery outside the trauma zone thus, supplying the foot. When end to side anastomosis fails and the flap is to be salvaged ALT flap may be used as a flow-through flap. This is an important advantage of ALT flaps.

ALT flaps may also be used as chimeric flaps. In such cases skin and subcutaneous tissue is supplied by one or more perforators and muscle is supplied by another branch which is continuation of the descending branch of lateral circumflex femoral artery. Chimeric ALT flaps may be used when there is a dead space and is to be obliterated (Fig. 2). In rare cases where reliable skin perforator can not be found, a muscle flap from vastus lateralis may be harvested based on the descending branch of lateral circumflex femoral artery.

Figure 2a: *A Gustillo Type 3B fracture is seen in a pediatric patient which occurred after motor vehicle accident. It can be seen that tibia is exposed and surrounding tissue is skin grafted in another center. The defect is over the middle third of tibia.*

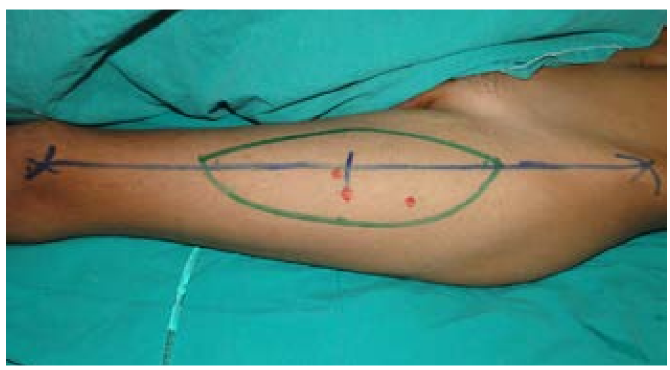

Figure 2b*: An ALT flap is planned for reconstruction of this defect and the planned flap is centered over the line between anterior superior iliac spine and superolateral corner of patella*

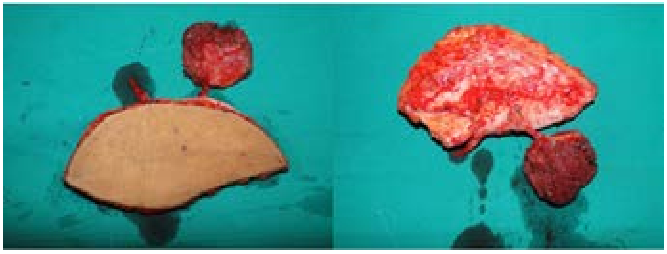

Figure 2c: *ALT flap is harvested as a chimeric flap. One branch of the pedicle supplies the flap and the other branch supplies the muscle cuff from vastus lateralis.*

Figure 2d: *Adaptation of the flap onto the defect*

Figure 2e: *Muscle cuff is secured over the exposed tibia*

Figure 2f: *The patient is seen during postoperative one mont*

The recipient artery and communicating veins are dissected off the surrounding tissue in order to prepare for anastomosis. However, during the operation, tissue around the recipient artery and vein will be swollen. Therefore, after the anastomosis is completed, instead of forcing the tissue around recipient artery and vein for primary closure, the excess flap tissue is set over the anastomosis to prevent pressure over the anastomosis site (Fig. 3). If there is excessive pressure over the artery and vein which are anastomosed, stasis and thrombosis may result. Therefore, flaps must be harvested longer than the defect.

Figure 3a: *A Gustillo Type 3b fracture is seen and soft tissue defect is noted over the middle third of tibia*

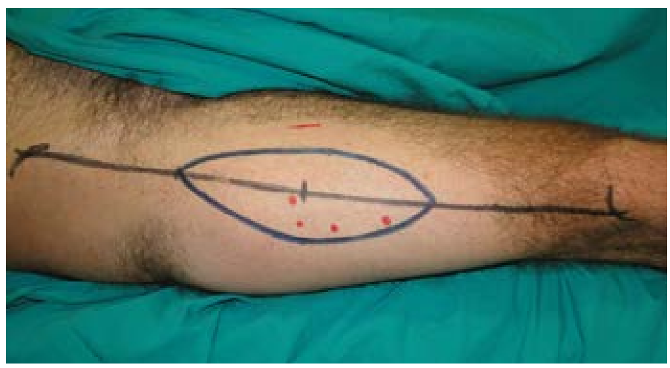

Figure 3b: *ALT flap is planned for reconstruction of this defect.*

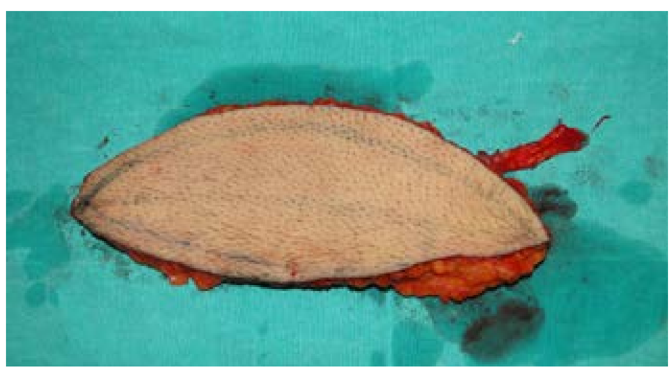

Figure 3c: *ALT flap is harvested*

Figure 3d*: Patient is seen during postoperative three months*

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20

DESIGN INSTRUCTIONS FOR THE MEDIAL SURAL ARTERY PERFORATOR

FLAP AS A LOCAL FLAP FOR LOWER EXTREMITY COVERAGE

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Introduction

The medial sural artery perforator [MSAP] flap essentially can capture the skin territory overlying the medial head of the gastrocnemius [MG] muscle. Although this is based on a musculocutaneous perforator of the MG, in their anatomical dissections seeking a potential free flap donor site, Taylor & Daniel (1) [1975] named this the "popliteal flap." Daar, et al (2) [2019] in a systematic review and meta-analysis of the use of the *free* MSAP flap concluded that it has now become a workhorse flap for all body regions. Cavadas, et al (3) [2001] generally are credited as being the first to clinically use the MSAP flap, although a presentation by Montegut and Allen (4) [1996] preceded their published report. The initial series by Cavadas, et al (3) primarily concentrated on use of the MSAP flap as a free tissue transfer, but a single case was included that was a local flap. On this basis alone they stated, but did not prove, that as a pedicled flap, a MSAP flap could reach the popliteal fossa, upper three quarters of the tibia, and even more proximally into the suprapatellar region (3). Others have since proven that this supposition was indeed correct (5-8).

Surgical Anatomy:

Nearly always a dominant musculocutaneous perforator will be found arising from the medial gastrocnemius muscle [MG] (9). When absent as is true 5% of the time, inevitably a major median sural septocutaneous artery or lateral sural musculocutaneous perforator will instead be present (9-11). The location of the medial sural perforator unfortunately can be highly variable. Kim, et al (12) suggest that if a line is drawn from the center of the popliteal crease to the prominence of the medial malleolus, a medial sural [MS] perforator will be found about 8 cm. below the crease and a second, if present, 15 cm. below [Figure 1.]. A perforator theoretically can then be found within a circle of 4 cm. radius whose center is at the intersection of these line Dusseldoral(10) in cadaver dissections found that the MS vessels had 3 types of intramuscular branching patterns with one, two, or even three or more main branches.The dominant perforator could arise from any branch, and this location was 10-12 cm. from the popliteal crease if a single dominant perforator were present, or 8-12 cm. below and again at 11-16 cm. if 2 large perforators existed (10).

Figure 1.: *This schematic from Wang, et al (11) proposed that the expected location of a medial sural [MS] artery perforator requires that a line be drawn from the mid-point of the popliteal crease to the promontory of the medial malleolus. A second line should then be drawn from the medial epicondyle of the femur to the promontory of the lateral malleolus.*

This proves that the use of landmarks or schematics to identify the MS perforator location will be unreliable.

The intramuscular course of the perforator usually is quite superficial, as within 1 cm. of the muscle surface a MS branch will be reached, although this could be deeper depending on the number of branches.

The typical length of the intramuscular pedicle will be 9 ± 3 cm. before the MG hilum is reached on the undersurface of the muscle at the level of the fibular head (10), which corresponds to the knee joint (13). The extramuscular MS vessels then traverse anteriorly and medial to their origin from the popliteal vessels between the femoral condyles (13). This extramuscular course varies from 2.6 cm. (13) or sometimes more than 5 cm. (10), so that total length of this orthograde pedicle could be in a wide range from 5-20.5 cm. (2,3,5,10,12,14), depending, of course, on the location of the perforator itself.

Surgical Technique

The presence of a medial sural [MS] perforator must first be verified. A rapid, bedside method to begin this quest is to use thermography to find “hotspots” that with a high concordance rate suggests that the corresponding vascular plexus denotes the existence of an appropriate perforator (15). This capability is now universally possible in any operating room via an inexpensive thermal imaging camera attached to the ubiquitous smartphone that uses an app supplied by the vendor [Figure 2.] [16].

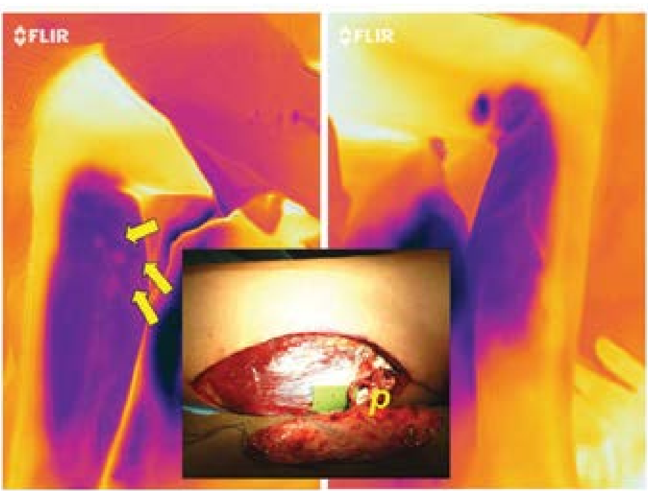

Figure 2.: *A potentially more rapid means to find a medial sural perforator cold challenge to the medial calf, then evaluate “hot spots” with a thermal imaging camera as they appear. In this example in a supine patient, the left leg demonstrated the presence only of subcutaneous veins. The right calf had 3 “hot spots” [arrows]. The right calf was then chosen to raise a MSAP free flap, with the in situ pedicle of the harvested flap shown [on microgrid] whose perforator [p] location was identical to that as seen on the thermogram.*

Once the suggested perforator site is identified, this can then be better ascertained in a somewhat now less laborious manner using color duplex ultrasound (17) or sometimes just an audible Doppler. The design of the MSAP flap about that perforator will be determined by the location of the defect requiring coverage. Flap width depends on the individual patient, as a pinch test will determine if primary closure will be possible or a skin graft needed. No matter what design is chosen, an exploratory incision should always be first made to confirm this perforator location. Some then use an endoscope for a wider view of the subfascial course of the perforator (18). Some will always use a tourniquet, without prior limb exsanguination, to keep the field highly visible. Somemore simply use a subfascial approach before beginning the intramuscular deroofing of the pedicle as far as the MS vessel origin from the popliteal vessels themselves if necessary to allow reach to the defect.

Knee & Proximal Leg: Antegrade Island Flap

An eccentric design of the MSAP flap about a proximal positioned perforator extends the reach of the flap to this region [Figure 3.].

Figure 3.: *(A) Antegrade MSAP island flap designed eccentric to*

the requisite perforator [black dot] in the proximal end of flap, to extend reach, (B) after intramuscular pedicle dissection, this easily allows reach anteriorly to the patella, or posteriorly to the popliteal fossa.

The intramuscular dissection can cease once transposition to the suprapatellar region or posteriorly to the popliteal fossa is possible without tension. A wide subcutaneous tunnel to minimize pedicle compression is always prudent. If the pedicle is short, as sometimes will be unpredictable, microsurgical extension with vein grafts may be necessary, although this is unusual.

Anterior Middle Third Leg: Antegrade Propeller Pedicled Flap

To reach the anterior middle third of the leg, the flap must have 2 points of rotation. The first will be that possible after completion of the proximal pedicle dissection, then the second with rotation of the flap about the perforator itself like a propeller [Figure 4.].

Figure 4.: *(A) Antegrade MSAP flap intended for coverage of an anterior middle third leg defect should chose a more distal perforator [black dot] if it exists, with that placed eccentrically in the distal part of the flap that will itself be proximal to that perforator, (B) after sufficient intramuscular dissection of the source pedicle, the flap can be rotated toward the anterior tibia, (C) then a second rotation of the flap either clockwise or counter-clockwise about the perforator like a propeller will allow inset into the defect*

The initial technique otherwise is identical to that for raising an antegrade island flap, except that the eccentric flap design preferably requires use of a more distal dominant MS perforator with that perforator located as distal as possible within the flap. The projected reach then will be the sum of the source pedicle reach and the length of the flap itself that extends away from the perforator. Tee, et al have shown this to be a reliable option with total arc of rotation ranging from 22-36 cm. (7).

Posterior Middle Third Leg: Propeller Flap

If a more distal dominant perforator is available, a MSAP flap designed with that perforator eccentrically placed in the distal portion of the flap can then be rotated about it like a propeller to reach the posterior aspect of the middle third of the leg [Figure 5.]. Eser, et al, have found this to be an excellent means to close the donor site of a distal-based sural flap by avoiding a skin graft (8).

Figure 5.: *(A) A distal-based sural fasciocutaneous flap [arrow] will leave a posterior middle third leg defect that could be skin grafted. Instead, if a more distal medial sural perforator exists, an MSAP flap can be eccentrically designed with that perforator [black dot] distally positioned, (B) to allow the flap to then be propellered about that perforator to synchronously close the distal-based sural flap donor site while its own is closed primarily.*

Distal Leg: Retrograde Propeller Pedicled Flap

To reach the more distal leg or even the more distal anterior middle third, the MSAP flap must rely on tenuous retrograde perfusion (6,7). A more distal dominant perforator must exist. The source branch must be skeletonized proximal and distal to the perforator [Figure 6.], with extension of the distal pedicle dissection to no more than several centimeters above the insertion of the medial gastrocnemius muscle into the triceps surae to insure retention of collaterals (7). A microclamp is then placed on the orthograde flow side, and if the flap appears to be adequately perfused, then that side ligated and the flap rotated as needed on the pedicle and about the perforator itself to the defect. If not adequately perfused, another option would be conversion to a free flap, which should always be considered pre-operatively as a potential sequela .

Figure 6.: *(A) To reach a distal leg defect, the MSAP flap will have to rely on retrograde perfusion. A distal perforator [black dot] must exist and positioned in the distal portion of the flap. The medial sural branch from which the perforator arises should be skeletonized proximal and distal to the latter's origin. (B) After placement of a microclamp proximal to the perforator, if circulation to the flap seems sufficient, the proximal source vessel can be divided, and the flap as needed into the defect.*

Discussion:

The medial sural artery perforator [MSAP] flap no longer is just another free flap donor site. When appropriately designed, coverage of many small or medium sized lower extremity defects is possible as a local flap. This does not mean that microsurgical capabilities can now be avoided, as these relatively diminutive perforators still will require a delicate dissection, but without any microvascular anastomoses (19). A major difficulty is finding the exact location of potentially adequate perforators. No schematics are reliable to facilitate this search. Color duplex ultrasound may prove to be the ultimate best option (17), although simple thermography can certainly be helpful [Figure 2.] (16). As with any flap, reliance on retrograde perfusion alone can be hazardous, so that use of the MSAP flap routinely for distal leg defects should always be approached with appropriate trepidation (6,7). The MSAP flap when used as a local flap has definite attributes, as well as detriments that should be carefully considered whenever deciding to use this "workhorse" donor site [Table].

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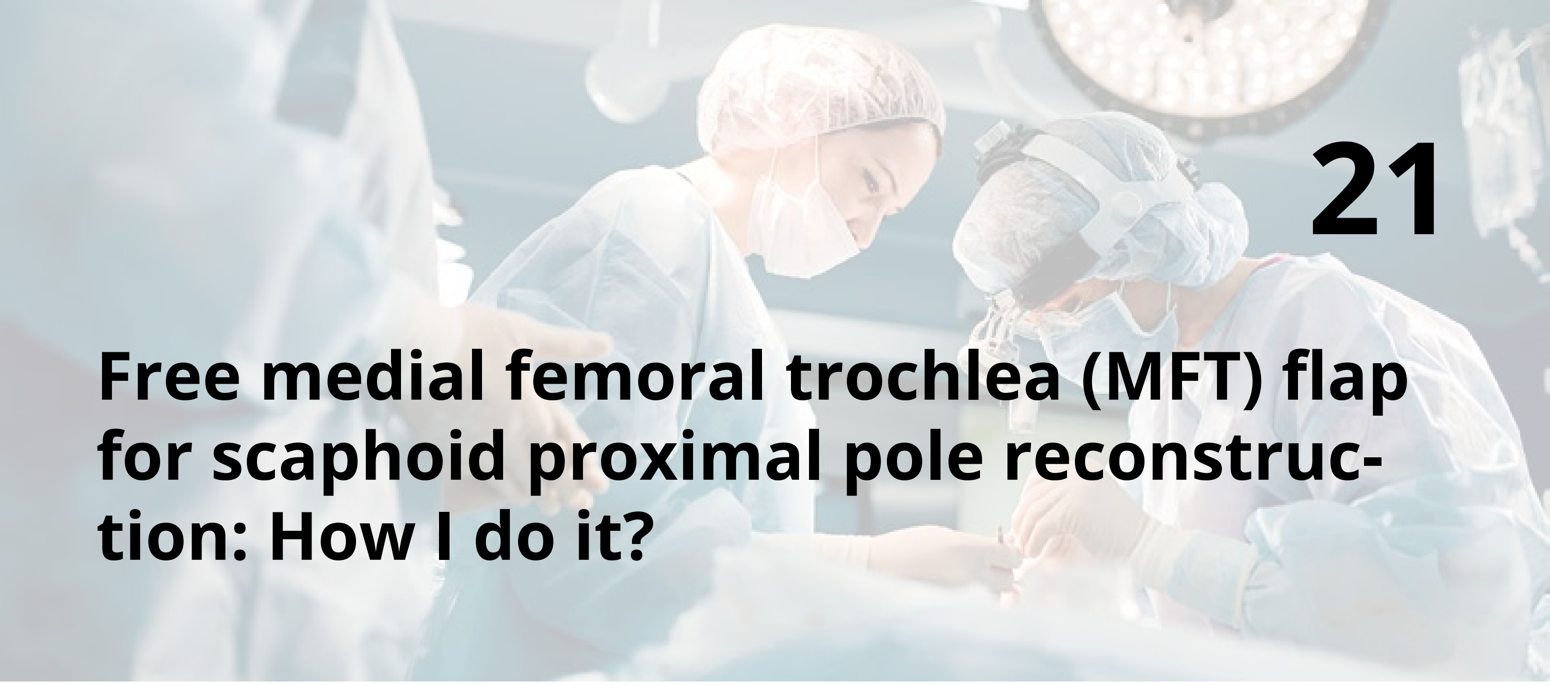

21

Free medial femoral trochlea (MFT) flap for scaphoid proximal pole reconstruction: How I do it?

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Introduction

The medial femoral trochlea flap (MFT) provides a vascularized osteochondral flap first described by Kälicke *et al.* in 2008(1). Its harvest from the non-weight-bearing patellofemoral joint minimizes donor-site morbidity, while its convexity makes it an excellent match for replacing the proximal pole of the scaphoid for the treatment of scaphoid nonunion with avascular necrosis (AVN) of the scaphoid proximal pole. Animal(3) and human(4) studies have demonstrated the MFT's ability to reliably transfer vascularize articular cartilage to the wrist, with favorable results compared to non-vascularized grafts. Here, we review our technique for performing the free MFT vascularized osteochondral flap for proximal pole scaphoid reconstruction, as an alternative to the free medial femoral condyle (MFC) flap and pedicled vascularized bone flap options.

Anatomic Considerations

The MFT is supplied by the descending geniculate artery (DGA) or, rarely, by the superomedial geniculate artery (SMGA). The DGA is present in 85% of cases and arises from the superficial femoral artery (SFA) 15 cm proximal to the femorotibial joint(2). The DGA travels anterior to the adductor magnus tendon and gives rise to the saphenous artery branch (SAB), muscular branches, and cutaneous branches (DGA-CB) before coming densely adherent to the femoral periosteum and dividing into transverse and longitudinal branches. The transverse DGA branch supplies the MFT osteochondral flap(5).

When the DGA is not present, the transverse and longitudinal arteries of the medial femoral condyle are supplied by the SMGA, which is present in 100% of cases. The SMGA originates from the medial aspect of the popliteal artery 7 cm proximal to the femorotibial joint. It then crosses above (33%), below (56%), or bifurcates around (11%) the adductor tubercle and supplies the transverse and longitudinal arteries(2).

If significant scarring is present at the recipient site, the MFT may be harvested with a skin paddle centered over the medial femoral condyle, which facilitates recipient site closure without tension on the pedicle and also aids in postoperative monitoring. Cutaneous circulation is supplied by both the saphenous artery branch and the DGA-CB. The SAB is present in 92% of cases, and it originates 14 cm proximal to the joint line of the knee, supplying 361 cm^2 of skin. Three different origination patterns of the SAB have been identified: from the DGA (64%), from a common ostium with the DGA (27%), and from the SFA (9%). Distally, the SAB perforators pass either anterior (45%) or posterior (55%) to the sartorius(6). This is important to note, because the osseous component of the flap is anterior to the sartorius. If the SAB perforators pass posterior and the SAB is chosen to supply a skin paddle, the skin paddle will need to be carefully elevated and passed under the sartorius to unite it with the osteochondral portion of the flap. The DGA cutaneous branches originate distally from the DGA where the vessel transitions from subcutaneous to periosteal. DGA cutaneous perforators have been identified in 94% of cases and are always located anterior to the sartorius in the same interval as the bone(5).

Preoperative Evaluation

We consider the MFT flap as an option for younger patients with proximal pole scaphoid nonunion with AVN. In older patients, our preference would depend on the nonunion pattern and whether there is AVN, and we would favor the medial femoral condyle (MFC) free flap or pedicled vascularized bone flap, if possible, since the cartilage harvest may induce increased morbidity and pain in older patients. Otherwise, a salvage procedure like proximal row carpectomy (PRC) or scaphoidectomy and four-corner fusion would be the logical choice. In patients younger than 40 years, these salvage operations may not be as durable(7), so we offer the vascularized MFT osteochondral graft. When considering this flap, it is important to discuss the risk of donor-site morbidity with patients. The reported data on this flap suggests that patients return to normal knee function at around 3 months postoperatively(8-10). Obese patients may be at higher risk for chronic knee pain and should thus be counseled appropriately(11). Caution should also be exercised in patients who place high demand on their knees, such as athletes, as data in this population is limited.

Intraoperative Details

Figure 1A. *X-rays of the right wrist demonstrate a very proximal nonunion of the scaphoid proximal pole. Figures 1B and C. CT scans verify how small the fracture fragment is. Note the scapholunate diastasis. Contralateral x-rays of the left wrist confirmed that the patient has bilateral, symmetric scapholunate widening.*

Our harvest technique is similar to that described by Bürger and colleagues(12). This 18 year-old right hand-dominant patient had a longstanding history of pain in his right wrist, and imaging studies (Figure 1) demonstrate a right scaphoid proximal pole nonunion that would be extremely difficult to repair or reconstruct without a vascularized MFT osteochondral flap. A stepwise description is as follows:

1. The patient is placed supine on the operating table, with the upper extremity and ipsilateral lower extremity prepped and draped. Sterile arm and thigh tourniquets are placed.
2. A pencil Doppler probe is used to identify an arterial signal over the medial femoral condyle corresponding with the DGA-CB if a skin paddle will be harvested with the flap. Typically, the senior author does not harvest a skin paddle when using a free MFT flap for scaphoid proximal pole reconstruction.
3. The posterior patella, distal medial femoral condyle, and tibial plateau surfaces are marked. A long straight incision is designed beginning at Hunter's canal terminating at the distal medial femoral condyle (Figure 2).

Figure 2. *Incision for MFT harvest. The tibial plateau, deep surface of the patella, and the medial femoral condyle (curved line) are marked for reference. Incision is marked over Hunter's canal continuing to the distal extent of the medial femoral condyle.*

4. The recipient site at the wrist should then be exposed. For scaphoid proximal pole, we prefer a dorsal approach with a curved incision over the course of the extensor pollicis longus (EPL) tendon to permit access to both the scaphoid proximal pole and the dorsal radial vessels for anastomosis (Figure 3).

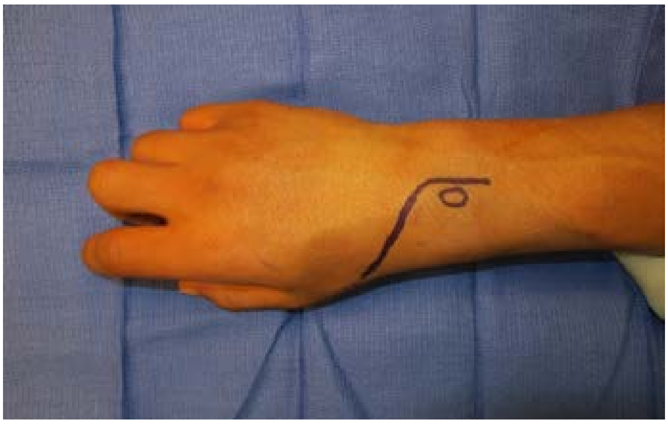


Figure 3. *Incision for dorsal approach to the wrist for proximal scaphoid excision. A curved radial extension over the course of the extensor pollicis longus (EPL) tendon is made for access to the anatomic snuffbox. This exposure provides the best access to the scaphoid proximal pole and the dorsal radial vessels.*

5. The scaphoid fossa of the radius should be inspected to ensure that it is intact. We consider arthritis at the scaphoid fossa to be a contraindication to performing MFT reconstruction.
6. The scaphoid nonunion is identified (Figure 4), and the scaphoid proximal pole should be resected to healthy bone (Figure 5). Any preexisting hardware should be removed. The cartilage of the scaphocapitate joint should be preserved, along with the distal portion of the scapholunate ligament, if possible, to facilitate postoperative stability.

Figure 4. *The scaphoid nonunion is identified (marked by Freer elevator);*

Figure 5. *The proximal pole is excised*

A template is then created by placing methylmethacrylate into the void left by the resected proximal pole (Figure 6).

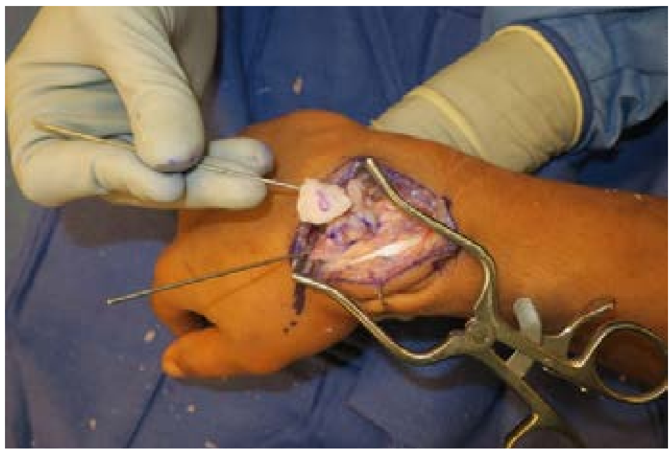


Figure 6. *A methylmethacrylate template is created using the void where the proximal pole used to be. A Kirschner wire is placed in the template to mark where the vascular pedicle will emerge from the osteochondral flap.*

Care must be taken to cool the methylmethacrylate while it is in contact with the distal scaphoid to avoid thermal damage to the bone. The senior author prefers to place a 0.045-inch Kirschner wire into the template to mark where the vascular pedicle of the MFT will emerge from the fla. Attention is then directed to the thigh. An incision is made, and dissection is carried down to the subfascial level between the sartorius and the vastus medialis. The vastus medialis is retracted anteriorly to expose the distal femur. There is a fibrofatty layer on the superficial surface of the medial femur that should be elevated to expose the periosteum. The DGA is visualized traveling with the periosteum of the femur as the vastus medialis is retracted (Figure 7).

Figure 7. *Exposure for MFT harvest. Vastus medialis has been retracted laterally, with the DGA visible along the anterior surface of adductor magnus. The DGA is seen to bifurcate into transverse and longitudinal branches.*

The transverse branch of the DGA is identified, and the osteochondral flap is designed, using the methylmethacrylate template as a guide (Figure 8).

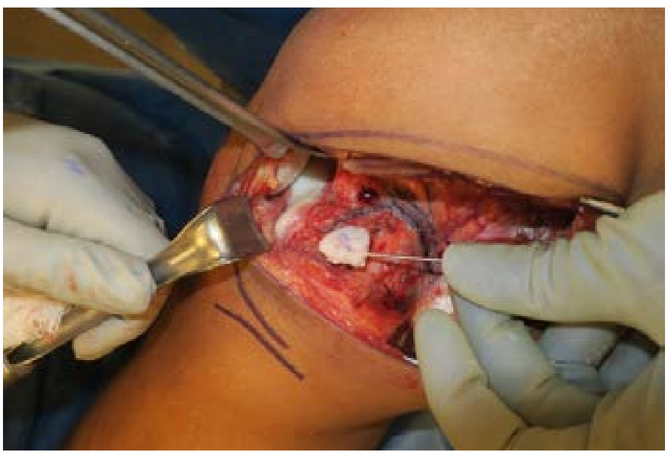


Figure 8. *The template is used to design the MFT osteochondral flap.*

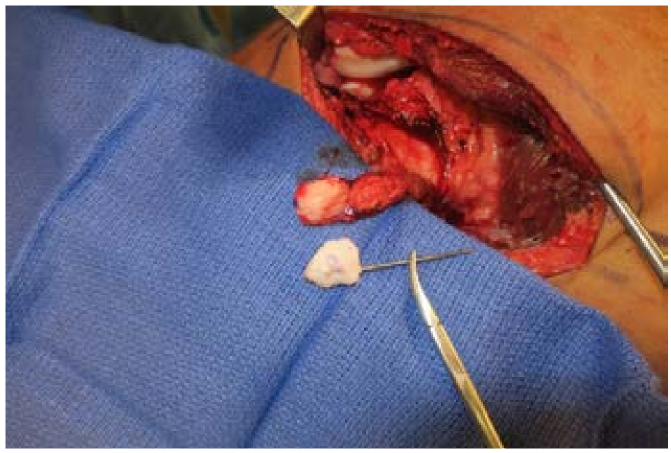
The dimensions of the flap should be as follows:

The proximal-distal aspect of the flap should approximate the radial-ulnar defect size;

a. The anterior-posterior dimension of the flap should approximate the proximal-distal defect size; and

b. The medial-lateral dimension of the flap should approximate the volar-dorsal defect size.

7. A sagittal saw or osteotomes are used to make the osteotomies, being careful not to injure the vascular pedicle. The MFT flap is then inspected to verify that there is bleeding along the cut surfaces of the bone. Either before or after the osteotomies are made, a wide (greater than 1 cm) cuff of periosteum that includes the transverse branch of the DGA is dissected. ***It is extremely important to harvest as wide a cuff of periosteum as possible*** (Figure 9).



Figures 9 and 10. *The MFT flap is harvested with a sagittal saw and straight osteotomes. Note the wide (>1 cm) cuff of periosteum included with the flap, which is essential to maintain perfusion to the osteochondral component.*

8. The longitudinal branch is ligated, and the pedicle is dissected toward its origin

from the SFA. Typically, the senior author dissects only 5 to 7 cm of vascular pedicle length, since anastomosis will be performed end-to-side into the dorsal radial vessels in the anatomic snuffbox.

9. Attention is returned to the wrist, and the recipient vessels are prepared. Some surgeons have described harvesting a longer vascular pedicle to tunnel to the volar radial vessels; however, we prefer an end-to-side anastomosis to the radial artery in the snuffbox.
10. The MFT flap is harvested from the knee (Figure 10), and the flap artery is flushed with heparinized saline. The flap is transferred to the wrist with the vascular pedicle emerging dorsally (Figure 11).

Figure 11. *Fixation is achieved with a headless compression screw in an antegrade fashion andshould be buried deep to the ca rtilage. The vascular pedicle emerges dorsally. Temporary fixation is achieved with Kirschner wires, and permanent fixation is achieved with a headless compression screw placed in an antegrade fashion (Figure 5) with the aid of intraoperative fluoroscopy. When imaging the reconstructed scaphoid, the headless compression screw will appear prominent proximally, which is expected due to the thickness of the cartilage from the medial femur. The screw should be advanced so that it is completely buried under the cartilage surface with enough purchase of the distal scaphoid to achieve sufficient compression across the osteosynthesis site.*

11. Under the microscope, the flap vessels are separated from the periosteum, and at this level, the flap artery is typically less than 1 mm in diameter. An end-to-side anastomosis is performed into the dorsal radial artery, and end-to-side or end-to-end anastomoses are performed to the radial venae comitantes or cephalic vein, which is nearby. The skin is closed loosely over the vascular anastomoses.

Postoperative Care

Postoperatively, the patient is placed in a bulky short-arm splint with no pressure over the vascular anastomoses. As our routine is to not harvest a skin paddle, the patient is admitted as an inpatient for pain control and discharged when ambulating and tolerating a diet, which is usually on post-operative day 1 or 2. No restrictions are placed on the knee, though some patients receive physical therapy. Harvesting the graft from the ipsilateral lower extremity allows patients to use their non-operated upper extremity for support as needed. At the first postoperative visit, the patient is transitioned to a short-arm cast for an additional 4 to 6 weeks postoperatively. The senior author prefers to obtain a CT scan 6 to 8 weeks post-operatively to verify healing across the osteosynthesis site, after which the patient is placed in a custom thermoplastic removable splint for an additional 4 to 6 weeks. Hand therapy is started at this time for gentle range of motion exercises, and weight-bearing as tolerated is typically allowed at 12 weeks postoperatively. Five-month post-operative images (Figure 12).

Figure 12A and B. *5-month follow-up x-rays demonstrate good alignment of the reconstructed scaphoid with stable (symmetric) scapholunate widening. Note the appearance of proximal screw prominence, which is expected due to the thickness of the cartilage from the medial femur.*
And range of motion photographs (Figure 13) are shown here.

Figures 13A, B, C, and D. *5-month photographs demonstrating good range of motion with some limitations to right wrist flexion and extension. It should be noted that the patient had no pain in his right knee by 6 weeks post-operatively and was running and jumping without any issues.*

Conclusion

The medial femoral trochlea flap provides a vascularized osteochondral flap that can reliably transfer articular cartilage to the proximal scaphoid after proximal pole nonunion and AVN. We favor it for use in the young patient with proximal pole nonunion as the durability of salvage operations in this population has come into question. Long-term results from the MFT are still being accumulated, but short- and intermediate term results are favorable.

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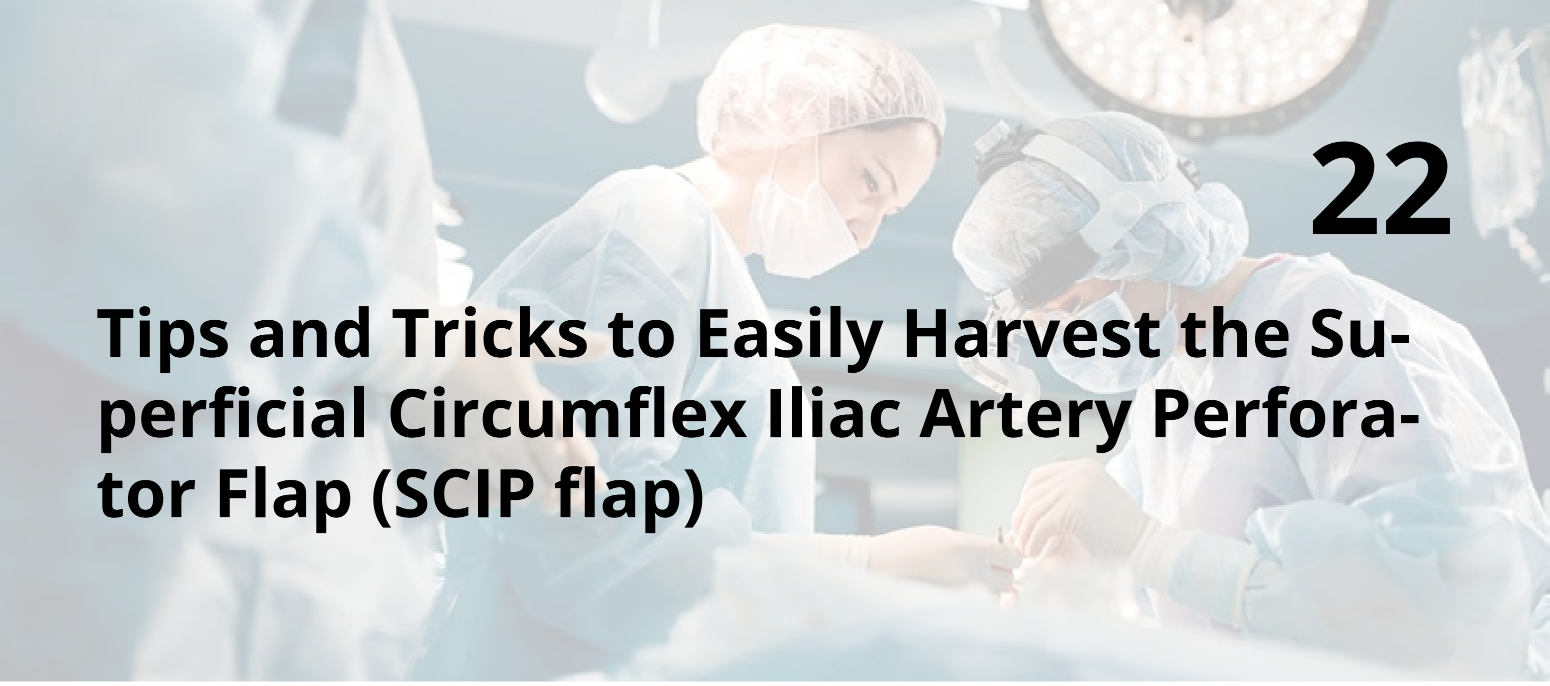

22

Tips and Tricks to Easily Harvest the Superficial Circumflex Iliac Artery Perforator Flap (SCIP flap)

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Clínica Las Condes / Hospital del Trabajador

History

The inguinal area has been used as a donor site since a long time ago. Initially, McGregor described the pedicled inguinal flap in 1972,[1] which later become the first free flap performed by Daniel and Taylor.[2] However, given the frequent anatomical variations of its vascular anatomy, it did not achieve great popularity as a free flap. Afterward, in the perforator flaps era, the inguinal area reappeared as the superficial circumflex iliac artery perforator flap (SCIP). Since its description by Koshima in 2004,[3] it has been used in head and neck,[4,5] external auditory canal,[6] penis,[7] scrotum[8], vulvar[9], groin[10], bone[11] and lower limb reconstruction.[12,13]

Anatomy

The SCIP flap is based on perforators of the superficial circumflex iliac artery, originated from the femoral artery vessels in most of the cases. There are two major types of perforators: the medial perforator with a direct cutaneous or axial pattern type (superficial branch) located relatively medially on the flap, and the lateral perforator traveling laterally beneath the deep fascia and often with an intramuscular pathway penetrating the deep fascia on the lateral aspect (deep branch) of the flap. The medial branch, after penetrating the deep fascia, generally provides some branches to the inguinal lymph nodes before penetrating the superficial fascia. Therefore, the perforating site of the medial branch on the deep fascia is usually different from the perforating site on the superficial fascia, which must be considered for preoperative planning (Figure 1).[14] SCIP flap is generally thin and pliable, of moderate size and with a concealed donor site. Their limitations include a restricted width to allow a primary closure, increased thickness in overweight patients and short pedicle with low caliber, which limit its use to defects with nearby recipient vessels. Although, there are well described studies about the anatomy of the arterial vasculature[15], designing and elevation of the flap are different issues because there is always some potential of anatomical variations such as pedicle anatomy, location of lymph nodes, and thickness of superficial fascia. The presence of internal pudendal artery and superficial inferior epigastric artery in the groin may add to the confusion. To face these disadvantages, dissection above the superficial fascia based on the media branch and the use of supermicrosurgical techniques for perforator-to-perforator anastomosis, have expanded its uses.[13]

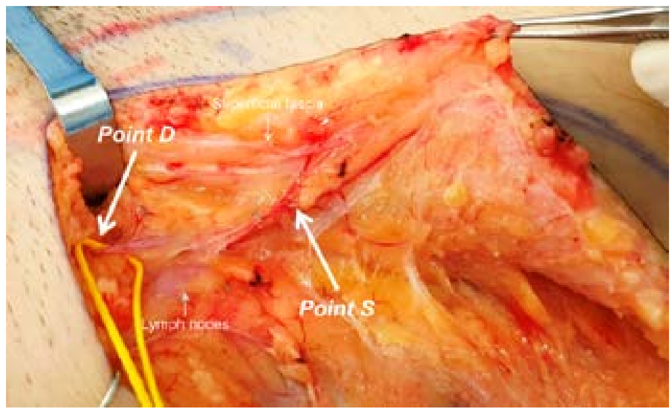

Figure 1. *Perforating sites of the medial branch of superficial circumflex iliac artery on the deep (point D) and superficial (point S) fascia.*

Preoperative planning

As with other free flaps, preoperative planning has been described by different authors using hand-held doppler, color doppler ultrasound (CDU),[16–18] angiography and computed tomographic angiography (CTA).[13,15] The wide majority describes the use of CTA and CDU.[19] However, these reports are mostly limited to pointing out the use of such technologies without making a complete description of the way in which the information is used to plan the flap.

Our preoperative planning protocol is based on CTA due to its availability, easy interpretation and time savings. Lower extremity

CTA images are obtained using a 64-detector row helical CT system (Brilliance 64; Philips®, Amsterdam, Netherlands) with perforator protocol, maximum intensity projection, and 1-mm slice width; in order to study recipient vessels (lower extremity cases) and for free flap preoperative planning.

Identification of perforating sites in the axial view[14]

CTA images are analyzed by the surgeon preoperatively. Different measurements are performed in both inguinal areas, considering the midline as "y-axis" (1-mm slice width) and a perpendicular line to the latter as the "x-axis".

- Step 1: In the axial view we study the course of the superficial circumflex iliac artery (SCIA), from its origin on the femoral artery (most of the cases). We identify the perforating site of the medial branch on the deep fascia. Distances are measured from the center of the umbilicus in the "y-axis" and from the midline perpendicularly in the "x-axis" (Point D - *Deep fascia*) (Figure 2A).

- Step 2: In the axial view we identify the perforating site of the medial branch on the superficial fascia, usually when it separates from the lymph nodes. Measurements are taken from the center of the umbilicus in the "y-axis" and from the midline perpendicularly in the "x-axis" (Point S - *Superficial/Scarpa's fascia*) (Figure 2B).

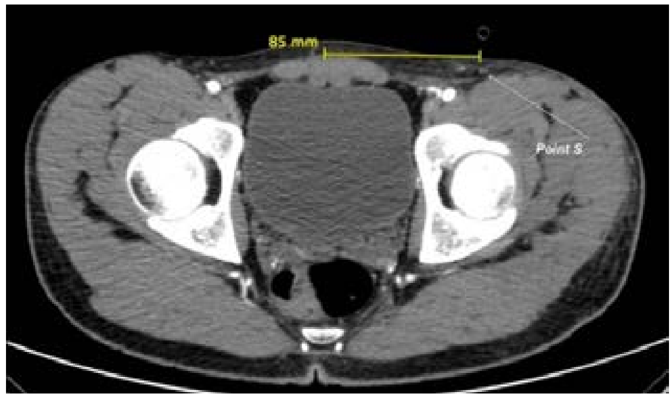

Figure 2A, 2B: *Identification of perforating sites of the medial branch of the superficial circumflex iliac artery on CTA. The perforating site on the deep fascia was named as "Point D" (A) and on the superficial fascia as "Point S" (B). Distances were measured from the center of the umbilicus in the "y-axis" (not shown) and from the midline perpendicularly to the latter, in the "x-axis" (yellow line).*

Points D and S are marked on the patient's skin of both inguinal areas preoperatively (Figure 3). Handheld doppler ultrasound (8 MHz probe) is performed to check the presence of the perforator on the marked points.

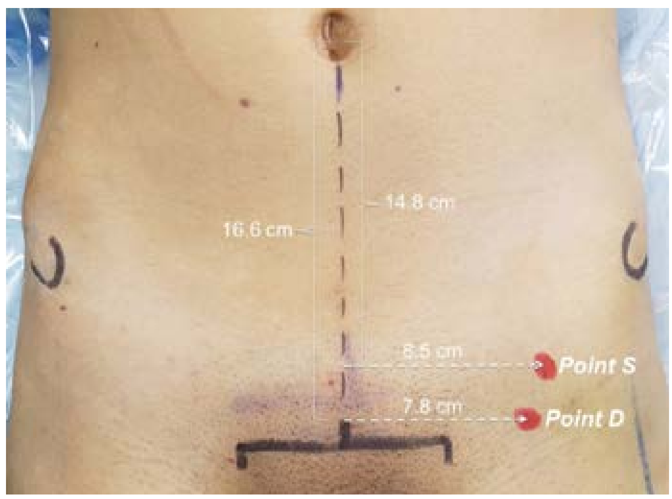

Figure 3. *Points D and S were marked on the patient's skin of the inguinal area preoperatively (same patient as in Figure 2*

Augmented Reality Microsurgical Planning with a Smartphone (ARM-PS)[20]

A 3-dimensional (3D) reconstruction image of inguinal and lower abdomen vascular anatomy is performed using a Multi-Modality Advanced Vessel Analysis software (AVA) (Philips, Amsterdam, Netherlands), identifying referential landmarks; umbilicus, both anterior superior iliac spines (ASIS) and superior border of pubic symphysis (PS) (Figure 4).

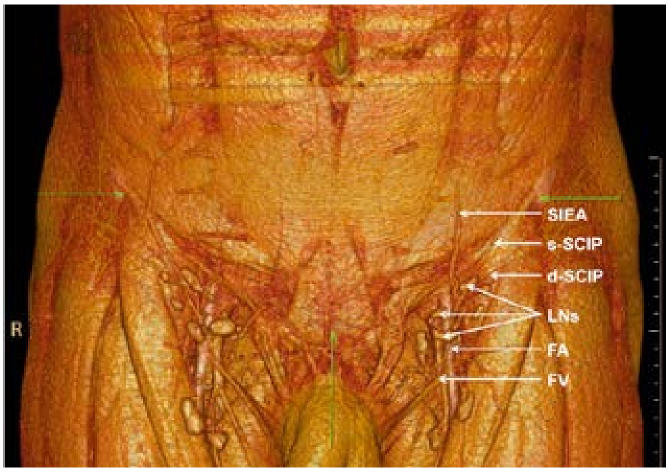

Figure 4. *3D reconstruction image of inguinal and lower abdomen vascular anatomy. Landmarks used are umbilicus and green arrows (both anterior superior iliac spines and superior border of pubic symphysis). (SIEA: superficial inferior epigastric artery; s-SCIP: superficial branch of superficial circumflex iliac artery perforator; d-SCIP: deep branch of superficial circumflex iliac artery perforator; LNs: lymph nodes; FA: femoral artery; FV: femoral vein).*

The 3D image from CTA is reviewed online in a smartphone and is downloaded directly to the picture's gallery. The 3D image is imported from the smartphone's gallery to an AR app (ie. Camera Lucida AR, Seattle, Washington) to overlap the image with the camera. Free hand drawings are performed guided through the smartphone screen, fixing the image to the landmarks (umbilicus, both ASIS and PS) identifying arteries and veins derived from the femoral vessels (superficial inferior epigastric (SIE), superficial branch of SCIP (s-SCIP), deep branch of SCIP (d-SICP)) and groin lymph nodes (Figure 5).

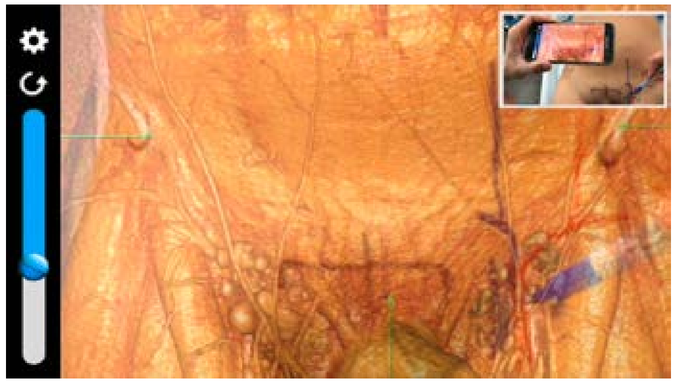

Figure 5. *The 3D image is overlapped with the image of the camera and free hand drawings are performed guided through the smartphone screen.*

Surgical technique

The SCIP flap is designed with the axis centered on the medial branch of the SCIA, generally in a line from the inguinal crease to the anterior superior iliac spine (ASIS) (Figure 6). A pinch test is performed to confirm primary closure of the donor site. The maximum width of the flap that can be raised while permitting primary closure is around 8 cm.

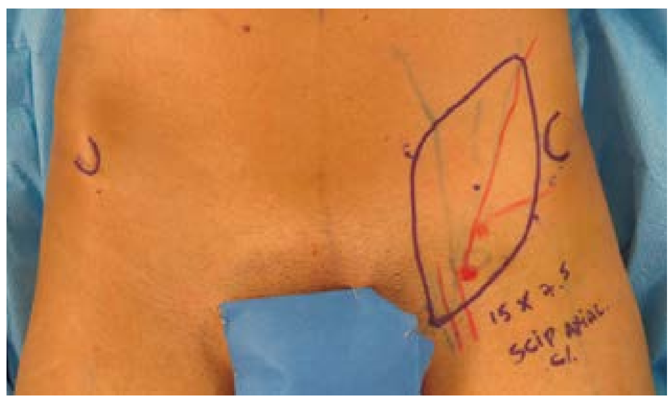

Figure 6. *SCIP flap designed with the axis centered on the medial branch of the SCIA.*

An exploratory incision is performed in the inferior-lateral aspect and the flap is raised above the superficial fascia, a thin white film layer between the deep and superficial fat (Figure 7).

Figure 7. *Exploratory incision in the inferior-lateral aspect of the flap and harvest above the superficial fascia*

The superficial fascia is an avascular plane and allows identifying the perforators easily. One of the key techniques to identify the superficial fascia is traction of incision margin and to keep a bloodless field. At 1-2 cm from *point D* where we deepen to look for the perforator on its origin and a vessels loop is placed once it is identified (Figure 8).

Figure 8. *Identification of the perforator when it pierces the deep fascia*

The incision of the flap is completed and the dissection continued above the superficial fascia up to point S, from lateral to medial with enough traction to clearly see the plane (Figure 9). Once the perforator is determined, the dissection proceeds toward the source vessel to obtain an adequate length. By opening the deep fascia, one may obtain a longer pedicle with an increased vessel diameter.

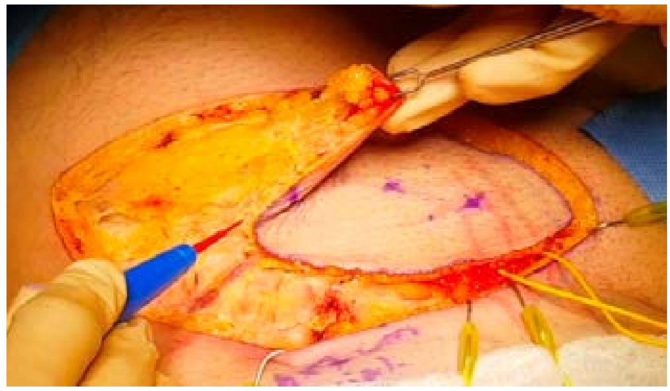

Figure 9. *Elevation of the flap above the superficial fascia up to point S, from lateral to medial*
The superficial vein has an axial pattern and is usually encountered at the distal margin of flap during elevation. The vena commitans of the SCIP often drains to the superficial vein thus can simplify the anastomosis by just taking this superficial vein.

After the flap harvest is done, adequate hemostasis is performed. Suction drain is left in place and closure of the superficial fascia above the drain is performed using 2-0 Vicryl (Ethicon, Sommerville, New Jersey, United States). Primary closure is then performed using 4-0 Vicryl for the subdermal plane and 4-0 Monocryl (Ethicon, Cornelia, Georgia, United States) for intradermal closure. Incisional negative-pressure wound therapy is applied immediately after wound closure. The polyurethane foam is placed in direct contact with the wound. Adjacent skin to the wound edges is protected from contact with the foam using transparent adhesive drape. Therapy was set at a pressure of -120 mm Hg in continuous mode for 7 days, after which it is changed to a traditional dressing (Figure 10).

Figure 10. *Incisional negative-pressure wound therapy after wound closure*

Conclusions

Medial branch based SCIP flap can be easily harvested by a preoperative planning with CTA using the points D and S method and ARM-PS. Flap elevation and pedicle dissection have a slow learning curve, but with an adequate planning and some surgical tips and tricks, a reliable technique that allows performing a safe and predictable raise of the flap is possible.

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23

Anterolateral thigh flap

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Introduction

The anterolateral thigh flap is one of the most common flap used for reconstruction of soft tissue defects of the upper or lower extremity, being described in 1984 by Song et al. Even though originally was described as a septocutaneous flap, only 13 % of the flaps are based on septocutaneous vessels, the others being based on musculocutaneous perforators. The flap has optimal variable dimensions and is pliable, being commonly used in head and neck reconstruction. Among thigh flaps, the anterolateral flap is the most frequent use because is easy to raise and is the thinnest. It has a great versatility being possible to harvest multiple soft tissue components in different combinations like skin, fascia, fat, muscle or nerve. Considering the multiple perforators that vascularize the skin paddle and the wide pedicle, the flap is easy to harvest, being a common choice for defects on the anterior part of the body because does not require repositioning of the patient.

Donor site morbidity is low in comparison with other flaps, the defect being closed primarily or by using a split thickness skin graft.

Anatomy and surface markings

The anterolateral thigh flap is situated on a longitudinal axis that connects the anterior superior iliac spine with the superolateral part of the patella, which represents the intermuscular septum between the vastus lateralis and rectus femoris muscles. The arterial vascularization is realized by septocutaneous (13%) or musculocutaneous (87%) perforators that arise from the lateral circumflex femoral artery. This artery has its origin in 75% of the cases from the profunda femoris artery and in 25% of the cases directly from femoral artery.

The pedicle of the lateral circumflex femoral artery has a length of 8 to 16 cm, a diameter between 2-2.5 mm and two adjacent veins with a diameter between 1.8 to 3.3 mm. Motor innervation is realized by the femoral nerve and sensitive innervation by the lateral femoral cutaneous nerve.

Type of transfer

Anterolateral thigh flap can be used as a free flap for reconstruction of the head and neck, upper extremity, thorax or as a pedicled flap for reconstruction of the perineal region ad groin to the knee, being a good option for compromised patients. The pedicled flap is usually tunneled in a subcutaneous plane, and when additional length is necessary this can be tunneled under the rectus femoris and sartorius muscle. Additional care is necessary to avoid injury to the femoral nerve branches.

Flap design

A line is marked from the anterior superior iliac spine to the superior lateral border of the patella. The midpoint of the line is measured and a circle is drawn with the center in this circle and a 3 cm radius. In this circle are located mostly of the perforators that can be also evaluated using a hand held Doppler.

The flap is marked considering the defect dimensions, 8 to 22 cm could be harvested using one vessel. The skin paddle is drawn over the perforators in an ellipse design with a third in the anterior part of the line and two thirds in the posterior part of the line. The flap design can also be modified intraoperatively after assessing the perforators.

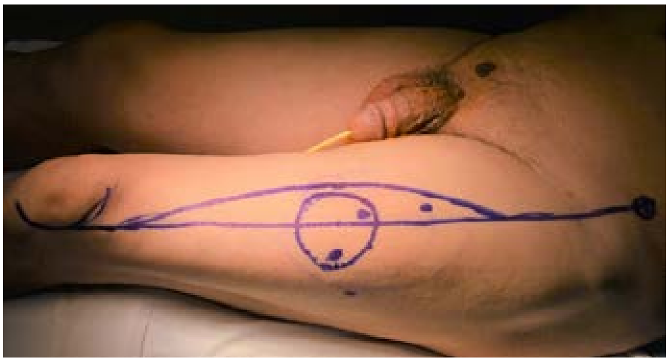

Figure 1. *Anterolateral thigh flap design*

Technique of harvesting

- Positioning the patient and anesthesia

The patient is usually positioned in a supine posture with the leg straight in a neutral posture. General anesthesia is necessary with muscle relaxation, but spinal anesthesia could also be utilized in some situations. One of the main advantage of this position is the possibility of working in two teams: one harvesting the flap, and the other preparing the recipient.

- Raising the flap

Considering the defect and the morbidity of the donor site, the anterolateral thigh flap could be harvest in a subfascial or suprafascial plane. If a thin flap is necessary and the sensitive preservation of the thigh is mandatory, suprafascial dissection is realized, otherwise subfascial is preferred.

- *Subfascial flap*

Incision is realized on the anterior part of the thigh until the subcutaneous plane. Fascia is incised 1 cm medial to the skin incision in order to preserve the perforators oriented oblique. Complementary sutures between fascia and dermis are necessary in order to preserve the prefascial plexus. The flap is elevated in a lateral direction with preservation of the cutaneous perforators. Identification from the distal to the proximal part of the intermuscular septum between the vastus lateralis and rectus femoris is realized. Splitting of the two muscles permits visualization of the descending branch of the lateral circumflex femoral artery and the perforators. The best perforator is considered to be the largest and with the minimal intramuscular traject and is usually the most proximal, that originates from the descending branch or even from the lateral circumflex femoral artery. Once the perforators are identified, the skin paddle can be also designed by realizing the posterior incision. Dissection is realized using a monopolar or bipolar cautery until connection with the descending branch of the lateral circumflex femoral artery. Elevation of this perforators is more easily to be realized by attaching a part of 0.5 cm of vastus lateralis muscle. Preservation of the motor branch of the femoral nerve is realized. Once the pedicle is dissected, the transfer can be realized. Consider the defect dimensions, the donor site can be closed using primary closure or covering using a split thickness skin graft.

- *Suprafascial dissection*

Lateral incision is realized until the subcutaneous plane and suprafascial dissection is started. Identification and preservation of the perforators that arise from fascia is done using magnification loupes. The dominant perforator is chosen and medial incision of the flap is performed, realizing a dissection in a suprafascial plane from medial to lateral. Deep dissection until the source pedicle is performed by preserving surrounding tissue around the perforator. The flap is then elevated with only the attached perforator. The fascia is closed using interrupted sutures and the donor site by primary suture or skin graft.

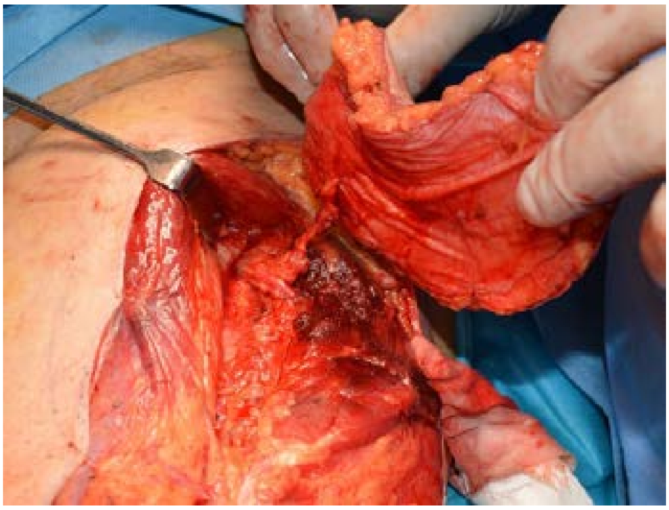

Figure 2. *Subfascial dissection of the anterolateral thigh flap*

Figure 3. *Muscular component included. The most robust perforator is selected.*

Figure 4. *Anterolateral thigh free flap pedicle*

Postoperative care

The flap should be evaluated in terms of color and Doppler signal hourly for the first 24 hours. Care must be taken for flap position in order to eliminate any risk for pedicle compression. If a skin graft is used for covering the donor site, bed rest should be instituted.

Figure 5. *A. Anterior foot reconstruction with an ALT flap. B. Frontal extensive composite defect reconstruction with ALT fasciocutaneous muscular flap.*

Conclusions

The anterolateral thigh flap is a predictable and versatile flap used in many types of reconstruction including head and neck, limb, trunk or perineal reconstruction.

Having a consistent anatomy, this can be harvest without preoperative angiography in a quite fast time (average of 30 to 45 minute).

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IV
Trunk

24

ABDOMINAL WALL TRANSPLANTATION WITH MICROSURGICAL TECHNIQUE: BOLOGNA EXPERIENCE

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Introduction

One of the most important challenges in intestinal (ITx) and multivisceral transplantation (MVTx) is a safe abdominal wall closure for the loss of the recipient's abdominal domain: properly transplanted organs cover is mandatory to reduce postoperative complications reducing the high risk of morbidity and mortality.

Conventional traditional abdominal wall closure, as simple tension free closure, component separation, use of syntethic or biological meshes (better absorbable), staged tissue expanders, local or free flaps, is not always possible. The main causes are a past history of complete midgut removal with the loss of the domain of the abdominal compartment or severely damaged abdominal walls from repeated laparotomies or enterocutaneous fistulae. The result of these conditions is an abdominal cavity too small to receive transplanted organs; further, at the end of the visceral transplantation, organs are often more edematous and a tight closure could increase morbidity and mortality risk, leading to the Short Gut syndrome, that is the primary cause of intestinal failure (about 80%). Furthermore, in this kind of transplantation, diversion stomata and intraperitoneal drains are required, leading to a challenging abdominal wall closure [1]. The patients candidated to intestinal or multivisceral transplantation, may have several problems that may lead to a difficult abdominal wall closure [2, 3]; the main issues are reported in Table n°1.

INDICATIONS TO ABDOMINAL WALL TRANSPLANTATION (AWTx)
Multiple scars and fibrosis due to previous abdominal surgery
Multiple enterocutaneous fistulas
Ostomies
Donor/recipient size mismatch (donor to recipient unfavourable weight ratio)
Loss of bowel lenght for previous bowel resection
Postoperative oedema of the intestinal loops

TAB. 1 *Indications to abdominal wall transplantation (AWTx)*

Abdominal closure under tension might result in a wide range of complications, such as wound dehiscence, infections, necrosis, exposure of bowel loops, vascular thrombosis of the graft, abdominal compartment syndrome and respiratory complications [4].

To overcome these problems, two main strategies have been proposed:

- reduction of donor graft size, choosing smaller donor (but this procedure can extend the waiting time, increasing the risk of mortality in the waiting list);
- abdominal domain enlargement (preferred approach), as described for the first time by Levi et al. in 2003 [5], with the introduction of abdominal wall transplantation simultaneously to intestinal or multivisceral transplantation.

The use of a composite tissue allograft in such patients has the main advantage of solving a real problem without requiring further immunosuppression. Abdominal wall transplantation is a feasible and safe procedure: it allows primary closure of the abdomen, avoids the potential morbidity of exposed viscera, and allows early mobilization and rehabilitation of these patients. The technique was first described by Levi et al. in 2003 [5], and, nowadays, in selected patients, it is the first choice to overcome a difficult abdominal wall closure.

Nowadays abdominal wall transplantation (AWTx) is recognized as a cornerstone manuscript in the transplant field.

MAIN FEATURES OD AWTx

Abdominal wall transplantation (AWTx) is a full-thickness vascularized composite allograft. Since 2014 it is included as a VCA (Vascularized Composite Allotransplantation) in the UNOS (United Network for Organ Sharing) Registry [6] as a myocutaneous graft, composed of:

- skin
- subcutaneous tissue
- rectus abdominis muscles
- (part of the) obliques muscles
- Scarpa's fascia
- parietal peritoneum

The procurement of the abdominal wall graft does not interfere with the procurement of other organs and tissues. Transplantation of the abdominal wall composite graft can take place during the intestinal transplant procedure or several days later, with a graft from a different donor. Delaying implantation of the abdominal wall graft allows reduction of perioperative oedema and stabilization of patient's condition, before abdominal closure. This strategy may be preferable in wide abdominal recipient defect; a temporary negative pressure therapy (TNP) is applied to reduce the infection risk in these cases.

Although the procedure is well standardized, todate, there are few papers on the AWT in literature. More recent and complete review [7], reports only 38 cases of total AWT worldwide, about half of which were performed in the USA.

Since 2006, in Bologna University Hospital, our group has performed six complete abdominal wall transplantation. Cipriani et al, [8] for the first time in 2006, applied microsurgical techinique to AWTx, modifying traditional macroanastomoses on the iliac vessels proposed by Levi, with microanastomoses on deep inferior epigastric system.

Nowadays, the microsurgical approach is well defined and the additional advantages of this surgical technique are well recognized (Table n° 2).

GENERAL ADVANTAGES OF THE AWT	ADDITIONAL SPECIFIC ADVANTAGES OF AWT MICROSURGICAL TECHNIQUE
Safe coverage of the multivisceral graft	Safe coverage of the multivisceral graft
NO further immunosuppression	NO further immunosuppression
Reduction of morbidity and mortality	Reduction of morbidity and mortality
	Anastomoses on extra peritoneal vessels mean no compression on transplanted organs
	More superficial vessels than iliac ones are rarely involved in scar tissue
	Donor iliac vessels are available as vascular graft for other surgeons

TAB. 2 *Advantages of the abdominal wall transplantation (AWTx)*

Traditional surgical technique (LEVI et al.)

The harvesting of the abdominal wall graft is performed at heart-beating donor [9, 10].

The abdominal wall composite graft described by Levi is a full-thickness, vascularized, myocutaneous free flap [5]. In the original description, it consists of one or both rectus abdominis muscles and fascia, the overlying subcutaneous tissue and the skin; the blood supply is derived from the donor inferior epigastric vessels, left in continuity with the larger iliac vessels.

The procedure begins with a bi-subcostal incision. Longitudinal incisions are made following both lateral edges of the rectus muscles. These incisions continue into the groin area, bilaterally. The common iliac vessels are identified. Finally, a transverse, suprapubic incision is performed, connecting the two longitudinal incisions. The abdominal wall graft is packed with ice in situ during other organs procurement; then, the distal aorta is cannulated, and the graft is flushed with cold preservation solution. The graft can be removed "en bloc" with the iliac vessels, with a short segment of distal aorta and inferior

vena cava. Closure of the donor's abdomen may be facilitated by mobilizing skin and subcutaneous tissue flaps from the lateral abdomen and flanks.
The abdominal wall graft is transplanted as a separate organ. Anastomosis are performed on the recipient's common iliac artery and vein. Alternatively, the infrarenal aorta and inferior vena cava can be used as recipient vessels.
The abdominal graft is sutured in layers to the recipient's abdominal wall during closure of the abdomen. Abdominal wall graft skin colour indicates adequate perfusion. The flow through the inferior epigastric vessels of the graft is monitored with a handheld Doppler ultrasound device. Cutaneous biopsies are randomly performed and they are indicated when clinical features are suspected for rejection.

BOLOGNA microsurgical technique

Microsurgical approach for AWT was introduced in Bologna University Hospital in 2006 [8]. The harvesting of the abdominal wall graft is performed at heart-beating donor, during a multiorgan procurement. The flap consists of a median oval cutaneous extended from xiphoid to pubis, from one oblique muscle to the other (average size: 16x22 cm); the flap is composed of cutaneous and subcutaneous tissues, both rectus abdominis muscles and a small part of the oblique ones, the deep muscular fascia, and parietal peritoneum. The vascular pedicle consists in the deep inferior epigastric arteries and veins, isolated bilaterally, if possible. The flap is planned and harvested by a microsurgeon (FIG. 1A)
Flap harvesting starts with a superior incision of the skin and subcutaneous tissues, including the deep fascia under rectus muscles; then the flap is dissected preserving laterally a small part of oblique muscles. The dissection is stopped at the inferior edge of the flap, where a transverse suprapubic incision is performed connecting longitudinal ones and the abdominal flap is turned over to face downwards to allow the procurement of the other abdominal organs. During this phase, the flap is packed with cold water and ice, while the other organs are flushed with preservation solution during their harvesting.
After that, the epigastric pedicles of the abdominal wall flap are sectioned at the origin from iliac vessels (FIG. 1B). A further cold perfusion is performed through incannulation of the two epigastric arteries; the abdominal graft is then stored in a container with ice and Celsior solution for the transport. (FIG. 1C). Primary closure can be performed in the donor site, previous generous undermining of the residual lateral abdomen and flanks tissues.

The AWT is performed after abdominal organs transplantation. End-to-end anastomoses were performed between donor epigastric pedicles and recipient deep inferior epigastric vessels, bilaterally; the circumflex deep inferior vessels are a second choice. (FIG. 2). Microsurgical AWT procedure adds about 2 hours to the procedure's operative time. The surgical procedure is completed with ileostomy and multilayers suture without tension. The patient is dressed leaving a window to allow continuous monitoring of flap vitality. Sutures are removed after 15-20 days.

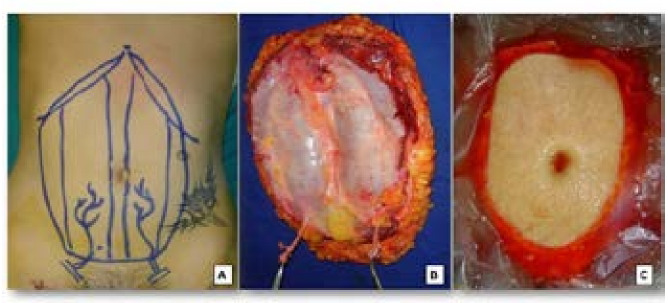

FIG. 1 *1A: Pre-operative drawing of AWTx*, *1B: Abdominal flap harvested*, *1C: The abdominal graft storage with ice and Celsior solution*

Post-operative management

The AWT is monitored like a free flap by clinical observation of the skin perfusion, by the color and the temperature of the skin paddle and by capillary refill, particularly in the first days. The viability of the AWT and further intestinal rejections are monitored by navel skin punch biopsies (1/biopsy every week for the first month).

About immunosuppressive post operative therapy, the baseline agent is the Tacrolimus.

BOLOGNA experience

Since 2006 up todate, we have performed 6 consecutive complete abdominal wall transplantation. Tables n° 3 reporting data collection (Table n° 3).

	1	2	3	4	5	6
AETIOLOGY	CHURG – STRAUSS VASCULITIS	CHRONIC INTESTINAL PSEUDO-OBSTRUCTION	GARDNER SDR	BOWEL ATONY	CROHN DISEASE	SHORT GUT SDR
RECIPIENT GENDER	M	M	M	F	M	F
DONOR GENDER	M	M	M	F	M	M
Tx	ITx	ITx	ITx	ITx	MVTx	MVTx
COMPLICATIONS	//	acute cellular rejection	//	Recurrent episodes of GVHD	//	//
TREATMENT	//	Steroids	//	Steroids + extracorporeal photopheresis	TPN + SG	//
RESULTS	PTLD (after [illegible] months) ✗	Sepsis (after [illegible] months) ✗	Lung Neoplasia (after [illegible] months) ✗	Alive ✓	PTLD (after [illegible] months) ✗	Alive ✓

TAB. 3 *Data collection of the Bologna abdominal wall transplantations (AWTx)*

FIG. 3 *Clinical case ITx + AWTx. A complete bowel atony treated with total intestinal resection and transplant (3A), combined to abdominal graft (3B). Intraoperative view (3C) and 6 months post operative result (3D).*

Four patients underwent to ITx (intestinal transplantation) (FIG. 3) and two patients to MVTx (multivisceral) one simultaneously to AWTx (FIG. 4)

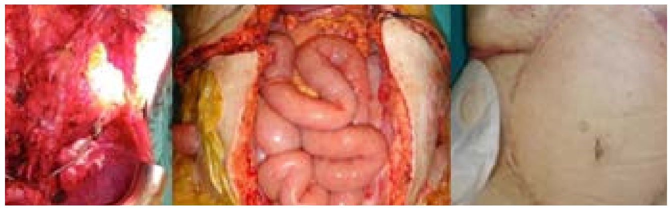

FIG. 4 *Clinical case MVTx + AWTx. Multivisceral transplantation required for multiple enterocutaneous fistulas in Chron disease (4A – 4B), combined to AWTx (4C). In this case we reported a dehiscence of the suture, treated with negative pressure therapy.*

End-to-end anastomoses were performed between the deep inferior epigastric vessels bilaterally in four cases; in one patient we use only a unilateral vascular pedicle without signs of ischemia and in another patient we perform anastomoses on deep iliac circumflex vessels because epigastric system was disrupted by previous conditions. Todate, only two patients are yet alive.

Discussion

One of the most important challenges in intestinal (ITx) and multivisceral transplantation (MVTx) is a safe abdominal wall closure for the loss of the recipient's abdominal domain.

Properly cover transplanted organs is mandatory to reduce postoperative complications reducing the high risk of morbidity and mortality, but it is not always possible with traditional procedures.

The ideal candidates to AWTx present heavily scarred abdominal wall for previous multiple intestinal resections, or, more often, have a "virtual" abdominal cavity [1, 11] precluding a primary abdominal closure for donor/recipient size mismatch. Fishbein et al. [12] reported that the most acceptable donor/recipient weight ratio is between 1.1 and 0.76, indicating that, ideally, abdominal closure should be performed as quick as possible.

Several previous laparotomies and of partial/ total enterectomy were predictive of difficult closure of the abdomen, even if the reported ratio is respected.

Any attempt to close under tension might result in a wide range of abdominal complications, such as wound dehiscence, infections, necrosis of bowel loops, vascular thrombosis of the graft, abdominal compartment syndrome and respiratory complications [4]. Different strategies have been proposed to overcome these problems, as the reduction of the graft size, use of prosthetic meshes, abdominal wall expansion, NPT (negative pressure therapy), pedicled flaps, free flaps and, in selected cases, abdominal wall transplantation.

To respect donor/recipient weight ratio, is indicated to prefer donor size 50–100 % of the recipient according to body weight. Overresuscitation with fluids should be avoided, and colloid solutions should be used if possible. Moreover all dysfunctional remaining bowels should be removed, and all adhesions should be lysed to completely develop all potential intraperitoneal space. Other space-creating options include splenectomy, but this procedure increases the risk of death for sepsis.

Partial transplanted intestine resection can be useful to control donor/recipient size discrepancy, but it can cause inadequate absorption and function.

A prosthetic mesh for definitive primary closure or combined to a pedicled flap can be considered in partial abdominal wall defect. The prosthetic material allows a quick recovery, but, unfortunately, it may complicated by the infections of the mesh and formation of enterocutaneous fistulae [13].

Abdominal reconstruction using pedicled flap allows one stage closure avoiding the placement of alloplastic materials, but it requires longer operative time and an additional donor site wound. The pedicled anterolateral thigh (ALT) flap is the gold standard for medium and large sized defects. ALT flap is a fasciocutaneous or cutaneous flap from the thigh, supplied by perforators of the descending branch of the lateral circumflex femoral artery, a branch of profunda femoris artery. The successfull use of the ALT flap for abdominal wall reconstruction was first reported by Kimata et al. in 1999 [14]. Its use as a pedicled flap has become very popular for abdominal wall reconstructions as it does not require microsurgical anastomosis. Moreover, the wide arc of rotation (pivot point of the pedicled ALT flap is approximately 2 cm below the inguinal ligament) and long pedicle allow to reconstruct even proximal abdominal defects, and the fascia lata can be incorporated to prevent hernia formation [15].

In our opinion, in cases of complete loss of the domain in patients undergoing visceral organ transplantation traditional abdominal wall closure procedures are not always applicable. In selected cases, AWTx is the gold standard. It represents a feasible and safe procedure allows primary closure of the abdomen, avoids the potential morbidity of exposed viscera and permits early mobilization and rehabilitation of the transplanted patients.

Abdominal wall transplantation (AWTx) is a full-thickness vascularized composite allograft included as a VCA (Vascularized Composite Allotransplantation) in the UNOS (United Network for Organ Sharing) Registry [6]. Despite other composite tissue allografts (as face and hand transplantation), doesn't need further immunosuppressive therapy.

Nowadays, although AWTX is a well standardized procedure, there are few papers in literature.

More recent and complete review [7], reports only 38 cases of total AWT worldwide, about half of which were performed in the USA.

Since 2006, in Bologna University Hospital, our group has performed six complete abdominal wall transplantation. Cipriani et al, [8] for the first time in 2006, applied microsurgical techinique to AWTx, modifying traditional macroanastomoses on the iliac vessels proposed by Levi, with microanastomoses on deep inferior epigastric system.

Bologna microsurgical technique allows to harvest an abdominal graft in the same operative time, without impairment to other organs or pedicles, without vascular complications or increasing the risk of vascular thrombosis, saving the donor's iliac vessels to use as vascular grafts [16].

Every AW-VCA performed to date has been non functional, non neurotized composite allograft with consequent loss of the strenght and the ability to maintain muscle mass, to resist atrophy, to provide dinamic support and movements, to optimize respiratory mechanism (FIG. 5).

FIG. 5 *ITx + AWTx (5A). Loss of the strenght and the ability to maintain muscle mass: evident abdominal muscle atrophy at 12 months after surgery.*

The role of the innervation of the abdominal wall graft in achieving a functional result is todate unclear. Current research on cadavers and animals are exploring the potential for reinnervation to maintain muscle viability and function, but todate, no functional and neurotized composite abdominal allograft was performed in vivo, while motor function and sensory recovery is expected in other forms of VCA [17,18].

This condition led to the major disadvantages of the procedure that is the loss of the abdominal strenght and dinamic support to patient's day activities.

Conclusions

Abdominal Wall Transplantation (AWT) is nowadays the gold standard for the complete loss of the domain in patients undergoing visceral organ transplantation, where no alternatives for traditional wall repair are possible.

Despite the potential advantages and acceptable outcomes (AWT risk of rejection and graft versus host disease – GVHD, appear to be similar to ITx without AWT), AWT remains an uncommonly performed procedure, and it is not a solution for wide abdominal wall defects in patients not receiving visceral transplant.

We think that, in the future, the indications could be expanded to other conditions thanks to new protocols and progresses in immunomodulation that could substitute immunosuppression for an elective non-life-saving procedure.

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V
Genital Reconstruction

25

VULVAR RECONSTRUCTION WITH PEDICLED PERFORATOR FLAPS

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Introduction

Vulvar reconstruction can be required following oncological surgery (e.g. vulvar or anorectal carcinomas), trauma, chronic wounds, infections (e.g. Fournier's gangrene), congenital anomalies (e.g. vaginal aplasia) or in the setting of MtoF sex reassignment surgery. [1-5]. Reconstruction of such a complex anatomical region is technically challenging due to its functional, aesthetic and sexual role. [6-9]; it can be performed with several techniques, ranging from skin grafts to local or free flaps. The best results are achieved with the use of well-vascularized tissue, similar in color and texture to the recipient site, and a minor donor site morbidity; for this purpose, pedicled perforator flaps represent an optimal reconstructive option, as they can be harvested from a region close to the vulva (like-with-like reconstruction), they provide a thin vascularized tissue, simultaneously sparing the underlying muscle and fascia, and they require a shorter operating time and a lower morbidity compared to free flaps. Bilateral flaps can reconstruct also extensive defects, respecting the symmetry of the vulva. [1, 5, 10-15]

In the literature, a great variety of pedicled perforator flaps are described for vulvar reconstruction, based on the rich arterial network of the adjacent vascular territories.

The aim of this chapter is to revise relevant locoregional anatomy and provide a comprehensive review on the most popular pedicled perforator flaps for the reconstruction of the vulvar region.

Vascular anatomy

Blood supply of the vulva and perineum

The perineum (defined as the region located between the vaginal introitus and the anus) can be divided into an anterior triangle, that includes the vulva (urogenital triangle), and a posterior one, that includes the anal orifice (anal triangle). [12]

The anterior triangle is supplied by branches of the internal iliac arteries (internal pudendal arteries - IPA) and femoral arteries (superficial and deep external pudendal arteries – SEPA and DEPA). The IPAs anastomose with the external pudendal arteries, thus forming a rich vascular network in the external genitalia through the intralabial plexus. [16, 17]

The posterior triangle is nourished by branches of the internal iliac arteries (IPAs, inferior gluteal arteries – IGA and obturator artery - OA). The IPA meets the IGA forming a communicating branch. The IGA and the OA anastomose with the medial circumflex femoral artery (MCFA), a branch of the profunda femoris artery. [16-18] (Figure 1)

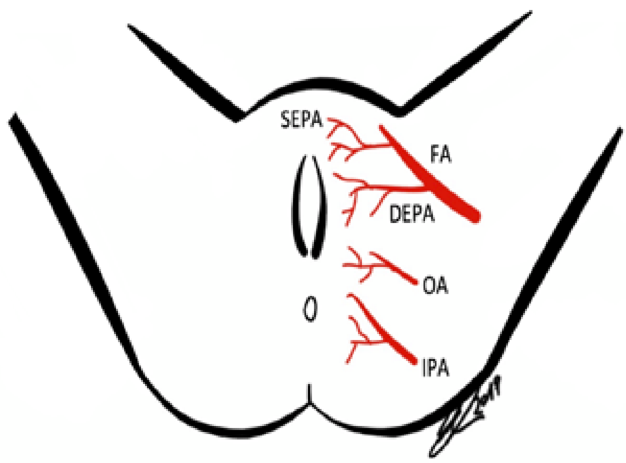

Fig 1: *Vascular supply of the perineum. FA: Femoral artery; SEPA: Superficial external pudendal artery; DEPA: deep external pudendal artery; OA: Obturator artery; IPA: Internal pudendal artery.*

Blood supply of the thigh and gluteal region

The gluteal region is supplied by both the superior (SGA) and inferior (IGA) gluteal arteries, that are branches of the internal iliac artery. The former nourishes the upper half of the gluteus maximus, while the latter supplies the lower portion of the gluteus maximus. Both send perforators to the overlying gluteal skin. [19] (Figure 2)

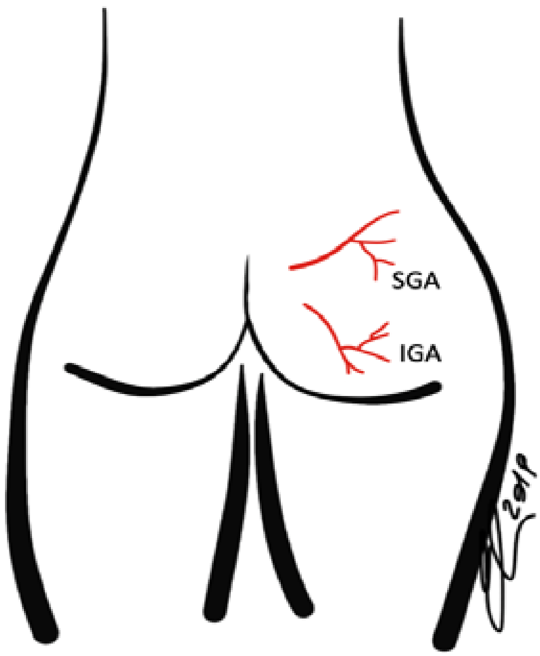

Fig 2: *Vascular supply of the gluteal region. SGA: Superior gluteal artery; IGA: Inferior gluteal artery*

The medial aspect of the thigh is nourished by branches of the medial circumflex femoral artery (MCFA) while the lateral aspect of the thigh is supplied by branches of the lateral circumflex femoral artery (LCFA). Both the MCFA and the LCFA arise from the profunda femoris artery (PFA). [20] (Figure 3)

Blood supply of the lower abdomen

The vascular supply of the inferior quadrants of the anterior abdominal wall is ensured by branches of the external iliac artery (deep inferior epigastric arteries - DIEA and deep circumflex iliac arteries - DCIA) and by branches of the femoral artery (superficial inferior epigastric arteries - SIEA and superficial circumflex iliac arteries - SCIA). [20-23] (Figure 3)

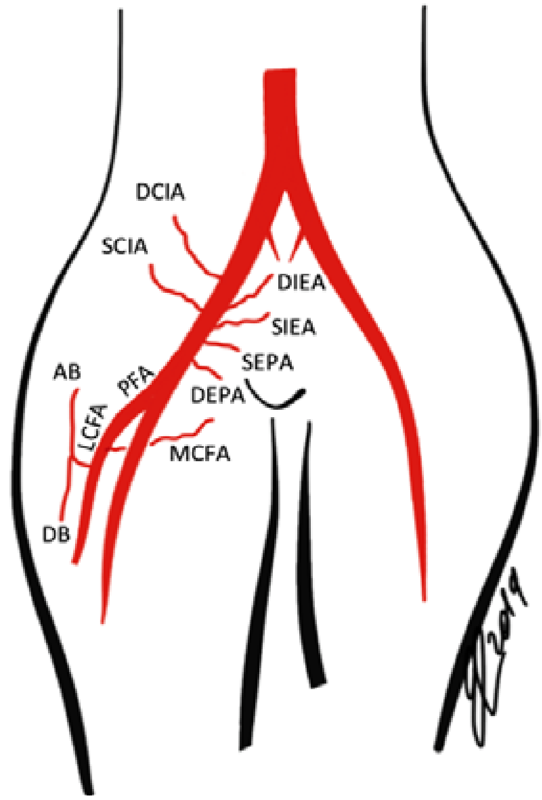

Fig 3: Vascular supply of the thigh and lower abdominal region. DCIA: Deep circumflex iliac artery; SCIA: Superficial circumflex iliac artery; DIEA: Deep inferior epigastric artery; SIEA: Superficial inferior epigastric artery; SEPA: Superficial external pudendal artery; DEPA: deep external pudendal artery; MCFA: Medial circumflex femoral artery; PFA: Profunda femoris artery; LCFA: Lateral circumflex femoral artery; AB: Ascending branch; DB: Descending branch

Each of the above-mentioned arteries, also called "source vessels", emits numerous small branches that travel vertically, sometimes passing through the overlying muscle or the intermuscular septa, and then pierces the deep fascia to reach the skin and subcutaneous tissue. The great number of such "perforating vessels" in the vulva and perineum and the extent of the perforasome territories connected by multiple linking vessels furnishes an anatomical basis for the huge variety of local perforator flaps that can be harvested in these anatomical regions for vulvar reconstruction. [24-26]. In addition, some locoregional perforator flaps from the thigh, the gluteal region and the lower abdominal wall can be useful in selected cases for this purpose.

Main pedicled perforator flaps

The main pedicled perforator flaps for vulvar reconstruction are presented in figure 4 and described in the following text.

Fig 4: *Donor sites of perforators flaps used for vulvar reconstruction. Flaps marked with dotted lines are located in the lateral aspect of the thigh and in the gluteal region. DIEP: Deep inferior epigastric perforator flap; V-DIEP: Vertically-oriented DIEP; SCIP: Superficial circumflex iliac perforator flap; ALT: Anterolateral thigh flap; SGAP: Superior gluteal artery perforator flap; IGAP: Inferior gluteal artery perforator flap; IPAP: Internal pudendal artery perforator flap; EPAP: External pudendal artery perforator flap; aOAP: Anterior obturator artery perforator flap; LOTUS: Lotus petal flaps; PAP: Profunda artery perforator flap; MCFAP: Medial circumflex femoral artery perforator flap.*

Perineal flaps

Many perforator flaps from this region have been described in the literature. The majority of them are located near the sulcus genitofemoralis, thus providing thin and moldable tissues that are similar in characteristics to the recipient site, thus ensuring the best vulvar reconstruction. [18] However, due to their small size, bilateral flaps can be required to provide enough amount of tissue. Moreover, reconstruction with perineal flaps is not feasible in case of extensive resection of the genital area, vascular injury or poor local conditions (e.g. previous radiotherapy). [6, 27]

Lotus flap

Historically, the first perforator flap in the perineum was published in 1996 by Yii and Niranjan and reported the use of "lotus petal flaps" for vulvo-vaginal reconstruction. [16] The flaps, designed in a manner that resembles the shape of a petal of the lotus flower, are based on the perforators of either the internal pudendal arteries and the external pudendal arteries, with the former being preferred because they are not compromised by previous demolitive surgery in case of vulvar cancer. Moreover, perforator flaps that are harvested on the internal pudendal artery (lower petal flaps) ensure better cosmetic results if compared to those supplied by the external pudendal artery (inner and intermediate flaps) because the scar is hidden in the gluteal fold and do not require the sacrifice of the pudendal nerve (figure 5). [16, 28] In their first description, lotus petal flaps were raised including the fascia as fasciocutaneous flaps. In 2004, Warrier et al. proposed a refinement of the classical lotus flap, modified by sparing the deep fascial layer. [29] The main advantages of the lotus petal flaps are their versatility and the opportunity to be tailored to the patient's defect. Their main drawback is the postoperative discomfort while the patient sits down during wound healing. In some cases, especially in the setting of gynecologic cancers, these flaps cannot be employed due to previous radiotherapy damage. [16, 28, 30, 31]

External pudendal artery perforator (EPAP) flap

The flap is based on the perforators of the external pudendal artery. The EPAP flap is reliable, thin and pliable and the scar in the donor site is minimal. It is indicated for vulvar and for vaginal reconstruction [32-35]

Internal pudendal artery perforator (IPAP) flap or gluteal fold flap (GFF)

The first fasciocutaneous flap based on the internal pudendal artery was described in 1989 by Wee and Joseph who reported a new technique for vaginal reconstruction with a pudendal thigh flap (also known as Singapore flap). [36] After the introduction of perforator flaps by Koshima et al. [37], the technique has been refined and the suprafascial IPAP flap has been developed and widely used for vulvar, vaginal and perineal reconstruction [38-41]. The flap is nourished by the perforators of the internal pudendal artery; these vessels are classified as direct perforators because they emerge into the ischiorectal fossa and reach the skin travelling only through the subcutaneous fat. Three to five perforators can be identified preoperatively in a triangle formed by the apex coccyx, the vaginal introitus and the ischial tuberosity (vascular triangle) that represents the cutaneous projection of the fossa. The IPAP flap has a reliable blood flow with a low incidence of vascular failure, is easy to harvest, has a good mobility, adequate skin matching and requires short operating time. The cosmetic outcome is excellent with the scars being conceiled in the gluteal fold. It can be considered the flap of choice in case of small-to-moderate sized vulvar defects [6, 8, 9, 11, 24, 42, 43]

Anterior obturator artery perforator (aOAP) flap

This flap is based on the anterior obturator artery perforator, that is a cutaneous branch of the anterior division of the obturator artery. The flap can be raised in either a subfascial or suprafascial fashion; however, the subfascial dissection is usually preferred because it is easier and safer and allows for a clearer visualization of the small perforating vessel while emerging from the surface of the gracilis muscle in proximity to the inferior pubic ramus. It can be transferred as a sensate flap if branches of the obturator nerve is included in the dissection. A propeller variant of this flap has been reported by Chih-Wei Wu et al. in 2016 with good functional outcomes. [44] The aOAP flap is a good alternative in case of inadequacy or unavailability of internal pudendal vessels. The best results are achieved in isolated reconstruction of labia majora, labia majora and fornix. Scars are hidden in the anatomic boundary between the urogenital area and the most proximal aspect of the medial thigh, with minimal self-image discomfort. [6, 18]

Gluteal flaps

Superior gluteal artery perforator (SGAP) and inferior gluteal artery perforator (IGAP) flaps

Pedicled gluteal artery perforator flaps are widely used for reconstruction of lumbar, ischial and sacral bedsores and perineal and vaginal defects with good outcomes. [45-55] The SGAP and IGAP flaps are supplied by perforating branches of the superior gluteal artery and inferior gluteal artery respectively. The perforators of the SGA can be easily located nearby the medial two thirds of a line drawn from the greater trochanter to the posterior superior iliac spine while the perforators of the IGA can be found around the midpoint of a line joining the posterior superior iliac spine and the inferomedial border of the gluteal fold. [19]

A unique feature of the gluteal region is the high number of small-caliber cutaneous perforators that travels in an oblique direction through the subcutaneous tissue. [45] For this reason, adequate perforator selection can be tricky especially for unexperienced surgeons. The long vascular pedicles of the flaps allow a wide mobilization, facilitating flap insetting into the recipient site. [46] The IGAP flap is less known and few studies are reported in literature about its clinical applications; however, it has some advantages compared to the more popular SGAP flap: it has a larger cutaneous territory, it is easier to harvest and it is closer to the vulvar region. Nevertheless, proximity of inferior gluteal artery to the sciatic nerve may lead to nerve exposure and can cause unpleasant postoperative paresthesias. [19]

Groin flaps

Superficial circumflex iliac perforator (SCIP) flap

The SCIP flap is based on perforators that branch off about 3 cm medially to the anterior superior iliac spine, arising from the superficial and deep branches of the SCIA. [56-58] It requires careful pedicle dissection and can reach the anterior perineum.

In the literature, few articles are available on the reconstruction of the genital area with flaps supplied by perforators of the superficial circumflex iliac artery, and the majority of them deal with reconstruction in men [59-61]. Nevertheless, in our experience these flaps find indication also for vulvar reconstruction. Before perforator flaps became popular in clinical practice, our group described a case of incomplete vaginal aplasia reconstructed with bilateral island extended groin flaps based on a subcutaneous pedicle containing the superficial circumflex iliac artery. [62] Also, we recently performed a vulvar reconstruction after radical vulvectomy with the use of bilateral SCIP flaps combined with bilateral gluteal V-Y flaps (unpublished).

Medial thigh flaps

Medial circumflex femoral artery perforator (MCFAP) flap

MCFAP flap has been described especially for perineoscrotal reconstruction in men. [63, 64] but it is also a feasible option for vulvar reconstruction, providing a well-vascularized tissue similar in characteristics to the vulva with unnoticeable scars concealed in the inner thigh. Perforators can be located approximately 10 cm inferiorly the pubic tubercle and just posteriorly to the tendon of the adductor longus muscle. [65]

Profunda artery perforator (PAP) flap

The PAP flap has been used for vulvar and for perineum reconstruction, either as V-Y advancement flap or island flap, with good functional and aesthetic results and low donor site morbidity. [66, 68]. Also, bilateral flaps based on the perforators of the profunda femoris artery have been used by Chen et al. for total vulvectomy defect. [67]

The perforators of the PAP flap usually travel in the septocutaneous fascia between the gracilis muscle and the adductor magnus muscle and can be found with pencil doppler along the posterior edge of the gracilis muscle. [69]

Posteromedial thigh (PMT) perforator flap

The PMT perforator flap is a new reconstructive option developed by Scaglioni et al. and based on the perforators of both the MCFA and PFA. When utilized as a pedicled flap, the skin island is oriented vertically in order to harvest a longer flap and ensure a wider arc of movement. It has been used with excellent results in three patients for the reconstruction of vulvar and perineal defects. [70]

Lateral thigh flaps

Anterolateral Thigh (ALT) flap

The pedicled ALT perforator flap finds indication in case of extensive vaginal or perineum defects and should be considered as a precious lifeboat flap when alternative options are not feasible. [71-73]

The flap is supplied by perforators arising from the descending branch (DB) of the lateral circumflex femoral artery (LCFA). It can be harvested with or without fascia with a maximum width of the skin paddle of 8 cm to allow for primary closure. The majority of perforators are located in the middle third of a line that joins the anterior superior iliac spine and the superolateral corner of the patella, called anteroposterior line. [71-72] Several cases of vaginal reconstruction in the setting of Fournier's gangrene, vaginal agenesis or vaginal reconstruction have been reported in literature. [74-76]

Abdominal flaps

Local advancement flaps harvested from the pubis and based on perforators from the deep arterial network of the pubis have been described by our group as "V-Y amplified sliding flap" for anterior symmetric defects; sensory innervation is provided by branches of the ileo-inguinal nerve. [77] Reconstruction with larger pedicled abdominal flaps is required in case of more extensive defects or if reconstruction with local perforator flaps is not suitable due to previous vascular injury or radiotherapy. The main disadvantage is a poor aesthetic outcome of thick abdominal flaps, compared to the thinner perineal flaps. [6]

Deep inferior epigastric perforator (DIEP) flap

The pedicled DIEP flap can be used for reconstruction of extensive genital and perineal defects. [78-82], although few articles on reconstruction of the female genitalia are available in the literature. [5, 83-85]. The main advantage of pedicled DIEP flap is that it can provide adequate coverage of huge defects, since a large amount of skin and subcutaneous tissue can be harvested, while its main drawback is the excessive thickness of the abdominal tissues, especially in obese patients, which can require secondary defatting. [5, 6, 78]
The flap is usually designed with a vertically-oriented skin paddle and a longer perforator dissection is needed to augment the arc of movement of the pedicled DIEP flap. [78]

Conclusions

Perforator-based local flaps have proven to be a reliable and versatile option for vulvar reconstruction. A large number of local perforator options are available and allow for reconstruction of almost all defects which, according to the extent, can be accomplished by a single or multiple monoliteral or bilateral flaps; in very selected cases, locoregional perforator flaps such as DIEP flap and ALT flap can be useful too. Reconstruction with perforator flaps can be tailored to the patient's needs, with minimal donor site morbidity and good functional and aesthetic outcomes and may be considered as the technique of choice in the reconstruction of the vulvar region.

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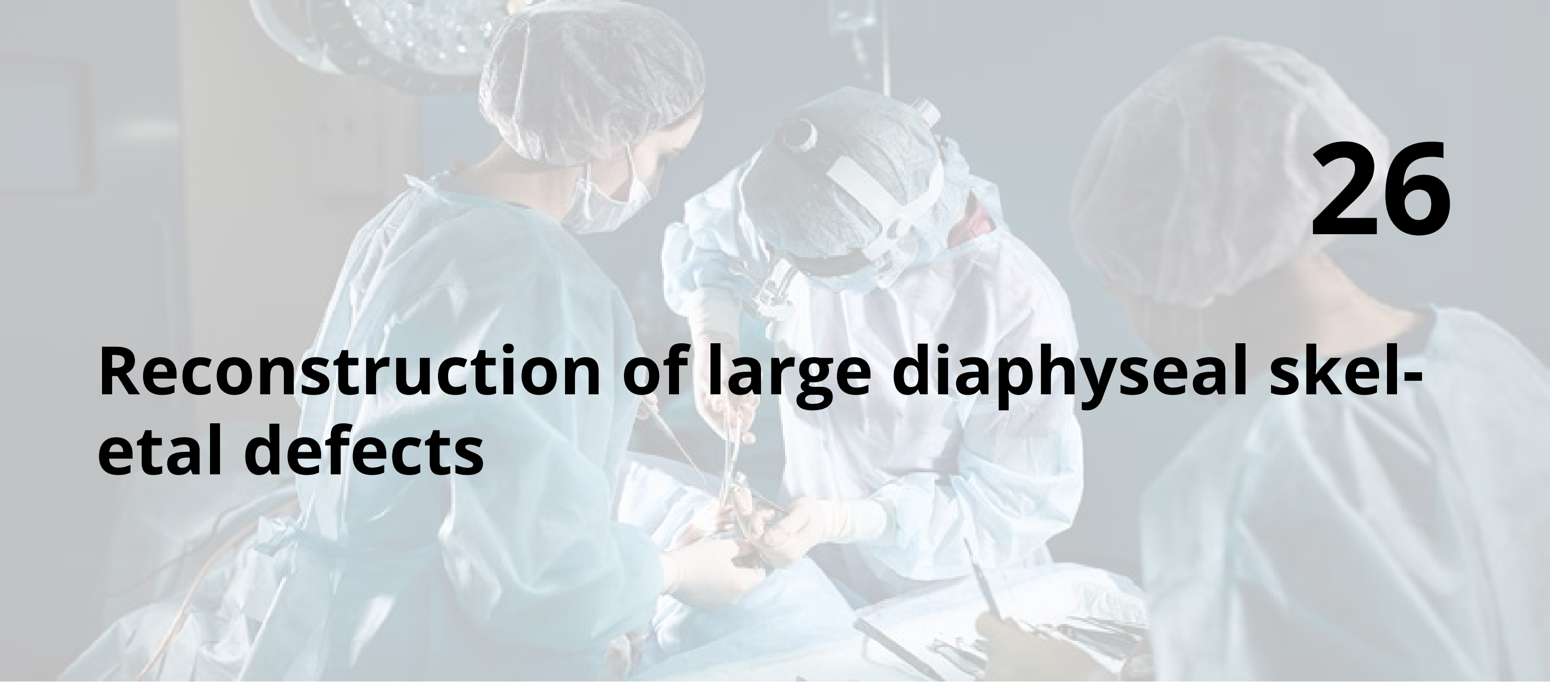
VI
Bone



26

Reconstruction of large diaphyseal skeletal defects

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Introduction

A large diaphyseal skeletal defect is defined as a loss of bone of over 5cm, given that this is the threshold over which simple bone grafting is usually insufficient to obtain bone healing[1]. Indeed, achieving bone healing while maintaining skeletal length when a bone defect of 5cm or more exists remains one of the biggest challenges in Orthopaedics, and the purpose of the present chapter is to review our surgical armamentarium.

A large surgical skeletal resection may be the consequence of the curative treatment of a bone tumour, either benign or malign. Frequently, a soft-tissue defect is associated, imposing for the skeletal reconstruction to include some kind of flap coverage. Treatment of osteitis leads as well to bone defects, resulting either from an open fracture, the treatment of a periprosthetic infection, or other causes like drepanocytosis. Indeed, a large skeletal defect is frequently the late consequence of a comminuted open fracture that gets frequently infected and is associated to surrounding soft tissues of poor quality[2]. To prevent this terrible situation, the recommendation in treating the initial fracture is an aggressive attitude of "fix and flap", performing simultaneously, in the early days after the fracture, bone fixation and adequate soft tissue coverage, usually by a flap[3]. Sometimes, in case of limb devascularisation, the flap may act as a flow-through vascular graft. The "fix and flap" therapeutics is best achieved by a multi-specialised team. Nevertheless, this ideal sophisticated treatment is rarely applied, for various reasons. The delay of flap coverage is thought to increase the risk of soft and bone infection, leading eventually to a large skeletal defect. One frequent unfortunate reason is the limited availability of plastic surgeons or trained in microsurgery orthopaedic surgeons. Another relatively frequent situation is related to the initial energy of the trauma, making the extent of the soft tissue lesions evolve over time, revealing progressively, in the days and weeks after the trauma, the true extent of soft tissue necrosis, with late exposure of the internal fixation implants. Indeed, the indispensable debridement of necrotic tissues may be difficult in the postoperative days. Often, the general condition of the polytrauma patient precludes early flap surgery. Following the principle of damage control, the open fracture is then treated during the critical period by external fixation[4], and the soft tissues, by iterative debridements and negative pressure wound therapy (Vacuum-Assisted Closure). According to some authors, there is neither increased rate of osteomyelitis and non-union, nor increased rate of delayed flap failure, after this initial period of provisional treatment[5,6,7,8]. However, prolonged vacuum-assisted closure technique may result in late osteitis and finally in a large skeletal defect. Another not too infrequent cause of late osteitis is flap failure, exposing the bone which becomes desiccated and infected. Direct skin closure under tension in an emergency setting is similar to flap failure, as skin necroses and the bone finally gets exposed.

Even simple closed fractures can evolve towards non-union and finally lead to a large skeletal defect. About 10% diaphyseal fractures do not heal after bone fixation. The main factors leading to non-union are tobacco, contamination/infection, bone devascularization, comminution, and inadequate bone fixation. It may then happen that after several revisions of internal fixation, deep infection is encountered, leading eventually to a large infected skeletal defect.

How do we manage large diaphyseal skeletal defects?

Amputation

The first option to consider when faced to a large skeletal defect is limb amputation. The decision is relatively easy to take in the case of a localised malignant tumour, for oncologic reasons, because of the extent of the resulting skeletal defect, or because the tumour infiltration of the vascular and neural axes doesn't allow limb preservation. In contrast, the decision to amputate in the setting of emergency treatment of a trauma case is difficult, despite the fact that an immediate amputation may save the life of the patient, by avoiding myoglobinuria, renal insufficiency and secondary infection. Early amputation could spare the patient months or sometimes years of surgical efforts that are not always successful, leaving a shortened, stiff and sometimes painful extremity. During this long period many patients lose their job and become isolated. Multiple reconstruction procedures have a psychological as well as financial cost[9,10], though it is obvious that patients prefer keeping their limbs and surgeons try to save them. Later on, after many attempts to reconstruct a large bone defect, the decision to perform an amputation becomes even more difficult.

The decision to perform in emergency the amputation of a limb with an open fracture can be based on injury severity scores. Following the Mangled Extremity Severity Score (MESS), a score of 7 or more is an indicator of amputation. However, several authors have questioned this score threshold[11,12,13], demonstrating a posteriori a 69-78.9% survivorship, in a civilian sample, as well as 35% survivorship in a military setting, of limbs scoring more than 7 at initial evaluation[14,15,16]. Nerve injury is no more considered as a reason to amputate, given that nerve recovery can be seen after initial severe contusion ; neither the severity of the bone trauma[11,16,17].

The decision of amputation is sometimes based on the coexistence of vital organ dysfunction. The age of the patient is also an important factor. A transtibial amputation with a good stump in a young patient leads usually to excellent function, with even the possibility of going back to sporting activities. However, stump problems are not infrequent, causing pain and functional limitations. The functional results also deteriorate with age, given that walking with a prosthesis represents a high metabolic demand; in the case of a trans-femoral amputation, the functional results are so poor that most aged amputees do not walk anymore and use a wheelchair. Regarding the upper extremity, it is unreasonable to treat a large skeletal defect by an amputation, if the hand is normal. The psychological impact of the amputation at the upper extremity is greater than that of the lower limb. Even with a poor hand, patients tolerate relatively well a bad or not functioning upper limb, that remains nevertheless a hand of assistance[18].

A particular amputation at the lower limb is the Van Ness turniplasty, in the objective to maintain knee function[19,20]. However, patients need to be prepared psychologically to accept the radical change of their body image.

Bone infection

Healing of a large skeletal defect is illusory in case of osteitis/osteomyelitis, therefore, before considering the reconstruction of a large bone defect, the infection must first be controlled. The cardinal principle of treating a bone infection is the resection of all devascularized infected bone and sclerotic ends. The previous material of osteosynthesis has to be removed and if possible given to the microbiology laboratory for sonification. Many times the infection is by low virulence micro-organisms, not easy to detect by cultures. Therefore, multiple microbiology samples in the form of biopsies and prolonged laboratory cultures are necessary. Stabilisation and preservation of bone length is usually performed by external fixation, with the pins implanted in healthy bone. The insertion of the fixator should be carefully planned, in anticipation of the future treatment of the bone defect and soft tissues. External fixation can either be temporary or be kept until final bone healing. A good technique is the temporary insertion of Genta-beads or of a cement spacer (polymethyl methacrylate - PMMA) impregnated by antibiotics, at the site of bone resection, for a period of several weeks, provided that the soft tissues are healthy or that a flap is performed. The cement spacer mechanically impedes fibrous tissue invasion, simply by taking up space[21,22], allows the local release of antibiotics, offers the opportunity to objectify whether the infection persists or not during treatment, and is beneficial for secondary bone graft (see the section Masquelet technique later in this article). Further debridements can take place to eradicate the infection, changing the spacer, if there is evidence of persistent infection. Restoring the soft tissues envelope is also important. This is achieved by pedicled or by free flaps, especially indicated in distal lower limb bone infections, due to the lack of abundant soft tissues surrounding the extremities. The choice of the flap is based on the location, the size of the soft tissue defect and the length of the vascular pedicle needed, in case of microsurgical techniques. Anastomoses are performed to healthy vessels at some distance from the site of the lesion[3]. Note that there is not an absolute necessity to cover the bone, if the exposure is limited, provided that desiccation is prevented: in the past the open bone grafting technique of Papineau has been used with success, but not in large skeletal defects.

The principle of cement spacers can also be used in the treatment of open fractures, to prevent late infection. Indeed, one can use a cement spacer during the first operation of a complex traumatic case. Its use doesn't threaten the viability of the soft tissue adjacent coverage[23]. Temporary cement spacers can also be inserted after primary tumour resection, while the histology of the resected bone segment is studied to make sure that the operation is curative. The final reconstruction is delayed by a few weeks, helping also in its planning.

Two-stage bone graft (Masquelet technique)

As mentioned before, interposed cancellous autografts when treating a bone defect of more than 5cm usually are not successful, given that resorption has been noticed when the gap exceeds this threshold[1]**.** This is why surgeons need to turn to other techniques. Masquelet has described a two stage surgical procedure based on his observation of the development of a vascularised membrane around a cement spacer[24, 25]. The "induced" membrane is in continuity with the neighbouring periosteum and creates a protective micro-environment favouring the integration of a bone graft, regardless of the size of the defect treated.

Practically, the first stage is to actively debride the defect up to bleeding bone, removing all necrotic tissue and internal implants, maintaining skeletal length by external fixation and performing if necessary flap-coverage. Then, a cement spacer, usually impregnated by antibiotics, is placed at the site of the bone defect, overlapping the surrounding bone extremities[22]. After a minimum of six weeks, a period during which adapted antibiotherapy is administered if infection is present, the second stage takes place. By carefully preserving the membrane, the spacer is replaced by cancellous bone graft, which can be purely autologous, harvested for example at the iliac crests, or a mix of cancellous autografts and allografts, though the most effective proportion of autografts to allografts remains to be defined[22]. Autologous cancellous bone grafts have shown their superiority in terms of osteogenesis and osteo-induction and pure allografting should be avoided. The external fixator is usually kept until final bone healing, but it can also be replaced at some time by a system of internal fixation.

The integration of the bone autograft can be improved by performing during the first step a procedure of osteo-periosteal decortication according to Robert and Jean Judet[26,27], consisting in creating a sheath of vascularized bone by raising with sharp osteotomes the superficial part of the cortical bone, keeping its attachments to the soft-tissues. It is an excellent technique to stimulate bone healing in the case of an atrophic non-union, even without a bone graft. However alone this technique cannot heal a large skeletal defect, but it may be helpful in combination with the Masquelet technique.

Cortical Bone grafting

The use of autogenous cortical non-vascularized grafts has been long ago described in literature[28]. The fibula is a good choice and in children it may allow healing of a large skeletal defect, provided that there is good vascular supply of the surrounding healthy tissues and strictly no infection. The fibula can be used as single or double barrel reconstruction, according to the defect treated[29]. The stabilisation of the graft can either be done by plates, screws or simply by wedging the fibula into the neighbour bone stumps. Failure is reported to be higher when performing single fibular transfers, in comparison to double or triple ones[30]. A non-vascularized bone autograft is not a good choice in adults to reconstruct large skeletal defects.

Microsurgical treatment of chronic bone defect

A large bone defect is an excellent indication of reconstruction using a vascularised bone transfer[31,32,33]. Theoretically, it allows bone healing independently of the status of the surrounding soft tissues. Microvascular bone transfers early in the treatment of the bone defect may offer exceptional results, saving time and sparing patients from multiple surgeries.

Indeed, vascularized bone transfers have excellent osteogenic potential and remodel over time, according to the applied loads. The type of vascularised transfer chosen depends on the defect size. For long bones the most frequently used donor is the fibula. The iliac crest is an alternative, though it has to remodel to resist the applied stresses. Moreover, it has been found that vascularised fibular transfers function better when dealing with defects of more than 10cm, whereas iliac crest vascularised grafts are superior in smaller defects[34]. The vascular anastomoses should be performed to healthy vessels, far from the bone defect location. Sometimes a two-stage surgery can take place, inserting a cement spacer firstly, performing a microsurgical fibular transfer secondarily – it has been our impression that the integration of the vascularized bone transfer is then even quicker.

At the lower extremity, the fibula is frequently used at a double or even triple barrel configuration, to have more bone to resist the high stresses[35,36,37]. It is also possible to add around the vascularized fibula non-vascularized bone autograft chips or even a cut fresh-frozen cortical allograft (strut). The entire construct can integrate quite well, leading to a solid reconstruction of the large skeletal defect. To monitor the viability of the fibula, the transferred bone can be accompanied by a skin flap. The size of this island can be variable, with a double function, assisting in local coverage and vascular monitoring. Fibula vascular reconstructions are so well integrated that they allow even lengthening of the limb at a later stage, via the traditional means of osteotomy and external fixation[38].

Limb shortening - secondary lengthening

Another possibility to heal a large skeletal defect is to firstly perform shortening of the limb, aiming at the consolidation of the defect, performing later progressive relengthening. The main indication is a large bone and soft tissue defect, when it is not possible to provide healthy soft tissue coverage, because of vascular reasons or flap failure, or when there is associated segmental nerve tissue loss in more than one major nerve axis[39]. With shortening, contact is possible between the bone stumps, so as for them to consolidate, being at the same time able to suture directly neural or vascular lesions[40]. Treating limbs' length discrepancy secondarily is possible, performing osteotomies in a healthy ground, far from the initial trauma site, under favourable conditions for consolidation.

Segmental bone transfers

Large bone defects can be treated also by Ilizarov progressive segmental bone transfer along external fixation or lengthening centromedullary devices[41,42]. Frequently, there are problems to obtain bone healing at the end of the bone transportation time, when the transferred bone segment comes in contact with the extremity of the bone defect. Healing a large bone defect by segmental bone transfer takes much more time than by microsurgical bone transfer and there are more complications.

Fresh frozen cortical allografts

In case of a large diaphyseal skeletal defect, the reconstruction can be performed by a massive fresh frozen cortical allograft and solid internal fixation, provided there is good soft tissue coverage and strictly no infection. This situation, rarely encountered in traumatology, is seen after resection of bone tumours. Allografts are readily available, and can be easily fixed using common techniques of osteosynthesis. The risk of disease transmission is limited. The immediate results are usually quite good. Because bone is a mesenchymal tissue, there is usually no or minimal phenomena of allograft rejection, despite the absence of immunosuppression. However, the replacement of the allograft by living bone from the host is usually limited to its extremities, and the graft remains essentially a large dead tissue, not undergoing Haversian remodelling. Late infection, failure of internal fixation, non-union, fatigue fracture and bone resorption are frequent, frequently imposing new surgery several years after the initial bone reconstruction, ending sometimes up in late amputation.

Mega-prosthesis

In the presence of bone defects in proximity to joints, the use of a megaprosthesis allows limb salvage. Those non-biological reconstructions allow for early weight bearing and rehabilitation. What is more, expandable endoprosthesis can be lengthened, so as to minimise limb length discrepancy in the paediatric population[43].

However, the rate of infection is high, in particular in patients under chemotherapy. Indeed, in this subset of patients, only those with a microsurgical bone transfer have a limited risk of infection, those reconstructed by allografts or megaprostheses have a relatively high probability of deep infection[44].

Fig 1: A 25y.o. patient treated for a localised adamantinome (a,b) by resection, application of a cement spacer and ExFix (c). The margins were free of tumour. Reconstruction by fibula vascularised transfer enhanced with a femoral allograft strut (d). Integration and adaptation of the grafts to the applied load at four years follow-up (e,f). The fibula has hypertrophied and fused at both extremities and with the allograft.

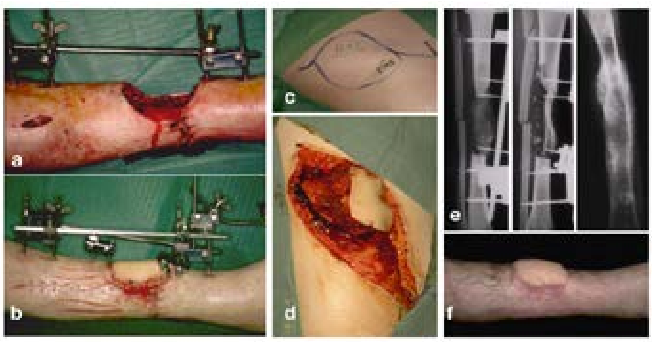

Fig 2: Gustilo III-B open fracture of the tibia with large bone defect (a) treated by vascularized osteo-cutaneous transfer of the anterior iliac crest (b,c,d,f). Bone healing and adaptation of the integrated bone to the applied loads (e).

Conclusions

The above mentioned techniques are solutions to deal with a large bone defect. All have their indications and contra-indications. It is the responsibility of the surgeon to evaluate the patient's and the bone defect's characteristics so as to choose the technique or combination of techniques most appropriate to success and offering the quickest way to reintegrate the patient to his previous life. Among these techniques, microsurgical bone transfers occupy an important place.

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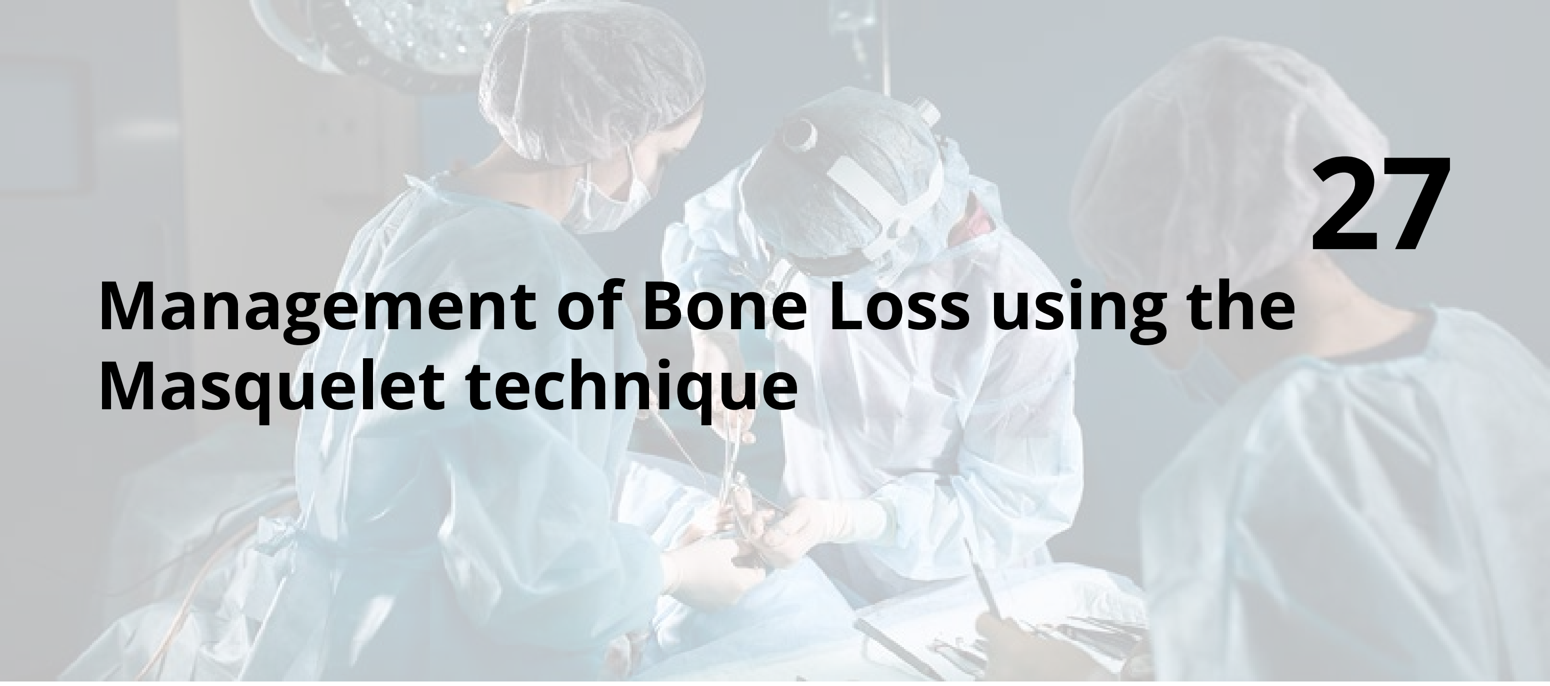

27

Management of Bone Loss using the Masquelet technique

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Summary

The Masquelet technique is a successful method of repairing areas of challenging massive bone loss. It is a two-stage process. During the first stage, initial debridement and packing with cement spacer, and temporary/permanent fixation of the bone defect area takes place. Any soft tissue reconstruction is performed then. The second stage takes place 6-8 weeks later when the cement spacer is removed whilst preserving the induced membrane that has formed, followed by grafting of the defect area. The key to its success is induction of a biologically active membrane around the cement spacer previously inserted which facilitates bone healing. It has proved to be a reliable treatment modality where the ascribed technique is rigorously followed, which we discuss herein.

Technique Indications:

The Masquelet technique is especially useful for helping restore areas of massive bone loss (1) (up to 25cm), following:

1. Acute traumatic bone loss
2. Bone loss following debridement of infection and/or non union
3. Avascular bone debridement
4. Tumor resection

Technique Aim:

The aim of the Masquelet technique is to achieve healing of bony defects, either as a primary or revision procedure. The premise behind the technique is its ability to induce a biologically active membrane, which is a highly vascularised synovium-like epithelium rich in osteoinductive factors, including bone morphogenic protein 2 (BMP-2) and growth factors including vascular endothelial growth factor (VEGF), angiotensin-II (ANG-2), fibroblast growth factor 2 (FGF-2), prostaglandin E2 (PGE-2) and transforming growth factor β (TGF-β). (2, 3) This membrane encourages and facilitates human bone marrow stem cells to differentiate into osteoblasts and therefore initiate osseous regeneration, and also help protect any soft tissue graft vascular pedicles used as part of the repair. If one is able to effectively harness this natural phenomenon through careful attention to the technique (a two-stage procedure), evidence shows that remarkable results can be achieved. (1) Throughout the whole procedure, one must bear in mind the principles of the 'diamond concept' of bone healing: the defect will only heal if the mechanical and biological aspects are considered equally. Throughout, one must make sure that the vascular integrity and soft tissue envelope surrounding the defect are respected as much as possible. By the second stage, one must ensure that appropriate osteosynthesis has restored mechanical stability to the defect, as well as optimising global host (patient) factors, such as smoking cessation and optimisation of medical comorbidities such as diabetes (4, 5).Finally, one must focus on the local biological environment, and ensure there are sufficient osteoinductive growth factors, osteogenic cells, and osteoconductive graft material in situ to allow for optimal healing. However, unless an appropriate method of 'containment' to keep everything within a biological chamber, or "bioreactor" is employed (in this case the Masquelet membrane that has been induced), there is a high risk or resorption and loss of this potent stimulus, which would render all these efforts futile,. (**Figure 1**). (4)

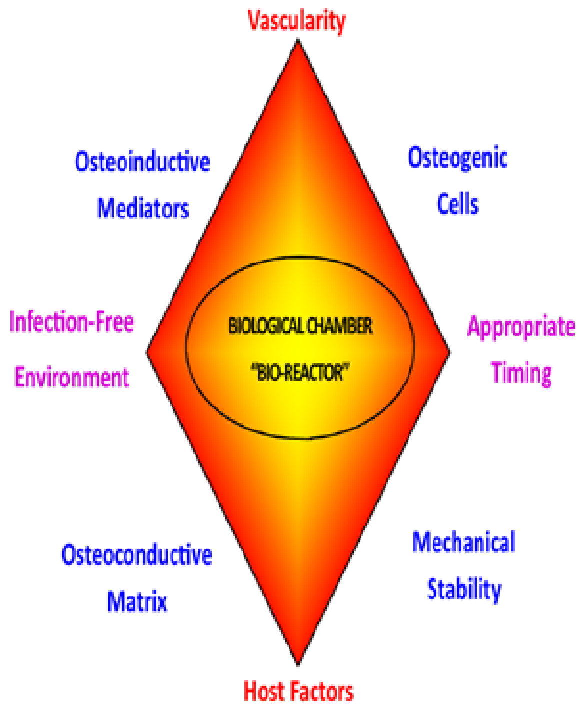

Figure 1 - *The Diamond Concept (4)*

Surgical Technique:

The procedure is broken down into two main stages, which are discussed below, with images provided from a case: a patient following a Gustilo 3b Open Femur fracture, (**Figure 2**). He was initially treated with debridement and bridging fixation with a locking plate. Despite good initial management using a locking plate construction, there was minimal sign of healing at 5 months, (**Figures 3 A-C**).

Figure 2 *- AP Radiograph of Left Femur - Gustillo 3b open fracture at initia; Figure 3A - AP Radiograph of Left Femur at 5 months - note no evidence of healing ; Figure 3B – Lateral Radiograph of Left Femur at 5 months - note no evidence of healing Presentation; Figure 3C - Coronal CT Scan of Left Femur at 5 months - note no evidence of healing*

First Stage

Step 1. Debridement

Thorough inspection and debridement must take place at the site of the defect, ensuring any foreign bodies, infective material, necrotic bone, or tumour are fully removed. In cases where this is not performed fully, the success rate of the procedure is significantly lower. The soft tissues surrounding the defect, and neurovascular structures must be respected, and their integrity kept intact as they are an essential part of the subsequent healing process, (**Figures 4 A-C**). In the case presented, a low-grade infection was suspected, so multiple microbiology samples were taken and the area thoroughly debrided, (**Figure 4D**).

Figure 4A *- View of bone defect on initial inspection.*

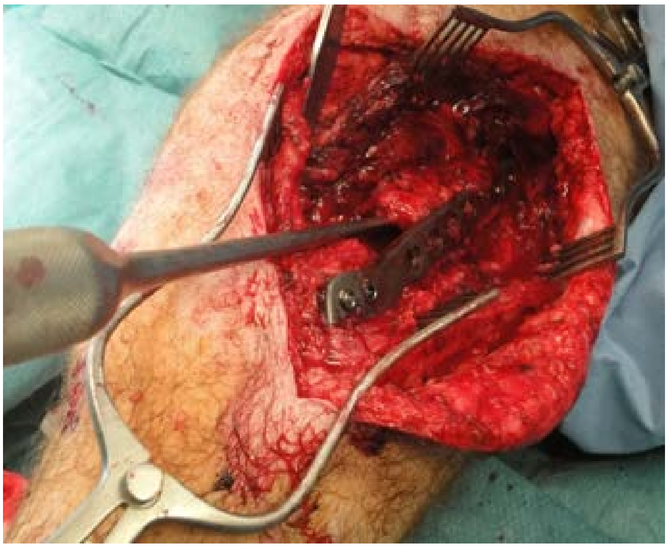

Figure 4B *- Thorough debridement of defect, including curettage of bone ends and medullary canal*

Multiple tissue samples must be sent for microbiology to rule out infection and treat as necessary. Unless the patient is critically unwell, antibiotics, including prophylactic antibiotics during surgery, must be avoided until after samples have been taken, to improve accuracy of microbiological investigations,(**Figure 4D**).

Figure 4C *– View of defect following thorough debridement*

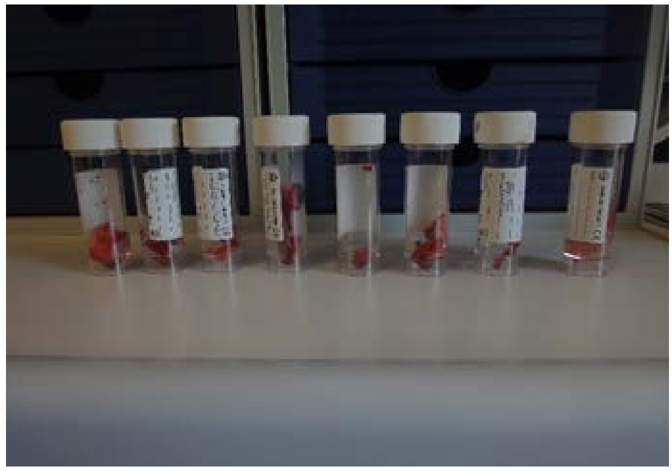

Figure 4D *- Multiple deep tissue specimens must be taken*

Progress must be screened using C-Arm Xray in theatre, to ensure that sufficient debridement of fragments has taken place, and whether any revision is needed of the osteosynthesis before proceeding, (**Figure 4E**).

Figure 4E - *AP Radiograph taken intraoperatively to ckeck debridement*

Step 2. Cement Spacer

Various forms of cement spacer can be used. Most authors use polymethylmethacrylate (PMMA) bone cement with antibiotics, however, Masquelet himself prefers not to use antibiotic-loaded cement. The cement can be applied en-masse and moulded to the area, or applied in the form of handmade antibiotic cement beads or pellets which allows for easier subsequent removal, and experience suggests the induced membrane (IM) is of similar quality. Evidence suggests however that for large defects of posttraumatic osteomyelitis the moulding method is more effective for overall healing, (6) (**Figure 5A**).

Figure 5A - *Bone defect following insertion of cement spacer, note cement 1cm beyond edges of defect*

Postoperatively, XRays should be taken to confirm position of cement (**Figures 5B-C**).

Figure 5B - AP Radiograph following application of cement spacer

Figure 5C - Lateral Radiograph following application of cement spacer

- In cases where external fixation is used as a temporary measure, we recommend to use the moulding method, with a 2mm Kirschner wire can be incorporated into the cement spacer and inserted into the medullary canals of each side of the defect to prevent displacement; it is also beneficial to incorporate some of the cement in the medullary canals each side, to augment stability.
- Place cement at least 1cm over periosteum at each side, which induces membrane production away from the site of the bone defect, improving results, (**Figure 5A**).
- Ensure that surrounding soft tissues are protected with a suitable barrier whilst the PMMA is setting, to protect against heat from the exothermic reaction, such as a glove surrounded by constant saline irrigation to counteract and avoid thermal injury.
- Where antibiotics are added to cement, care must be taken to maximise its porosity during preparation, which includes adding the antibiotic powder last, and avoiding use of suction whilst mixing the two cement phases.

Step 3. Bridging Fixation

Fixation can either be temporary or permanent at this stage, whether this is internal or external fixation. The method chosen must be sufficiently stable to allow membrane formation and prevent displacement of the cement spacer. If this procedure is a revision operation, and there are no concerns about stability of the previous fixation, this can be left in situ as it was done in this case, (**Figure 4C**).

- Following bridging fixation, the surrounding soft tissues must be reconstructed, often in consultation with plastic sur-

gery colleagues. This ensures a vitalised, well-perfused soft tissue envelope surrounding the site, which is essential for good IM production.
- Careful attention must be paid to pin-sites if an external fixator is used to minimise risk of subsequent infection.

Step 4. Closure
Closure must be done in layers, with care for the soft tissue envelope, ensuring minimal neurovascular compromise.

Interim period
Following the first stage, close attention to clinical and biochemical markers must be taken to monitor for risk of local infection which would impair progress. If there is any suspicion of recurrence of infection, further imaging and investigation is required. If confirmed, then a repeated thorough debridement needs to take place. The membrane must be excised, and cement spacer replaced. As previously, intraoperative prophylactic antibiotics should be avoided until deep tissue samples are taken. This process must continue until extended deep tissue cultures confirm no infection remains.
Appropriate antibiotics should be prescribed as per microbiologist advice pending on the results of the cultures. The timing of antibiotic administration should be discussed with the microbiologist and normally depends on the type of bacteria grown and the degree of resistance.

<u>Second Stage</u>: After 6 to 8 weeks from stage 1.
Step 1. Incision and Inspection
- Incise down to the membrane using the previous scar. At this stage, carefully incise the membrane longitudinally. If a soft-tissue flap has been used for reconstruction, be sure to approach away from the vascular pedicle anastomosis (**Figure 6A**).
- If the anatomical site of interest is the tibia and extensive scarring or fragile tissue prohibits a direct medial or anterior approach, one can perform an extended bypass inter-tibiofibular graft to bridge the tibial defect; or if elsewhere the same logic can be applied, approaching through a safe alternative direction.
- Inspect for any sign of infection, and if present proceed with samples, repeated debridement and spacer insertion, going back to stage 1 (**Figure 6B**).
- If there was previously any infection present, but the area looks clean samples must still be taken to ensure no recurrence.
- Either way, the cement applied previously must be removed at this stage.

Figure 6A - Careful longitudinal incision through membrane, respecting soft tissue envelope

Figure 6B - Raising of membrane, note vascular structures within membrane, and absence of infection at defect site, with cement in situ

Step 2. Cavity debridement

Carefully debride the cavity, ensuring the membrane is preserved and soft tissue envelope respected, (**Figures 7A-B**).

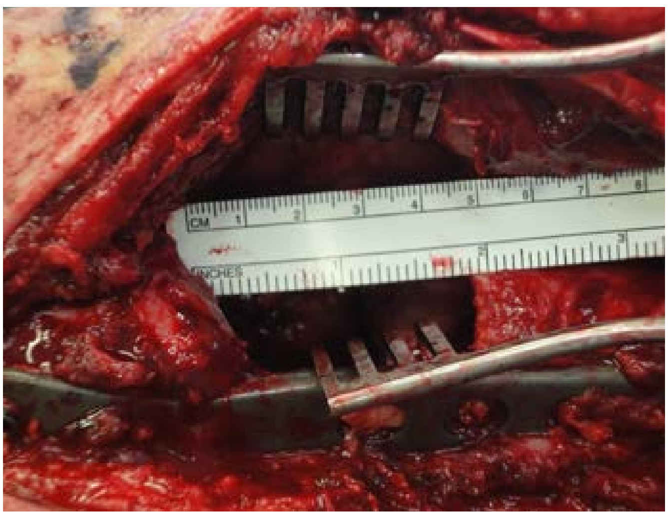

Figure 7A – Measuring length of cavity defect following debridement and cement

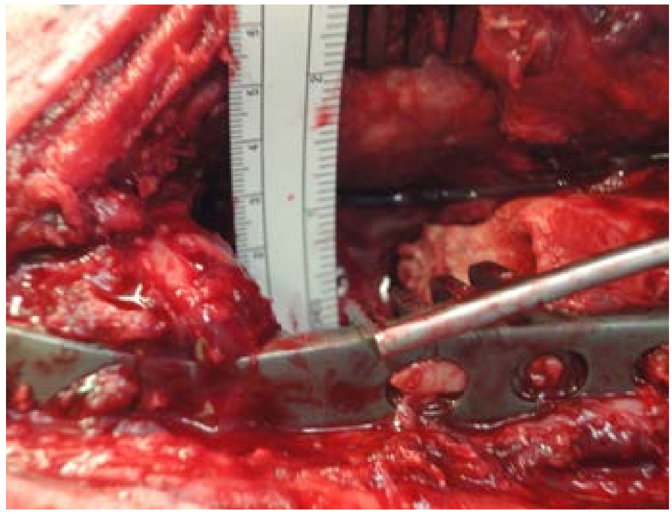

Figure 7B - Measuring width of cavity defect following debridement and cement removal

Step 3. Bone edge debridement

- Curette the ends of bone to fresh bleeding tissue to facilitate healing.
- Open the medullary canal to allow endosteal communication to the graft.

Step 4. Graft harvest

- The gold standard is autologous bone graft (ABG).
- This can be taken from the anterior (Figures 8A-D) or posterior iliac crest (**Figures 9A-D**), or harvested using the reamer-irrigation-aspiration (RIA) technique (**Figures 10A-D**), which we discuss below.

Anterior iliac crest bone harvest (7):

1. Raise the pelvis 30-40° by inserting a bolster underneath the buttocks posteriorly, with patient in supine position.
2. Make an initial incision 5cm in length beginning 2cm posterior to anterior superior iliac spine (ASIS), and 2cm lateral to the iliac crest. This is to minimise risk of injury to the lateral femoral cutaneous nerve, which runs just behind the ASIS, and reduce the risk of irritation to the scar from clothing, (**Figure 8A**).

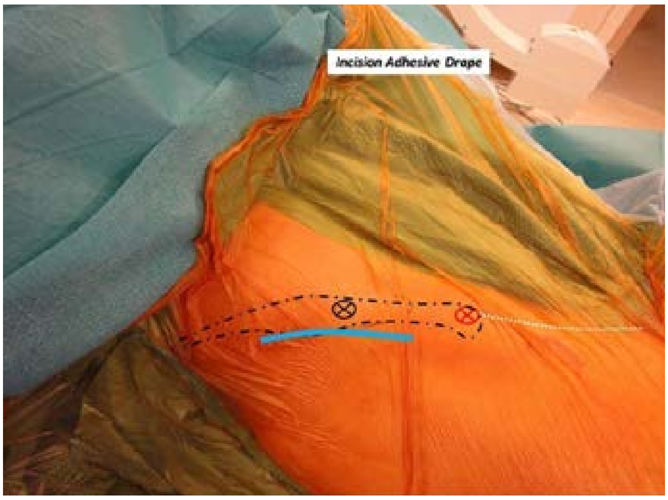

Figure 8A - *Anterior Iliac Crest Grafting incision marking*

3. Blunt dissection of subcutaneous tissues down to periosteum, strip desired portion of iliac crest of iliacus, (**Figure 8B**).

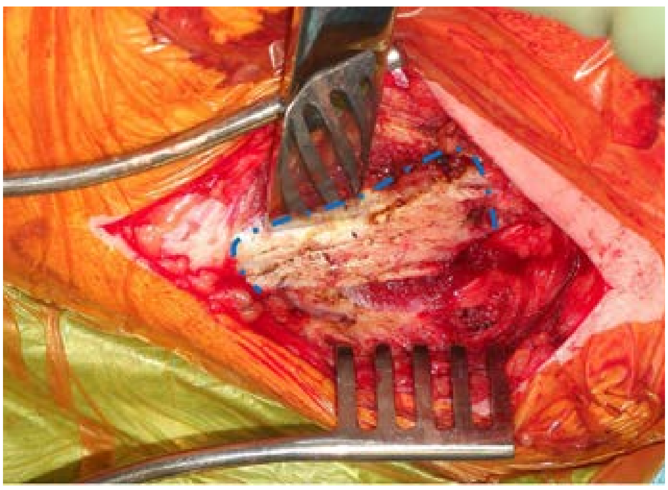

Figure 8B - *Dissection down to periosteum, identify area to harvest graft*

4. Incise periosteum of iliac crest
5. Obtain graft: this can either a be bi/tricortical bone block, or the crest can be opened in order to obtain cancellous bone from within using a small window (**Figure 8C**) and by creating a small window and using a rongeur to obtain 10-15cm^3 of cancellous bone from within, (**Figure 8D**).

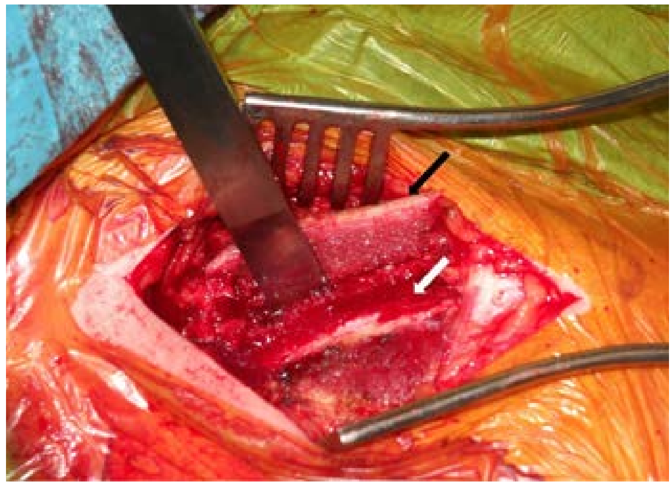

Figure 8C - Bone window lifted in anterior iliac crest

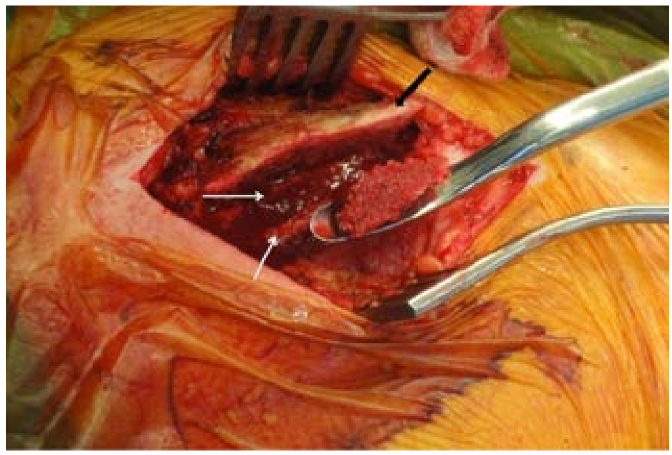

Figure 8D - Cancellous autograft taken from Anterior iliac crest

6. If a bone block has been taken, the defect should then be replaced with a graft using either an allograft or xenograft bone replacement, such as sterile bovine bone.
7. Close attention must be paid to haemostasis, and closure in layers.

Posterior iliac crest bone harvest (7):

1. Raise the pelvis 30-40° by inserting a bolster underneath the buttocks anteriorly, with patient in prone position.
2. Make a straight longitudinal incision 7-8cm long over the posterior superior iliac spine (PSIS), or an oblique incision from proximal-medial to distal-lateral, perpendicular to the iliac crest, but parallel and out of the way of the clunial nerves, which run 8cm lateral to the PSIS; transverse in-

cisions must be avoided to prevent clunial nerve injury also. (**Figure 9A**)

Figure 9A - *Incision site for Posterior iliac crest graft harvest*

3. Incise through the subcutaneous layers to gluteus maximus.
4. Using sharp dissection, incise gluteus maximus subperiosteally from its origin.
5. Use a key elevator to elevate the iliac crest along lateral and superior surfaces, taking care not to injure the sacroiliac joint complex, or the superior gluteal artery which runs nearby
6. Palpate the greater sciatic notch inferiorly before instrumenting the area. Bone harvest can take place to within 1cm of the notch.
7. With careful use of an osteotome and curettes, bone can either be harvested bi/tricortically as a block, or in the same way as the anterior crest, a small incision can be made superiorly and rongeurs used to harvest cancellous bone, (**Figures 9 B-D**)

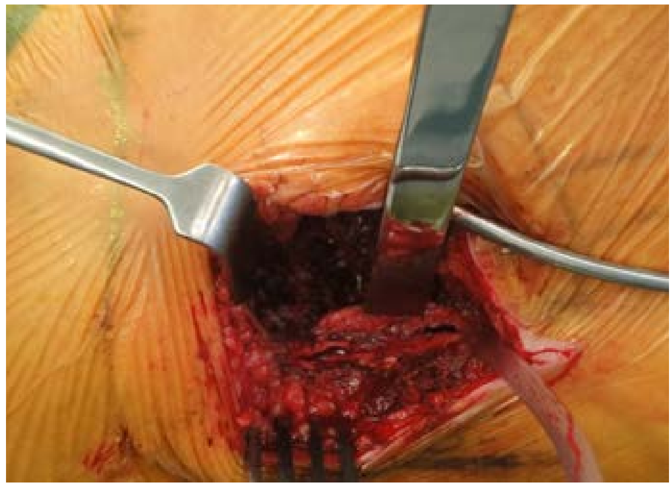

Figure 9B - *Use osteotome/rongeurs to gain access to posterior iliac crest and harvest*

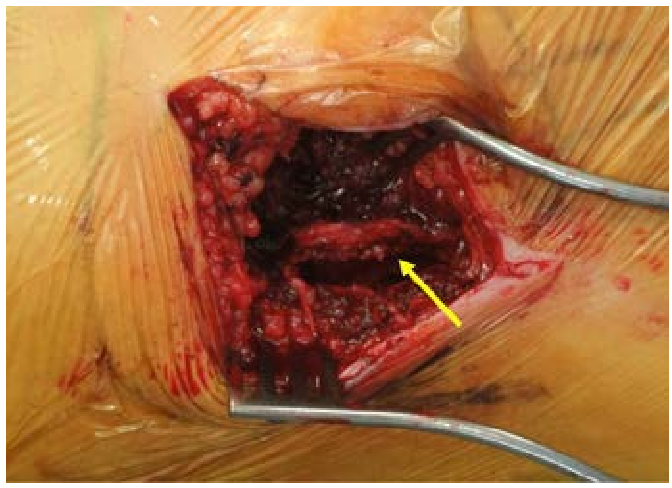

Figure 9C - *Posterior iliac crest following harvest*

Figure 9D - *Chippings harvested from posterior iliac crest*

8. If a bone block has been taken, the defect should then be replaced with a graft using either an allograft or xenograft bone replacement, such as sterile bovine bone.
9. Close attention must be paid to haemostasis, and closure in layers.

Reamer-Irrigator-Aspirator graft harvest (8)

1. Usually the femur is used, with either a proximal piriform-fossa or greater trochanteric entry point, or distal inter-condylar entry point if a retrograde nail is to be used as part of the same procedure.
2. Insert a guidewire over which the reaming takes place, (**Figure 10A-B**).
3. Set up as usual with an entry reamer as for an intramedullary nail, screening under image intensifier guidance.
4. If intending just to harvest bone, ream to 1-1.5mm wider than the isthmus.

Figure 10A - *Guidewire insertion for Reamer-Irrigator-Aspirator entry point*

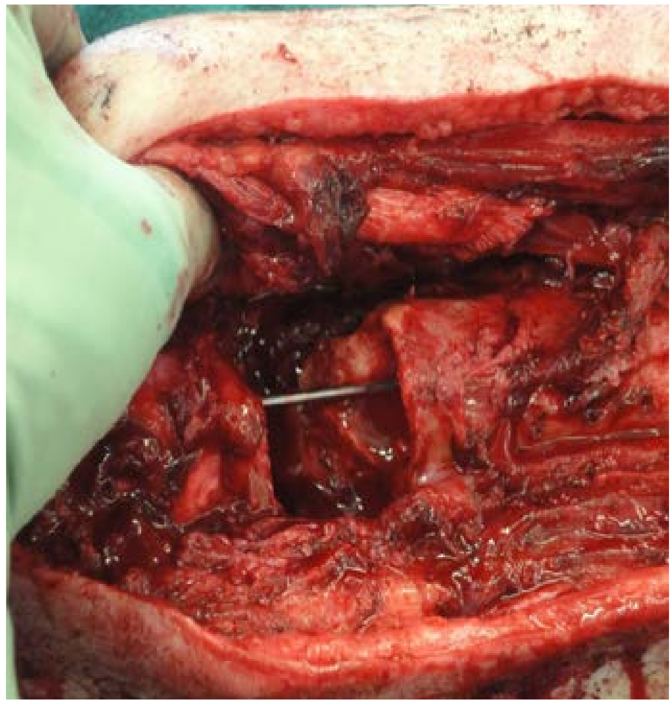

Figure 10B - *Confirming the guidewire has passed the area of bone defect*

5. Connect irrigator-aspiration equipment
6. Proceed with reaming and irrigation/aspiration, advancing 20-30mm then retracting 50-80mm to allow reduce the risk of clogging the system and thermal necrosis/damage to the osteoconductive graft and cells. (**Figure 10C**).
7. Screen using imager intensifier guidance throughout. (**Figure 10D**).
8. The harvested bone is trapped in a filter, which can then be used for grafting. Remove this once finished with harvesting, (**Figure 10C**).

Figure 10C - *Reamer-Irrigator-Aspirator in use, note the filter used to contain the graft, connected by a tube, below the reamer*

Figure 10D - *Image intensifier guided RIA*

Step 5. Graft preparation (including enhanced composite grafting)

The ABG can now be augmented according to diamond concept principles (4), using the following agents as needed, according to the individual patient:

- Osteogenic agents, including Bone Marrow Aspirate Concentrate (BMAC) which is a centrifuged supernatant of bone marrow, extracted from the iliac crest, containing a high concentration of multipotent stem cells, (**Figure 11A**).

Figure 11A - *Method of bone marrow aspiration from the iliac crest*

- Osteoconductive elements, including allograft/demineralised bone matrix, xenograft, calcium triphosphate, or a gelatin sponge can be added to the autologous graft obtained in the previous stage, (**Figure 11B**).
- Osteoinductive agents, including Bone Morphogenic Protein-2 (commercially available) or Platelet-Rich Plasma (PRP) obtained after centrifugation of the patient's own blood serum.
- One should aim for at least 60-70% autograft and 30-40% allograft as a volume expander.

The patient we present had RIA autologous graft, BMAC, and calcium triphosphate chippings to form his composite graft (**Figure 11B**).

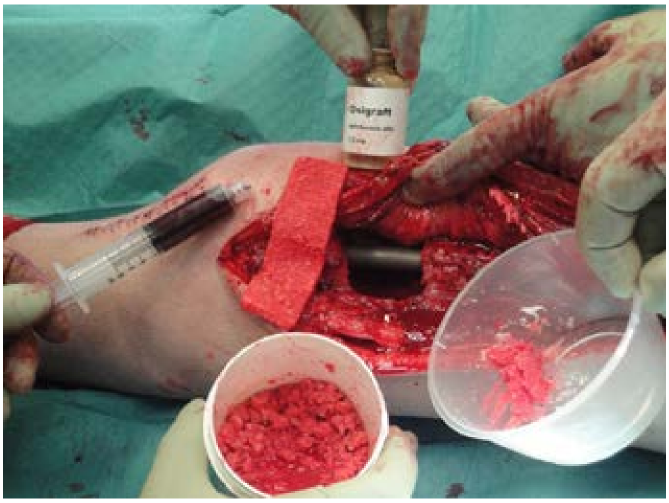

Figure 11B - *Note the BMAC ready to add to the graft, , RIA autograft and BMP-7 and calcium triphosphate expander (which can be used as a containment adjunct as well) ready to insert into the bone defect.*

Step 6. Assess/revise fixation

Depending on the method chosen for primary fixation, this can be revised at the second stage. Whichever option is chosen it must be a strong, stable construct to engender healing as per the diamond concept (4). This could include an internal bridging plate, an intramedullary nail ± plate, or an external circular frame. Whichever method of fixation is chosen, the soft tissue envelope must be respected, using a method with minimal periosteal/tissue stripping.

The patient we present underwent removal of metalwork, reaming, retrograde intramedullary nailing of his femur, and composite bone grafting implantation to the bone defect area (**Figures 12 A-D**).

Figure 12A - Insertion of retrograde intramedullary nail into femur

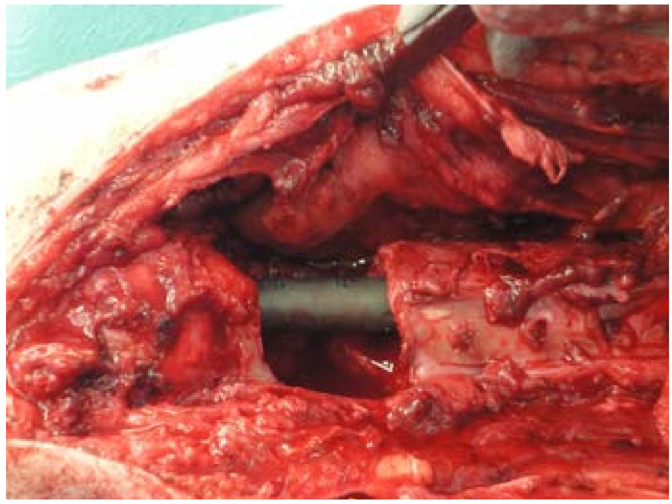

Figure 12B - Intramedullary nail passing bone defect

Regular check radiographs should be taken throughout insertion of the intramedullary nail, including the locking screw constructs, (**Figures 12 C-D**).

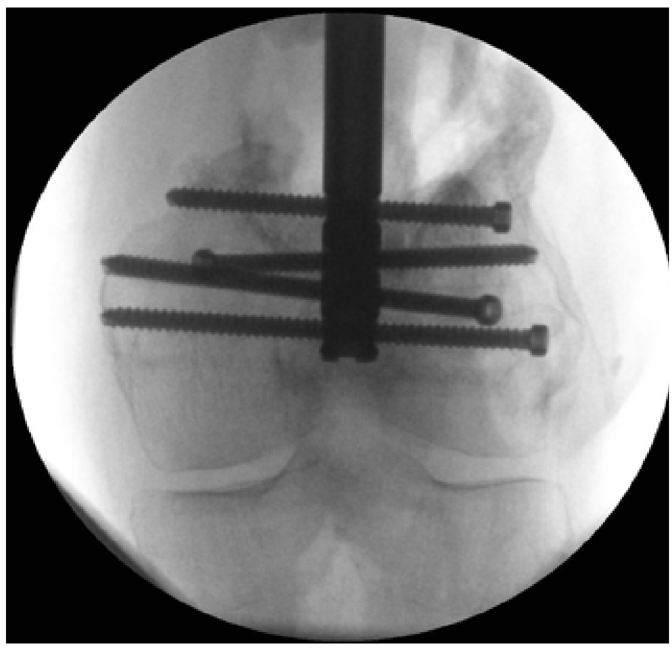

Figure 12C – Intraoperative AP Radiograph confirms satisfactory distal locking screw placement

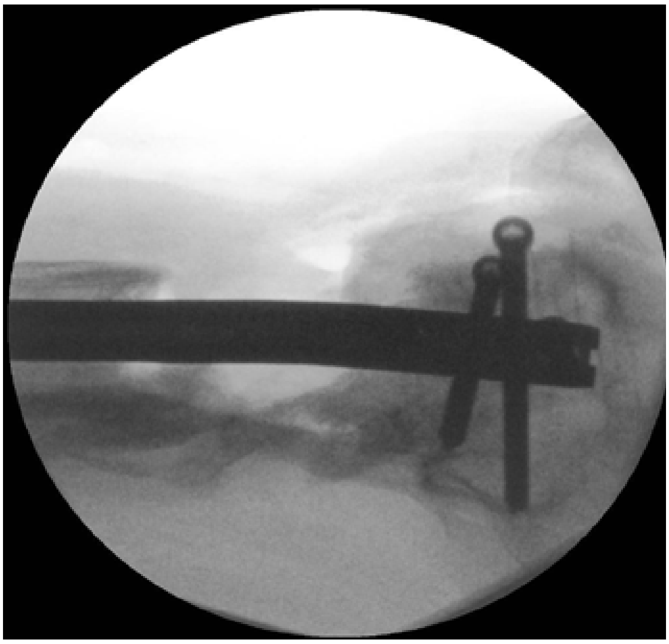

Figure 12D *- Intraoperative Lateral Radiograph confirms satisfactory proximal locking screw placement*

Step 7. Graft implantation

- The enhanced graft should now be implanted within the induced membrane, between the bone ends, (**Figures 13 A-C**).
- It should not be packed too densely, not to inhibit prompt revascularisation, allowing passage of cells across the area and facilitate healing.
- The volume should be enough to cover the defect, yet not too much to inhibit closure of the membrane which would impair graft revascularisation.

Figure 13A - *Initial graft insertion. Note the anterior knee wound has been closed, and intramedullary nail is now in situ.*

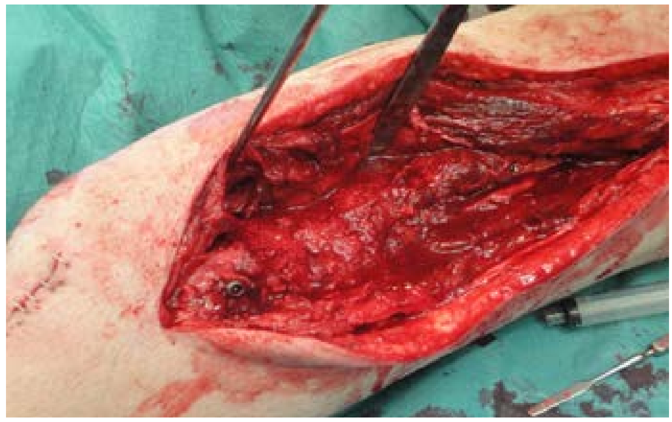

Figure 13B - *All graft material has now been inserted, note the liquid appearance - which is why containment is so important*

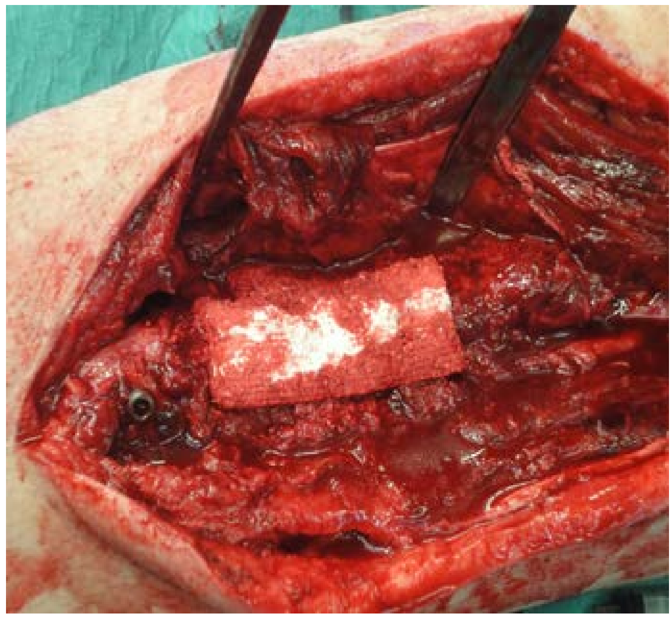

Figure 13C - *A tricalcium phosphate sponge is inserted over the defect, which has been packed with graft, to help bridging of the defect, prior to closure of the membrane which is still being retracted*

- At this stage, if there is any concern of varus malalignment of the construct, a non-vascularised fibula graft can be placed close to the membrane at the medial aspect of the defect to improve its stability and position.

Step 8. Closure

- The membrane must now be closed using a tension-free technique, using a slowly-absorbable suture.
- The surrounding soft tissues should be closed completely in layers, aiming to

create a tight seal around the defect, to ensure containment of the graft material, and support the vascular integrity membrane, without which the healing potential is significantly reduced.

Follow-up Radiographs:
Immediate post-operative check radiographs (Figure 14A-B).

Figure 14A *– AP Radiograph taken post-operatively, showing satisfactory position, and relatively well-contained graft material*

Figure 14B *– Lateral Radiograph taken post-operatively, showing satisfactory position, and relatively well-contained graft material*

6 Weeks post-operatively (Figure 15A-B):

Figure 15A - *AP Radiograph at 6 weeks showing good callous formation*

Figure 15B *- Lateral Radiograph at 6 weeks showing good callous formation*

3 months post-operatively (Figure 16A-B):

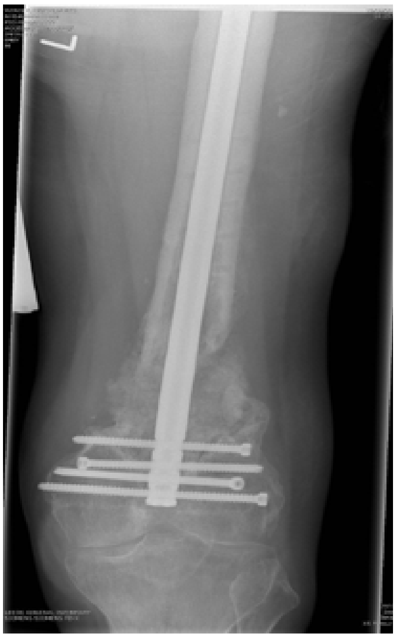

Figure 16A *- AP Radiograph at 3 months showing increasing hard callous*

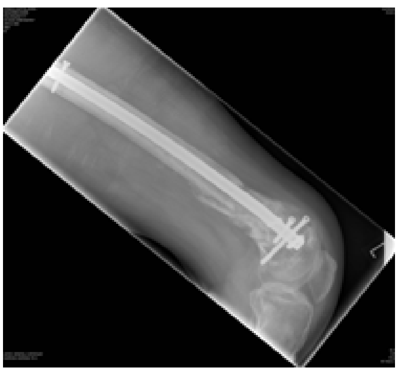

Figure 16B *- Lateral Radiograph at 3 months showing increasing hard callous*

6 months post-operatively (Figure 17A-B):

Figure 17A *- AP Radiograph taken at 6 months showing progressive graft integration and healing*

Figure 17B *- Lateral Radiograph taken at 6 months showing progressive graft integration and healing*

Discussion

The technique we have described has been shown to have excellent results, even with very large defect sizes, up to 25cm in length (1, 9). It is important to adhere closely to the method as we have described to obtain optimal results. A recent systematic review, which investigated among other things mixed results which have been reported with the technique identified that most cases which were not successful were due to inadequate debridement leading to ongoing infection at both stages. It is crucial to success that any avascular, devitalised, necrotic and potentially infected material is removed; this both removes the inhibitory effect on healing of this material and promotes neoangiogenesis, without which regeneration cannot occur. In cases where this was done well, and attention was paid to all aspects of the diamond concept, there is an average healing rate of 1cm of bone per 1.24 months. (10)

Whilst some authors (Masquelet) advocated the cement not to be mixed with antibiotics, in our practice we use routinely antibiotics and have not observed any adverse events as a result of this (11). Similarly, other authors have adapted its use and include local delivery of antibiotics into the cement, which achieves 3-10x the minimum inhibitory concentration for bacteria, resulting in effective local treatment. (1) Furthermore, it has been shown that local infection, such as Staphylococcus Aureus inhibits osteogenesis and upregulates the osteoclastic pathway. Antibiotics have been shown to reverse this through eradication of the bacterial load, and also through upregulation of osteoproteogrenion (OPG) which counteracts Receptor activator of nuclear factor kappa-B ligand (RANK) – an osteoclast inducer. Interestingly, the effect on OPG remains, regardless of the presence of infection or not, suggesting that use of antibiotics in cement can further improve healing to the area. (12) This is an area of ongoing research.

There has been much work to investigate the ideal timing of the second stage. In vitro and in-vivo human and animal experiments suggest that the induced membrane is most active, and thicker, peaking between 4-6 weeks (2, 3), although if the soft tissue envelope surrounding the defect is compromised resulting in a slow membrane formation, the final stage can be performed between 6-8 weeks. In our practice we routinely execute the 2nd stage between the 6-8 week time frame.

For ideal graft composition, one must consider the whole of the diamond concept, as discussed above. Unless all of its components are adhered to, the chance of success diminishes, although where the principles are all included in the treatment strategum the results of the technique are excellent.(1, 4, 10, 11, 13) The majority of people use autograft taken from the iliac crest. However, when a big volume of graft is needed the RIA device is used routinely which allows harvesting of up to 80 cc of autologous graft material from the intramedullary cavity of the femur. (4). If more volume of graft material is needed, the RIA graft can be mixed with a graft expander (allograft, synthetic (tricalcium phosphate) in a ratio 60-70% versus 30-40%. In addition, in elderly patients who have a reduced regenerative potential (14) (more fatty, yellow bone marrow with fewer and less potent stem cell lineages available), it is even more important to augment their harvested autograft with high concentrations of osteoinductive adjuncts such as BMP, PRP, and concentrated bone marrow aspirate to enhance the biological stimulation given, minimising the risk of failure.

Finally, one should not forget other factors that can compromise bone repair such as systemic disease like diabetes, smoking and medication (4, 5), which must be addressed by the surgeon. Individualised treatment should be ideally considered for each patient, and in this respect, such tools as the Non-Union Scoring System can be used to guide treatment. (15, 16).

With regards to fixation, in cases of chronic infection, after debridement a temporary external fixator is best until it can be replaced at the second stage. Following this, based on the location of the bone defect, the most appropriate method of stabilisation must be used (i.e. for metaphyseal defects plating can be used), providing optimum fixation until osseous healing takes place. For diaphyseal bone defects a load-sharing-in-axis construct using an intramedullary nail allows for earlier return to function and weight-bearing for patients, with recent results suggesting superior results to plating (17). It should also be noted that circular frames are an acceptable option, and that other adjuncts, such as strut-grafting, often taken from the fibula, can be used to aid with load-sharing and prevent varus malalignment (1).

Research is still ongoing in the area, and further work is required to assess how different combinations of the treatments discussed in terms of timing, graft composition, and adjuncts can affect outcomes. Future studies focusing on these aspects would be desirable.

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27

Medial Femoral Condyle Graft for Small Bones of Carpus – Tip and Tricks

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Vascularized bone grafts (VBG) have been used in reconstructive surgery since a long period of time for the treatment of non-unions and large bony defects starting with Huntington who applied a pedicled fibula to a tibial defect.[1] Conventional grafting techniques are also successfully used to treat the non-unions. Various union rates given in the literature state that this treatment is still a challenge especially in the presence of avascularity. Pedicled or free, VBG have many advantages over non vascularized bone grafts, including the preservation of cell viability, bone formation similar to primary fracture healing and accelerated graft consolidation.

Quite after the anatomic study of Rogers and Gladstone on the arterial anatomy of the distal end of the femur, medial femoral condyle (MFC) started to be used as the source for pedicled or free skin and bone flaps[2]. Free saphenous flap, vascularized adductor magnus tendon transfer and pedicled corticoperiosteal flaps or grafts were the introductory steps of the reconstruction options from this very fertile area.[3-5] Masquelet presented some cases of avascular necrosis of the femoral head and talus and even anterior cruciate ligament rupture of the knee treated with flaps vascularized by descending genicular artery (DGA) originating from superficial femoral artery (SFA) in 1985.[4] Sakai used free thin corticoperiosteal graft from the MFC for his six patients with non-unions of the upper extremity where conventional treatments had failed.[6]

In recent years, there is a progressive expansion in the indications of this free graft. The medial femoral condyle became the source of a variety of bone and skin flaps that can be used in upper and lower extremity surgery but also has been applied in head and neck microsurgical reconstruction.[7-11]

It's possible to harvest three type of free vascularized bone graft:

1. A corticocancellous bone which is used for long bones as structural wedge graft including femur, tibia, humerus, radius, clavicle, small bones like as scaphoid non-union with hump back deformity and also maxillofacial defects.
2. An osteochondral flap for cartilaginous defects of small carpal bones like as proximal pole of scaphoid and lunate bone
3. A corticoperiosteal flap applied as wrap around technique in cases of nonunion of tubular long bone (clavicle, humerus, ulna and also femur) in combination of non-vascularized autografts.

Indications

Mostly Scaphoid and less often lunate bone from small bones of the carpus has been treated with vascularized grafts. High osteogenic capacity of this type of grafts are well studied in the literature and especially pedicled bone grafts have been widely used for scaphoid non-unions.[12-15.] VBG seem a good alternative to achieve successful results. Because of the cell viability maintenance, they provide bone healing similar to primary fracture healing ad increase the union rate while providing rapid consolidation as a result of provision of osteogenic stimuli.[15] After the detailed anatomic study of Sheetz on dorsal radius vascular anatomy, distal radius became the source of numerous vascularized grafts for carpal problems.[16,17] Distal dorsal radius grafts, especially 1,2 intercompartmental supraretinacular artery (1,2 ICSRA) graft, have been generally used for proximal and waist non-unions whereas volar radius grafts have been the best for hump back deformity[18]. Also, VBG have been used in early stages of Kienböck's disease as a vascularized strut in lunate.

Even though pedicled grafts are successful, free vascularized bone transport becomes necessary for situations with poorer outcome. The union rates of scaphoid pseudoarthrosis is similar with 1,2 ICSRA and MFC graft (86.3% versus 88.8%). But scaphoid proximal pole avascular necrosis (AVN) and fragmentation, recalcitrant non-unions over 5 years and previously failed surgery are difficult situations to treat with conventional techniques.[19] The blood supply of 1,2 ICSRA with 0.35 mm. of internal diameter in average is not sufficient at all times. However, The MFC graft assures abundant feeding with larger arterial diameter and offers a better solution for difficult cases.

In Kienböck's disease, chondral breakdown of radial articular side of lunate could only be treated with arthrodesis. In this situation osteochondral MFC graft could be an alternative option as is for proximal pole AVN of scaphoid. Failed surgery and old scaphoid waist non-unions are best managed by osteocancellous MFC graft.[20-23]

Anatomy

The vascular anatomy of this region is studied firstly by Rogers and Gladstone but en detail in recent years by many authors.[1,24-26] The supracondylar and condylar regions of the medial femur are supplied by two branches emerging from superficial femoral artery and one from popliteal artery. The most proximal one is emerging in the adductor canal and goes distally to the dorsolateral part of the distal femur. It anastomoses to upper transvers branch of the descending genicular artery (DGA) just proximal to chondral zone. DGA is the most distal branch of the femoral artery, which arises just proximal to the adductor opening within the adductor canal. It descends within the vastus medialis muscle to the medial aspect of the knee. Here, it anastomoses with the superomedial genicular artery (SMGA) emerging from popliteal artery.

The DGA is originating from the SFA 13.7 cm. in average from the joint.[24-26] In the specimens, the presence of the DGA was found as 89% by Yamamoto and 87.5% by Van Der Woude.[25,26] After leaving the adductor canal it gives off the saphenous artery which is the main posteriorly directed cutaneous branch, and continues distally, very closely to the adductor magnus tendon on its anterior side. Along its course, the DGA gives off one or two anteriorly directed muscular branches to vastus medialis. Then it anastomoses with SMGA just before giving off two terminal corticoperiosteal branches: Upper transvers artery and central longitudinal artery.[26] Upper transvers branch goes to the dorsal femur to nourish central condyle and proximal chondral zone (Figure 1). Longitudinal artery continues distally and turn upward near the chondral area and returns proximally to anastomosis with the transvers artery and the first osteal branch of SFA.

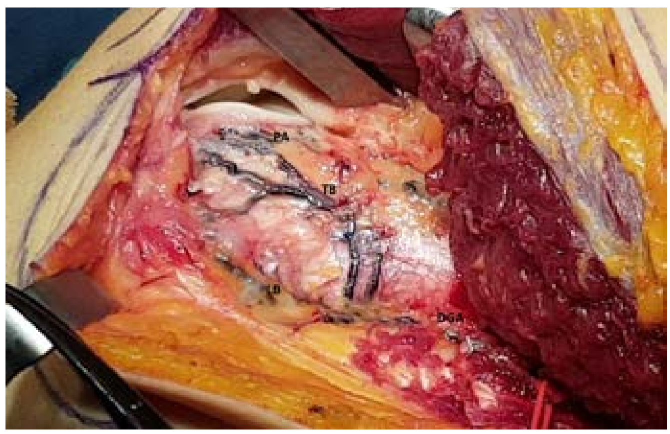

Fig. 1. *The branches of DGA feeding medial femoral condyle. DGA: Descending genicular artery. LB: Longitudinal branch. TB: Transvers branch. PA: Periosteal arteries to proximal chondral zone.*

SMGA originates from popliteal artery 5.2 cm. from the joint line. Internal diameter is smaller than DGA (0.78 mm. versus 1.5 mm.). The presence of the artery is 100%. The DGA is the main source of flaps from medial femoral condyle. If it is not available the SMGA is the artery of choice (Figure 2).

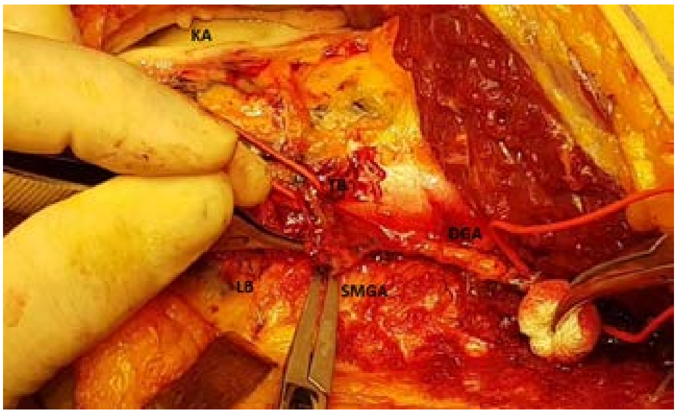

Fig. 2. *SMGA originates approximately 5 cm. from the knee articulation. KA: Knee articulation. DGA: Descending genicular artery. LB: Longitudinal branch of DGA. TB: Transvers branch of DGA*

Surgical Technique

Scaphoid Preparation

Proximal pole avascular necrosis and fragmentation usually necessitate an osteochondral graft. We think that it is unnecessary to take a chimera flap for monitoring the vascularization. Under general anesthesia the patient is placed in a supine position such that the ipsilateral leg is flexed at the knee and the hip is externally rotated. Ipsilateral knee is chosen to facilitate using a cane for assistance postoperatively.

A dorsal incision starting from the Lister's tubercle to the first web space is used. After the opening of the second dorsal compartment, wrist capsule is L-shaped opened starting transversally from radial styloid and then turned distally for to see whole scaphoid bone. A proximal block of 0.8 mm. x 20 mm. is marked which including the non-union site (Figure 3).

Fig. 3. *Scaphoid preparation. SLL: Scapholunate ligament*

One must leave 1 mm. of bone from the scapholunate (SL) ligament to facilitate bone incorporation. With the aid of a K wire the bone is weaken and the proximal part of the scaphoid is removed with a chisel (Figure 4-5). Remaining distal radial part of the scaphoid is maintained as a bed for the transferred chondral graft which will be fixed with a cannulated headless screw under fluoroscopy.

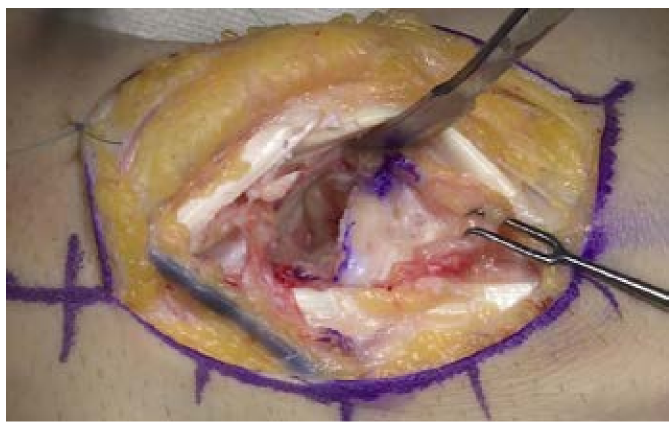

Fig. 4. *Removing of proximal part of scaphoid bone for graft placement.*

Fig. 5. *Image intensification view of Scaphoid bone before graft implantation. 1 mm. of bone must be leaved near SL ligament.*

If an osteocancellous graft is used for a hump back deformity, a longitudinal volar incision over the flexor carpi radialis (FCR) is used. After the ulnar retraction of the FCR tendon, the radioscaphocapitate and radiolunate ligaments are sharply cut and volar side of the scaphoid is reached. The non-union site is cleaned with a curette and the fibrotic tissues are removed (Figure 6). For the reduction of humpback deformity radiolunate articulation is fixed with a Kirshner wire at maximum wrist flexion and then wrist extension assures the proper length of the scaphoid. The edges of non-union site are prepared with a sagittal saw. Usually a graft 10 mm. x 10 mm. in size is sufficient.

Fig. 6. *Volar approach for scaphoid non-union with humpback deformity*

Kienböck's Disease

There are a lot of options to treat Kienböck's disease. In early stages of the disease, joint levelling procedures, capitate shortening and pedicled vascularized grafts have generally good results. But if there is chondral disintegration including coronal fracture, a radiolunate arthrosis is expected. In stage IIIA, IIIB and IIIC of Lichtman with collapse and without arthrosis of radial lunate fossa the MFC graft should be indicated.

We prefer dorsal approach to reach lunate bone. In the depth of 4th dorsal compartment the radiocarpal capsule is elevated to expose proximal pole. Initially the chondral part of lunate is examined. If there is visible degeneration or fragmentation MFC graft is indicated; if not other treatment options should be considered. The proximal ¾ part of the lunate is removed paying attention to not injure the SL and lunotriquetral (LT) ligaments. A fine piece of bone should be leaved near both ligaments to facilitate the incorporation. Then the osteochondral graft is placed into the created space. Fixation could be done using directly headless screws or with Kirschner wires from the adjacent bones (scapholunate and lunotriquetral).

Graft Harvest

Under tourniquet control an anteriorly oblique 20 cm. medial incision is made starting from the knee (Figure 7). Under the superficial fascia, vastus medialis muscle is exposed. Carefully elevation of the muscle is necessary especially on the distal part for to not injure the vessels. DGA is generally found close to adductor magnus tendon. If the caliber is sufficient for anastomosis the DGA is the artery of choice. If it is small or absent one can use the SMGA.

Fig. 7. *Medial femoral incision is approximately 20 cm.*

The central and longitudinal branches of DGA are clearly visible with careful ablation of the fine fatty tissue on the femoral condyle. The periosteal nutrient vessels are concentrated in the distal dorsal quadrant of the MFC. If a corticocancellous graft is desired, the block of bone is outlined with periosteal stripping in this zone. The graft is centered over 2 or 3 major bony perforators. A periosteal incision is made on both side of the transvers artery and continued proximally. The longitudinal branch is ligated and the DGA is liberated from adductor tendon. For graft removal, firstly, the outlined graft area is drilled with a Kirschner wire to weaken the bone, the vascular pedicle is gently lifted and then with a small osteotome the graft is elevated. The deflation of the tourniquet before dividing the pedicle allows to examine the bleeding over the surface the graft and also permits local circulation until the implantation (Figure 8).

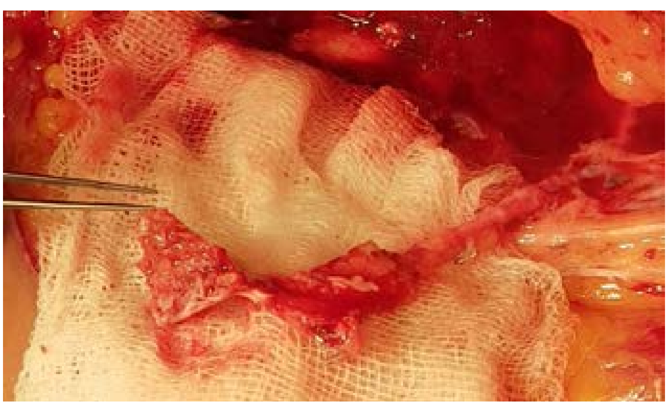

Fig. 8. *Corticocancellous graft bleeding after tourniquet release*

The time for the elevation of the osteochondral graft is little longer. Once the artery is isolated (usually chondral branches of transvers artery), the knee articulation is opened with great care to not injure the medial collateral ligament. The required size of the graft is drawn on the most proximal chondral surface of the condyle (Figure 9). Generally, two or three perforators are nourishing this area. The transvers artery and the DGA (or SMGA if the other is absent or very small caliber) is dissected in retrograde fashion. Distally we prefer to strip a large periosteum starting from the volar part of the condyle including dorsal retrograde branch of the longitudinal artery to protect the chondral vessels. Then the distal and volar part of the osteochondral graft is cut with a micro sagittal saw. It is not easy to use the saw for the lateral part because of the patella so the final cut is done with an osteotome. Finally, the tourniquet is opened to confirm the vascularity of the graft.

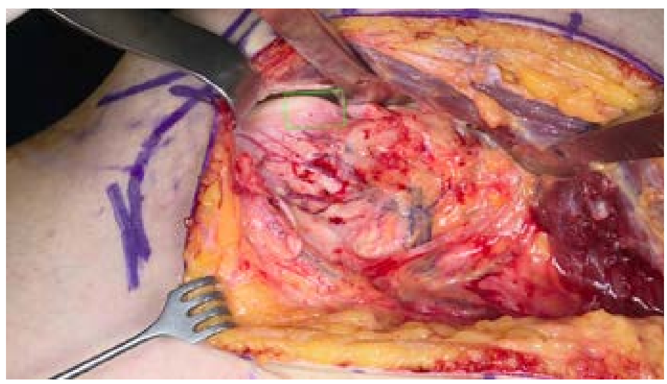

Fig. 9. *Donor site of the osteochondral graft. Two or three periosteal artery to the chondral area are visible*

The graft harvest takes more or less 60 to 90 minutes. The total operating time is generally under three hours including carpal bone preparation, graft harvest and vascular anastomosis.

Vascular Anastomosis

The dorsal branch of the radial artery is used for vascular anastomosis in osteochondral transfer. This artery is easily found in the beginning of the first web space (anatomical snuff box). The arterial anastomosis is done end-to-side and vein anastomosis is realized end-to-end to one of the collateral veins. In the volar approach directly radial artery and veins could be used.

Complications

Most common complications are about the donor site. Paresthesia and numbness in the saphenous nerve distribution is the most frequent one. The saphenous nerve assures the sensation of the medial distal thigh and knee. The knowledge of the anatomy of the saphenous nerve is very important to reduce nerve injury (Figure 10).

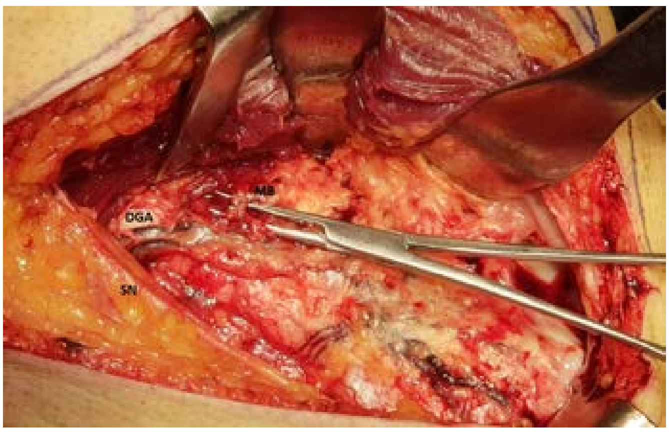

Fig. 10. *Detailed anatomical knowledge is very important to prevent complications. DGA: Descending genicular artery. SN: Saphenous nerve. MB: Muscular branch to vastus medialis.*

Less commonly seroma formation, infection, limitation of knee range of motion, knee pain or discomfort, femoral osteonecrosis and supracondylar fracture could be seen.[27,28] The size of the graft is important for the complications about the knee such as femoral fracture.[11] Usually the grafts sized under 2 cm. used for small bones are very safe.

The limitation of knee range of motion could be seen after osteochondral graft elevation. One must pay attention to not injure the medial collateral ligament. Usually the range of motion increase and pain diminishes in two or three months.

Another important trick is the thickness of the osteochondral graft (Figure 11). The periosteal vessels to the chondral area enter from the cancellous bone. If the graft does not contain sufficient cancellous bone the vascularity become suspicious. In this case the union may not be achieved.

Fig. 11. *Sufficient cancellous bone is sine qua non for good graft vascularity.*

Conclusion

Medial femoral condyle is a popular site of many types of flap because of the rich vascular structure of the region and the ease of harvest from this readily accessible donor site. The vascularized free or pedicled bone grafts as much as the chimeric flaps are used in the extremities and in maxillofacial region. For small bones, especially for scaphoid bone the pedicled grafts are sufficient in most of the cases but one must think also the MCF graft is a good option in appropriate indications with relatively short operating time. We think that the MCF graft is particularly indicated in chondral lesions of carpal bones.

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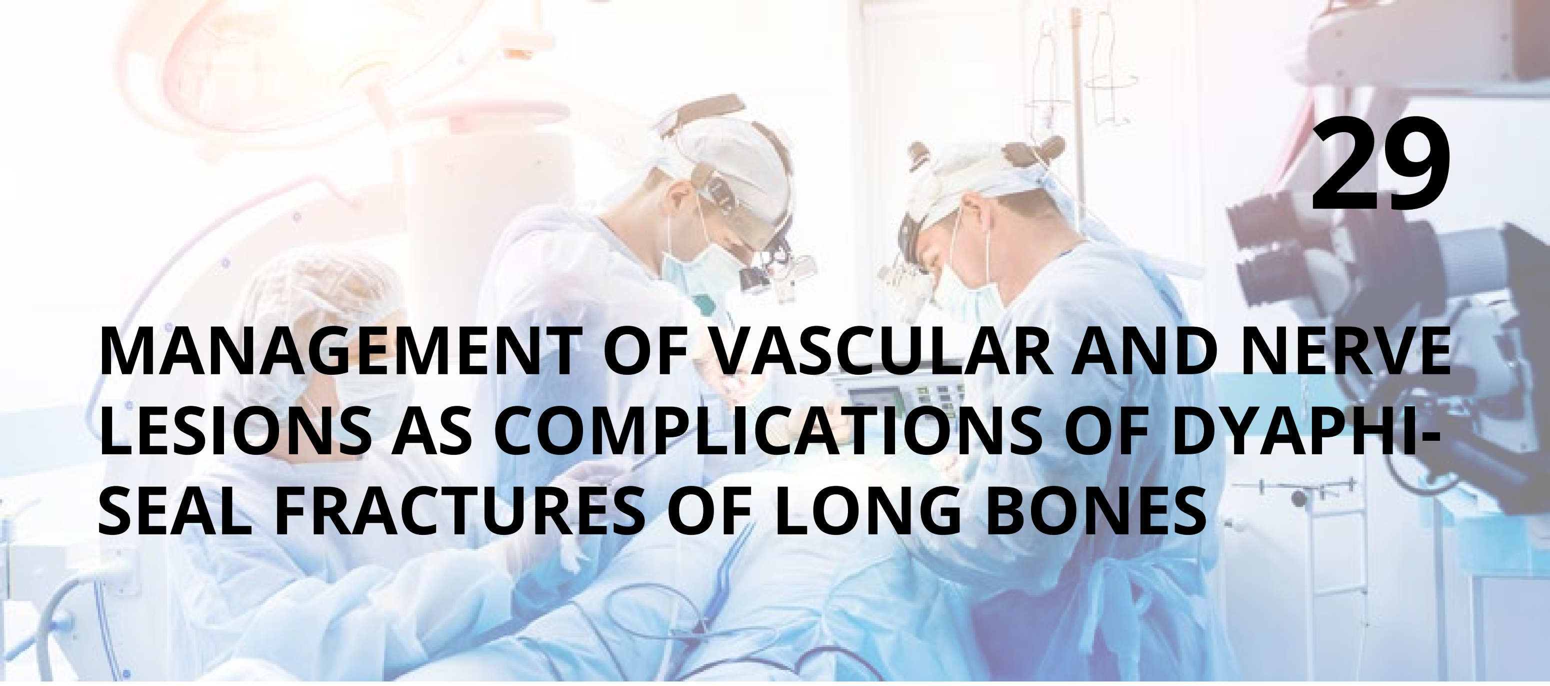
VII
Nerves



29

MANAGEMENT OF VASCULAR AND NERVE LESIONS AS COMPLICATIONS OF DYAPHISEAL FRACTURES OF LONG BONES

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Complex limb injuries with fractures and associated vascular or nerve injuries or even subamputations or amputations are on the rise due to high-energy traumas from road accidents or occupational injuries. The evolution of sophisticated microsurgical techniques has offered the possibility of limb salvage even in the most extreme cases, although post-operative complications are possible (general complications such as heart or kidney failure, local complications such as necrosis, compartmental syndromes, infections) that may require multiple surgeries. The final result is no longer accepted only in terms of survival of the injured segment but in a relevant way in terms of functional recovery: this obviously depends on the segment involved, the extent of the lesion, the number of tissues involved. However, it is above all the presence of associated vascular and/or nerve lesions that requires clear reconstructive concepts. Certainly, some basic principles must be respected in order to avoid complications and to obtain satisfactory functional results. Otherwise, an unnecessary limb salvage procedure can destroy a person physically, psychologically, socially and financially.

The problem is particularly difficult when dealing with complex lesions such as diaphyseal fractures associated with vascular lesions with a clinical picture of acute ischemia and necessarily urgent treatment. After stabilizing the patient according to the rules of ATLS (Advanced Trauma Life Support) with hemorrhage control and reintegration of hemodynamic parameters, the management of the complex peripheral lesion can be dealt with. The first evaluation should determine which are the problems of distal vascularization, sometimes not so easy to determine especially in closed lesions. A vascular trauma of the limbs requires an extremely fast and effective diagnostic procedure. Some authors suggest the systematic use of an angiographic examination, but often an ultrasonographic examination allows to have already sufficiently precise data, especially in polytraumatized patients who cannot waste time in prolonged investigations. It is important to distinguish how much of the clinical picture is due to vascular lesions and how much to possible other lesions. In an Italian case study of 61 patients with vascular lesions in limb traumas there was a nerve lesion associated with vascular damage in 8% of cases (1). Our experience (2) supports this concept: in axillary and humeral artery lesions associated with brachial plexus damage, the picture of ischemia can often mask the neurological deficit, leading to the intraoperative discovery by the vascular surgeon of the nerve lesion, which is sometimes considered secondary and evaluated and/or treated inadequately. In our opinion, these patients should be referred to high level Centres (Hubs) and therefore have in addition to vascular surgery a availability of hand surgery and microsurgery to be able to deal with these lesions jointly (vascular and microsurgery).

The clear assessment of both vascular and nerve lesions is certainly easier in widely open lesions (subamputations or amputations of the limb). In limb or segment amputations, the problem, rather than diagnostic, is the indication to reconstruction and it is therefore necessary to assess whether the segment can be technically reconstructed and what functional result can be obtained at a distance (3). When dealing with the problem of reimplantation of an amputated limb, it is necessary to distinguish between lesions of large segments and those of small segments. This is because it changes the extent of the lesions that can be caused by the ischemia (presence or absence of muscular masses) and consequently also of the times in which the reconstruction must be carried out (possible indication or contraindication to carry out the reimplantation), and because the technical problems of the intervention and the prognosis “quoad functionem” change. In the reimplantation of large segments, surgery is simpler (larger vascular and nerve structures); on the other hand, however, there are greater risks associated with the consequences of ischaemia on large muscle masses with the production of toxic catabolites. It should be remembered that numerous studies have shown that the tissue most sensitive to ischaemia is the muscle tissue, followed by vessels, tendons, nerves and bone. Under ambient temperature conditions (warm ischaemia) the muscle suffers irreversible damage after only 4 - 6 hours of ischaemia (compared to 24 hours of other structures). According to various experimental studies, the tolerance time to ischemia can be doubled by cooling the tissues (cold ischemia). Functional results in the large segments are often less good than in the small segments because they are mainly affected by very proximal nerve lesions, with consequent more problematic motor and sensory recoveries. In small segment replants, the surgical gesture is more difficult due to the small size of the neurovascular structures to be reconstructed. On the other hand, the risks associated with ischemia are almost zero, so much so that there is an increasing number of cases of digital re-implants more than 24 hours after the lesion. As far as the results are concerned, they are generally good except for transarticular amputations or in particular anatomical regions (e.g. the “no man’s land” - zone 2 of the hand). With regard to the indications for reconstruction, local and general problems can be considered. Local indications: sharp amputations or with only crushing of the lesion margins. The time of cold ischemia should be less than 6 hours for large segments and 12-24 hours for small segments. In order to obtain a good functional result, single digital re-implants are indicated when distal to the PIP (but the lesion must be neat); exceptions are women, musicians and children where the re-implantation can also be carried out in zone 2 for aesthetic reasons or for reasons of absolute importance of recovery of all rays. If the lesion is in zone 2 and is not neat but affects more than one digital segment, an attempt must also be made to reconstruct it, however, according to the patient’s requests. The reimplantation of the thumb should almost always be attempted, even in the case of avulsion or crushing lesions. General indications: healthy patients under 60 years of age. Local contraindications are: lesions with diffuse crushing, avulsion, double level lesions, poor state of conservation of the amputee segment. In our opinion, the level of injury is not in itself a contraindication to replanting, as some authors claim (Meyer classified arm and elbow injuries as a contraindication for replantation), but is only a prognostic index of the final functional result. In fact, we can expect good results in amputations at the forearm, wrist, transcarpal and digital distal levels. Functional failure in very proximal amputations may depend on ischemic retraction of large muscle masses or on difficulty in reinnervation. In any case, even a poor functional result is still superior to current upper limb prostheses. If the ischemia is longer than 4-6 hours (6-8 hours in case of refrigeration), large segment replanting is contraindicated. General relative contraindications are also: age over 60 years, smoking patients, systemic diseases (diabetes, etc..), presence of associated major injuries (head trauma, visceral, etc..). More precise details may be found in literature (3) or in the Consensus publishe on ghe site of the European Federation of Societies for Surgery of the Hand (FESSH – www.fessh.com)

The timing of the reconstruction of the different structures both in the case of closed vascular lesion and in subamputation or amputation provides priority for bone stabilization even if temporary, compared to the circulatory restoration that is then carried out in conditions of stability. This is followed by the repair of any nerve lesions and other structures. A stable internal synthesis with plates and screws is often the best solution, especially in diaphyseal segments. External fixation, recommended in the event of major contamination or loss of substance, can sometimes interfere with the reconstruction of the soft tissues. Surely, for lesions to be repaired urgently, synthesis with endomidollar nails has no place. In the case of nerve lesions associated with the vascular problem, the possibility of immediate or delayed reconstruction should be considered. A net lesion of a peripheral nerve gives the best results if reconstructed immediately. However, in the case of a lesion with contamination, difficulty in covering the skin or risk of subsequent necrosis, it is better to delay the nerve reconstruction at a later date.

Problems are different in case of isolated nerve injury in association with a closed diaphyseal fracture. Representative for this problem is the lesion of the radial nerve in diaphyseal fractures of humerus. In humeral diaphysis fractures, which represent 1-3% of all fractures, Noble et al. (4) in 444 patients reported the incidence of a lesion of nerve structures of 9.5% for the radial nerve, 3% for the median nerve and 1.5% for the ulnar nerve. Radial nerve paralysis therefore appears to be the most frequent nerve injury in fractures of the humeral diaphysis with a frequency varying in the literature from 4 to 16%. The radial nerve, being in close contact with the posterior face of the humerus, may be damaged by the fracture itself, by bloodless reduction maneuvers, or during surgical reduction procedures. The incidence of iatrogenic lesions varies between 10% and 20% depending on the author. Iatrogenic lesions of the radial nerve in these fractures may be due to excessive nerve stretching or stretching during reduction maneuvers, excessive dissection with nerve devascularization, compression by reduction forceps, plates or accidental injury with the scalpel. In external fixation there is the possibility of generating nerve and/or vascular lesions and attention must therefore be paid to the positioning of the screws in the “safety zones”. Endomidollary nails are associated with the risk of iatrogenic lesions in the axillary nerve, due to the point of entry of the anterograde nail through the deltoid fibres, but especially in the radial nerve, during fracture reduction manoeuvres or in the positioning of the distal block screw. If the radial nerve is trapped between the fracture ends, the introduction of the nail could severely damage it. At the base of the spiroid fractures of the middle-distal third of the humerus there is almost always a high-energy mechanism during which, if the distal fragment rotates externally, the nerve can slide over it and interpose itself between the two stumps of the fracture. When the bloodless reduction manoeuvres are subsequently carried out with intrarotation of the distal fragment, in the introduction of the nail the nerve would inevitably be trapped. Therefore, in the displaced spiroid fractures of the distal third with extrarotation of the distal fragment, the trapping of the radial nerve should be always suspected and verified prior to the reduction maneuvers and prior to the introduction of any endomedullary nail. When an osteosynthesis is required for the good management of the diaphyseal fracture, open reduction and stabilization with plates and screws is the gold standard for many of the fractures with combined nerve lesion for the possibility of exploring the nerve. However, different authors treat this type of lesion differently, as there is a debate between simple clinical observation, with at least initial orthopaedic non-surgical treatment, and early surgical exploration. In the meta-analysis of 1045 cases of radial nerve lesions performed by Shao (5), primary radial lesions show a recovery in 88.6%, while iatrogenic lesions show a recovery in 93.1%. Clear indications for early exploration are associated vascular lesions and the suspicion of neurological lesions with interruption of continuity in high energy injuries or in high risk fractures as the spiroid ones of the distal third of the humerus (Holstein fractures), especially with the support of good imaging (ultrasound). In our opinion, early exploration has many advantages: it is easier and safer than a remote intervention, it allows to shorten the humerus making easier a direct nerve suture in case of complete nerve injury, better than it can be done when the fracture is already consolidated; moreover, early exploration with a fresh fracture reduces the possibility that the nerve is incorporated in the formation of the bone callus because it can be isolated and protected. Moreover, a delayed exploration of the nerve could result in the retraction of the nerve stumps in the event of a complete lesion, with the need for much longer nerve grafts and therefore less brilliant recovery. However, if a conservative approach is decised, as suggested by many authors, patients are to be monitored and generally a surgical indication is given if no sign of recovery appears in3-4 months. Compared to primary lesions of the radial nerve, lesions consequent to a medical procedure (hyatrogenic) deserve a different approach, especially in cases of open surgery where the nerve has not been well visualized or in closed reduction with external fixation with screws placed in dangerous locations. We believe that early exploration of the radial nerve can avoid underestimating an important nerve lesion, thus also reducing the medical-legal consequences. However, it must be said that a delayed exploration in case of persistent palsy could avoid surgery in patients who could obtain a spontaneous recovery. In the case of a wait-and-see decision, the optimal time for surgical exploration could be 3-4 months from the lesion, as suggested by many authors (4,5). Assuming that a nerve regenerates at a rate of about 1 mm per day, measuring on the X-ray the distance between the site of fracture and the innervation point of the nearest distal muscle, the waiting time for a spontaneous recovery of the nerve lesion can be estimated approximately. This concept is generally valid for any peripheral nerve injury. The presence of an advancing Tinel sign may help in assessing recovery. EMG is an important tool to objectify the lesion of a peripheral nerve, but it must be performed no earlier than 3-4 weeks after the onset of the deficit. Less used are instruments that directly evaluate the continuity of the peripheral nerve or its entrapment, such as ultrasound and MRI. MRI provides a good indication of the extent of nerve damage, avoiding excessive surgical exposure. More and more, however, the ultrasound scan, performed by expert hands, allows to visualize a continuity or not of the nerve, thus helping the surgeon in deciding the treatment.

Similar concepts can also be applied to isolated nerve lesions in association with diaphyseal fractures of the lower limb, the most frequent of which is the lesion of the Peroneal nerve. The latter is most frequently injured actually in severe sprains or dislocations at the knee joint. When the lesion of the peroneal nerve is associated with a diaphyseal fracture of the proximal fibula or proximal fracture of the leg, the cause is as for the radial nerve linked to an anatomical factor: it runs around the neck of the fibula with a point of fixity in the entry of the peroneal muscles. As with the radial nerve, open lesions should be explored immediately; this may also be done in the case of high-energy traumas with significant dislocation, which require surgery to stabilize the fracture or even in association with vascular lesions at the level of the knee. Iatrogenic lesions due to compression from pinstripes, prolonged incorrect postures, osteosynthesis with external circular fixators, etc., are not uncommon for SPE either. Many of these lesions recover spontaneously because they are lesions with continuity of the nervous trunk (neuroapraxia or axonotmesis). Also in this case a good clinical examination repeated over time associated with instrumental diagnostics (EMG, ultrasound) helps us in the decision-making process. However, we should not wait more than 6 months after the onset of the lesion in case of non-recovery to decide on an exploratory and possibly reconstructive intervention.

In conclusion, vascular but above all nervous complications in the treatment of traumas at the diaphyseal level of the long bones are not frequent but must be known and, in addition to the attention in preventing them, when they appear they must be diagnosed and treated correctly because they assume a fundamental importance for the final functional result. We are perfectly in agreement with several authors that polarizing the attention only on the skeletal lesion is a limiting choice if you have to compare with global parameters of final function and not only with radiographic pictures of reduction and perfect synthesis.

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30

Targeted Muscle Reinnervation Utilizing the Distal Anterior Interosseus Nerve

David T. Netscher, MD; Nikhil A. Agrawal, MD

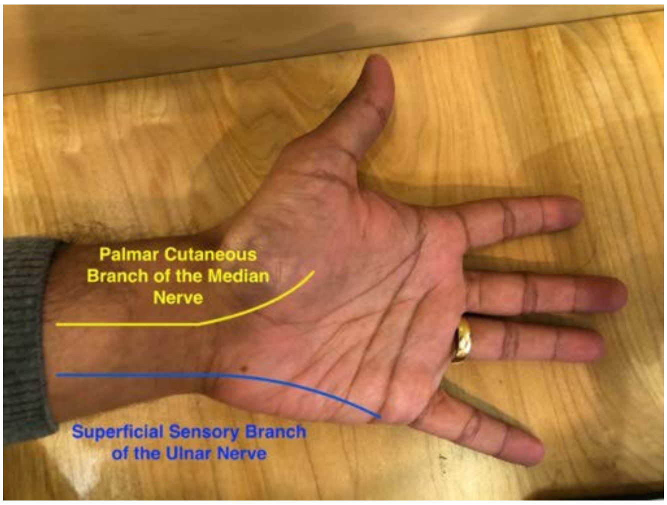
The treatment of neuromas has developed significantly over the past few years. We have gone from traction neurectomy to nerve caps and now with targeted muscle reinnervation and regenerative peripheral nerve interfaces. As we have developed better treatments for late presenting neuromas, we are also becoming more aware and diagnosing more. Trauma and surgery are two common etiologies for this condition. Sensory nerve lacerations of the wrist are commonly missed especially when no major structures are injured. The diagnosis is difficult for emergency room providers and the injury can lead to debilitating neuromas. Similarly, persistent pain after surgery around the wrist can be from missed sensory nerve injuries.

All the superficial nerves around the wrist including the dorsal ulnar sensory nerve, the distal lateral antebrachial cutaneous nerve, the distal branches of the superficial branch of the radial nerve, and the palmar cutaneous branch of the median nerve are sources of peripheral nerve neuromas. (Figure 1) The traditional described methods of dealing with symptomatic neuromas are often unsuccessful (Nerve caps, nerve wraps, living nerve barriers such as fat flaps, transposition proximally under muscle or bone). The most reliable way to treat neuroma pain is to restore nerve continuity, however this is not always possible. At the wrist the distal nerve branches can be small and difficult to find. Here we present a patient with a peripheral nerve neuroma of the palmar cutaneous branch of the median nerve that was treated with targeted muscle reinnervation.

A middle-aged male who presented with pain on the volar wrist that persisted for 2 years after carpal tunnel release. The numbness and tingling in his digits had resolved after surgery however he had focal pain in the distal forearm proximal to the incision. There was a positive Tinel sign and the pain temporarily resolved with diagnostic lidocaine injection in clinic.

At the time of surgery, the previous incision was opened and extended proximally. The distal cut end of the palmar cutaneous nerve was identified at the exact location of the painful Tinel sign. Attention was then paid to harvesting the anterior interosseous nerve (AIN). Dissection proceeded radial to flexor carpi radialis and the radial artery. The AIN was identified 10cm proximal to the wrist crease sitting on the interosseous membrane. It was dissected proximally until adequate length was easily mobile. The AIN was cut proximally and the injured nerve just proximal to the neuroma until there was axonal sprouting from the epineurium as this is the sign of healthy nerve fascicles. Coaptation was completed on top of the interosseous membrane and with four 8-0 nylon sutures. (Figure 2) The flexor pollicis longus (FPL) was then placed gently over the nerve repair as protection. The patient continues to do well six months post-operatively with complete resolution of symptoms and no recurrence.

We do not always think of the distal AIN. It can be taken with a long proximal tail with the only muscle sacrifice is to the pronator quadratus. All of the distal sensory nerves around the wrist can be reached by the distal AIN. This nerve transfer is an excellent option for targeted muscle reinnervation for neuromas of the wrist.



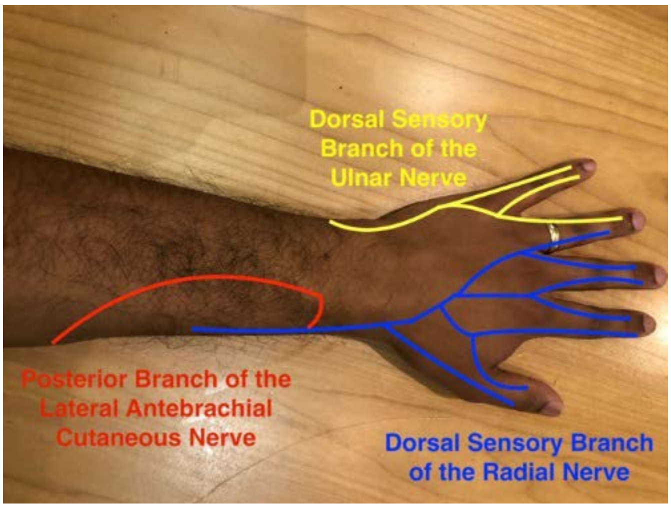
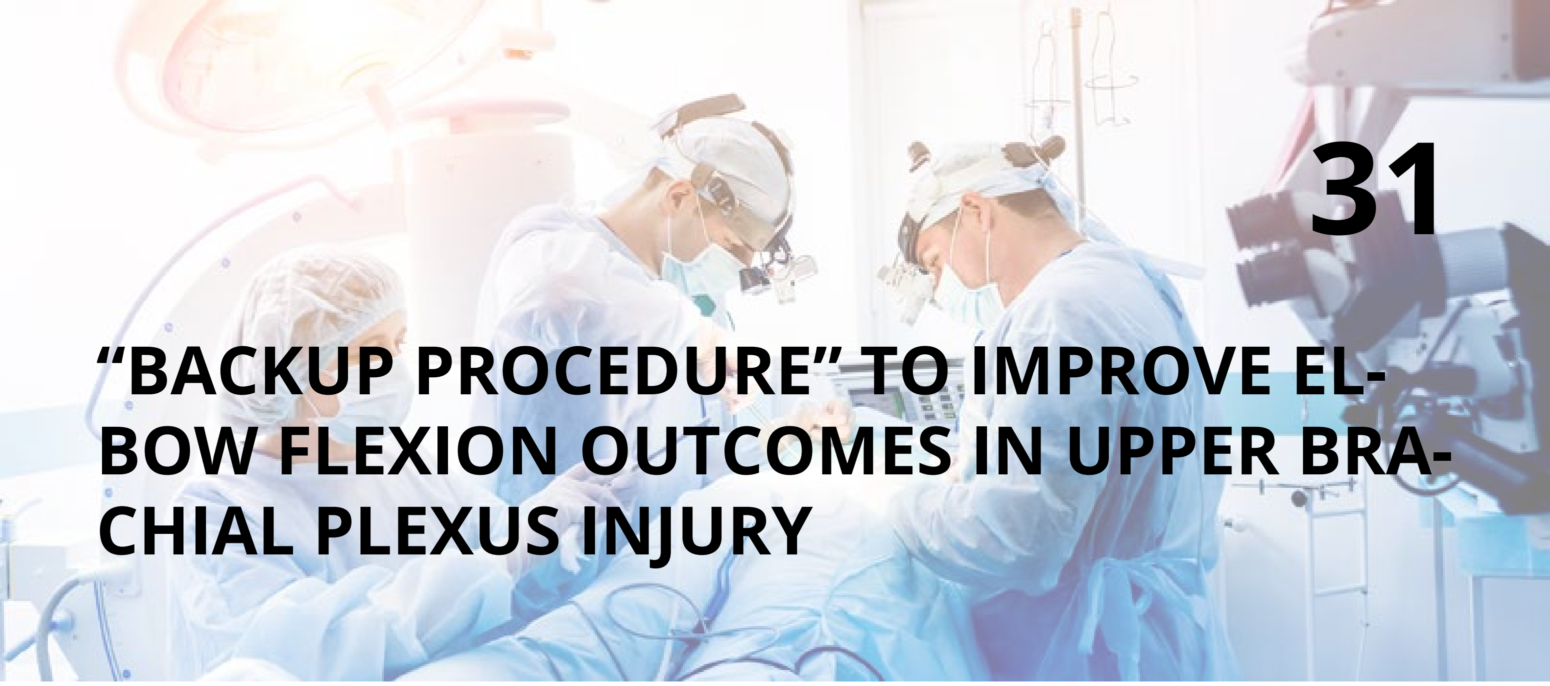


Figure 1 A and B: *The volar and dorsal sensory nerves that can be injured with surgery or trauma around the wrist*

Figure 2*: Coaptation of the distal cut end of the Palmar Cutaneous Branch of the Median Nerve to the Anterior Interosseous Nerve*



31

“BACKUP PROCEDURE” TO IMPROVE ELBOW FLEXION OUTCOMES IN UPPER BRACHIAL PLEXUS INJURY

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Introduction

Brachial plexus injuries are often caused by high energy traumas that lead to avulsion or rupture of nerves[1,2]. New Researches and analysis of the outcomes have contributed to develope new surgical techniques to solve upper limb deficit due to brachial plexus injury.

Most of the trauma of brachial plexus concern young males and all nerve roots. Upper Brachial Plexus injuries with lesion of C5 and C6 roots are about 25% of all brachial plexus injuries treated by Authors between 2000 and 2018 with a total of 389 cases, with 98 cases of upper plexus injury.

Before the wide use of nerve transfers era, brachial plexus surgery was based on the restoration of anatomical integrity through nerve grafts. Sometimes however, although from an anatomical point of view restoration with nerve grafts is more correct, it did not allow acceptable functional recovery given the inevitable degeneration of the neuromuscular plaque after 18 months of denervation.

This chapter aims to frame the treatment of upper brachial plexus paralysis with a focus on elbow flexion recovery. Specifically, the Authors will present an integration to Oberlin's technique, the 'backup procedure', in order to optimize functional outcomes.

Surgical options for elbow flexion recovery in upper brachial plexus injury (c5-c6)

Injuries involving C5-C6 roots (upper plexus) are characterized by elbow flexion, shoulder stability, abduction and external rotation palsy. If the gap between the nerve stumps is short, the continuity can be restored by direct nerve repair, but this one is very infrequent to perform. Most often restoration can be achieved with nerve grafting or nerve transfers. Indications for nerve transfer are:

- Irreparable preganglionic injuries
- Selected postganglionic injuries
- Reinnervation of Free Functional Muscle Transfer[3]

In the specific case of loss of elbow flexion the most used nerve transfer are:

- Ulnar fascicular nerve transfer to the biceps motor branch (Oberlin's procedure type 1)
- Median nerve fascicular transfer to brachialis anterior motor branch (Oberlin 2). This technique , in Authors experience is burdened with complications like wrist flection co-contraction or weakness of 1st and 2nd finger flexors.
- Spinal accessory nerve transfer to muscolocutaneous nerve. It is occasionally performed when the previous procedure is not available.
- Intercostal 3rd, 4th and 5th nerves transfer.

Contralateral C7 nerve transfer is another described option, but it is not the first choice in upper brachial plexus lesion.

The Oberlin's method is reliable for restoring elbow flexion in patients with C5-C6 injury and with associated C7 injury. It is available only in patients with preserved C8-T1 function. It is based on the selection by electrical stimulation of nerve bundles of the ulnar nerve for the Flexor Ulnaris Carpi (Oberlin procedure type 1) which are interrupted and coapted directly with the first motor branch of muscolocutaneous nerve (motor branch for Biceps brachii). Timing of the reconstruction is crucial and it is ideally before 6-9 months from injury. Obviously some limits for this technique must be considered, such as ulnar nerve distribution weakness and sensory deficit. Before using this surgical technique is mandatory to examine Flexor Ulnaris Carpi that should be scored more than M4. Observable complications are: transient numbness in the ulnar territory, sometimes transient muscle weakness of hand intrinsic muscle. In long time follow-up, there is no apparent consequence related to removing fascicles of the ulnar nerve, in terms of lost grasp or pinch strength. The importance of Oberlin's method is underlined by technical ease of the surgery, less invasive procedure and earlier recovery[4,5].

Functional outcomes in oberlin nerve transfer associated with "backup procedure"

The aim of this paper is to focus on the recovery of elbow flexion in the upper brachial plexus injury (C5-C6). In the presence of a preganglionic avulsion lesion, Oberlin type 1 neurotization is the most suitable option in Authors experience to restore elbow flexion in these patients. The fascicles for the Flexor Ulnaris Carpi of the ulnar nerve are transferred to the motor branch for the biceps of the musculocutaneous nerve. In root avulsion injuries, the Oberlin procedure used alone has shown better results than tendon transfers or nerve grafting in reparable injuries[7].

Factors determining improved outcomes include:

- proximity of the donor nerve to the motor end plate of the recipient muscle
- shorter reinnervation time
- need for only a single anastomosis as opposed to the two required for nerve grafting

Given the factors outlined above, allied with advances in dissection techniques, electrostimulation to select the best fascicle, magnification of the surgical field of view and improved neurorrhaphy techniques, nerve transfers are becoming the treatment of choice for nerve injuries[8-9].

Despite this, Oberlin procedure on its own, is not always able to reach the goal of elbow flexion with a satisfying biceps strength in upper brachial plexus injuries. Indeed, according to Literature:

- Little K.J et al, showed that 85% (31 patients) of cases had good recovery of elbow flexion after Oberlin type 1 neurotization[10]
- In Sedain et al study, 77.8% of cases (9 patients) had a M3 biceps after Oberlin procedure[11]
- Oberlin et al, showed a successful rate for elbow flexion after Oberlin procedure in 75% of cases (35 patients)[12]

In Author's experience, 46 patients (88%) out of 52, controlled at 3 years after Oberlin type 1 neurotization performed between 2005 and 2013, showed biceps stronger than M3. It is not clear why some Oberlin transfer do not work. After an accurate analysis of this result, Authors decided for a new strategy in the management of upper brachial plexus to optimize functional results of elbow flexion and to reduce the percentage of failure, supplementing the Oberlin procedure with nerve grafts as a '*backup procedure*'.

Surgical technique details

The '*backup procedure*' consists in nerve grafts, harvested from the sural nerve, from an available root in a postganglionic lesion (C5 or C6) to the anterior division of the primary upper trunk (see Fig. 1 and 2).

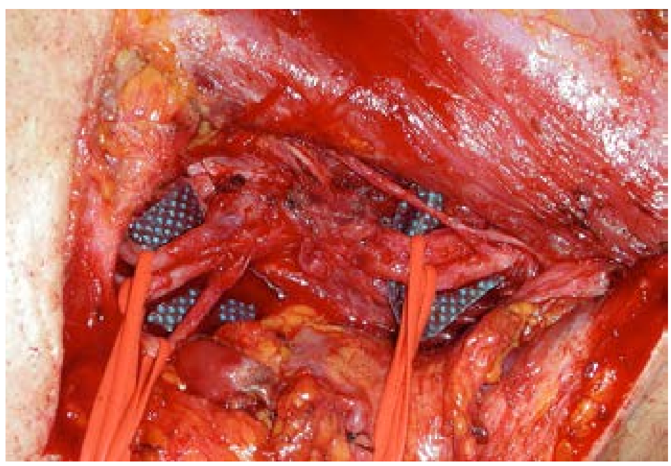

FIG.1- *Intraoperative findings of a C5 C6 C7 brachial plexus injury with C7 avulsion*

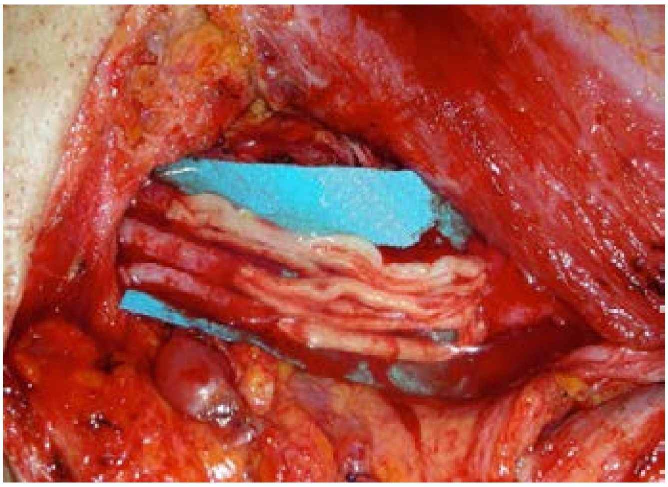

***FIG.2**- 'Backup procedure' – Reconstruction of Upper Trunk with Nerve grafts from C5 C6 roots.*

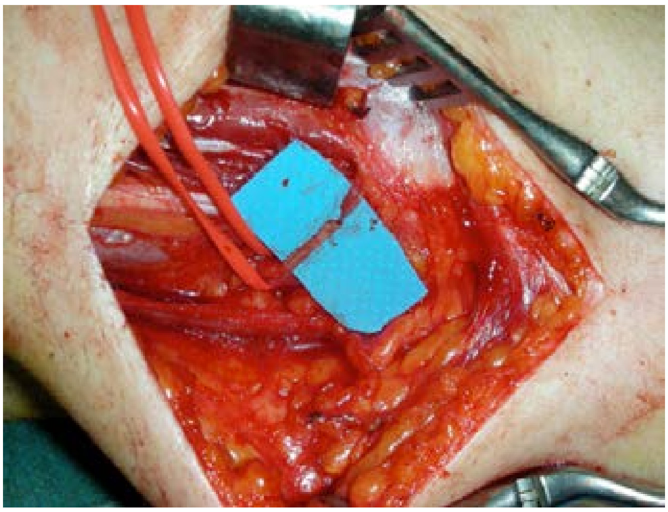

***FIG.3-** Oberlin type 1 neurotization with fascicles of the ulnar nerve to the motor branch of musclocutaneous nerve*

Of course it is associated to Oberlin 1 nerve transfer (Fig.3). The nerve grafts act as a second path for the reinnervation process in that cases where Oberlin procedure fails. Even if, for elbow flexion recovery, nerve transfer is somewhat more effective than nerve repair[13], the '*backup procedure*' allows to enhance functional result with the reinnervation of the brachialis and brachioradialis, that contribute to elbow flexion, and even of the clavicular portion of the pectoralis muscles which increase the shoulder stability. The *'backup procedure*', furthermore, shows to restore sensibility of the thumb and the index.

This approach represents a part of the wider panel of surgical techniques for upper brachial plexus injury. Author's strategy for C5-C6 palsy is:

- triple nerve transfer (Accessory nerve for the Suprascapular nerve; Oberlin procedure; motor branch for the triceps of the Radial nerve to the anterior branch of the Axillary nerve)
- nerve grafts in presence of available root with postganglionic lesion, from the C5 or C6 root to the anterior division of the upper trunk of the brachial plexus in order to restore elbow flexion, which has the highest priority, followed by external rotation and shoulder abduction.

Results

From 2013 to 2017 Authors performed the backup procedure for Oberlin in 13 cases: 9 cases of C5 C6 Injury and 4 cases of C5 C6 C7 Injury. All the patients showed a recovery of elbow flexion at 2 years control. In particular, two patients showed a late recovery and the electroneurographic study showed a voluntary contraction of brachialis muscle at 20 and 22 months respectively (Fig 4). No specific complications occurred.

FIG.4-- *Elbow flexion recovery at 30 months follow-up (functional recovery started 20 months post-op).*

Thus all Oberlin procedure were performed by the same senior surgeon, coaptating ulnar nerve fascicles to motor branch for biceps, it may be assumed that Oberlin nerve transfer did not work in the two late recovery cases and that elbow flexion was recovered via backup grafts.

Conclusion

Using the backup procedure, Authors almost overcome the failure rate of Oberlin procedure but a longer follow-up is mandatory, rather than in that cases where only nerve transfer is performed. This technique seems to be safe and effective, adding something more to standard Oberlin nerve transfer for elbow flexion reanimation. Preganglionic avulsion of C5, C6 and C7 represent the only contraindication.

While the debate over nerve grafting versus nerve transfer has been ongoing among peripheral nerve surgeons over the last few decades, it is still unclear how one approach produces better outcomes than another. This is due in particular to several limitations of the studies such as lack of uniformity of the indications for surgery or the difficulty to strictly compare the reported groups. Despite this, the concept of a '*double via*' to recover a functional deficit of the upper limb, specifically elbow flexion, considering our data and Literature, seems to be a valid approach because not only prime movers of a joint are considered but even secondary movers and joint stabilizers have a leading role to obtain a successful recovery of the function[14].

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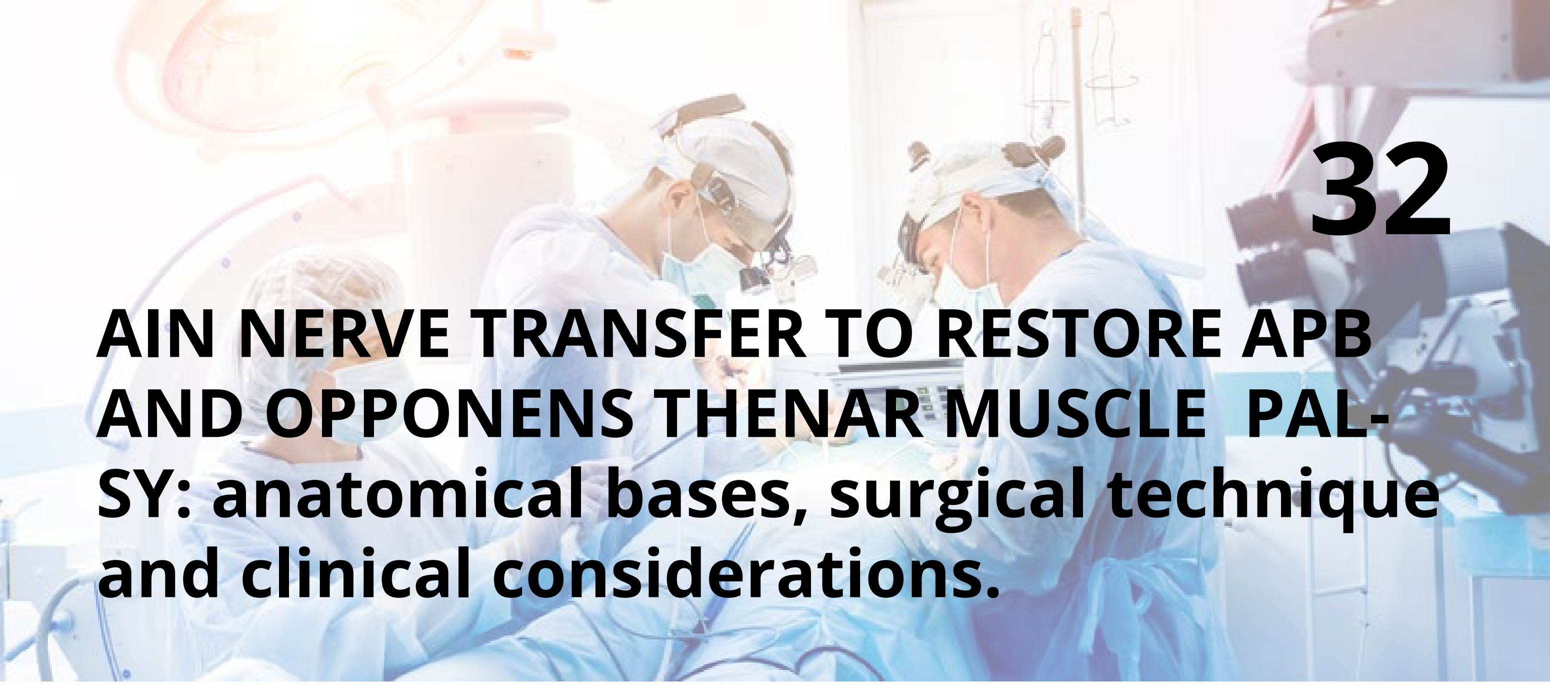


32

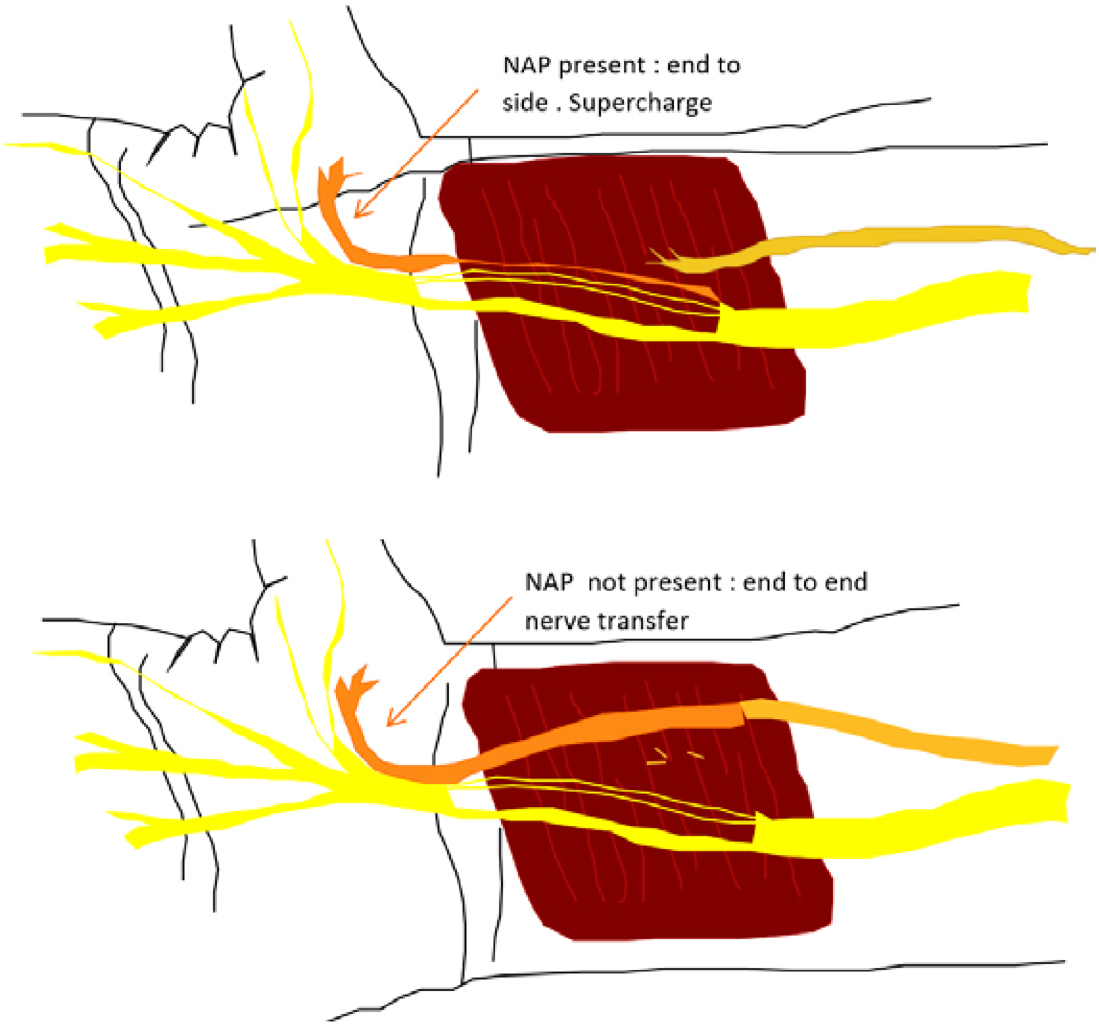
AIN NERVE TRANSFER TO RESTORE APB AND OPPONENS THENAR MUSCLE PALSY: anatomical bases, surgical technique and clinical considerations.

*J Casañas, D Ortega, I Fernandez, R Morro, M Pérez-Montoya, M Llusá**J Casañas, D Ortega, I Fernandez, R Morro, M Pérez-Montoya, M Llusá*

Introduction

Nerve transfer has changed peripheral nerve and brachial plexus expectative to restore functions of damaged nerves. Several transfers have been described accordingly lack of function and each patient must be studied carefully in order to offer the best plan to recover functionality.

Anterior interosseous nerve (AIN) has been described to restore ulnar motor function in patients with ulnar nerve palsy, severe compression or low brachial plexus injuries. We decided to use AIN as a motor nerve to restore thenar branch (Fig.1) with absent APB and Opponens thenar function and not viability of AIN after partial brachial plexus injury or low median nerve palsy. Accurate nerve conductions studies (NCS) are crucial to indicate this nerve transfer.



Material and methods

Accordingly this principle, 3 patients have been treated on the period between 2014 -2015. Age ranges from 28 to 57; 2 females and one male. Preoperative diagnosis supported by precise NCS is crucial to be sure pronator quadratus function is normal (Fig. 2), as well it was uninjured or successful reinnervation was achieved.

ELECTROMIOGRAFÍA:

		Actividad Espontanea y/o Voluntaria						Actividad Voluntaria Máxima		
Muscle		Fibs	+Waves	Fasc's	Poly	Amp	Dur	Amp	Pattern	Effort
Flex. Car. Rad.L		3+	3+		++				PS	
Biceps Brachii.L		1+	1+		++				PR	
Flex. Dig. Sup.L	dificil local*	3+	3+						PS	
Pronator Quad.L	dif localit*	1+	2+						PS	
abd curt polze L		1+	2+						0	

ELECTROMIOGRAFÍA:

		Actividad Espontanea y/o Voluntaria						Actividad Voluntaria Máxima		
Muscle		Fibs	+Waves	Fasc's	Poly	Amp	Dur	Amp	Pattern	Effort
Deltoid.R		0	0		++				PI	
Biceps Brachii.R		2+	2+		++	N			PR	
Flex. Car. Rad.R		0	0		++				PR	
Extn. Dig. Com.R		0	0		+++	Inc			PR	
Triceps.R		0	0		+	Inc			PR	
Infraspinatus.R	no relaja								PI	
1st Dorsal Int.R		2+	2+						PS	
Abduc. Pol. Br.R		3+	3+						0	
Flex. Car. Uln.R		2+	2+		+++				PR	

***Fig. 2** Preoperative Nerve conduction studies. Correct pronator quadratus and ulnar nerve function.*

Surgical technique

Axillary block anesthesia is used and limited tourniquet time is important. No curare drugs are used because the intraoperative nerve recording is an essential part in this technique in our practice.

1. Standard straight incision in the distal forearm extended to the thenar crease, with angulation at the level of the wrist crease to avoid scar retraction.
2. Identification of the median nerve main trunk between palmaris longus and flexor carpi radialis tendons at wrist level.
3. If we suspect a partial lesion of the motor branch we look for a compound motor action potential in thenar muscle (CMAP), inserting two needlesin the thenar muscles (Abductor pollicis brevis and oppon-

ens pollicis) ,to identify any residual activity; if that is the case we proceed to do a reverse end to side from distal AIN to median nerve fascicles to thenar branch ((supercharge transfer). In this way we avoid to do intraneural dissection and add more damage to the nerve.

4. If you have a complete thenar branch lesion or median nerve lesion, we identified the recurrent motor branch within the carpal tunnel and neurolysed it , under miscroscope and microsurgical instruments and technique; we proceed from distal to proximal ,until the median nerve is close to pronator quadratus muscle or until the nerve injury limit more proximal dissection (usually 10-12 cm proximal to the wrist) .In this way the motor branch fascicles are separated from the sensory ones of the median nerve . At that point is possible to identify any residual nerve action potential (NAP) on motor branch of median nerve or compound motor action potential in thenar muscle (CMAP) but with not functional result; in that case we do not perform intraneural dissection but thenar fascicles identification trough intraoperative nerve studies. .
5. We move to the distal forearm and the median nerve, the flexor digitorum superficialis and profundus tendons, and flexor carpi ulnaris are retracted to the ulnar side; the flexor carpi ulnaris tendon and flexor pollicis longus are retracted to the radial side using self-retraining retractors. Now we identify the proximal edge of pronator quadratus muscle and the anterior interosseous neurovascular bundle in the center of the proximal edge; the anterior interosseus nerve is located just in the lateral part of this bundle.
6. The distal branch of the AIN is traced distally and dissected until it begins to branch in order to obtain an additional length of it. For that purpose is necessary to section and split the proximal muscular fibers of the superficial component of pronator quadratus muscle.
7. Release of the tourniquet, hemostasis and wait for 15 minutes for reperfusion and recovery of nerve ischemia before intraoperative nerve recording (INR) studies. Usually we register the amplitude of the AIN to transfer (75- 100 mV) and the quality of the remining thenar branch trough NAP studies (Fig.3).
8. Now we are ready to do the final nerve transfer from distal branch of AIN to the remaining thenar branch that are preserved in good conditions (at this point is possible to reinflated the tourniquet); the proximal end of this branch is transected as far proximally as possible. Again ,intraoperative nerve recording studies help us to identify the level of neurotomy . Usually is not necessary to use interposition nerve grafts but if that is the case you can use a piece of medial antebrachial cutaneous nerve as a graft. Be sure that you can obtain a tension free coaptation and that it would be possible to flex and extend the wrist in both supination and pronation.
9. The coaptation is done using the miscroscope and with 9-0 or 10-0 nylon sutures and fibrin glue (Fig. 4).
10. Closure of the wound in layers. Drain is not usually necessary.
11. The wrist in inmobilized in neutral position, but with the fingers and thumb free, with a posterior splint for 2 weeks.
12. Postoperative rehabilitation exercises star as soon as inmobilization is removed. Reinervationappears at 3-4 months in nerve conduction studies but clinically APB and opponens function is not useful until 5-6 months after surgery.

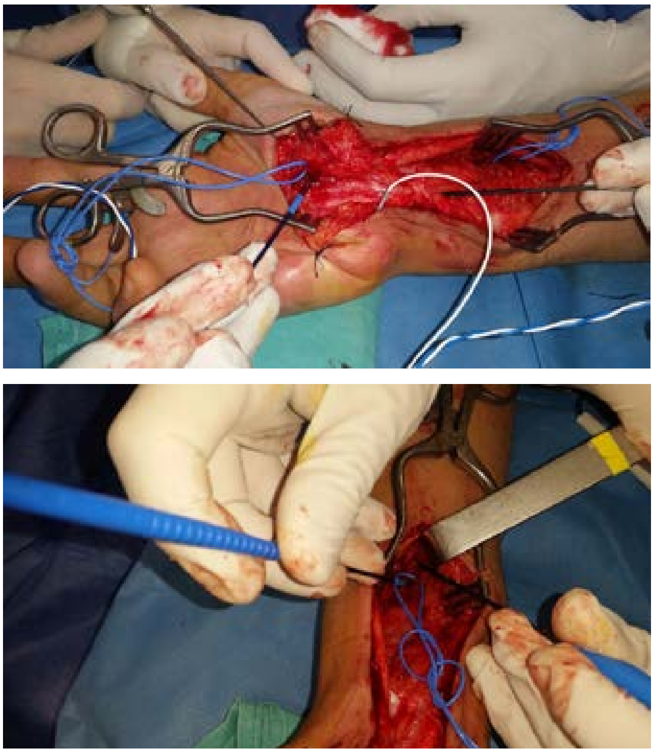


Fig. 3 *Intraoperative nerve recording (INR) to identify residual nerve action potential (NAP) on motor branch or compound motor action potential in thenar muscle (CMAP). And evaluation of AIN amplitude.*

Fig. 4. *Nerve transfer of terminal branch of AIN to pronator quadratus to motor thenar branch of median nerve.*

Results

Reinnervation was measured by NCS (Fig. 5). Improve in CMAP at thenar muscle was achieved in all three cases. initial reinnervation was detected at 4 months and improve of thenar CMAP was measured and medium rate was 2,4 mV. Clinically patients recover some abduction function and atrophy of thenar muscle (Fig 5 and 6).

	Injuried Side Amp APB	Contralateral Amp APB
1 M 55yo	2.2 mV	(8.6)
2 F 27yo	2.7 mV	(7.3)
3 M 45yo	1.7 mV	(9.1)

Motor NCS

Nervio / Lugares	Muscle	Latency ms	Amplitude mV	Rel Amp %	Durat ms	Segmentos
R Median - APB						
Wrist	APB	6,35	2,7	100	9,32	Wrist - APB

Fig. 5. *NCS and clinical results at 17 months. Observe the thenar muscle recovery.*

Motor NCS

Nervio / Lugares	Muscle	Latency ms	Amplitude mV	Rel Amp %	Durat ms	Segmentos	Lat Diff ms
L Median - APB							
Wrist	APB	7,71	0,2	100	11,51	Wrist - APB	
Des de cubital	APB	4,32	2,2	1734	11,61	Axilla - Elbow	-2,29

Needle EMG

EMG Summary Table											
			Spontaneous					MUAP			Recruitment
Músculo	Nervio	Raíces	IA	Fib	PSW	Fasc	H.F.	Amp	Dur.	PPP	Pattern
L. Abductor pollicis brevis	Median	C8-T1	N	1+	1+	None	None	N	N	N	Discrete

Fig. 6. *NCS and clinical results at 9 months.*

Conclusions

Although there are not so many cases for indication of this nerve transfer, the results are successful to restore thenar abduction and opposition with no added morbidity if you use intraoperative nerve conduction studies. Usually we prefer end to end suture but reverse end to side suture could be used in some cases with preservation of some NAP.

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33

RECURRENT COMPRESSION OF PERIPH-ERAL NERVES – HOW I DO IT

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Introduction

The term "compression neuropathy" implies compression of a nerve by an adjacent anatomic structure. The etiology has been attributed to several factors: alcoholism, systemic diseases, diabetes, exposure to poisons, medications (e.g. chemotherapy) and infections. Other causes can be inherited disorders , trauma / direct pressure on the nerve, tumors, vitamin deficiencies, bone marrow disorders or other diseases. In some cases, no specific etiology can be identified and the nerve compression must be characterized as idiopathic. The pathophysiology for this condition is ischemia of the nerve, venous congestion, anoxia, capillary vasodilatation and edema, resulting eventually in axonal and cellular degeneration.

Nerve compression can be classified as acute or chronic. Acute compression is the consequence of a fracture/ dislocation or a compartment syndrome. Chronic nerve compression may be mild, moderate or severe. Severe nerve compression has a higher rate of recurrence, due to limited vascular supply of the nerve and the relevant surgical handling which can be very challenging.

Simultaneous compression in more than one site, which is called "double crush syndrome", though uncommon, yet it does exist and we should keep it in mind. The most common pathologies implicated in double crush syndrome are cervical spine nerve root compression and thoracic outlet syndrome.

Treatment of a peripheral nerve compression can be conservative or surgical. Surgical decompression of a nerve is a routine procedure for both the Orthopaedic Surgeons and the Surgeons of the Hand and has consistently yielded excellent outcomes. The majority of patients are completely free of symptoms after a period of a few months. Normally, the results are permanent for the rest of their life. However, complications following nerve decompression are common. Incorrect release, nerve laceration, painful scar and reflex sympathetic dystrophy- RSD, are the most common complications. Nevertheless, a lot of other complications can occur too.

Recurrent nerve compression is not common. There are two major categories to classify recurrence. The first one is not associated with the primary pathology and the relevant surgical release, such as a distal radius fracture, tumors, pregnancy, diabetes or a systemic disease such as rheumatoid arthritis, all of which lead to hypertrophic tenosynovitis of the flexor tendons. The second group includes pathologies associated with an extensive scar formation and traction neuropathy following the first operation. Post-operative hematoma is the major cause for the appearance of this complication. When a hematoma occurs, reoperation for drainage and irrigation is necessary, in order to avoid nerve and tendon adhesions. Evaluation and understanding of the causes for recurrence is very critical for the subsequent treatment. Clinical examination is also very important and further studies (CT-scan or MRI) may be necessary for a correct diagnosis. EMG findings are useful. Nerve conduction velocities usually determine the areas of nerve scarring, with delayed motor and sensory latencies. In cases with traction neuropathy from scar formation without nerve compression, nerve conduction tests may be normal. The first group requires typical management with revision of nerve decompression when needed, as the treatment of choice. Additional procedures may be necessary, such as a correction osteotomy for distal radius malunion or a tumor excision. The second group needs special management. External or internal neurolysis must be followed by vascularized soft tissue coverage, anti-adhesion gel or devices, or the use of the vein-wrapping technique.

Treatment of recurrent compression of the peripheral nerves

A lot of techniques have been described for the treatment of recurrent compression of the peripheral nerves. Revision neurolysis alone has been used, but after a period of 3-4 weeks, there is again a recurrence due to scar formation. The combination of neurolysis and soft tissue coverage provides the environment for better healing (1). The first step is neurolysis, external or internal. The second step involves the relocation of the nerve to a well vascularized bed, which enables adequate gliding. A lot of flaps, pedicle or free have been used. For recurrent carpal tunnel syndrome scarred areas and atrophic overlying skin with severe nerve irritability, muscles flaps have been described that may help form scar reappearance, promote vascularization of ischemic fascicular surfaces providing also padding to the verve. Such flaps are pronator quadratus, abductor digiti minimi, lumbricals and palmaris brevis. Pronator Quadratus provides good coverage proximally but is limited distally. The muscle is detached from its insertion on the radius and rotated distally and superficially. Abductor digiti minimi is another useful flap. For better mobility the muscle is exposed through separate hypothenar incision. The muscle is detached from both origin and insertion leaving the neurovascular bundle intact and then is transferred radially on it is proximal pedicle. The Lumbricals flap provides limited coverage. The muscle is detached distally and rotated 180 degrees proximally on its proximal pedicle. For the Palmaris brevis flap the muscle is detached from its ulnar insertion into the subcutaneous tissue and folded over itself radially. Finally, synovial flaps from tendon flexor, fat pads and free vascularized flaps have also been proposed by authors. Accordingly, intramuscular transposition of the ulnar nerve for neuropathy is used for recurrent cubital tunnel syndrome. Local flaps do not provide adequate coverage, because they cannot be wrapped around circumferentially. Key factors for selection are the presence of extraneural or intraneural scar tissue formation, the clinical symptoms and signs, as well as the chronicity and the number of previous operations.

The use of Allograft from glutaraldehyde-preserved human umbilical vein was proposed by some authors because of its relative lack of antigenicity and degradation. Masear V.R and Colgin S. report good or excellent results in 79% of cases (2).

On the other hand, gels, anti-adhesion and silicone devices have also been suggested to envelope the compressed or injured nerve and to improve nerve gliding, but the results are not always acceptable.

Vein wrapping

Nerve wrapping with a vein graft for the treatment of a scarred peripheral nerve has been reported first by Masear VR in 1990 (3) and Gould JS in 1991 (4). Koman on 1994 (5) presented also the advantage of the technique. In 1995, D.G. Sotereanos published the preliminary results of this encouraging technique (6). Finally, in 1998 Xu and Sotereanos described the effect of vein wrapping of the nerves in a rat model and they found that autogenous vein graft wrapping did not lead to any recurrent nerve entrapment (7).

The hypothesis was that vein graft wrapping of a compressed nerve will prevent the recurrence of scar formation, which is believed to be the reason for a recurrence of nerve entrapment. Ideally, the wrapping substance is needed to be inert and nondegradable, providing smooth nerve gliding, along with a barrier to adhesions and scar tissue forma-

tion around the nerve (8.9).
The major indication for the use of vein wrapping technique is the treatment of recurrent compression of peripheral nerves, both in the upper and lower extremities, where there is significant scar tissue formation around the nerve (10, 11). Median nerve at the wrist (carpal tunnel syndrome) and ulnar nerve at the elbow (cubital tunnel syndrome) are the most common nerves with recurrent compression (12). On the other hand, radial nerve scar tissue formation is common after radial tunnel release and the treatment is extremely difficult. Tibial nerve at the tarsal tunnel is the most common site of recurrent compression of a peripheral nerve in the lower extremity.
Bad soft tissue envelope of an injured nerve is also an indication for the use of this technique. Superficial sensory nerves such as the superficial branch of the radial nerve at the dorsal side of the wrist, as well as the superficial branch of the peroneal nerve at the dorsal side of the foot, can lead- when injured- to a painful neuroma even after an acceptable repair. In my practice, I prefer to wrap the sutured site of these nerves with vein graft in order to decrease the possibility of scar formation and a painful neuroma. In addition, this procedure allows an easy harvesting of the graft, which is readily available and has minimal donor site morbidity.
The results are satisfactorily. Masear VR reported 79% good or excellent in her series of more than 100 patients, and Gould JS had moderate success in 10 of 12 patients. Sarris JK and Sotereanos DG found all their 15 patients improved for recurrent median nerve compression (13). Furthermore, Kokkalis ZT and Sotereanos DG described encouraging results in 17 patients with recurrent compression of ulnar nerve in the cubital tunnel (14).

Basic science

In order to determine the safety and feasibility of the vein wrapping technique XU JX, Sotereanos DG et al carried out a study on an animal model (15). The study assessed the effect of vein graft wrapping around normal sciatic nerves of rats, which were first dissected and then wrapped with a femoral vein graft. The sciatic nerves of both control and experimental groups were evaluated at 9, 12 and 15 weeks postoperatively, along with functional, electrophysiologic and histologic testing and the results showed no significant differences between the two groups.
The histology of vein-wrapped nerves was normal and the population and organization of nerve fibers did not reveal pathologic changes. In longitudinal sections, nerve fiber flowed smoothly through the graft. Neither intrafascicular fibrosis nor axon collapse and demyelinization was observed. The extend and diameter of blood vessels within the nerve were similar in both groups. Moreover, absence of scar tissue formation around the nerve was observed. Finally, the technique did not result in any pathologic nerve entrapment providing good tissue compatibility, smooth endothelial surfaces as well as high donor availability and low morbidity.

Surgical technique

The procedure normally must be performed under general anesthesia, as the vein harvesting requires a separate incision in the lower limb. The surgical exposure of the nerve must be extended. If a tenodesis is found, tenolysis must be performed first. The dissection of the nerve must be carried out until healthy nerve ends. Careful external neurolysis must be performed, removing any scar tissue formation. Loops or microscope magnification is necessary for adequate scar tissue removal and to minimize the possibility of nerve injury. Internal neurolysis is not recommended in all cases, as the intra-neural post-operative scar formation is usually significant. The intra-neural hematoma leads to a recurrence of the scar tissue formation. In cases with partial nerve injury and intra-neural neuroma, an internal neurolysis, under microscope magnification, should be performed. At the end of neurolysis, we have to decide the length of the nerve which must be protected by the vein graft. We should keep it in mind that the total covered nerve must overlap at least 1 cm of normal nerve. It is important to perform careful hemostasis after tourniquet deflation and before the placement of the vein graft.

The greater saphenous vein is the most common used graft for this procedure, especially if a large graft is needed. The graft size must be 3-4 times of the scared nerve. Vein harvesting can be performed through a long incision or through several stab incisions. A specific instrument can also be used. In cases where the length of the scarred nerves is limited, especially the superficial sensory nerves, vein grafts from the dorsal aspect of the wrist or foot may also be used. In these cases, regional or local anesthesia is adequate.

Vein graft placement is the next step. It is very important to evaluate the vascular bed of the surrounding tissue, since the vein graft will be revascularized from this tissue. If necessary, nerve transposition may be performed, especially regarding the ulnar nerve in the cubital tunnel. The vein graft should be opened longitudinally and we have to pay attention to mark the adventitia, as the intimal side of the graft must be in contact with the scarred nerve. The vein wrapping is done as described by Masear VR. The graft is sutured by 8/0 nylon sutures and any pressure of the nerve from the vein graft should be avoided. I prefer not to overlap the graft ends, in order to make a more flat surface in contact with the nerve. Blood drainage is used in all cases to avoid any hematoma which may proceed to a recurrent scar formation. Postoperatively, typical wound care is associated with immobilization for 7-10 days.

Personal experience

Between 1996 and 2018, 13 patients with chronic recurrent nerve entrapment of peripheral nerves were treated by the senior author (P.N.G.). Out of these patients, six had recurrent cubital syndrome, four had recurrent carpal tunnel, one tarsal tunnel and two recurrent superficial radial nerve entrapment after De Quervain release. In addition, in 8 patients the technique was used as a preventive measure in order to protect the repair after an emergency treatment of an injured nerve (six for superficial radial nerve and two for superficial peroneal nerve).

The patients with cubital tunnel syndrome reported not only significant pain at the elbow, but they also had established a sensory defect of the small and the half of ring finger and limited key-pinch strength. The number of previous operations ranged from two to four and the period of disability was two years on average (range from 6 months up to six years). Accordingly, the carpal tunnel (CTS) group had pain at the wrist, numbness in the distribution of the median nerve and weakness of the abductor pollicis brevis. Out of the four patients with recurrent CTS two had symptoms of RSD. The duration of symptoms was 8 months on average and the number of previous operations was two for the two patients and one for the remaining patients. All patients of both groups had positive EMG findings for extensive compression of the nerves. After a mean follow-up period of 8 years (range 22-1 years), all the patients reported reduction in pain and significant sensory recovery. EMG improvement was also noticed. The patient with revision of tarsal tunnel release had similar outcome with the patients with CTS release. In the cases with neuroma of the superficial branches, the final outcome was significantly high. Although the patients had a residual disturbance, no one asked for an additional procedure. In the patients with the emergency vein wrapping of an injured superficial nerve, no painful neuroma was noted.

CASE 1

Figure 1A-*Female, 28 years old, with severe ulnar nerve compression after three previous surgeries. At the last one the ulnar nerve was wrapped with nerve conduits.*

Figure 1B*-Epineural neurolysis of the ulnar nerve.*

Figure 1C*- Harvesting of vein graft.*

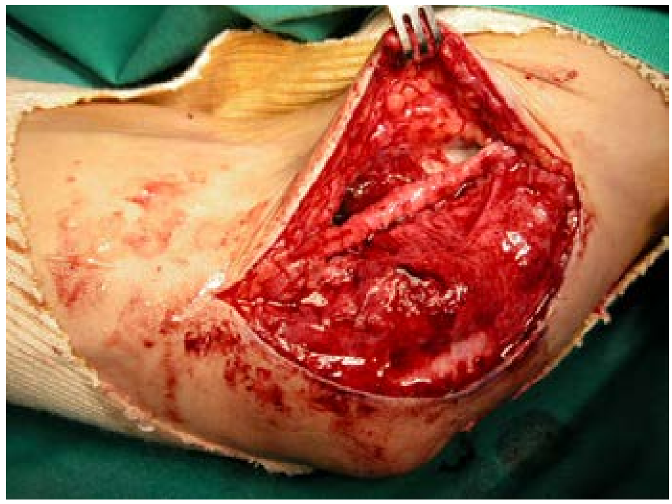

Figure 1D*-Wrapped vein graft around the ulnar verve.*

CASE 2

Figure 2A*- Neurolysis of the ulnar nerve at the elbow, with significant compression, after two previous operations.*

Figure 2B-*Final surgical result with the wrapped ulnar nerve.*

CASE 3

Figure 3A - *Injured superficial radial nerve after De Quervain release.*

Figure 3B-*Vein graft, next to the repaired nerve, ready for wrapping.*

Figure 3C - *Vein wrapping of the nerve after repair.*

Conclusions

The treatment of recurrent compression of peripheral nerves still remains a challenge for the Hand Surgeon and Microsurgeon. The morbidity of the patients is often significant and most of the times the results of the treatment are unpredictable. New surgery adds a new surgical trauma, resulting in a traction neuropathy. RSD is often associated with the disorder. The vein wrapping technique provides some credibility to this serious pathology. Although, there some reports questioning the vein wrapping technique, our experience shows that the technique is efficient for the treatment of these complex disorders. Adequate neurolysis of the compressed nerve, along with meticulous technique, as Masear VR described, is probably the key factor for a successful result. Further research studies are necessary, especially concerning the time of revascularization of the vein graft, and they may offer a better explanation of the effectiveness of the technique.

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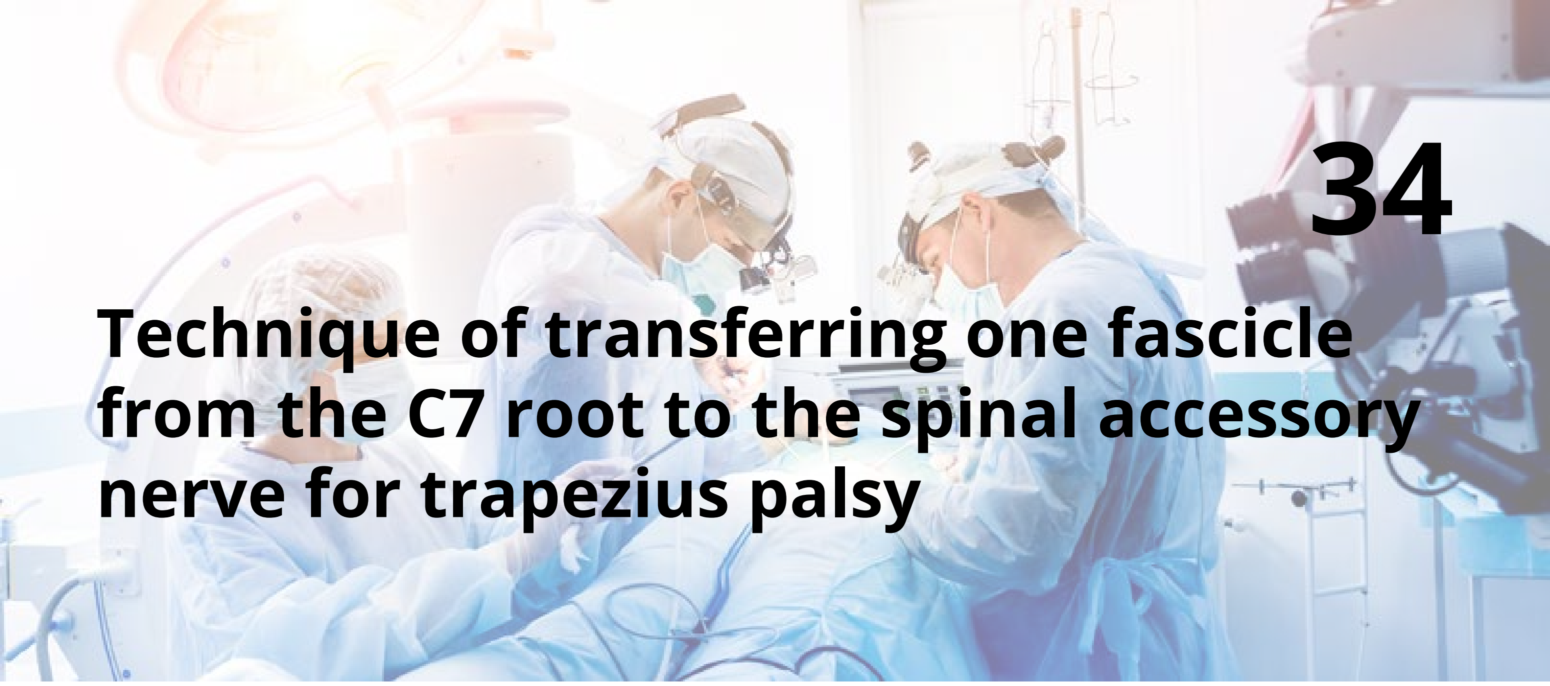

34

Technique of transferring one fascicle from the C7 root to the spinal accessory nerve for trapezius palsy

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Indication

Palsies of the trapezius are not uncommon and generally occur after lymph node biopsy or resection. If there is no spontaneous recovery within 6 months, surgical exploration is necessary. In this situation, nerve suture or graft is generally possible. However, when the proximal stump of the injured nerve is not retrieved because of scar fibrosis, nerve transfer may be indicated. In this case, the transfer from a fascicle of the C7 root to the spinal accessory nerve for reanimation of the trapezius muscle may be indicated [1].

Technique

The patient is brought to the operating room where a general anesthetic is administered. A seven-centimeter incision is made along a line from the top of the mastoid to the middle of the clavicle. The platysma is divided, then the posterior border of the sternocleidomastoid muscle is exposed to recover the SAN. Exploration of the proximal and distal stumps of the injured SAN is performed. If only the distal stump is retrieved, the C7 root must be used to perform the transfer.

The omohyoid muscle is divided, showing the phrenic nerve on the anterior scalene muscle and the C5 and C6 roots behind the posterior border of the anterior scalene muscle. Hemostasis of the transverse cervical artery is performed and C7 can be exposed. Epineurotomy is performed on the C7 root to separate the fascicles. Electrical stimulation allows identification of the fascicle for only the pectoralis major muscle, starting with a low intensity (0.02 mA). The chosen fascicle is dissected from the rest of the C7 root for a distance of 2 cm and divided distally. The fascicle is then turned laterally and superiorly toward the SAN (Fig. 1). The suture is performed under the microscope, with 3 separate 11-0 nylon sutures, and protected with fibrin glue. The skin is closed with separated sutures without a suction drain.

The upper limb is immobilized for three weeks. Then, a short rehabilitation is proposed to recover the shoulder's range of motion. Active muscle contraction of the trapezius starts from 6 to 8 months after surgery, up to 18 to 24 months.

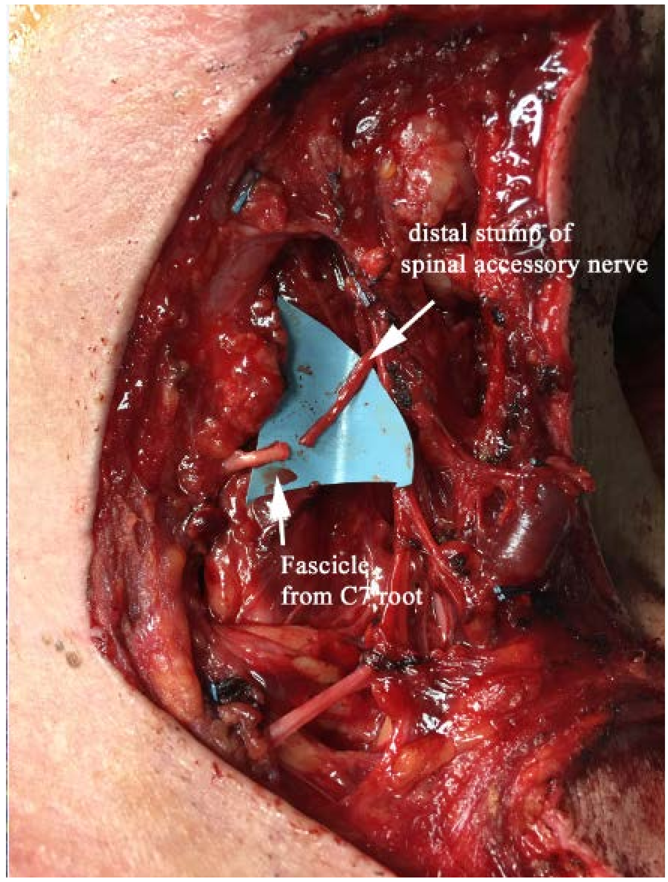

Figure 1: *Transfer of one fascicle from the C7 root to the distal stump of the spinal accessory nerve. The diameters of the stumps match perfectly and the suture can be performed without any tension.*

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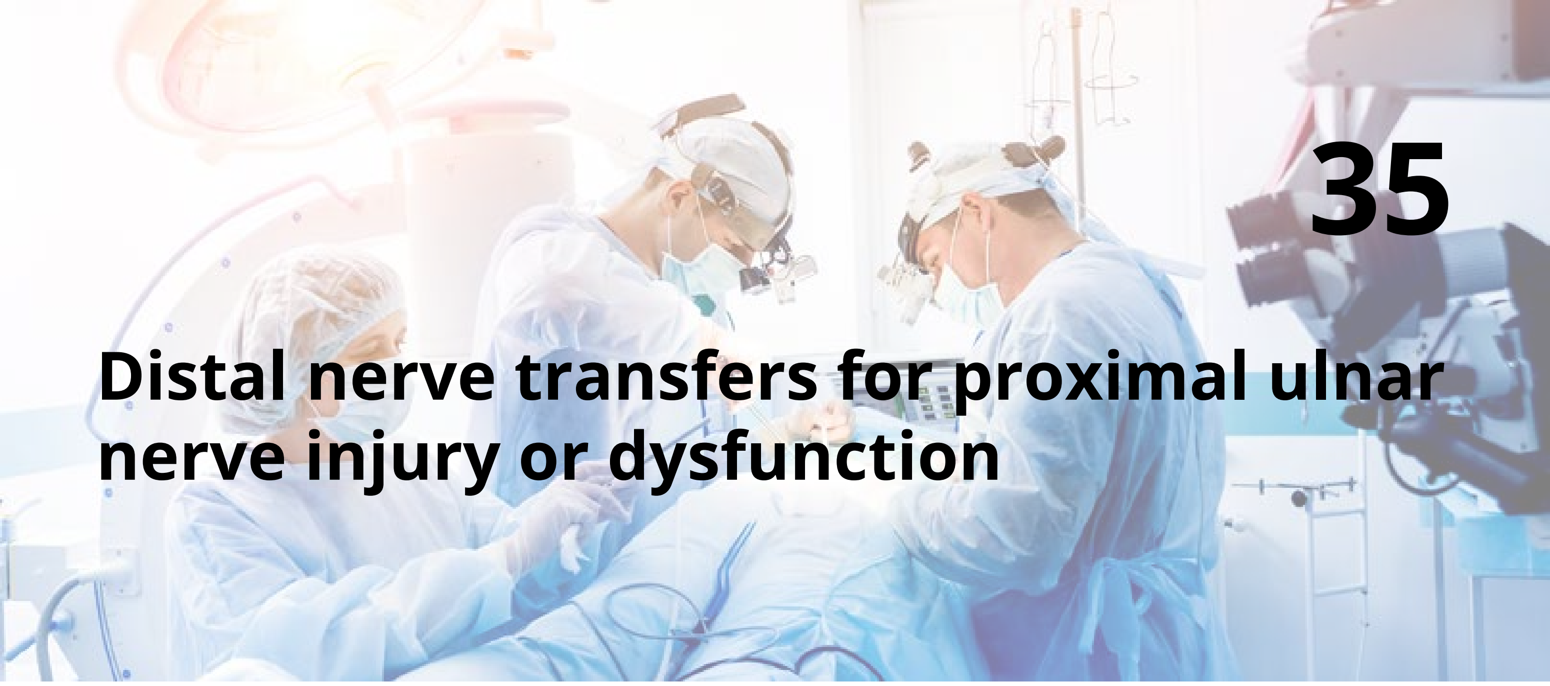

35

Distal nerve transfers for proximal ulnar nerve injury or dysfunction

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The ulnar nerve innervates the majority of intrinsic musculature of the hand and provides sensation in the ulnar part of the hand. Dysfunction of the nerve is characterized by sensory deficit in the ulnar part of the hand and dramatic pinch and grip weakness with clawing of the ulnar digits. Proximal ulnar nerve injuries or severe compressive nerve lesions, can be treated with interventions at the site of the injury or lesion and recovery of at least protective sensation to the ulnar digits can be expected. However, recovery of the intrinsic motor function is uncommon, even if the intervention is performed early. An alternative option for restoration of the motor function are distal tendon transfers, which are technically demanding secondary salvage procedures.

Considering the poor results of proximal injury or lesion intervention, distal nerve transfers have been suggested, both for the sensory and motor branches, with the distal motor transfer been performed more frequently. The donors are provided from the median nerve. The motor donor is the motor branch for the pronator quadratus, which is a branch of the Anterior Interosseous Nerve (AIN) and can be used in end-to-end or in a reverse end-to-side coaptation. The sensory donors are multiple and include digital nerves, the palmar cutaneous branch of the median nerve and sensory group fascicles of the median nerve.

This article provides technical notes on the surgical technique for these nerve transfers.

Indications

Indications for end-to-end distal nerve transfer include proximal ulnar nerve lesions (proximal to the mid- forearm), delayed presentation, extensive injury zone and ulnar nerve defect necessitating long nerve grafts. Indications for reverse end-to-side distal nerve transfer (the so-called “supercharging” procedure) include repairable proximal ulnar nerve injury (in conjunction with primary repair) and severe cubital tunnel syndrome with intrinsic muscle weakness.The indications for cubital tunnel syndrome have been further refined recently by Mackinnon using electrodiagnostic criteria. These criteria include a) reduced conduction velocity at the elbow (under 50 m/sec), b) decreased CMAP amplitude at the wrist (under 3 mV), c) fibrillation and positive sharp waves in the intrinsic muscles of the hand and d) normal EMG of the pronator quadratus or other median nerve innervated muscle. The cumulative existence of the above mentioned criteria is thought to confirm the need for the reverse end-to-side procedure.

Contraindications for distal nerve transfers include intrinsic muscle atrophy or severe clawing of the fingers (absence of target muscles) and median nerve injury or compression proximal to the wrist (compromised donor AIN).

The timing of the nerve transfer in relation to the time of injury for the motor component of the ulnar nerve is debated. Viable target muscles are needed and the three-month time frame is a logical option. For the sensory component of the ulnar nerve, the margin of recovery is wider, so the procedure can be performed months after the injury.

Surgical Technique

The exploration and management of the proximal ulnar nerve lesion is performed first. Under general anesthesia without muscle relaxation (for the possibility of nerve stimulation) and through ample skin incision the injury or compression of the ulnar nerve is explored and managed, under loupe or microscope magnification and using microsurgical techniques. An above elbow tourniquet may be used, but should be held deflated until all necessary nerve stimulation has been completed. Direct nerve repair or nerve grafting in repairable ulnar nerve lacerations is performed, even if a distal end-to-end motor transfer is planned, because of the wider recovery window for the sensory components of the ulnar nerve. In cubital tunnel syndrome patients the nerve is released, externally neurolysed and possibly transferred anterior to the medial epicondyle, according to surgeon preference.

Motor Nerve Transfer

The motor transfer is performed through a volar ulnar incision to the distal third of the forearm, which is usually extended distally with a typical Guyon's canal release incision and approach(Fig1A). Guyon's canal release facilitates the identification of the motor branch and removes one potential obstacle to nerve regeneration.

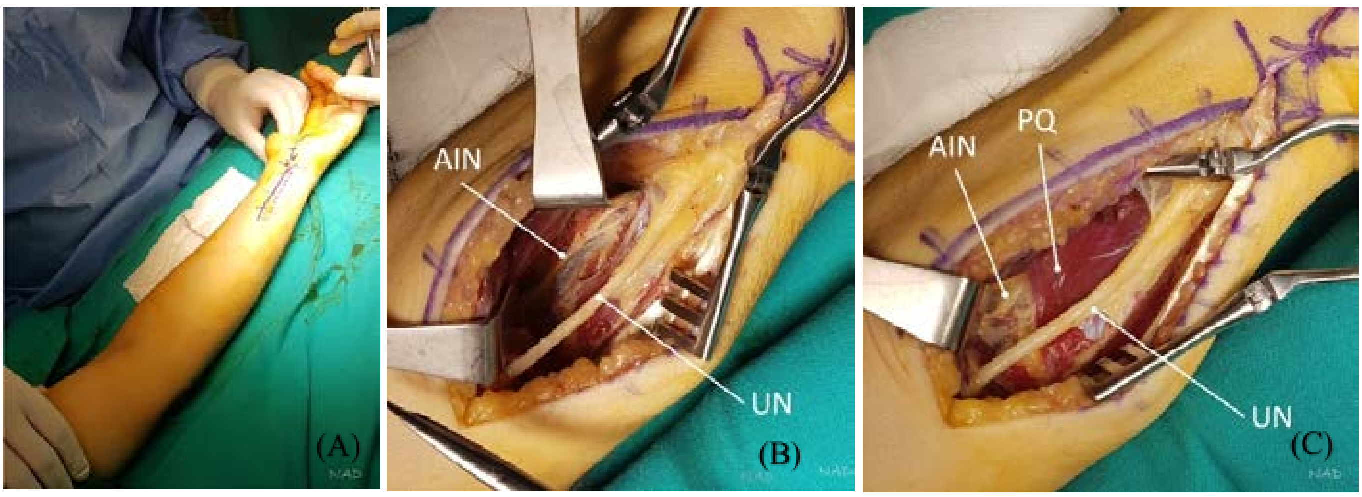


Figure 1 A,B,C: The skin incision (A) and approach for the motor nerve transfer. Note the distal dissection of the AIN in the PQ muscle (B and C). AIN: Anterior Interosseous Nerve, PQ: Pronator Quadratus, UN: Ulnar Nerve

Through this incision, the ulnar artery and nerve are first identified and then, the flexor muscle mass is retracted radial to reveal the Pronator Quadratus (PQ) muscle (Fig 1B, Fig 2).

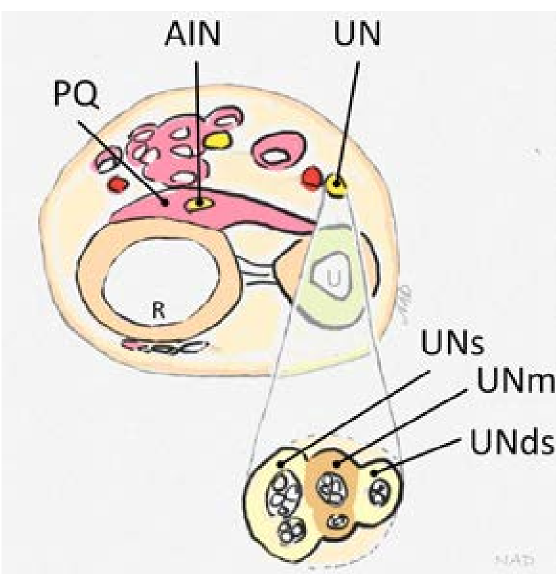
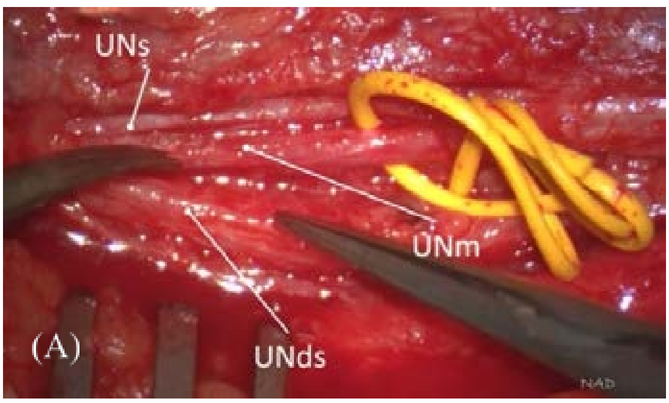
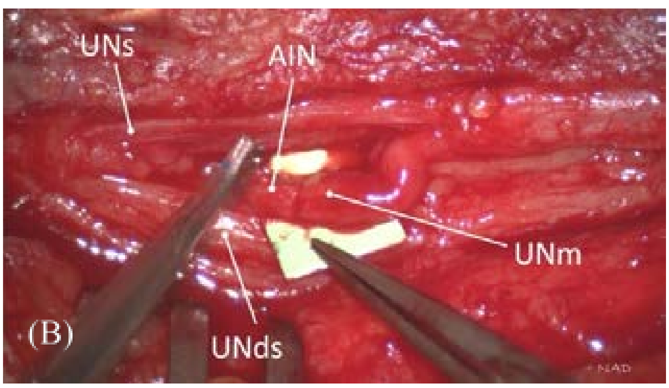


Figure 2: *Transverse cross section at the distal forearm level depicting the relative positions of the Anterior Interosseous Nerve (AIN), Pronator Quadratus (PQ), and Ulnar Nerve (UN). In the insert, the relative positions of the Ulnar Nerve sensory component (UNs), motor component (UNm) and dorsal sensory branch (UNds) within the nerve cross section are demonstrated. R: radius, U: ulna.*

The muscle is inspected ISBN 978-973-0-34731-9 for any sign of atrophy which would preclude use of the AIN as a donor. The AIN enters the PQ muscle proximal. It's size is one to two millimeters and is accompanied by small blood vessels. The nerve is dissected into the muscle, using bipolar elecrocautery to cut the muscle fibers (Fig 1C)

It should be followed until at least the middle of the muscle where is spreads to two or three fascicles. It is important to gain as much length of the AIN as possible, while maintaining the ability to coapt its distal end. The nerve is also dissected proximally as much as the approach permits.
Next, attention is turned to the recipient ulnar nerve. The dissection up till now is performed under loupe magnification but an operating microscope will be needed for this part of the procedure. The goal is to intraneuraly dissect the motor group fascicle (which is the recipient) from the sensory fascicles of the ulnar nerve. In many instances, at the distal third of the forearm, the ulnar nerve can be dissected easily into three group fascicles (Fig 2, Fig 3A)





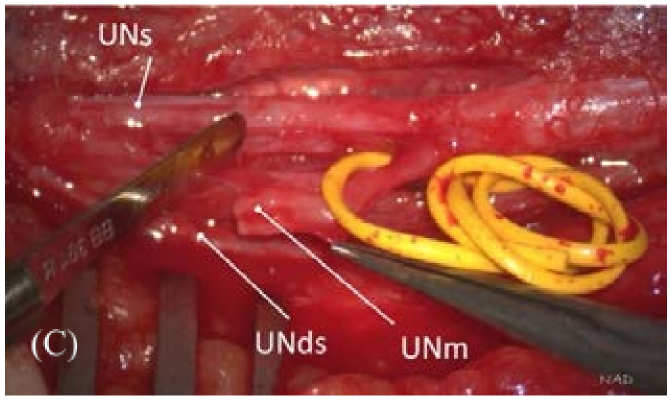


Figure 3 A,B,C: *Operative microscope photographs depicting (A) the Ulnar Nerve sensory component (UNs), motor component (UNm) and dorsal sensory branch (UNds). Distal is to the right of the picture. After proper identification the motor component (UNm) is cut proximally (B) and is sutured end-to-end (C) with the Anterior Interosseous Nerve (AIN)*

The most radial situated is the sensory component of the ulnar nerve. The most ulnar is also sensory and soon branches off the main trunk, as the dorsal sensory branch of the ulnar nerve. Situated between the two sensory components is the motor component. Sometimes, however, no distinct group fascicles can be dissected. In this case, the motor branch has to be identified distally at the end of Guyon's canal as it dives deep to the interosseous muscles, and visually followed back, under microscope magnification, to the forearm level, to confirm the correct motor fascicle. It should be noted that, through its course there will be interconnecting fascicles, but our goal is to follow the larger group fascicle that corresponds to the motor branch. Finally, in rare instances, when exploration is carried out within 72 hours from the injury, and if no muscle relaxation or tourniquet was used, the motor component can be identified by nerve stimulation.
Once the motor component has been iden-

tified, the AIN stump is brought over to the ulnar nerve and the exact point of the coaptation is selected. The tourniquet (if used) is deflated and meticulous hemostasis is performed. At this point, we re-check that the AIN can be brought over without undue tension and, only then, the motor component is either cut transversely (for an end-to-end transfer) (Fig 3B) or its perineurium is opened longitudinally (for a reverse end- to-side transfer).

Opening of the perineurium can be facilitated if a single 9.0 suture is passed through the perineurium and, under traction with this stitch, a small opening is made with micro-scissors. In the end-to-end repair, there may be a small size mismatch which can be overcome with meticulous coaptation. The repairs are performed with a couple of 9.0 nylon sutures (Fig 3C) and fibrin glue. The wound is closed in layers and a long arm splint is used or two to three weeks.

Possible adjuvant procedures to the motor transfer include Guyon's canal release and flexor digitorum profundus tenodesis to improve grip strength.

Sensory Nerve Transfers

The distal sensory transfers for the ulnar nerve are more rarely performed, since the window for sensory recovery after high ulnar nerve injury or compression, is a lot longer. They are, however, very useful if no sensory recovery is expected. The goal is to obtain at least protective sensation at the ulnar border of the hand and wrist. Possible donors include the digital nerves, the palmar cutaneous branch of the median nerve at the wrist, as well as the group fascicle to the third web space from the median nerve trunk at the wrist level. Mackinnon favors the transfer of the third web space fascicle to the ulnar nerve sensory component. The current authors, on the other hand, believe that intraneural dissection of the trunk of the median nerve is not justified to gain sensory function. Instead, we favor the following transfers: a) palmar cutaneous branch of the median nerve to the ulnar nerve sensory component, or to the dorsal branch of the ulnar nerve (depending on how important sensation τoυ the ulnar border of the wrist is to the patient occupational activities) (Fig 4), b) ulnar digital nerve to the long finger to the ulnar digital nerve to the small finger end-to-end transfer (complemented by and-to-side transfer of the ulnar digital nerve stump to the long finger to the radial digital nerve to the ring finger, to maintain some sensation on the ulnar border of the long finger) (Fig 4). In all these transfers the recipient is dissected to enough length to reach the donor (and not vice-versa). Besides that, the coaptation technique and postoperative protocol is identical to the motor transfer described above.

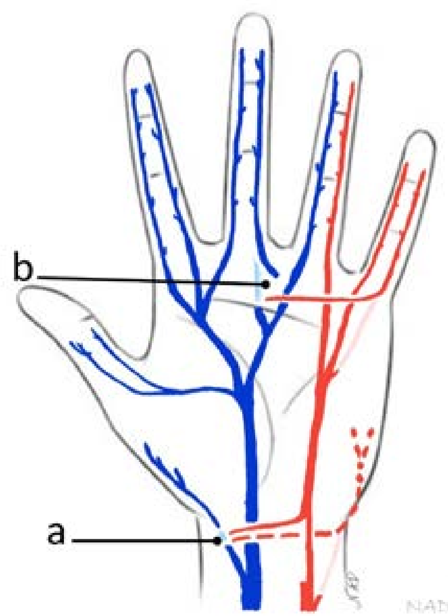


Figure 4: *The authors' prefered distal sensory transfers for the ulnar nerve: a) palmar cutaneous branch of the median nerve to the ulnar nerve sensory component, or to the dorsal branch of the ulnar nerve; b) ulnar digital nerve to the long finger to the ulnar digital nerve to the small finger end-to-end transfer (complemented by and-to-side transfer of the ulnar digital nerve stump to the long finger to the radial digital nerve to the ring finger). Note that the recipient is dissected to enough length to reach the donor.*

Any tendon transfer for ulnar nerve paralysis or the motor transfer described above, can be performed as an adjuvant to the sensory transfers.

Discussion

Intrinsic musculature is characterized by multifunctionality and is provided mainly by the ulnar nerve. Traditional operative techniques for addressing high ulnar nerve lesions cannot adequately restore this function. Furthermore, tendon transfers can improve only specific functions. Distal nerve transfers provide a faster, more reliable and with limited donor side morbidity alternative for addressing these injuries.

Appropriate patient selection is crucial. The onset of denervation in an acute injury is clear. On the contrary, the onset of axonal loss, as well as the condition of the motor end plates is less clear in cases of chronic injuries. Clinical examination and careful examination of the electromyography studies can help us distinguish the patients eligible for distal nerve transfers.

The technique of direct transfer of the branch for the pronator quadratus to the motor branch of the ulnar nerve has changed dramatically the treatment options of ulnar nerve lesions, replacing distal tendon transfers and obtaining reinnervation of all ulnar nerve innervated intrinsic musculature. The two nerve branches are suitable for coaptation with similar diameters and similar number of fibers, with the branch for the pronator quadratus containing about 900 nerve fibers and the ulnar motor branch approximately 1200 nerve fibers (1-3). This technique was initially performed by Mackinnon SE in 1991. Advantages of this treatment option are the proximity of the distal nerve transfer to the muscle targets, the direct coaptation without an interposition graft and the fact that is simple to perform. It is usually preferred in cases where the ulnar nerve proximal intervention is not expected to achieve intrinsic musculature functional recovery. Due to these good results, this technique has been used extensively by Mackinnon and her colleagues as well as by numerous centers worldwide (2,4-8).

On the other hand, in cases of severe cubital tunnel with intrinsic musculature atrophy, where neurolysis is performed proximally, end-to-end coaptation of the AIN terminal branch to pronator quadratus to the ulnar motor branch is not the preferred option, since some reinnervation through the native axons of the ulnar nerve is expected eventually. The preferred option is a reverse end-to-side coaptation of the same nerve in order to enhance or "supercharge", as frequently mentioned in literature, the motor fascicles of the ulnar nerve. This transfer is thought to "babysits" the motor end plates of the ulnar nerve innervated intrinsic muscles without division of the normal neural pathway of the ulnar nerve. When the native axons within the ulnar nerve regenerate following the proximal nerve lesion intervention (neurolysis or direct repair), the motor end plates are still functioning without signs of atrophy and recovery of the intrinsic motor function is further improved. Recent studies have shown that this technique does not only "babysit" the motor end plates, but it also provides axonal growth along this new pathway in addition to the existing neural pathway along the ulnar nerve. (9,10).

End to side nerve coaptation is generally considered as an alternative form of nerve transfer and aims to minimize the functional deficit of the donor nerve. Criticism about this method has motivated large number of experimental studies and is based on the fact that functional motor recovery is not predictable. Some authors reserve this technique for sensory reinnervation only. Nonetheless, many surgeons have used this technique for motor reinnervation as a supercharge technique for distal ulnar nerve transfers with good results (3,8-10).

Recent systematic review of supercharge end to side nerve transfer revealed that intrinsic function was recovered in 92% of the cases at an average of 3,7 months with no improvement in only 8% of the cases. Furthermore, no other complications were reported (12). Additionally, two independent studies, one prospective by Koriem et al (13) and one retrospective by Baltzer et al (11), that compared supercharged ulnar nerve repair by AIN transfer and isolated ulnar nerve repair in proximal ulnar nerve lesions demonstrated that the supercharge technique resulted in better results in intrinsic reinnervation.

An epineural or perineural window should be performed to allow regenerating axons to reach recipient donor (14). However, experimental studies have shown that end to side coaptation has led to sensory reinnervation in the absence of epineural window with simple external neurolysis (15) and has been used clinically for sensory reinnervation in distal nerve transfers of the ulnar nerve with good results (16).

The sensory role of the ulnar nerve is not as important as the median nerve counterpart, but it has to be addressed in ulnar nerve lesions. Gross protective sensation can be achieved slowly up to 2 years following proximal ulnar nerve repair. Repeated trauma to this anesthetized area during this prolonged period of denervation may result in repeated ulcerations. Therefore, sensory restoration of the ulnar nerve is an essential component of the reinnervation planning (3,16). The proposed techniques for sensory recovery in this article are simple, safe and with minimal morbidity, and can obtain at least S3 sensation in all areas (3,16,17).

Conclusion

These distal nerve transfers represent a simple and effective way to provide motor and sensory function in the hand in cases of high ulnar nerve injury. This technical note provides the anatomical and surgical keypoints to safely and reliably restore the ulnar nerve function.

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36

The Temporalis Muscle Transfer for Dynamic Facial Reanimation

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Introduction:

The facial nerve is the seventh cranial nerve and emerges from the pons of the brainstem, controls the muscles of facial expression, and functions in the conveyance of taste sensations from the anterior two-thirds of the tongue among others. The nerve typically goes from the pons through the facial canal in the temporal bone and exits the skull at the stylomastoid foramen. The injury of the facial nerve may inflict functional and aesthetic malfunctions (Table 1) which eventually can lead to psychosocial handicaps as well.

Table 1: House-Brackmann score	
Grade Description	**Characteristics**
I	Normal
II	Slight – mild weakness
III	Moderate – facial asymmetry and weakness but eye closes
IV	Moderately severe – total facial asymmetry and weakness with incomplete closure of the eye
V	Severe – barely detectable movement
VI	Total – no facial function

Patients with facial nerve paralysis may be treated as "different", suffering social and workplace discrimination [1]. This results in social isolation, decreased self-esteem, and negative self-image [2]. As it appears from the literature, there is a high frequency of depression in patients with facial palsy [3]. Additionally, as with any deformation, the severity of psychosocial disturbance does not necessarily associate with the degree of injury. Furthermore, psychological stress rather than functional deficits are often the key determinant in predicting social disadvantage and the need for surgery [4].

Whenever possible, surgeons should immediately repair facial nerve injuries to restore neuronal continuity from the central segment to the peripheral branches. Such repairs may involve direct microsurgical nerve reconstruction or even nerve grafts from the healthy to the injured side. If these techniques are not possible or if our patient is elder, then other options such as static repairs of the facial tissues or dynamic, performing local and/or muscle transfers, may be taken in consideration. Preoperatively the evaluation of the facial paralysis has to be performed and consequently define whether we have to deal with a central or a peripheral facial palsy. To achieve it, we have to examine the patient thoroughly to neck and head and evaluate the functionality of the cranial nerves. Also we have to proceed with an electro-diagnostic test and topographic diagnosis, such as Shirmer's test, stapedial reflex, and taste test. The temporalis muscle transfer represents an example of the local dynamic reanimation techniques.

Surgical Technique:

For the dynamic surgical treatment of the facial palsy one of the most common surgical approaches in our hands is the combined Gillies-McLaughlin's technique (Figures 1a,b & 2a,b).

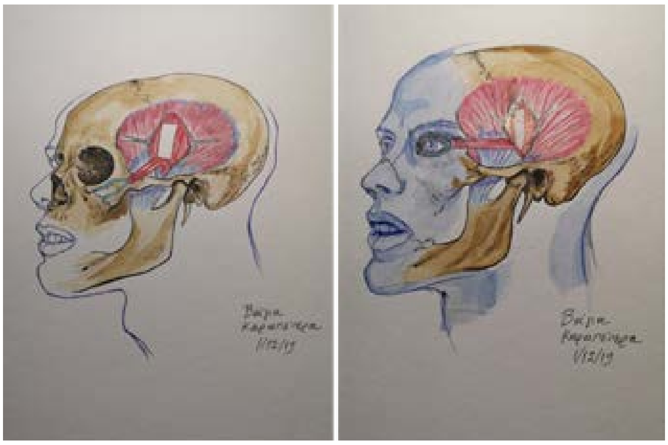

Figure 1a, b: *The Gillies technique schematically*

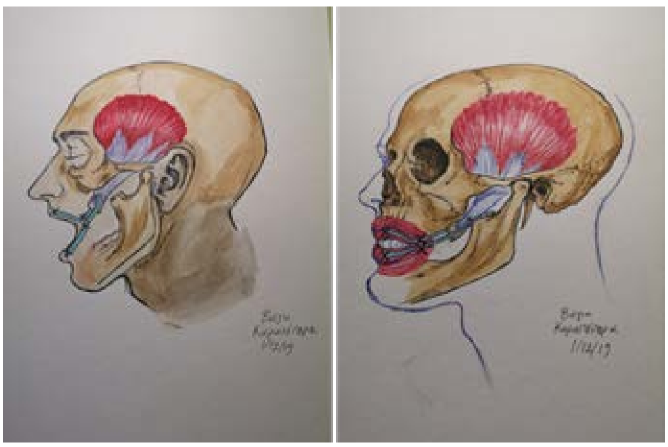

Figure 2a, b: *The McLaughlin's technique schematically*

Under naso-endotracheal intubation, we proceed to the preoperative design of our patient. We mark the coronoid apex, the nasolabial fold, as well as the modified facelift incision that we are intending to perform. Xylocaine/adrenaline (1:100.000) is injected alongside the incision and the rest of the face in the subcutaneous level that we are going to dissect. Xylocaine will provide analgesic effect to our patient after surgery and help us by the dissection of the middle-face. Adrenaline will keep our surgery with less bleeding. Then, the facelift incision is performed (Figure 3a,b) as we preoperatively planed, exposing the temporalis muscle and its fascia, as well as the middle face at the subcutaneous level.

Figure 3a: *Modified facelift incision*
Papadopulos N, Markou M. A modified temporalis transfer technique for facial paralysis treatment in elderly patients. Injury 2020 (submitted).

Figure 3b: *Subcutaneous dissection to the oral commissure, as well incision made (shown by the scissors) along the nasolabial fold, in order to expose better the orbicularis muscle.*
Papadopulos N, Markou M. A modified temporalis transfer technique for facial paralysis treatment in elderly patients. Injury 2020 (submitted).

The McLaughlin technique

After the preparation of the middle face as previously mentioned, the coronoid process is dissected deeply and finally osteotomized (Figure 4). The bone section of the coronoid process is now free from the rest of the mandible, and above it, a hole is made in the temporalis tendon's insertion. Further, a tunnel is created in a subcutaneous level from the mobilized coronoid process to the perioral area (Figure 5). For the functional and aesthetic (symmetry) restoration of the mouth, an incision is made at the level of the oral commissure, along the nasolabial fold, to expose the orbicularis muscle. Complementary, the orbicularis oris muscle of the upper and lower lip is dissected until the middle line of the mouth, where an incision is made, in the upper and the lower red lip. Subsequently, the complex of the coronoid process with the tendon's insertion of temporalis muscle is stretched to the modiolum at the perioral region.

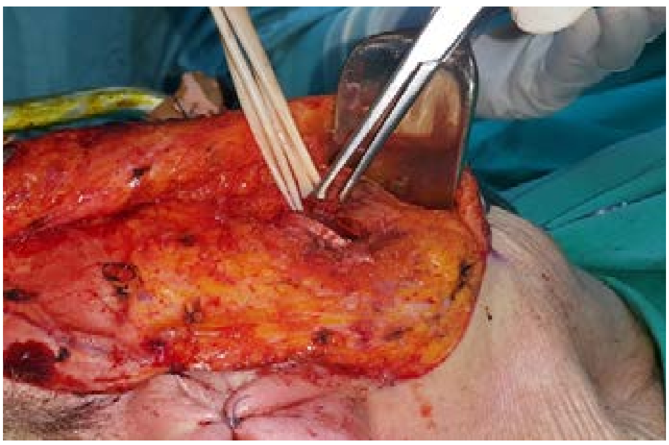

Figure 4: *Dissected coronoid process and its temporalis muscle insertion, shown by the penrose drain.*
Papadopulos N, Markou M. A modified temporalis transfer technique for facial paralysis treatment in elderly patients. Injury 2020 (submitted).

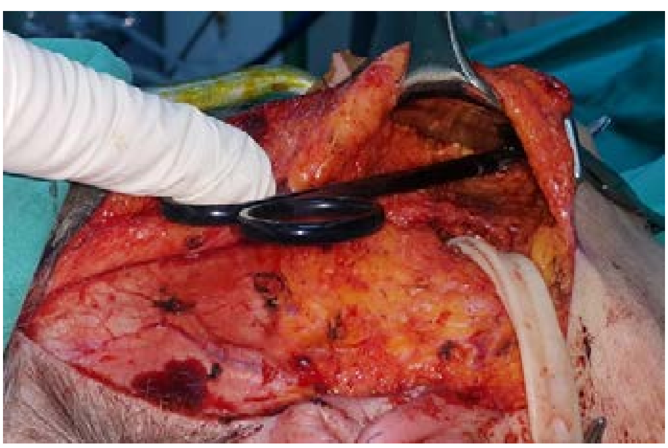

Figure 5: *The subcutaneous and subsequently the intramuscular tunnel, from the mobilized coronoid process to the lower lip central perioral incision, at the vermilion level*
Papadopulos N, Markou M. A modified temporalis transfer technique for facial paralysis treatment in elderly patients. Injury 2020 (submitted).

Parallel, for the standard Gillies-McLaughlin technique, a second team of surgeons is making a S-shaped incision on the lateral thigh (the donor-site), to expose fascia lata (Figure 6), and prepares it for harvesting. Then, the fascial lata strip will be placed through the hole, created previously above the coronoid process at the level of the temporalis' tendon insertion. Both legs of the strip are firstly secured together at the modiolum, and then the one end will attached to the upper and the other to the lower lip with Ethibond 2/4-0 (Ethicon LLC®, San Lorenzo, USA), intramuscularly at the vermilion level.

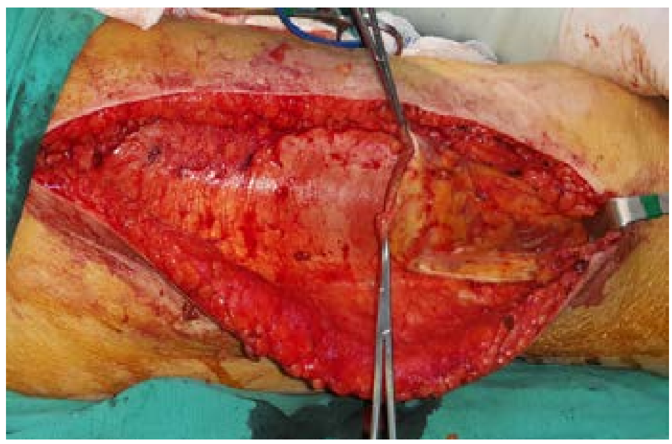

Figure 6: *The harvest of the fascia lata at the lateral thigh.*
Papadopulos N, Markou M. A modified temporalis transfer technique for facial paralysis treatment in elderly patients. Injury 2020 (submitted).

Technique's modification [12]

While performing the standard McLaughlin technique, and after osteotomizing the coronoid process we stress it with its temporalis' tendon insertion to the modiolum, according to Seung-Ha Park et al. [5], without harvesting fascia lata from the controlateral lateral thigh aspect! When, and if the tension on the temporal muscle and its tendon it permits, we proceed with the fixation of the coronoid process to the modiolum, without dissecting the upper and lower part of the orbicularis muscle! The fixation of the processus to the modiolum occur with at least two Ethibond 2-0 (Ethicon LLC®, San Lorenzo, USA), placed longitudinally, over the coronoid process, between the cached temporalis' tendon insertion and the modiolum (Figure 7).

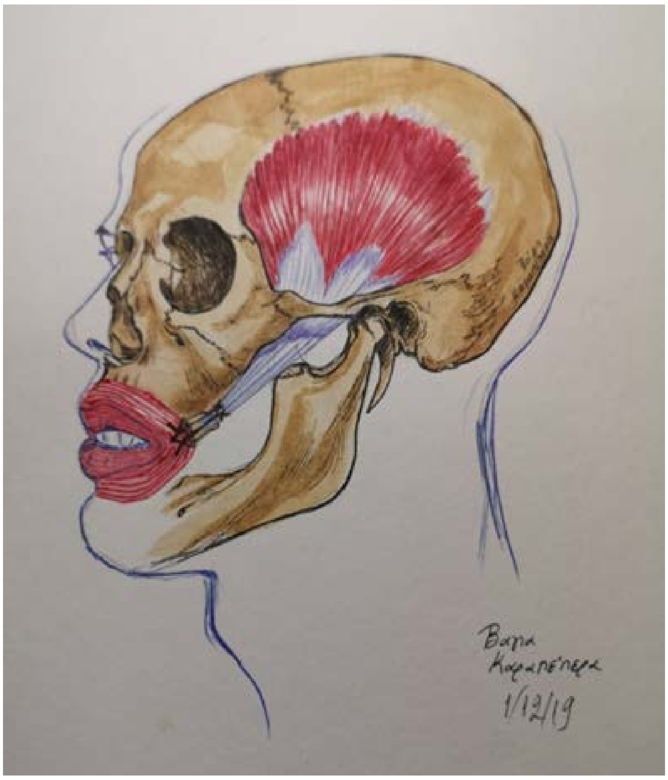

Figure 7: *The modified McLaughlin's technique schematically.*

The Gillies technique

For the eye restoration, a central section of the temporalis muscle is identified. For the eyelid functional restoration, a muscle strip of about 1-2 cm width, and 5 cm length is elevated and rotated towards the lateral canthus (Figure 8a). The fascia of the temporalis is detached, and at the free end of the raised muscle-strip, a durable seam is made to strengthen the connection between the muscle and the fascia. Further, the upper and lower eyelids are dissected under xylocaine/adrenaline (1:100.000) injection in order to create a submuscular tunnel, after making three incisions: one at the lateral canthus, one in the middle, and finally one at the medial canthus level. Then, the fascia is splited into two thinner strips (Figure 8b), of which one, taking advantage of the incisions made in both eyelids, passed through the upper eyelid and the other through the lower, and at the end, both firmly secured to the medial canthus (Figure 8c) with Prolene 4-0 (Ethicon LLC®, San Lorenzo, USA).

Figure 8a: *The elevation of the temporalis muscle and the splitting of its fascia, after a durable seam is made at the muscle's peripheral edge, to strength the connection between muscle and fascia.*

Figure 8b: *The split of the fascia into two strips, showing their position on both eyelids.*

Figure 8c: *The strips passed through the upper and lower eyelid and firmly secured to the medial canthus*

Finally, before suturing the modified face lift incision, careful hemostasis is made with bipolar cautery and a redovac drainage is applied. Then, the subcutaneous tissue is sutured with Vicryl 2-0 and 4-0 (Ethicon LLC®, San Lorenzo, USA), and the skin with intradermal seam with Monocryl 3-0 (Ethicon LLC®, San Lorenzo, USA). Finally, the eyelids will be sutured with Ethilon 4/5-0 Ethilon (Ethicon LLC®, San Lorenzo, USA).

After suturing, alongside the section, as well as the points of the suturing of the fascia and the tendon, paraffin gauzes is used. The wound is covered with deodorized gauze and a flexible bandage is placed.

The duration of the surgery is around 3-4 hours and the postoperative hospitalization of the patient is approximately 3 days. The drainage is removed the 2nd day and the dressing is changed every second day until the sutures cut off the 6th postoperative day from the eyelid ant the 10th from the middle-face.

Discussion:

Facial palsy management is associated with pharmacologic therapy, physical treatment, and surgical procedures, such as static and dynamic techniques [6], depending of the time of injury (Table 2).

Acute facial paralysis (<6 weeks)	**Intermediate-duration facial paralysis (6 weeks-2years)**	**Chronic facial paralysis (>2 years)**
Facial nerve decompression i. Transmastoid ii. Middle-fossa iii. Translabyrinthine	Cross-face nerve grafting	Regional muscle transfers i. Temporalis ii. Masseter iii. Digastric
Facial nerve repair i. Primary ii. Cable graft	Nerve transfers i. Hypoglossal ii. Masseteric iii. Spinal accessory	Free muscle transfer i. Gracilis ii. Serratus anterior iii. Latissimusdorsi iv. Pectoralis minor

Table 2: *Surgical treatment (Depending on Time of Injury)*

In the facial palsy treatment, the early administration of a combination of corticosteroids with an antiviral agent such as Valacyclovir is beneficial to the patients [7], in case the paralysis was due to virus or bacterial infections.

For the surgical treatment different factors have to be considered: patient's age, general condition, medical history, nerve injury's location, chronicity of the disease and of course patient's expectations and risk tolerance. Consequently an individual surgical approach is indicated for each patient separately.

In case of an acute facial palsy (<6 weeks), the procedure may includes the direct nerve suture/coaptation where possible, or decompression of the facial nerve: transmastoid, middle fossa, or translabyrinthine [8]. Alternatively, grafts from the great auricular nerve, sural nerve, and the medial as well as the lateral ante-brachial cutaneous nerve when needed [9], or, especially in elderly patients the static muscles procedures can be performed.

When the paralysis is of intermediate duration (6 weeks-2 years), the surgical procedures include nerve transfers, and the cross facial nerve grafting, if the contralateral facial nerve is functional and undamaged, as well as the static techniques for the reanimation. Procedures of nerve transposition are performed with the use of donor nerves such as hypoglossal, which is the most common, the masseteric branch of the trigeminal nerve, the spinal accessory, and the motor branches of the cervical plexus [10].

Usually, when the paresis of the facial nerve lasts more than two years, the facial muscles present atrophy. Therefore, for the successful facial reanimation, the use of alternative muscles is necessary. There are different techniques to achieve this, including regional and free muscle transfers. The most common regional muscle transfer is the temporalis muscle. Other muscles that are used are the digastric and the masseter. The gracilis, serratus anterior, pectoralis minor, and latissimus dorsi muscles are used for free muscle transfer [6,11]. Also, as previously reported, the static procedures can be used as treatment in special cases.

Our team adheres to an algorithm in which the technique we use is the combined Gillies-McLaughlin's technique. Lately, after a report of Seung-Ha Park et al. [5], we are using a new modification, which relies on this technique.

The advantages of this new method are numerous: By not harvesting the fascia lata from the lateral thigh we reduced the surgical time and therefore the stress of the patient. The faster surgery directly transform the procedure to an easier one, in which one team of surgeons can handle it, and accordingly there is no need of two-team surgery as in the standard technique; further, there is no donor-site morbidity! This leads to a faster recovery of the patients, and due to the lesser intraoperative burden, their subsequently faster integration back to the society. With this technique the surgical time is being reduced to almost 3 hours (in average: 2:53 h) and the postoperative hospitalization, typically 2 days, while with the standard technique the surgical time is almost 3,5 hours (in average at 3:28 h) and the hospitalization in average 4,3 days. Patients gain confidence more quickly and can return to their daily activities sooner. Last but not least, the results with the modified technique are long lasting with less possible complications than the standard Gillies-McLaughlin technique.

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37

Microsurgical Resection of Peripheral Nerve Tumors

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Introduction

Although peripheral nerve tumors are relatively rare pathological entities - benign tumors (schwannomas and neuromas) account for about 10% of total benign soft tissue tumors [1-2] and malignant pathologies (neurofibrosarcomas) have an incidence of about 1/100000 in the general population [3], however, when they appear, they may have a significant clinical resonance.

The diagnosis can often be incidental, the tumors being smaller than 10 cm in diameter, generally initially asymptomatic, but most patients who come to the hospital do so for subjective symptoms of nerve compression - pain, paresthesias, rarely real motor or sensory deficit, palpable tumor mass especially in the case of malignancies. Therefore, most of the times, their surgical indication is firm.

Surgical technique

- rigorous clinical history and examination
- imaging diagnosis - CT and MRI with contrast plus electromyography and nerve conduction tests
- surgery has to be performed by a professional with microsurgical training, aka a plastic surgeon
- careful preoperative planning, which must take into account from the beginning all the working hypotheses, including intraoperative surprises
- in case of a malignant tumor, the resection should be done within oncological safety limits, possibly after an image-guided biopsy to certify the diagnosis
- positioning the patient on the table so that the surgeon has very good access to the peripheral nerve involved
- classic plastic surgery surgical tray, complete microsurgery tray, mandatory nerve stimulator
- sterile surgical field realized both at the level of the segment involved and in the donor area, if the operating plan includes the harvesting of nerve cables for grafting
- incision centered on the lesion, longitudinally or in “S”
- careful initial dissection under operative loupes
- identification of the involved nerve, of the tumor and of the healthy nerve proximally and distally from the lesion, over a sufficient distance to allow its “relaxed” approach
- mounting the operating microscope and external neurolysis
- tumor dissection under the operating microscope, starting from healthy tissue and progressing toward the lesion, with careful hemostasis of the encountered epineurial vessels, aiming to “enucleate” it, practically performing an interfascicular dissection
- after the release of the tumor from the capsule and the pseudocapsule, the functionality of the bundle (s) of origin of the tumor is verified - with the help of the nerve stimulator - at this time being a known fact that even schwannomas ususally include nerve bundles [4,5]
- if the respective bundles are nonfunctional, the tumor is completely excised
- if the bundles transmit a nerve impulse at 1mA, a decision is made: either to cut them followed by grafting, or to leave them intact, therefore excising the tumor sub totally
- grafting, if necessary, involves harvesting of sensitive donor nerves, preferably from the same anatomical area, with as reduced morbidity of the donor area as possible
- hemostasis should preferably not involve the use of electro cautery
- the surgical wound is closed in anatomical planes, without tension
- we dress the wound with sterile gauze

although we usually don't splint the extremity, in cases of multiple nerve grafts we might use a splint for 14-21 days

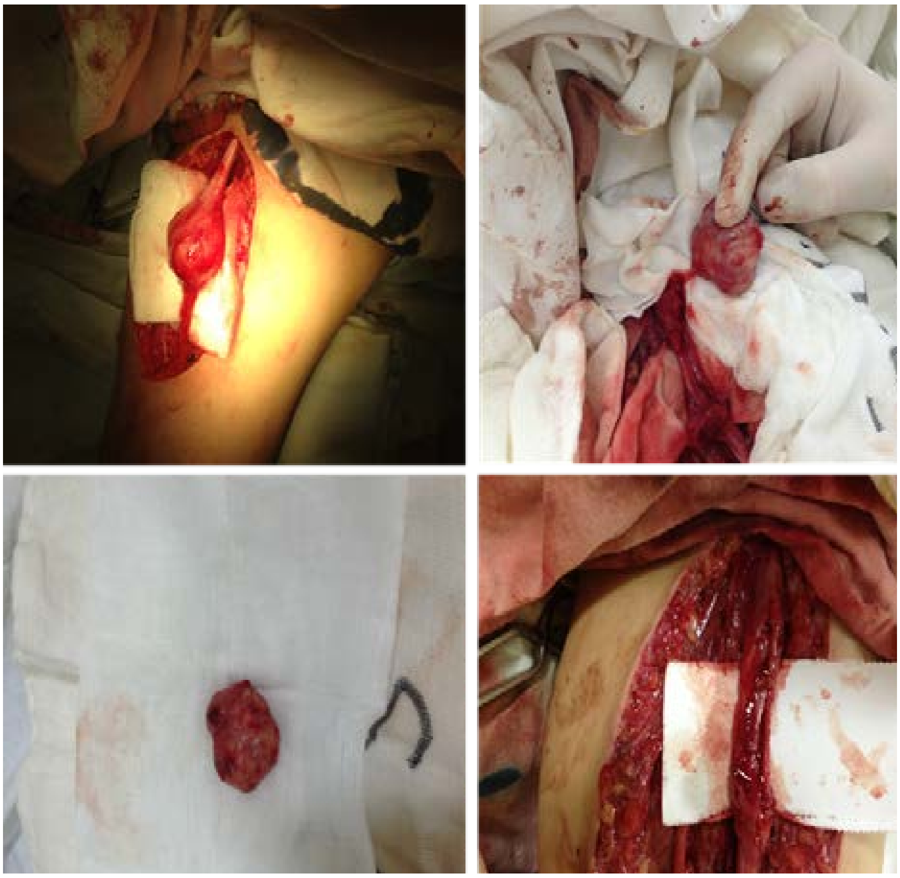

Fig 1,2,3,4 – *Large symptomatic median nerve schwannoma in the proximal third of the arm, with bundle involvement, that required cable grafting after complete excision. The patient reported complete regression of the symptoms and had intact function of the median nerve at 12 months postop.*

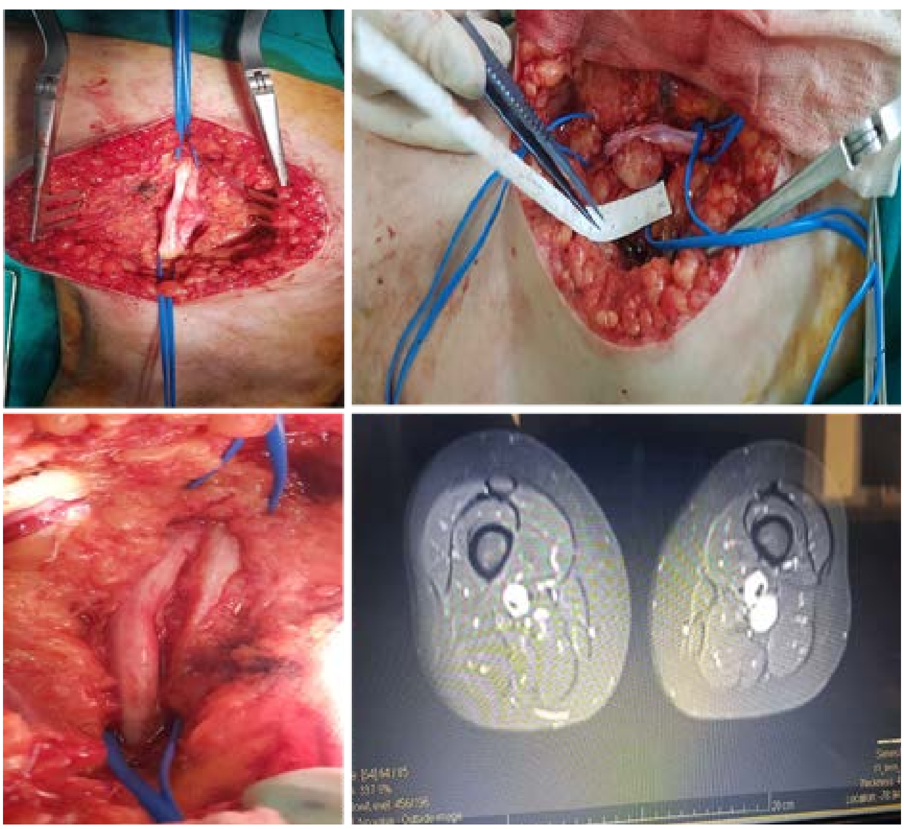

Fig 5,6,7,8 - *Symptomatic sciatic nerve schwannoma in the middle third of the thigh that respected the nervous anatomy ot the sciatic nerve body, therefore it was completely excised. The patient reported almost complete regression of the symptoms at 9 months postop.*

Results and discussions

In the case of solitary benign tumors, the results of the surgery are usually very good, with the progressive improvement of the symptoms and with the complete function preservation of the involved peripheral nerve. It should be mentioned that we choose to offer patients the option of surgery only if they describe pain or debilitating paresthesias or if the tumor is large or growing rapidly. [6]

The decision to use nerve grafts is made in young patients with large tumor formations and with motor response of the bundle (s) involved.

Neurofibrosarcomas require complex multispecialty treatment – chemotherapy and radiation - and surgery usually consists of large excision in healthy tissue, so preservation of function is generally impossible. [7]

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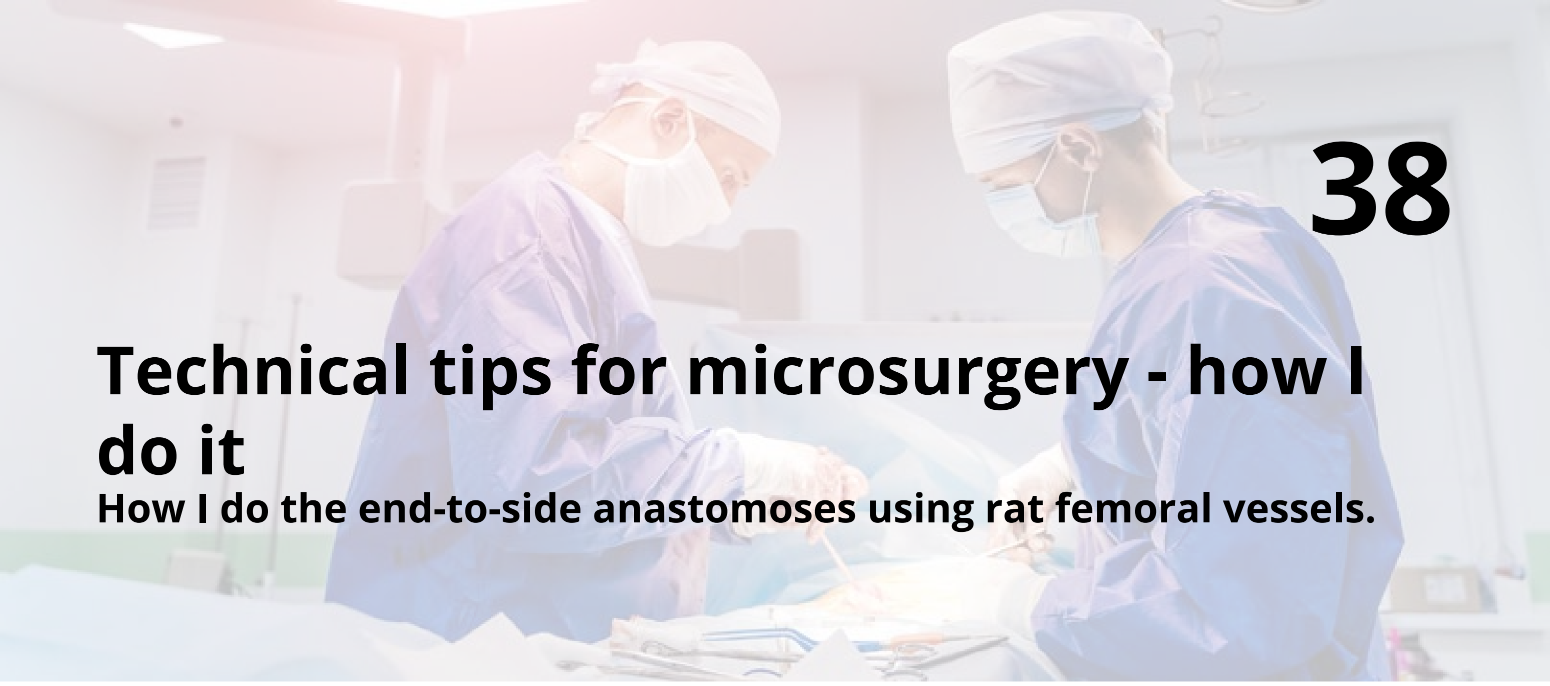
VIII
Miscelanious



38

Technical tips for microsurgery - how I do it

How I do the end-to-side anastomoses using rat femoral vessels.

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Introduction:

Microsurgery is a demanding surgical skillset, which requires constant attention and practice to succeed. Instructional courses around the globe allow students to learn from advanced microsurgery instructors through a variety of technical exercises. Expert instructors relay technical tips and tricks developed over decades of experience. By imparting these tips and tricks, student improvement through the course accelerates.

This instructional passage shares technical tips and tricks for the completion of the end-to-side (ETS) anastomosis (both arterial-to-venous and venous-to-arterial anastomoses) for the rat femoral vessels. Clinically, this procedure can be applied to re-vascularization during free tissue transfers, organ transplants, arterial-venous (AV) Fistula, and venous-arterial (VA) anastomosis for dialysis, among others. Clinical applications for this procedure are far reaching.

This article walks through a step-by-step procedure (offered in our basic course) for both exercises using the femoral artery and vein of the rat. While this procedure can be easily extended to a variety of veins and arteries, the use of two autologous vessels are highlighted due to the similarities in vessel size and anatomical proximity. Although clinically the end-to-side is more commonly performed either artery-to-artery or vein-to-vein, we use artery-to-vein and vein-to-artery anastomoses so students learn to perform both arteriotomy and venotomy.

In our advanced course, more clinically relevant procedures are offered. These include artery-to-artery ETS (utilizing either two carotid arteries or femoral artery to carotid artery bypass,) and vein-to-vein ETS (utilizing epigastric and femoral veins Fig. 1). Additional coursework is tailored to student surgical specialties as needed. These procedures are not going to be explicitly discussed, as technically similar procedures are described in detail below.

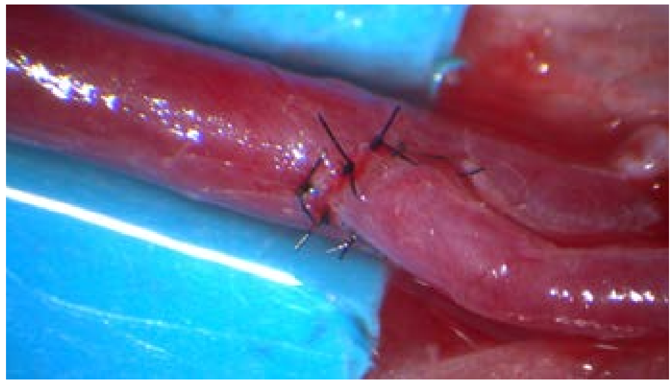


Figure 1: *End-to-Side: End of Epigastric Vein to the Side Femoral Vein*

Step by step procedure to perform end-to-side anastomosis (arterial-venous fistula):

Preparing Femoral Artery (end vessel):

1. Carefully dissect both femoral artery and vein by separating the vascular sheath surrounding both vessels. Use blunt dissection under high magnification. Ligate and coagulate all of the Murphy's branches on both vessels.
2. Place a single clamp on the proximal end of the femoral artery and ligate all the way distally towards the epigastric artery.
3. Transect the artery close to the ligature and flush with heparinized saline.
4. Prepare the edge of the artery by trimming adventitia before dilating the edge using vessel dilators.

Preparing the Femoral Vein (side vessel):

5. Place two single clamps on both the proximal and distal end of the femoral vein.
6. Position the artery next to the vein to help visualize the space needed for the venotomy (Fig. 2).

Keep the following two factors in mind when visualizing the venotomy.

- Do not place too much tension on the artery by planning the venotomy too far distally on the vein.

- Try to avoid placing the venotomy directly on top of the Murphy's branch.

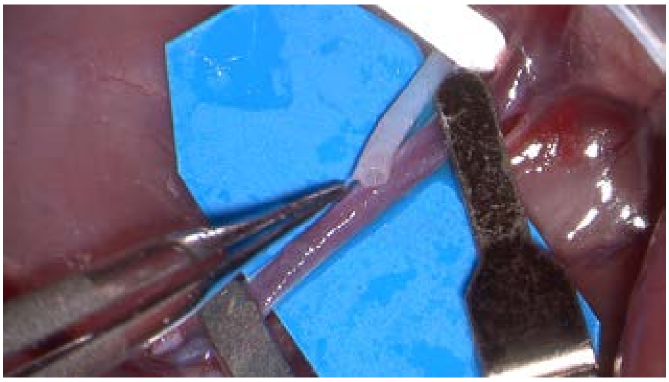


Figure 2: *Positioning Femoral Artery Next to Femoral Vein to Locate the Site for the Venotomy*

Performing the Venotomy:

7. Gently lift the vein wall with straight forceps and make a small "v shaped" cut underneath the forceps. To do so, position your scissors longitudinally along the vein at a 45 degree angle, and make a small nick in the vein.
8. Flush the vein fully through the newly made cut with heparinized saline.
9. Dilate the venotomy opening using a vessel dilator to a size that is approximately 20% larger than the diameter of the artery (Fig. 3).

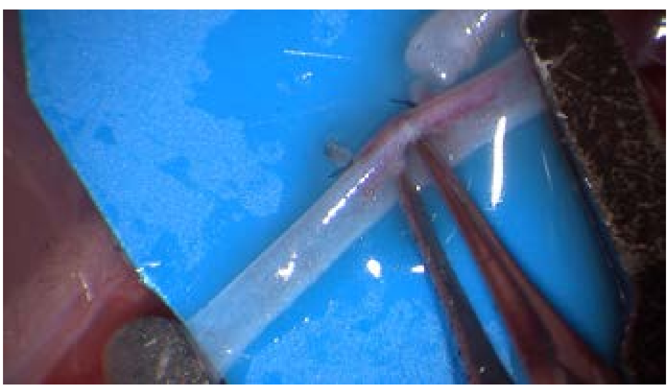
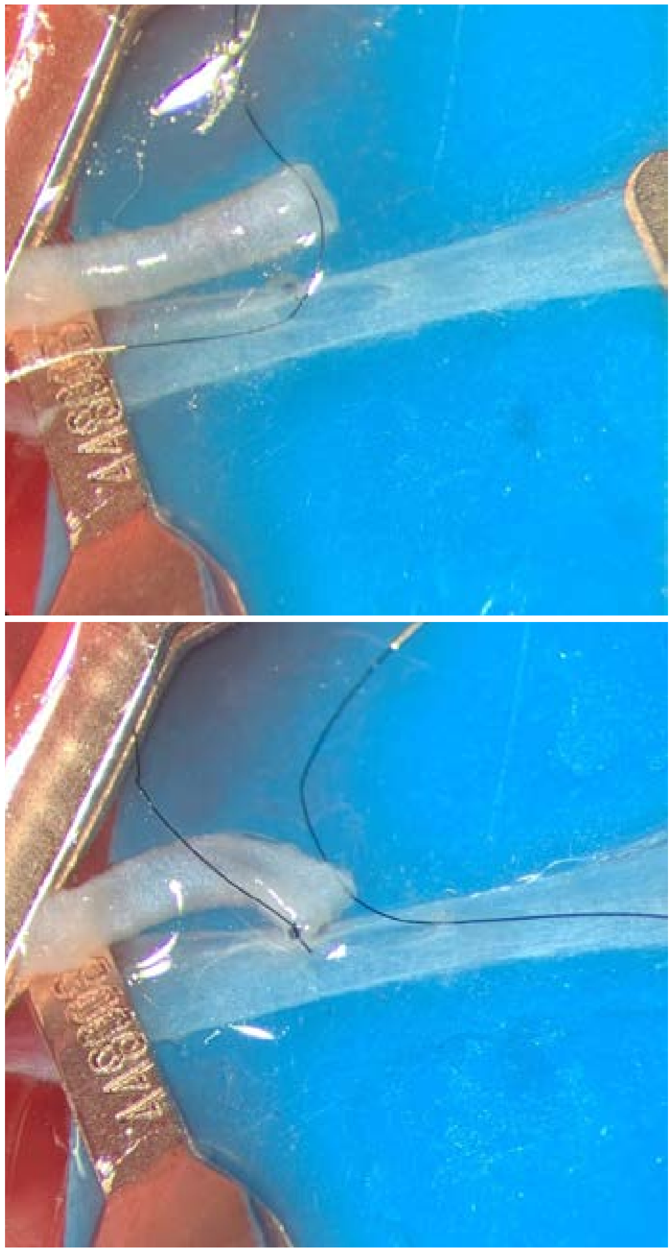


Figure 3: *Creating Venotomy in Femoral Vein by Dilating the Small Hole in the Vein*

Performing End-To-Side Anastomosis:

10. Connect the end of the artery with the side of the vein with the first stitch that should be placed closest to the proximal end of the artery at the longitudinal aspect of the elliptical venotomy (usually 9 o'clock position)
11. The second stitch should be placed 180 degrees opposite the first stitch (usually 3 o'clock)

Make sure the stitches are made "outside in, inside out" (Figs. 4, 5).



Figures 4 & 5: *Placing the 9 o'clock and 3 o'clock Stitches of End-to-Side Anastomosis*

12. After this, we suggest completing circumferential stitches on the wall that is oppo-

site the surgeon (i.e. complete the back wall first). This will help prevent inadvertent back-wall stitches throughout the procedure. It suggested completing more difficult wall first.

13. In order to more readily view the back wall, we suggest flipping the arterial clamp to the opposite side and placing a retraction stitch through the adventitia of the murphy branch before securing to nearby muscle (Fig. 6).

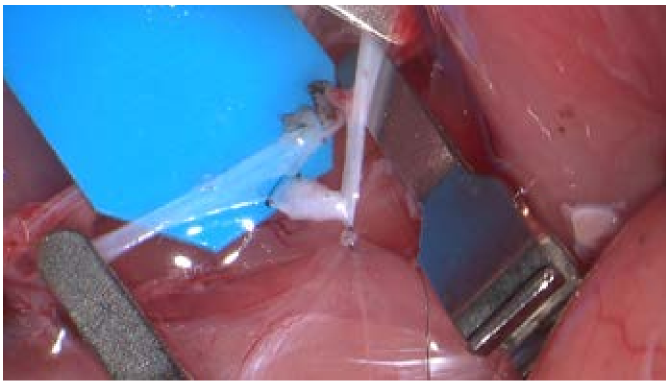


Figure 6: *Securing a Retraction Stitch Through the Adventitia of the Murphy Branch to Nearby Muscle*

14. Make sure the middle stitch is placed straight and two others radially. Pay attention to the spacing between the stitches. Be sure to make small bites when throwing stitches (between 1 and 2 needle widths from the suture line).
15. After completing the back wall, complete the front wall (side closest to the surgeon). In order to avoid the back wall, we suggest keeping the middle stitch open while also placing two radial stitches. Then, close both radial stitches before closing the middle stitch. Again, place all stitches in the same "outside in, inside out" manner. While this requires 2 separate needles to complete, students are more likely to produce successful and patent vessels.
16. Examine the anastomosis for gaps before releasing the clamps. The order of clamp release should follow the lowest blood pressure to highest blood pressure.

- Remove the clamp from the proximal vein.
- Remove the clamp on the distal vein.
- Remove the final clamp from the artery.

17. Some bleeding will occur. This is normal. Place the fat pad over the anastomosis and wait one to two minutes. Remove the fat pad and examine the anastomosis (Fig. 7).

Figure 7: *Complete End-to-Side Femoral Artery to Femoral Vein Anastomosis*

18. To check the patency of the end to side anastomosis, you can occlude the arterial blood flow with straight jeweler forceps (Fig. 8). This will only allow venous blood to enter the vein (seen visually with deoxygenated blue blood flow). Next, release the artery and carefully observe a color change from blue to pink as oxygenated arterial blood starts entering the vein.

Figure 8: *Checking Patency of End-to-Side Anastomosis by Occluding Arterial Blood Flow*

Step by step procedure to perform end-to-side anastomosis (venous-arterial anastomosis):

The main difference from the end-to-side arterial-venous fistula is performing the arteriotomy instead of a venotomy. Preparation of vessels are largely the same. Remove all adventitia thoroughly over an area twice as large as the arteriotomy.

Preparing the Femoral Vein (end vessel):

1. Clamp the distal end of the vein and cut proximally.
2. Transect and prepare the vein edge. Be careful when trimming the adventitia of the vein, this process is best performed under water and on the high magnification to better differentiate venous adventitia from lumen.

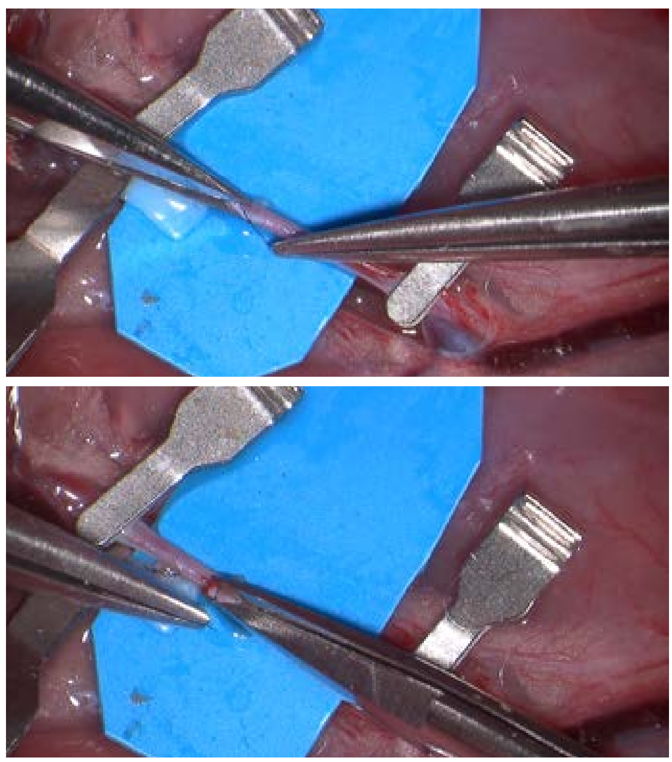
Preparing Femoral Artery (side vessel):

3. Place two single clamps on both the proximal and distal end of the femoral artery.
4. Position the vein next to the artery to help visualize the space needed for the arteriotomy. Keep the following two factors in mind when visualizing the arteriotomy.

- Do not place too much tension on the vein by planning the arteriotomy too far distally on the artery.
- Try to avoid placing the arteriotomy directly on top of the Murphy's branch.

Performing the Arteriotomy:

5. First, at the place for the arteriotomy place a suture transversely through the vessel wall, tie it, and leave the suture long. This will provide the surgeon with a clear way to hold on to this piece of the vessel, which that be excised.
6. Lift the artery up using that suture and make two scissor cuts from opposite directions at a shallow degree angle to the vessel such that both cuts meet evenly from either side (Figs. 9, 10). To perform this more easily, switch the hand used to make both cuts each time. This will ensure proper alignment of the scissor blades.
7. Make sure the size of the arteriotomy corresponds to the size of the vein.



Figures 9 & 10: *Performing Arteriotomy by Cutting the Diamond Shape Opening*

Performing the End-To-Side Anastomosis:

8. To complete the end to side, follow the same steps as the end to side arterial-venous fistula.

- Take care to connect the vein to the artery in the same manner first at the 9 o'clock position and then again at the 3 o'clock position (Fig. 11).
- Stitches should be passed in the same "outside in, inside out" manner described earlier.
- Complete the back wall before the front wall. This will help students see their work more clearly and prevent backwalling stitches.

9. Check the patency by observing the vein get fully extended and pulsating with the arterial blood.
10.

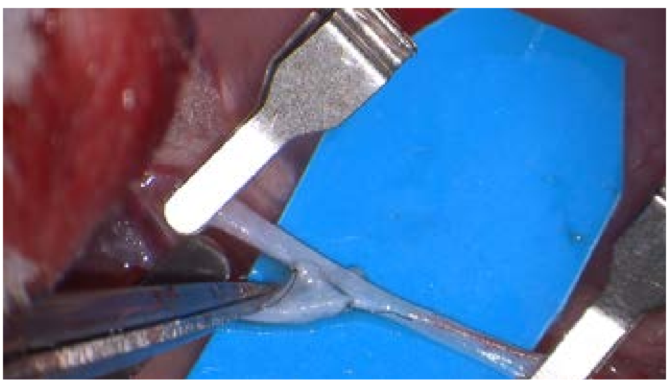


Figure 11: *Completed 9 o'clock and 3 o'clock Stitches of an End-to-Side: Femoral Vein to Femoral Artery Anastomosis*

Both procedures are considered excellent technical exercises to teach students how to perform both arteriotomy and venotomy. Equally important, however, is that microsurgical anastomotic decision making demands advanced surgical planning and attention to detail on top of a host of perioperative factors. We hope your enjoyed this step-by-step procedure and wish you the best in your microsurgical endeavors.

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39

Technical Tips & Tricks for Reconstructive Microsurgery: How I do it

Assessment of blood perfusion in microvascular free tissue transfers

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Introduction

In reconstructive microsurgery procedures, it is important to establish microvascular anastomotic patency and the desired free tissue transfer perfusion. The current gold standard for intra-operative anastomosis assessment is the Acland test, however, free flap monitoring extends and is carried out during the immediate post-operative days. Subjective methods of microvascular anastomosis and peripheral flap perfusion testing have been described for the assessment of immediate free flap (intra-operative) flow, however, this does not necessarily translates into free tissue perfusion over the 5 first days when the endothelial migration across the microvascular anastomosis has been completed or until the seventh post-operative day, when the free flap is considered safe. There are several well-recognized surgical technical reasons why flow may deteriorate over time (1, 2). Currently the main focus in microvascular anastomosis assessment is the objectivity in evaluation of free tissue perfusion and further quantification of flow in the attempt to predict failures.

The failure of microsurgical procedures may be due to poor clinical judgment, inappropriate patient selection and management, or occasionally inadequate technique. When planning a free tissue transfer procedure, a holistic patients' related factors and the general physical condition must be evaluated, to identify risk factors, such as, atherosclerosis, radiotherapy or hyper-coagulation status (3). Free tissue transfer pre-operative mapping, intra-operative algorithm and definitive flap design should follow a meticulous step-by-step hierarchy; for example the definitive flap design should be completed when the final defect to be reconstructed is known (after oncological resection or debridement), otherwise, flap design and size may prove inadequate and erroneous. Also, competency in microsurgical techniques by the surgeon is necessary in all aspects of free tissue transfer procedure, flap raising, pedicle and microsurgical dissection, to prevent technical errors that may damage the vascular pedicle which can cause vascular spasm due to inappropriate tissue handling, or total failure during flap anastomoses or flap inset.

Thrombosis is the main cause of microvascular anastomotic failures in free tissue transfer procedures (4), and it usually occurs during the first two post-operative days (5). Several factors have been though to increase the risk for thrombosis: malpractice or technical inadequacy during microsurgical anastomosis, improper vessels and tissue handling, endothelial/vessel wall damage or introduction of thrombogenic materials within the lumen (suture or adventitia), microvascular torsion and prolonged ischemic or operative times, among others (6). In addition to the intrinsic difficulties related to the microvascular inadequacy, extrinsic factors are equally significant and can compromise free tissue transfer success rates: infection, hypotension, systemic vasoconstriction, flap compression due to haematoma, and many more (7).

In advance reconstructive microvascular techniques such as perforator flap transfers, appropriate insights of the angiosome concept (8) should be applied in the process of choice of the single perforator vessel to establish adequate inflow to the tissue. Intra-operative decision making should include peripheral flap perfusion testing to ensure total free tissue blood supply. Objective evaluation using traditional clinical assessment methods or novel flowmetry technologies could establish free tissue perfusion or direct the surgeon to incorporate a further angiosome with another perforator vessel, or modify the final flap design, or even, discard poorly perfuse flap areas, and occasionally convert to a different flap pedicle or design.

Multiple devices have been tested experimentally and clinically to assess blood flow in free tissue transfer procedures: Indocyanine green angiography, laser doppler flowmetry, handheld doppler ultrasound, and transit time ultrasound flowmetry. Nevertheless, post-operative evaluation of flap perfusion is routinely based on the experience of the reconstructive microsurgical team through direct clinical observation: colour, temperature and capillary refilling time (9).

An accurate objective assessment tool that measures free tissue transfer inflow and outflow before and after of flap elevation/ vessels dissection, and after the completion of the microvascular anastomoses, might allow intra-operative prediction of failure or enable early post-operative detection, potential intervention and flap salvage.
Herein, several devices adjusted for free tissue transfers and microvascular flowmetry based on ultrasonographic or doppler, laser, thermographic and fluorescent methods have been described (10). These technological advancements in conjunction with the traditional clinical free tissue transfer evaluations of blood perfusion flap tests aim towards valid and objective prediction of free flap failures (Table 1).

	Invasive	Pre-op	Intra-op (Pre-A)	Intra-op (Post-A)	Post-op
Patency Test	√			√	
Pinprick Test	√		√	√	√
Combined ICG - Pinprick Test	√		√	√	√
Acoustic Doppler Sonography		√		√	√
Colour Doppler Ultrasound		√	√	√	√
Implantable Cook-Swartz Doppler	√			√	√
Laser Doppler Flowmetry					√
Laser Speckle Contrast Analysis		√	√	√	√
Dynamic infrared thermography		√	√	√	√
ICG Fluorescence Angiography	√	√	√	√	
Transit-time Ultrasound Flowmetry	√		√	√	

Table 1. Assessment techniques and devices in reconstructive microsurgery.
Pre- Intra- and Post- op, Pre- Intra- and Post-operative; Pre- and Post- A, Pre- and Post-anastomosis; ICG, Indocyanine Green;

Microvascular Patency (Acland) Test

The clinical on-table flap monitoring and distal perfusion can establish distal intra-flap circulation. The Acland test, a subjective manual patency test that has been used for several decades as the gold standard method primarily for arterial inflow assessment in free tissue transfers. It is routinely used from expert microsurgeons to evaluate the success of microvascular anastomoses (11), by emptying a vascular section at the distal portion of the anastomosis with two microsurgical forceps. A positive test is considered when the proximal forceps is released and a rapid re-fill of the vascular segment is demonstrated (Figure 1). In experienced hands the Acland test is considered gold standard and valid, however, studies its quantitative value is limited, since it demonstrates whether or not blood passes through the anastomosis, but does not indicate the quality or amount of blood flow through it (12).

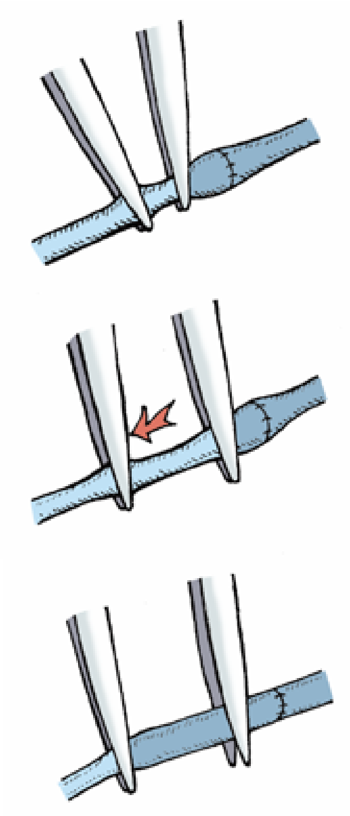

Figure 1. *Microvascular Patency (Acland) Test. Courtesy Dajiang Song and Georgios Pafitanis.*

Flap observations and the Pinprick test

Free flap monitoring is essential and comprises several methods, specifically, clinical bedside evaluations based on skin flap colour, capillary refill time, flap temperature, tissue turgor and texture, and peripheral bleeding on pinprick testing (13). Effective pinprick test, a method of testing skin free flap perfusion, is essential to establish and confirm blood inflow in free tissue transfer. A hollow straight 20-24G needle is used, in close to 90 degrees' insertion angle, to the more distal to the anastomosis pedicle skin paddle, on non-previously pinpricked or bruised skin. The needle is inserted through the dermis to the subcutaneous fat of the flap. A slower extraction speed of the needle allows fresh blood to enter the lumen, as the oblique bevelled shaped proximal needle side is exiting the skin surface. A drop of blood (above a millimeter) appears on the flap skin surface within maximum 5 seconds after full needle extraction (Figure 2). The needle hollowness and size, area and angle of insertion, speed of needle extraction through the dermal and subdermal plexuses and expected fresh bleeding time are essential during pinprick perfusion testing, especially in the hands of inexperience surgeons, to enable reliability, reduce multiple punctures and increase specificity of this test.

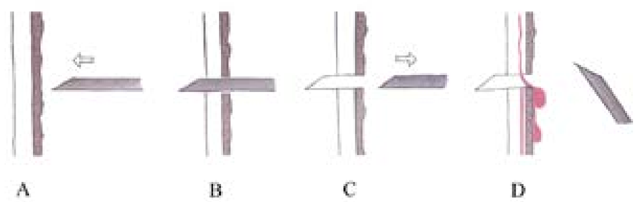

Figure 2. *The Pinprick Test, step by step: A) Use 20-24G straight hollow needle. B) Insert the needle at an angle of 90 degrees. C) Slow needle extraction speed. D) Wait up to 5 seconds until fresh blood appears.*
Courtesy Sara Ballestín.

Combined ICG-Pinprick test

Novel methods using the gold standard traditional bedside assessment, pinprick testing, combined with indocyanine green (ICG) near-infrared angiography has been reported to be useful in evaluating the distribution of flap blood flow (14). The combined ICG-pinprick flap perfusion test demonstrated effective perfusion-related outcomes in intra-oral free flaps monitoring; however, the effectiveness in execution of the pinprick test may have divergent outcomes in inexperienced hands. Especially during flap congestion, troubleshooting, or when ICG-pinprick test is performed in a very brightly perfused area.

Acoustic Doppler Sonography

Portable Doppler devices are used intraoperatively and postoperatively to monitor blood flow. The evaluation of blood flow after the anastomosis site serves as an intraoperative indicator of vascular patency. Acoustic Doppler sonography is based on the Doppler effect; emission of 5-10 MHz ultrasonic waves its reflected within the intravascular blood flow (red blood cells) and then received by the same probe. The reflected waves are translated into sound proportional to the magnitude and frequency of the reflected waves (15). Acoustic Doppler is valid in post-operative monitoring of fasciocutaneous flaps to evaluate skin perfusion through the vascular pedicle. Portable handheld Doppler probes are extremely useful, easy to use, and inexpensive.

Colour Doppler Ultrasound (CDU)

It is a non-invasive indirect method that can be used for flap monitoring, allowing to visualize vessels or the micro-anastomoses and demonstrating the direction of blood flow. The equipment involves an ultrasound probe and a monitoring device/screen. It provides, blood flow output in either sound or a dynamic screen visualisation of the vessel, with colour shading (red or blue) according to magnitude of blood stream velocity (16). It can be used as a pre-operative mapping tool for flap planning, as an intra-operative adjunct and it's a valid tool for post-operative free tissue transfers monitoring, indirectly for external skin paddle or even buried flaps (16, 17).

Colour Doppler Ultrasound (CDU) is a safe alternative technique that allows radiation-free dynamic pre-operative perforator mapping, but it's use is subjective and based on the experience of the operator. Recent studies have compared computerized tomography, CDU and Magnetic Resonance Angiography (MRA), demonstrating the pros and cons of each method. Recently, a hand-held ultrasound device, the Butterfly iQ (www.butterflynetwork.com), has successfully been used for these procedures (Figure 3). This is a portable and affordable ultrasound-on-chip technology that is compatible with most current mobile and tablet devices with a USB-port, that provides similar data to the traditional ultrasound transducer system with a single silicon chip.

Figure 3. Butterfly iQ – Colour Doppler Ultrasound device.

Implantable Cook-Swartz Doppler

Implantable Doppler devices allow continuous free flap monitoring by applying a wrap-around micro-probe distally to the vascular anastomosis. These implants have a crystal probe that emits ultrasound at 20 MHz, the probe is incorporated into a 0.5 cm wide silicone micro-cuff that is wrapped around the vessel. The line that connects the probe with the Doppler equipment is secured in the external aspect of the flap providing post-operative real-time monitoring of the flap blood inflow (arterial) or outflow (venous). This technique is particularly useful in buried flaps or in free tissue transfers without skin component (muscle or osteocutaneous flaps) (16, 18). It is a technology highly sensitive, however, with potential false positive outcomes (16).Since 2010, also mechanical devices for performing anastomoses allow the placement of 20 MHz Doppler probes (Implantable Flow Coupler) to assess the patency of anastomoses both intra- and post-operatively.

Laser Doppler Flowmetry

The Laser Doppler Flowmetry is based also on the doppler effect; a laser beam targets small vessels and detect blood cell motion within the free tissue skin (19). This scanner creates an image of the microvascular blood flow pattern of any skin surface. It is a non-invasive and does not require direct contact with the tissue. The Doppler frequency change is used to measure the speed of blood flow. The frequency change is proportional to the number and speed of the red blood cells found in the field evaluated (15). The results of the measurements are reflected in the form of relative velocity and in units of ml / min / 100g, sometimes abbreviated as LDF (Laser Doppler Flowmeter Units). The probes applied to the skin allow evaluation of flows to depth up to 8 millimeters (18).

Laser Speckle Contrast Analysis (LASCA)

Laser speckle is a technology that utilises an interference pattern produced by light reflected or scattered from different parts of an illuminated skin surface. It is a valuable technique for the semi-quantitative real-time mapping of skin blood flow (perfusion) (20). Distal free tissue skin perfusion results are demonstrated in arbitrary units and are not directly related to actual flow values (21). Despite of this, LASCA is a promising method for the evaluation of flaps and may prove to be a valuable tool that predict hypoperfusion and potentially early signs of flap partial necrosis (22).

Thermal Imaging

Infrared thermography a known concept since the 1800 when Sir William Herschel discovered “infrared” radiation (23). Since the invention of a camera that detect the “heat signal” of any object, further advancements adjusted thermographic camera that generates visible heat map to demonstrate the flow in perforator vessels(24). Currently, infrared thermography demonstrated promising applications as a modality for preoperative mapping of perforator vessels. Thermography is portable, inexpensive, non-invasive imaging method, especially when used with the Forward Looking Infrared (FLIR) ONE camera. The FLIR ONE is a smartphone camera that has shown to provide excellent objective data on the perforator’s location. Thermography demonstrated good results in different rewarming rates of perforator vessels, assist in identifying the inter-perforating anastomose vessels to allow the axon of flap design and gives objective data for angiosomes (25).

Recently, there is a trend towards the use of thermal imaging in preoperative mapping, intraoperative and postoperative free tissue transfer perfusion assessments, in particular in the field of breast reconstruction. In 2012, Whitaker et al. performed a comparison between infrared thermography and CTA (26), the gold standard of vascular imaging. He demonstrated provisional clinical application of thermal imagining to perform a unilateral breast free tissue reconstruction. In 2013 Sheena et al, compared thermal imaging device versus CDU and demonstrated that abdominal thermogram was an effective method for locating cutaneous perforators (27).

Infrared Thermography (IRT) is a promising method for flap planning and harvesting, it allows easy, cost-effective and non-invasive method of assessing perforator location and has potentials in assisting surgical decision-making in a dynamic real-time fashion. IRT however, does not provide evidence in regards to the morphology or physiology of the targeted vessels. In order to solidify its applicability, specificity and sensitivity in all aspects of free flaps planning and monitoring further studies must compare it to the current gold standards, however, its current technology allow to be part of a standard post-operative flap monitoring easy, cheap and pliable tool.

Indocyanine Green Fluorescence Angiography

This invasive method is based on intravenous injections of a fluorescent dye: indocyanine green (ICG, Indocyanine Green Dye). ICG is a hydrophilic dye that, when administered intravenously, binds to plasma proteins such as albumin and has fluorescent properties when excited with a light of wavelength 780 nm (near infrared) and captured with a filter of wavelength of 830 nm. Following administration, the ICG has a short half-life (3-4 minutes) therefore, a further injection may be required for repeated investigation.

The ICG is used to perform angio-fluorescent studies. ICG angiography allows to visualise more detailed micro-vascular patterns than fluorescein angiography, moreover, this method has been used to assess the viability of free tissue transfer, as well as to estimate partial or total perfusion of tissue when the perforator concept has been applied to the flap design (28). Currently, incorporated-infrared-camera operating microscopes enable dynamic and augmented angiography to be performed intraoperatively. It allows visualization of vascular anatomy and pedicle patterns in submillimeter vessels, something that could not be possible with conventional angiographic techniques (29). In addition, the contrast media used in conventional angiography is highly viscous and is not recommended in reconstructive microsurgery. It could cause hyper-viscosity in the microcirculation, as it can remain attached to the vessel intima, and potentially jeopardize the patency of anastomoses.

Transit-time Ultrasound Flowmetry

Flowmeters based on transit-time ultrasound technology are widely accepted as standard method for intraoperative evaluation of vascular patency in thoracic surgery. By using threshold values, the outcome of procedures in coronary vascular anastomoses and vascular grafts can be predicted (30, 31). However, there is limited evidence regarding the use of this technology in the field of reconstructive microsurgery (10). If there were sufficient scientific evidence and the indicated threshold values to predict the results of microsurgical interventions, this technology would allow the revision of anastomosis intra-operatively in the event that there was any type of problem (32).

It is a relatively novel tool for the qualitative and quantitative evaluation of vascular flow in submillimeter vessels, which is possible thanks to probes capable of measuring the flow in microvascular structures (33, 34). Nowadays, there are flow probes which can measure vessels ranging from 0.4 mm to 4 mm diameter. The target vessel should be place without any tension in the ultrasonic sensing window (between the reflector and the transducers of the probe) and when good ultrasonic coupling is achieved the blood flow is quantified (Figure 4). Recent studies indicate that this technology allows identifying incorrectly performed anastomoses and can also improve the selection of recipient vessels when making free tissue transfers (35).

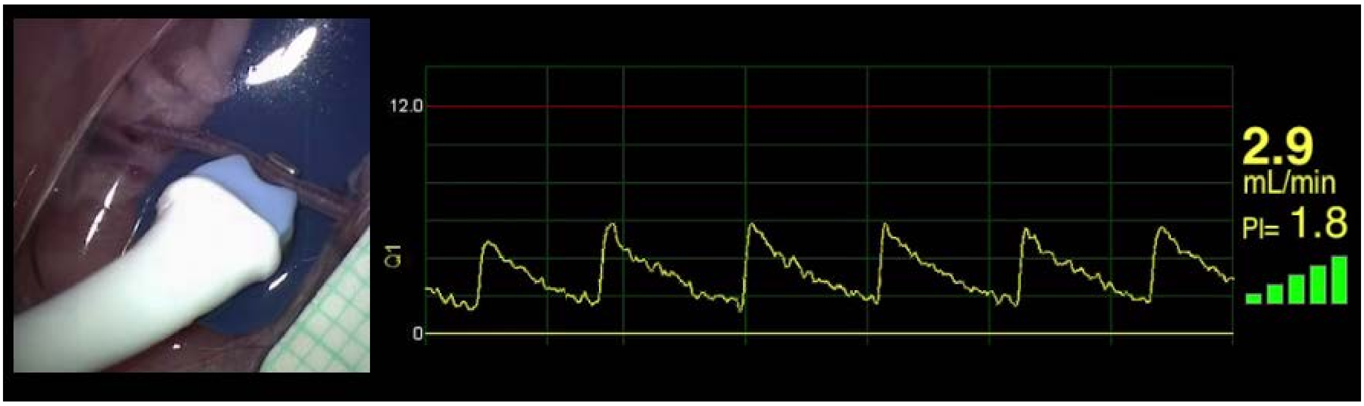

Figure 4. *(Left) 0.6mm diameter vessel placed in the ultrasonic sensing window of a transit-time ultrasound flowmeter probe. (Right) Results of the blood flow measurement: Stable and repeatable waveform, mean flow (mL/min) and ultrasonic coupling quality (green bars). Courtesy Transonic INC.*

Conclusion

Microsurgical free tissue transfers have nowadays a very high success rate (95-99%), however, there is a proportion of free flaps that require revision or exploration to minimise the impact of total or partial failure to the patients. Early recognition of partial or total flap failure could reduce the amount of complications in terms of the aesthetic and functional outcomes of any reconstructive procedure. Nowadays, there is no international robust consensus regarding flap monitoring. Reliable technologies are essential to identify failures early or to predict negative outcomes in reconstructive microsurgery. Current technologies allow objective assessment of free tissue transfers, aiding intraoperative decision making, helping in flap revision and improving patients' outcomes.

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Imaging & Staging-Guided Lymphatic Microsurgery According to the Genoa Protocol.

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Chronic peripheral lymphedema is a progressive and a relatively painless swelling of any peripheral tissue, including limbs, head and neck, breast, trunk or genitals that is the result of a reduced transport capacity of the lymphatic system. Chronic lymphedema can be classified as primary or secondary, according to the etiology. In patients with secondary lymphedema, a specific external cause (filariasis, previous surgery, radiation, malignancy, infection or inflammation, trauma, etc.) can be identified and is believed to impact on a presumed previously normally functioning lymphatic system by causing an obstruction in the lymphatic flow (either from the direct removal of lymph nodes and/or lymphatic vessels or damage to the same). The majority of the clinical conditions that are considered to be primary lymphedema are due to truncular lymphatic malformation that arise during the final stages of the lymphangiogenesis when there is the formation of the lymphatic trunks, vessels, and nodes [1]. These malformations result in dysplasias, hypoplasia, hyperplasia, or aplasia of the lymphatic vessels and/or the lymph nodes and may clinically manifest as obstruction or dilatation. Secondary lymphedema, instead, occurs as a later injury to a presumed normally developed lymphatic system as a result of surgery for cancer treatment, infection, or other trauma (see Table 1). In reality, it is not possible to determine if a peripheral lymphedema is primary or secondary simply from a physical or instrumental examination of the affected limb, as the clinical picture is the same regardless of etiology. What is useful, however, is to classify the lymphedema by stage of disease, as this predicts treatment outcome.

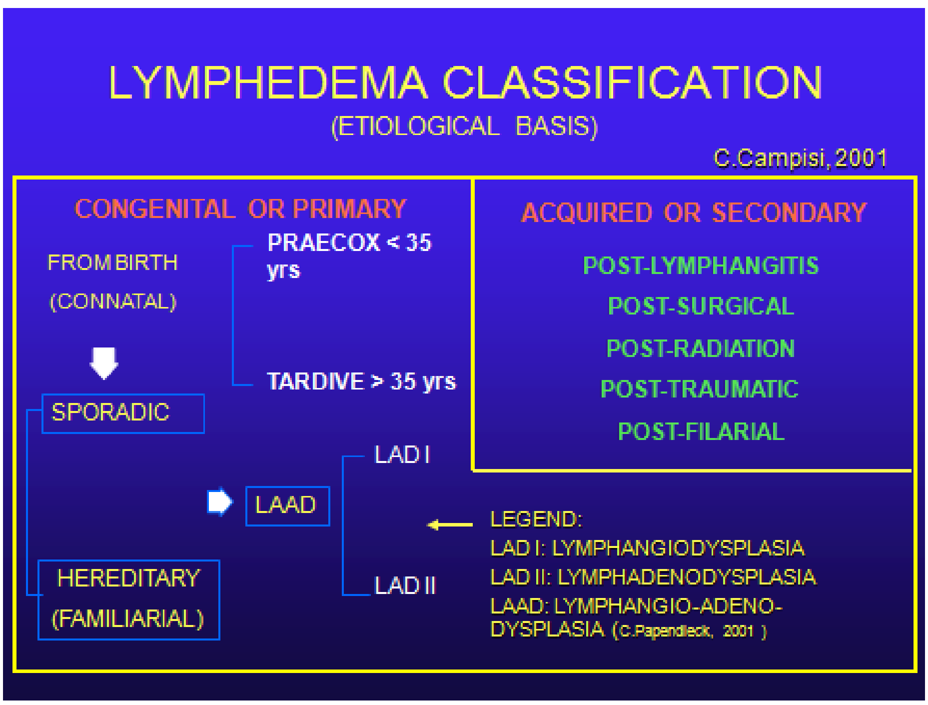

Table I. *Classification of Lymphedema (C. Campisi, 2001)*

In order to provide such a comprehensive classification system of lymphedema that encompasses immunohistopathological criteria, level of clinically evident edema, lymphoscintigraphic findings, and level of physical disability, we developed a three-stage model (Figure 1) [2,3]. In clinical practice, stages IA, IB, IIA and IIB can be considered as early manifestations of disease and stages IIIA and IIIB (properly known as elephantiasis) to be chronic and advanced. It should be noted that lymphedema is a progressive disease and can move rapidly between the stages without adequate treatment [4-7].

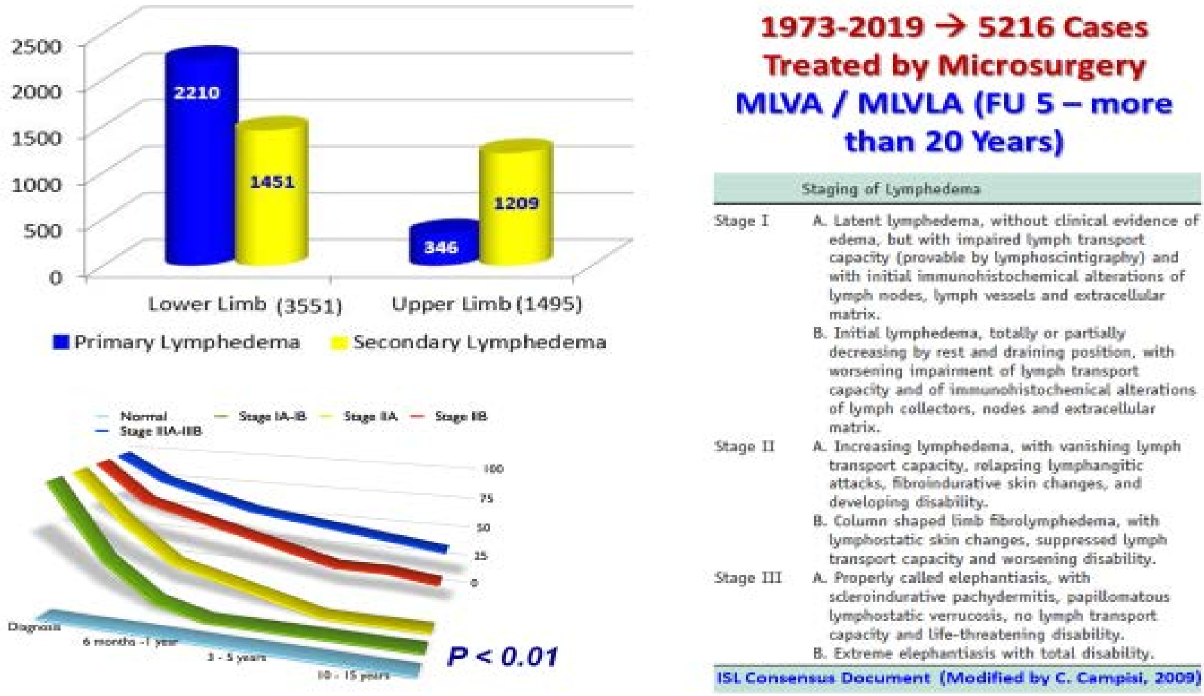

Figure 1. *Lymphedema Staging and Long-Term Clinical Outcomes of Microsurgery*
A proper surgical-microsurgical approach can represent today an effective system of treatment, when rationally combined with conservative (medical and physical) procedures for many lymphatic disorders [8-13]. Refractory chronic limb lymphedema, in particular, when unresponsive to conservative treatment measures, may be appropriately managed by surgical means.

The development, within the last 50 years, of surgical techniques to restore lymphatic flow offers a treatment that targets more than symptomatic relief, but provides a functional repair of the underlying problem of lymph-stasis. Indications for Lymphatic Microsurgery include: insufficient volume reduction by appropriate conservative methods (less than 50% reduction), recurrent lymphangitis or erysipelas episodes, intractable discomfort, usually associated with the excess swelling and inflammation, loss of limb function, increasing disability and poor quality of life, and patient dissatisfaction with previous treatment outcomes and willingness to proceed with surgery. The Center of Lymphatic Surgery and Microsurgery in Genoa, Italy, has obtained excellent stable clinical outcomes for 40 years by utilizing MLVA (Multiple Lymphatic-Venous Anastomoses) /MLVLA (by Multiple Lymphatic-Venous-Lymphatic Anastomoses) techniques. Anastomoses are performed at a single site using larger lymphatic vessels attached to collateral branches of the main veins close to vein valves in order to avoid backflow of blood and the closure of the anastomosis. A single-site approach also minimizes the number of incisions and thereby potential entry sites for infection.

Indications for Lymphatic Microsurgery include: insufficient volume reduction by appropriate conservative methods (less than 50% reduction), recurrent lymphangitis or erysipelas episodes, intractable discomfort, usually associated with the excess swelling and inflammation, loss of limb function, increasing disability and low quality of life, and (last but not least) patient dissatisfaction with previous treatment outcomes and willingness to proceed with surgery. In more advanced cases (late stage IIB, IIIA, IIIB – refer to the Campisi staging of Lymphedema – Figure 1), where the lymphoscintigraphy shows no visualization of lymphatic channels and regional lymph-nodes, it is necessary to reduce the stage of the lymphedema by intensive conservative methods prior to surgery, in order to reduce the clinical stage of the disease and best prepare the limb for surgery.

New techniques have also emerged for the combined treatment of these advanced stages of chronic peripheral lymphedemas where there is significant fibrotic adipose tissue deposits [13] [14] due to disease progression, which contributes to residual lymph-stasis and increased risk of infection. Our original technique of Fibro-Lipo-Lymph-Aspiration using a Lymph Vessel Sparing Procedure (FLLA-LVSP) was developed to improve this chronic swelling of patients with advanced lymphedema [15] [16].

Methods

Between July 1973 and December 2019, 5216 patients received microsurgical treatment for peripheral lymphedema in Genoa, Italy: both upper and lower limb lymphedema and primary and secondary etiology. Patients were followed for a minimum of five years to a maximum of 25 years post-operatively. The follow-up consisted of periodic clinical evaluations at 1, 3, 6 and 12 months after microsurgery, and then annually for a minimum of five years to more than 20 years. This close patient follow-up gives optimal control for the long-term clinical outcome.

Histological samples taken during surgery showed that primary lymphedemas typically involved lymph-node dysplasias (LAD II according to Papendieck's classifications [17]) with hypoplastic lymph-nodes associated with sinus histiocytosis and a thick fibrous capsule and micro-lymphangio-adenomyomatosis. These dysplasias caused an obstruction to lymphatic flow that was evident in the changes in the afferent lymphatic collectors: these are dilated, swollen, and tortuous with thickened walls and reduced numbers of smooth muscle cells, which are further fragmented by numerous fibrotic elements.

The *MLVA* procedure is the preferred approach as it creates output lymph transport through multiple lymph collectors anastomosed to one or more tributary(ies) vein(s) branch(es) of a main venous trunk. A lymphatic-venous anti-gravitational pressure gradient is achieved with well-competent venous valve apparatus, avoiding any kind of blood reflux and consequent possible thrombotic occlusion of the anastomosis. Both superficial and deep patent lymph collectors are selected under the guide of the BPV (Blue Patent Violet) lymphochromic test and/or Fluorescent Green Indocyanine Microlymphography (ICG Test – Figure 2).

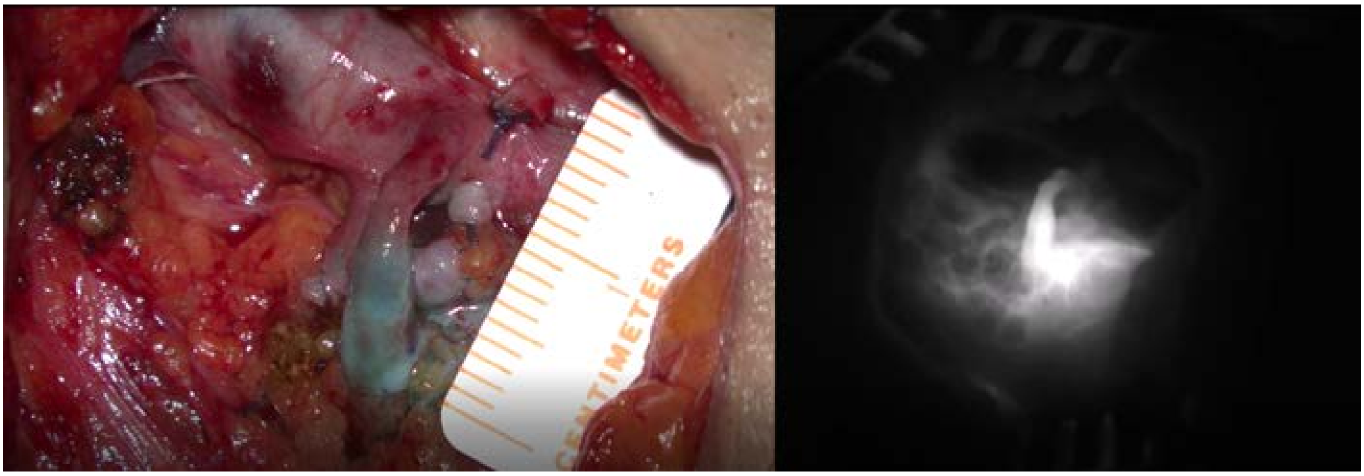

Figure 2. *Single-Site MLVA at the epifascial inguinal-crural region and the peri-operative confirmation of patency with ICG dye*

The *MLVLA* procedure involves an autologous interpostioned vein graft (preferably harvested from the volar surface of the forearm). The proximal stump of the vein graft is anastomosed with lymphatic vessels isolated above the obstruction and the distal stump is anastomosed with lymph collectors isolated below. From the physio-dynamic point of view, the most important aspect to achieve an effectively draining vein interposition graft is to anastomose a greater number of lymph collectors distally than proximally, creating a positive pressure and anti-gravitational lymphatic-venous-lymphatic pressure gradient.

Objective pre- and post-operative clinical outcomes included excess limb volume (ELV), frequency of dermatolymphangioadenitis (DLA) attacks [13], and use of conservative therapies. Patients were followed for a minimum of five years to over 20 years [3] [8] [9].

Microsurgical interventions are part of an integrated treatment protocol called 'Complete Lymphedema Functional Therapy' (CLyFT) [10], [11]. The other elements of the protocol consist of manual and mechanical lymphatic drainage and intermittent negative pressure therapy, in conjunction with appropriate compressive garments. Mechanical lymphatic drainage refers to the use of uniform and sequential pneumatic devices. In Genoa, Italy, CLyFT is applied in three phases: an intensive pre-operative phase to reduce the size of the affected limb as much as possible prior to the microsurgical intervention, followed by a gentle post-operative phase in which the pressure of the lymphatic drainage is gradually increased as healing continues, and finally, a long-term maintenance phase of daily mechanical lymphatic drainage and physical exercise (particularly swimming) to strengthen the anastomotic joins over time. The timing of the treatment protocol depends on the pre-operative stage of the disease but in general there is one-to-two weeks of pre-operative CLyFT, the microsurgical intervention, and then one-to-two weeks of post-operative CLyFT, before patients initiate the maintenance phase.

A selected group of 700 patients with advanced stages of primary or secondary lymphedema underwent FLLA-LVSP after the microsurgery. Lymphatic mapping was performed directly with the Fluorescent Micro-Lymphography with Indocyanine Green dye (ICG Test) of the superficial lymphatic pathways (and indirectly by the BPV lymphochromic test), so that these pathways were preserved, and therefore, avoided by the cannula. The procedure was performed without tourniquet and by a tumescent technique with standard Klein Solution subcutaneous infiltration (range of 0.2-0.8 L), delivered to control bleeding and to achieve a better analgesic immediate post-operative effect. Liposuction proceeded distally to proximally along the treated limbs, following the previous lymphatic mapping.

Results

In our clinical experience, secondary lymphedemas were usually related to lymphadenectomy and radiotherapy as part of oncological treatment (carcinoma of the breast, uterus, penis, bladder, prostate gland, rectum, and seminoma of the epididymis) or for complications of minor surgeries for varicose veins, groin and inguinal hernias, lipomas, tendinous cysts, or inguinal and axillary lymph nodal biopsies. Most of the lymphedemas treated were at stages IIA (39%) and IIB (52%), with 3.8% at stage IB and 5.2% at stages IIIA and B (according to the Campisi staging system for lymphedema – refer to Figure 1) [18] [19].

Compared to pre-operative measurements, patients obtained significant reductions in ELV of over 86 %, with an average follow-up of 10 years or more (Figures 3 and 4). DLA attacks were considerably reduced by over 92% compared to pre-treatment incidences. Over 87% of patients with earlier stages of disease (stages IB or IIA) progressively stopped using conservative therapies and 46% of patients with later stages (stages IIB and III) decreased the frequency of physical therapies.

Figure 3. *Preoperative photo of patient with lower limb lymphedema secondary to oncological treatment (Left). Immediate postoperative photo (Right).*

Figure 4. Preoperative photo of a patient with advanced upper limb lymphedema secondary to breast cancer treatment (Left). Long-term stable results of more than 10 years after MLVA (Right).

For the FLLA-LVSP, the average amount of fibrous adipose aspirated from the upper limb was 0.90L and from the lower limb was 2.44L. The length of the 120 procedures was relatively constant; with an average of 70 minutes for the upper limb (45' min-90' max, SD of 14.43) and 108 minutes for the lower limb (75' min-120' max, SD of 10.07) (Figure 5).

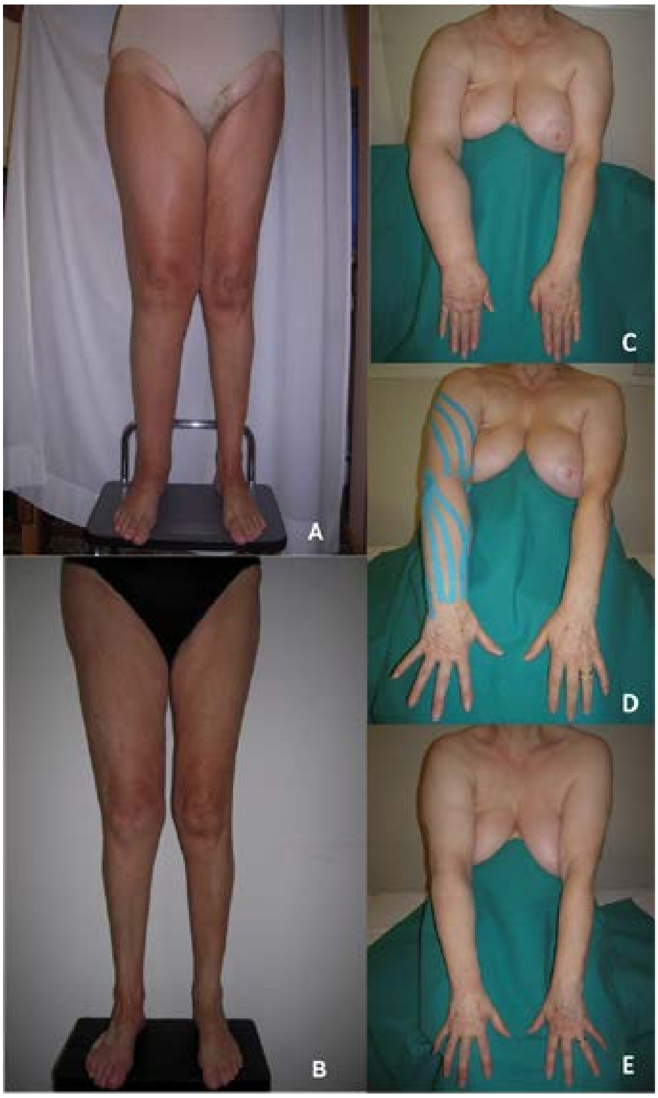

Figure 5. *Advanced Secondary Lymphedema: Right leg – Pre-op (A) and Post-op (B): Significant clinical long-term outcome after MLVA + FLLA-LVSP; Right arm – Pre-op (C), with stable long-term results: Post-op MLVA (D), and subsequent FLLA-LVSP (E)*

Conclusions

In recent years, Lymphatic Disorders, most particularly, Chronic Peripheral Lymphedemas are becoming better understood and more manageable problems with increased awareness in the medical community and earlier detection. Derivative and Reconstructive Microsurgery can restore lymphatic drainage, both in the short and long term, and the best results are obtained when these surgical procedures are applied in the early stages of disease and when appropriately combined with physical rehabilitative methods.

In the Centre of Lymphatic Surgery, Genoa, Italy, treatment for peripheral lymphedema is conducted according to a prescribed protocol. CLyFT represents the initial treatment for all patients. The surgical timing is based on the clinical indications: in the initial stages of lymphedema, microsurgery is applied early in the treatment process before the progression to fibrosclerotic tissue changes and excess adipose deposition occurs. These patients undergo one or two weeks of CLyFT to minimize the edema prior to surgery. In more advanced stages of lymphedema, where these tissue changes have already occurred, microsurgery is applied when the physical therapy component of CLyFT fails to obtain further edema reduction or prevent recurrent lymphangitis. Lymphatic microsurgery applied at this time allows further amelioration of the pathology.

Lymphatic microsurgery performed in Genoa, Italy, consists of MLVA or MLVLA performed at a single incisional site. We do not use superficial lymphatic venular “supermicrosurgery”, for the possible occlusion of these, too superficial, anastomoses that are easily compressed by elastic garments and can be also subject to the gravitational venous-lymphatic reflux with the consequent thrombotic occlusion of the anastomosis. Moreover, as this involves having to perform many anastomoses in different sites along the affected limb, this procedure mandates the need for many surgeons and many operating microscopes for each surgical session, thus increasing both the length and the cost of the surgery. The rationale behind using our single-site technique is two-fold. First, a proximal single-site surgery likely lowers the risk of infection, as there is less surface area for bacteria to breach the skin barrier. This is particularly relevant for advanced stages of disease with significant lymph stasis, where incisions made in the distal area of a lymphedematous limb may increase the risk of post-operative infection. Second, the caliber of the lymphatic vessels increases proximally. Not only are these vessels easier to use to create anastomoses, but they allow a greater amount of lymph to flow through the anastomosis. This is important when trying to redress the balance of fluid in and out of a limb.

Lymphedema can be a difficult disease to manage and is prone to progression without adequate treatment. In response to this, some surgical centers are now combining LVA with vascularized lymph node transfers or other excisional/ablative procedures such as liposuction or a modified Charles procedure [20] [21]. Unfortunately, this further muddies the water, as a successful outcome is difficult to interpret: is it due to the combined approach or would it have been obtained by a single technique if applied in isolation? Until there is standardization in the research methods for surgical treatment of lymphedema, we cannot begin to move forward to delineate the nuances of which surgery for which lymphedema patient.

In light of this, recent research findings from our lymphoscintigraphic study [22] may help to delineate which type of lymphatic microsurgery is appropriate for which type of patient. This study examined the lymphoscintigraphic exams of 248 patients with limb swelling and demonstrated that predominantly the deep subfascial lymphatic vessels are affected (either alone or in combination with the superficial vessels) in patients with primary or secondary upper or lower limb lymphedema [22] [23]. It is important to note that there are three layers of lymphatic vessels; one very superficial with the lymphatic blind collectors immediately under the epidermis that then give way to two levels of superficial sub-dermal epifascial collectors. Finally, there are the larger subfascial lymphatic vessels that arise from those draining the muscular compartment. The current study showed that these deeper vessels are pathological in lymphedema, either alone or in combination with the superficial vessels, in the majority of cases. Supermicrosurgery involves only the very superficial vessels. Instead, the single-site MLVA uses both levels of superficial vessels and the deeper ones and therefore may be more appropriate for most patients who have deep vessel involvement. It is recommended that patients with limb swelling undergo a pre-operative lymphoscintigraphy that studies both types of vessels and that the type of microsurgery performed is selected on the basis of the pathological TI and vessel type affected, as outlined in the treatment algorithm below (Figure 6).

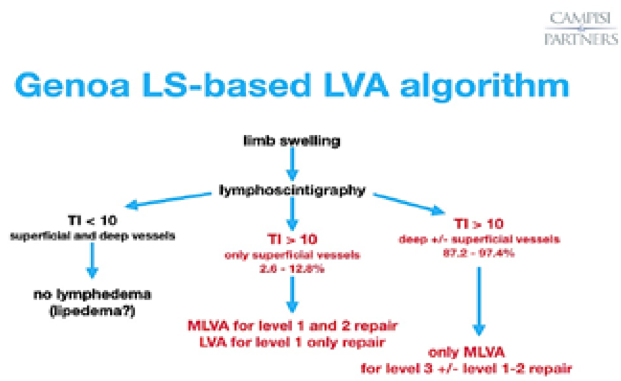

Figure 6. *Treatment algorithm for lymphatic microsurgery based on abnormal lymphoscintigraphy transport index (TI) scores. Percentages refer to the Campisi et al. 2019 study [22]*

In addition, lymphatic microsurgery also represents an efficacious expression of a modern and low-cost surgery, requiring only one operating microscope and two surgeons for each surgical session, according to the available budget in every hospital, in every area of the world. Given the high prevalence of both primary and secondary lymphedema, lymphatic microsurgery is a feasible treatment, particularly for the early stages of disease.

Furthermore, for advanced stages of lymphedema only partially responding to the previous conservative treatment and to the MLVA – MLVLA microsurgical procedures, according to our vast clinical experience, the *FLLA-LVSP* is achieving effective and significant results. It is possible to complete an entire leg within 90 minutes. Recovery time is short and cosmetic results are immediate. More importantly, the removal of excess tissue is completed without further damage to lymphatic vessels. When applied as a second surgery after the microsurgery, FLLA-LVSP offers the possibility of removing almost all obstacles to lymphatic flow, without fear of damage to lymphatic pathways restored by the previous MLVA / MLVLA [6] [11].

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41

Management of Microvascular Complications

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Introduction

In recent years, success rates for microvascular free flaps are commonly reported to be 95% or greater.[1-3] However, despite such high success rates, some patients will suffer a pedicle or anastomotic thrombosis and subsequent flap loss. Patients undergoing free tissue transfer following cancer resection present unique challenges to reconstructive success given the high prevalence of tobacco use, preoperative or postoperative radiation, and history of prior surgeries. Patients undergoing reconstruction following trauma present their own set of challenges including wound contamination and a hard to determine zone of injury within which potential recipient vessels may be prone to thrombosis. The goal of this chapter is to highlight ways to avoid microvascular complications as well as focus on exploring causes of flap loss, treatment of flap compromise, and salvage reconstruction following flap loss.

Prevention

Careful planning, sound technique, and anticipation of potential complications are the keys to free flap success. The pedicle and anastomoses should be examined prior to definitive closure to make certain there are no kinks, twists, or areas of compression that can precipitate a thrombosis. It is critical to ensure the subcutaneous tunnel is wide enough to prevent compression when the pedicle is buried under skin. Wounds should be irrigated prior to closure and prophylactic antibiotics should be administered in patients at high risk for infection. Finally, dressings and patient positioning in the postoperative period should be carefully considered since either could result in compression of the pedicle that may ultimately lead to flap demise.

Performing an additional venous anastomosis has not been definitively shown to decrease complication rates or improve flap salvage and, therefore, are not recommended in most cases since a second venous outflow has been shown to decrease flow rates through both anastomoses.[4] However, there is a caveat to this advice regarding performing a second venous anastomosis. When the quality of the recipient vein is suspect, or when a flap is drained by two co-dominant venous systems (e.g., in some abdominal flaps where the deep inferior epigastric vein and superficial inferior epigastric vein are both necessary to provide sufficient venous outflow) a second venous anastomosis may prevent flap loss. Of note, more recent studies[5] have not corroborated early studies[6] that showed that venous thrombosis was more common than arterial thrombosis, arguing against performing a second venous anastomosis just to have a "back up" in case one anastomosis thromboses.

Postoperative management is also critical to maximizing success rates in microvascular surgery. At our institution, trained nursing staff in a dedicated free flap unit perform hourly flap checks for the initial 48 hours and then every two hours for the next 48 hours, and finally every 4 hours until discharge. Any concern for a microvascular complication calls for immediate evaluation by a surgeon with a low threshold for operative exploration. The routine use of prophylactic anticoagulants such as heparin, dextran, aspirin, or low molecular weight heparin has not been demonstrated to improve flap survival or decrease pedicle thrombosis, and, therefore, are not routinely used except for as prophylaxis against venous thromboembolism.[8] In patients with pre-existing coronary artery disease, carotid disease, or peripheral vascular disease where the risk of an acute coronary event or thrombosis of a stent is possible, patients will be continued on aspirin during the post-operative period.

Causes of Flap Loss

Our experience at MD Anderson Cancer Center shows that, in many cases, the cause of free flap loss would have been difficult or impossible to predict at the time of the initial surgery, such as the development of severe infection, rupture of major blood vessels, hypercoagulable states not detected by routine preoperative blood tests, or external compression due to hard to control circumstances (Table 1).[9] In other cases, free flap compromise that might otherwise have been salvageable was not detected in a timely manner, either towards the end of hospitalization or after discharge from the hospital. However, the cost to benefit ratio of extended, intensive monitoring seems to be low since studies uniformly show that most thromboses occur within the first 48 hours and become extremely rate after the 4th hospital day.[10]

TABLE 1. *Causes of flap loss in 3090 head and neck free flaps performed between 2000 and 2012.**

Cause of Flap Loss	No. of Patients
Infection (without fistula)	8 (20.0%)
Problem with flap design/harvest	6 (15.0%)
Pedicle compression	5 (12.5%)
Kinked pedicle	4 (10.0%)
Hemorrhage	3 (7.5%)
Hypercoagulable disorder	2 (5.0%)
Fistula	2 (5.0%)
Hypotension	1 (2.5%)
Internal jugular vein (recipient vein) thrombosis	1 (2.5%)
Unclear etiology	8 (20.0%)

**Data from: Corbitt C, Skoracki RJ, Yu P, Hanasono MM.*
Free flap failure in head and neck reconstruction. Head Neck. 2014;36(10):1440-1445.

In our experience, kinking of the pedicle occurred in the region of an implantable Doppler cuff or combined implantable Doppler-microvascular coupler in 3 patients.[9] Although there is a long history of success with both these technologies, this underscores the need for careful attention to pedicle geometry in all situations, but especially when a rigid object that could act as a tethering point is introduced into the surgery.

For these reasons, we also typically recommend designing the flap with a monitoring segments to allow for direct clinical evaluation of flap perfusion rather than relying on an implantable Doppler device which can not only cause a kink, but also has significant lower sensitivity compared to clinical exam. [11] (Reference) However, kinks or twists in the flap pedicle vein often take some time to become evident, probably because partial venous blood flow continue for some time before a thrombus completely occludes the blood vessel lumen, and may be a reason for unsalvageable flap compromise. Interestingly, we did not observe a single flap loss where anastomotic error, such as a "back wall" suture was responsible for flap loss in our series.[9] This is almost certainly because such errors are noted during the initial surgery.

Additionally, 6 free flap losses in our series were believed to be due to improper design or injury to the flap pedicle or perforators at the time of harvest.[9] In such cases, signs of viability were present following microvascular anastomosis, and the decision was made by the surgeon to "wait and see" rather than to immediately abandon the flap and perform a new free flap at the time of the initial surgery, but, ultimately, the flaps proved to be non-viable. Experience and surgical judgment are needed to determine when to abandon and replace a potentially flawed flap and when to take the chance that circulation will be stable or improve with time.

Flap Salvage

The key to flap salvage in the setting of pedicle thrombosis is early diagnosis and rapid intervention, prior to the development of the "no-reflow" phenomenon, after which re-establishment of tissue perfusion is impossible.[7] In our experience, the flap salvage rate was 61% when flap compromise occurred within 72 hours and only 13% after 72 hours of surgery.[12] Most likely, lower salvage rates can be attributed to either late diagnosis secondary to decreased monitoring frequency after 72 hours, or because flap compromise has progressed slowly, in a subclinical manner, and intervention has been delayed to the point that saving the flap is not possible.[13,14]

When flap compromise is suspected, an immediate return to the operating room is indicated as long as the patient is medically stable for surgery. Upon return to the operating room, every effort should be made to diagnose the etiology of the flap compromise. Making the correct diagnosis is critical to salvage and prevention of future thrombotic events. The first step in diagnosis is to differentiate between arterial and venous thrombosis as the primary cause of flap compromise. Arterial thrombosis is usually associated with a pale, sunken, and cool flap with lack of capillary refill and loss of Doppler signal (Figure 1).

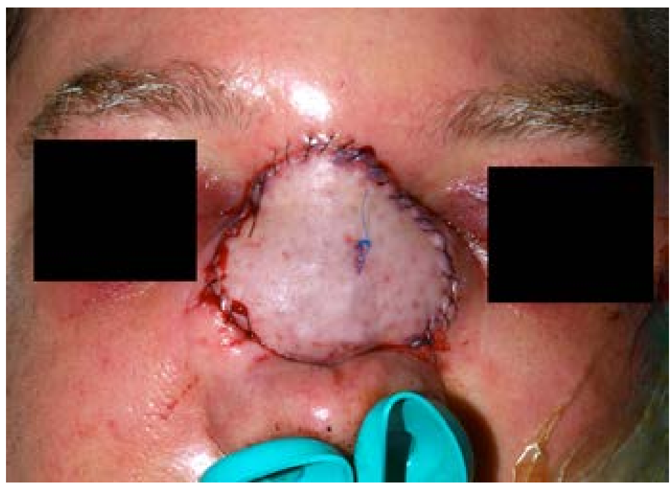

Fig. 1a

Fig.1b

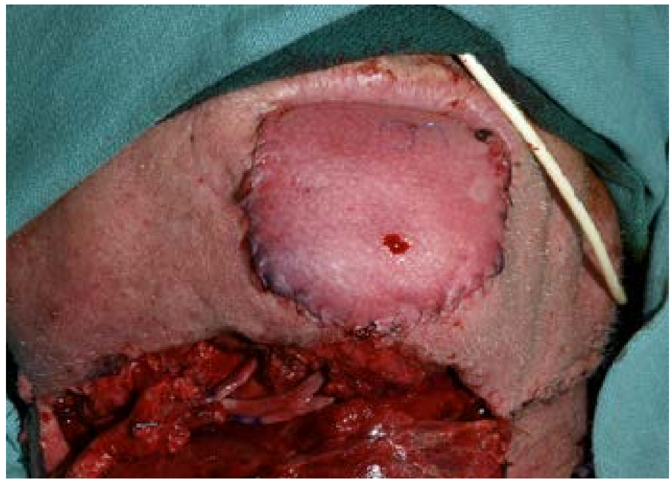

Fig2 b

Figure 1. *Arterial thrombosis resulting in a cool, pale flap with slow or no capillary refill, loss of turgor, and loss of Doppler ultrasound signal (a). Pinprick or scratch results in slow or no bleeding. After operative take back with removal or arterial thrombus and revision of the arterial anastomosis (b).*

Figure 2. *Venous thrombosis resulting in a swollen, bluish-purple flap with brisk capillary refill and pinprick resulting in rapid bleeding of dark blood. The Doppler signal was preserved. After removal of a venous thrombus and re-establishment of venous outflow (b). Note bright red bleeding from pinprick.*

There is little or no bleeding with pinprick or scratch. Venous thrombosis is usually associated with an edematous, blue-purple flap with brisk capillary refill (Figure 2).

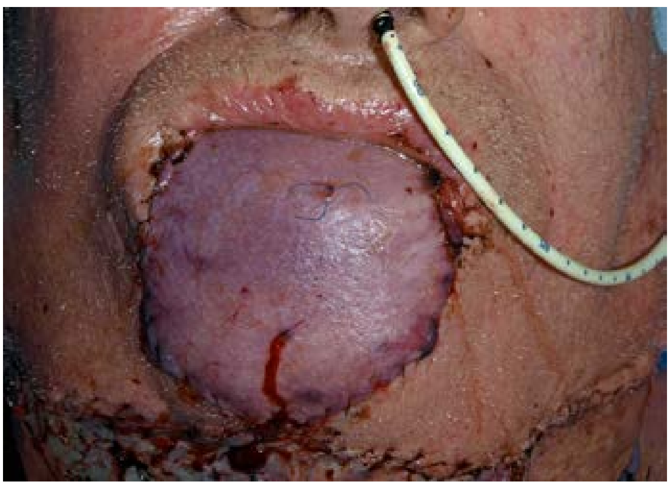

Fig 2a

The Doppler signal may be preserved in early thrombosis. Pinprick or scratch results in rapid bleeding of dark blood.

Hypercoagulable conditions may also result in flap compromise and should be addressed with anticoagulants after thrombectomy and anastomotic revision.[15] One problem with making a new diagnosis of hypercoaguability is that test results for many inherited hypercoagulable disorders take several days to obtain so treatment once a flap becomes compromised is based on clinical suspicion. While we do test for most major disorders (e.g., factor V Leiden, lupus anticoagulant, etc.) when evaluating a patient with prior flap loss, such testing is not routinely performed in patients with no prior history of flap loss or unprovoked thromboembolic disease. For women undergoing free flap reconstruction, particularly breast reconstruction, the history should include questioning regarding any history of unplanned miscarriages, abortions, or difficulty with pregnancy. In some patients, this may be indicative of a hypercoagulable condition, and consideration should be given towards anticoagulation during the

operation and in the post-operative period.
Prolonged vasospasm or hypotension resulting in flap compromise are extremely rare and should be considered diagnoses of exclusion. They can be treated with topical vasodilators and by intravascular volume restoration, respectively. More problematic are thromboses related to purulent infection, traction injuries to the perforator or main pedicle, poor flap design, or injury to the distal circulation during flap harvest. These are often unsalvageable conditions.[3,7]

In the operating room, the incisions are carefully re-opened and the vascular anastomoses are inspected for thrombosis or mechanical obstruction. If venous circulation is impaired due to mechanical reasons without thrombosis inside the vein, correction of the causes should immediately resolve flap congestion. The flap insetting and the position of the vascular pedicle should be carefully re-done to correct these factors.

If an arterial or venous thrombosis is present, the anastomosis should be excised and thrombectomy performed. The vessels should be thoroughly irrigated with heparinized saline and manual or Fogarty catheter extraction of the clot is performed as needed. Causes of flap compromise that can be corrected by clot removal and anastomotic revision include pedicle compression, kinking, or twisting, pedicle injury (e.g., intimal tears), and technical errors with the anastomosis.

Vein grafting is performed as needed to replace any injured section of the pedicle or recipient vessel or to minimize tension across the anastomosis and create more favorable pedicle geometry.[16] As an aside, the authors always obtain informed consent from the patient to perform vein grafting and prepare a lower extremity for harvest of a greater saphenous vein graft during any take-back surgery for flap compromise. If there is an arterial thrombosis, flow must be rapidly re-established, prior to the flap reaching the critical no-reflow threshold. Speed in redoing the venous anastomosis is less critical in venous thrombosis because once the obstruction is relieved, the vein can be left to bleed into the wound without compromise to the flap itself as long as the arterial circulation remains intact. In these settings, communication with the anesthesia team is critical to monitor blood loss and hemodynamics, and a blood transfusion is often necessary.

An intravenous dose of 3000 to 5000 units of heparin is usually given after revision anastomosis.[7] For simple mechanical obstructions or thrombosis, it is not necessary to continue heparin postoperatively. For extensive thrombosis or recurrent thrombosis, we usually start a heparin drip with the goal of therapeutic anticoagulation for 5 days because this is the approximate amount of time intimal healing takes in experimental models. Low dose aspirin (81 to 325 mg daily) is another prophylactic intervention, specifically aimed at decreasing the rate of platelet thrombosis.[7] In theory, aspirin is indicated for "white" or arterial clots, while heparin is more effective in prevent recurrent "red" or venous clots. In practice, both interventions are frequently used in combination.

If no venous outflow is observed after verifying the presence of arterial inflow, thrombosis may be present in the microcirculation within the flap. In order to dissolve these small vessel thrombi, thrombolytic agents such as tissue plasminogen activator (TPA) can be injected into the pedicle artery, either via opening a side branch or using a 30-gauge needle to inject the agent into the lumen of the vessel. There is no established dosage of TPA for free flap salvage. We typically start with 2 to 4 mg diluted to 1 mg/ml, based on our own experience.[7] A repeat injection can be given after 20 minutes or so if needed. In the meantime, the surgical field should be gently irrigated with warm saline and covered with a warm towel to help relieve vasospasm. Papaverine may also be applied topically to the anastomosis and blood vessels. It may take 20 to 30 minutes for the flap to regain perfusion after such management. The pedicle vein can be left open to drain out the thrombolytic agents in the flap before re-anastomosing the veins to avoid systemic effect of thrombolytic agents, although such low doses of TPA should have little or no risk for causing systemic bleeding.[7]

Management of a Flap Loss

The decision of whether to attempt salvage of a free flap versus abandoning the free flap can be a difficult one. In most circumstances, reviving a free flap requires a lengthy operation, potentially additional donor site morbidity for harvest of vein grafts, added blood loss with likely need for blood transfusions, and a prolonged hospital stay and recovery. We have demonstrated that delayed flap thromboses occurring later than 3 days following reconstruction and thrombosis of both the vein and the artery are associated with significantly lower salvage rates.[17] Similarly, compromised muscle flaps were also associated with worse outcomes compared to fasciocutaneous and osteocutaneous free flaps. Multiple attempts at salvaging a failing free flap is associated with a very poor flap survival rate with high morbidity due to the cumulative effects of several lengthy surgeries and is not recommended. [16,17] When the likelihood of flap salvage is low or when salvage has clearly failed, the surgeon is faced with the challenge of finding a secondary option for reconstruction.

A failed free flap reconstruction may have substantial long-term morbidity due to poor functional and aesthetic results.[7,18] However, there continues to be understandable hesitation to performing a subsequent free flap in the same patient, not only because of the considerable psychological toll to the patient and surgeon, but, in a more practical sense, because of concerns regarding lack of recipient vessels, as well as risk of repeat flap loss and other postoperative complications.[7]

In cases of free flap loss, a decision must be made about how to reconstruct the defect that results following removal of the flap. A time-honored paradigm in reconstructive surgery is the concept of a reconstructive ladder in which free tissue transfer is last on the list of possible solutions. However, in the setting of a loss of an initial free flap, the question arises as to whether the appropriate choice is to go back down the ladder when all other methods were deemed less acceptable prior to undertaking the original surgery.[18] Free flaps for head and neck oncologic defects are usually chosen because they are felt to provide the best functional and/or aesthetic outcome. With the exception of innervated muscle transfer, free flaps in extremity surgery are usually aimed at limb preservation as an alternative to amputation. Free flaps used in breast reconstruction differ from head and neck and extremity flaps in that they do not necessarily perform a functional or organ-preserving role. Implant-based reconstruction or a pedicled latissimus dorsi muscle flap with or without an implant may still be a very acceptable salvage solution following free flap loss. However, in general, the authors recommend a secondary flap if the primary flap fails, once the patient has been deemed medically stable and there are no other factors that preclude another free tissue transfer. If all potential risk factors have been addressed, the possibility of a hypercoagulable condition should be entertained and therapeutic anticoagulation is warranted.

The overall success rate of a second attempt at free flap reconstruction in 28 head and neck reconstructions in our series of free flap losses was 96.4%, a figure that is similar to success rates usually reported for initial free flaps.[9] Our success rate in this situation mirrors the experience of Wei et al.,[18] who reported 16 successful subsequent free flaps used to treat 17 head and neck free flap failures (94.1%), and Alam et al.,[19] who reported 16 out of 16 (100%) successful subsequent free flaps. Such success rates suggest that free flap reconstruction can still be highly reliable, even in the setting of an initial free flap failure.

A delayed attempt at free flap reconstruction might be one way to minimize medical complications by giving the patient time to recover from the initial surgery and any attempts at flap salvage, and might be a way to reduce medical complications occurring after the second free flap reconstruction. During the delay the patient's nutritional status can be optimized and adequate treatment of infections and debridement of non-viable tissue can be performed. Unfortunately, in many cases, the risk for infection, fistula, and exposure of critical structures precludes delaying many free flap reconstructions for an extended time period.

The decision to perform a second free flap should to some extent depend on being able to identify the cause of the initial flap loss. An underlying genetic thrombophilic predisposition is more often a diagnosis of exclusion than the true etiology for a flap loss. However, if there is a suspicion for a hypercoagulable state (e.g., disorders involving factor V Leiden, antithrombin III, protein S, protein C, or lupus anticoagulant), consideration should be given towards a hematology consult as previously noted.[11] However, for many of the more extensive defects, if a free flap was indicated for the initial reconstruction, a free flap is still warranted in the setting of a flap loss and should be considered as the primary option if there are no definitive contraindications.[8,17]

Conclusions

Even in experienced hands, free flap losses can occasionally occur. Early diagnosis, a rapid return to the operating room, and appropriate treatment are the keys to saving free flaps. Late diagnosis, recurrent thrombosis, or an unstable patient may be indications for abandoning the flap rather than attempt a potentially morbid salvage attempt with a low probability of success. In select patients, a second free flap can be performed with high success rates even after a flap loss, especially if the cause of the initial flap loss can be identified and steps taken to reduce the risk of future pedicle thrombosis.

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42

Use of the slit arteriotomy for end-to-side arterial anastomosis

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Introduction

The advantages of the end-to-side arterial anastomosis include decreased arterial spasm, elimination of vessel mismatch, and preservation of distal run-off[1]. Cutting a hole as the arteriotomy is widely practiced today[2] but presents problems such as over-excision of vessel wall, jagged vessel edges and an oversized hole leading to vascular steal.

We prefer using a slit arteriotomy as it is dependable, with an arterial anastomotic patency rate of 98%[3]. A slit is easily created with the microknife and its length adjusted to the diameter of the donor vessel. There is no narrowing of the recipient vessel because of the "patch" effect of the donor vessel on the recipient.

Technique

A 3cm segment of recipient artery is prepared by clearing away perivascular tissue and ligating side branches. The position of the slit on the recipient is determined by marking with a sterile surgical marker. The arterial segment is held between double microclamps and the clamps approximated to create laxity for handling purposes.

The donor artery is beveled 30-45 degrees to create a takeoff angle of between 60 – 45 degrees (Fig. 1-1). Alternatively, one corner of the vessel is slit open and trimmed to create a hood.

A 5mm longitudinal slit is made using a 30 degree microknife, cutting in opposing directions to ensure that the corners are even(Fig. 1-2). The clamps are approximated together to open the slit (Fig. 1-3). The lumen is irrigated to clear away blood and to ensure that the posterior wall had not been pierced. If so, repair is undertaken immediately.

Beginning at the heel, interrupted sutures are placed sequentially, distributing the donor's redundancy towards the toe(Fig. 1-4). We commonly use 9/0 ethilon sutures for the anastomosis. If the slit is too deficient, it can be extended midway through the operation. In this way, the donor vessel is stretched optimally over the slit. If the slit is too long, the excess is simply repaired with an interrupted stitch. A common practice is to fix the toe and the heel as an initial step, but this prematurely fixes the length of the slit and hence the diameter of the anastomosis.

When suturing, the needle bite on the thinner donor vessel is taken before the thicker recipient so as to keep the edges well everted and buttressed. Make sure to tag the intima of the recipient vessel. When approaching the corners, the sutures are placed more obliquely to skew the pull on the slit. (Fig. 1-4,5)

Over on the far side, suturing adjacent to the corners is the most difficult and these should be placed first (Fig. 1-6). The suturing sequence aims to finish at the mid-lateral point. For better visualization, the final 3 sutures are left untied until all are in position (Fig 1-7). The end product should be a optimally stretched vessel end cupped over the slit arteriotomy.

Discussion

Using computer modeling, we studied three factors that contributed to slit opening, namely, residual stress, the coupling effect of the donor on the recipient vessel, and blood pressure. Biological tissues in the physiological state are under 'stress'. An artery which is cut transversely will retract from the cut end due to contraction of the longitudinal fibers. Similarly, when a longitudinal slit is made the circular fibers contract to open the slit. This effect contributed approximately 20% to slit opening in our model. The second factor is a coupling effect when two vessels are joined. The slit is deformed by the donor vessel, which generates a patch arterioplasty effect. Additionally, elastic recoil of the donor in the longitudinal axis of the recipient keeps the slit open. This factor contributes about 40% to the slit opening. The third factor is blood pressure which contributes another 40% to opening. Blood pressure is the force that propels the blood through the segment bearing the anastomosis and its effect is evident with tourniquet release.

In our practice, the slit end-to-side anastomosis is indispensable to extremity reconstruction and it is especially useful in the single vessel leg.

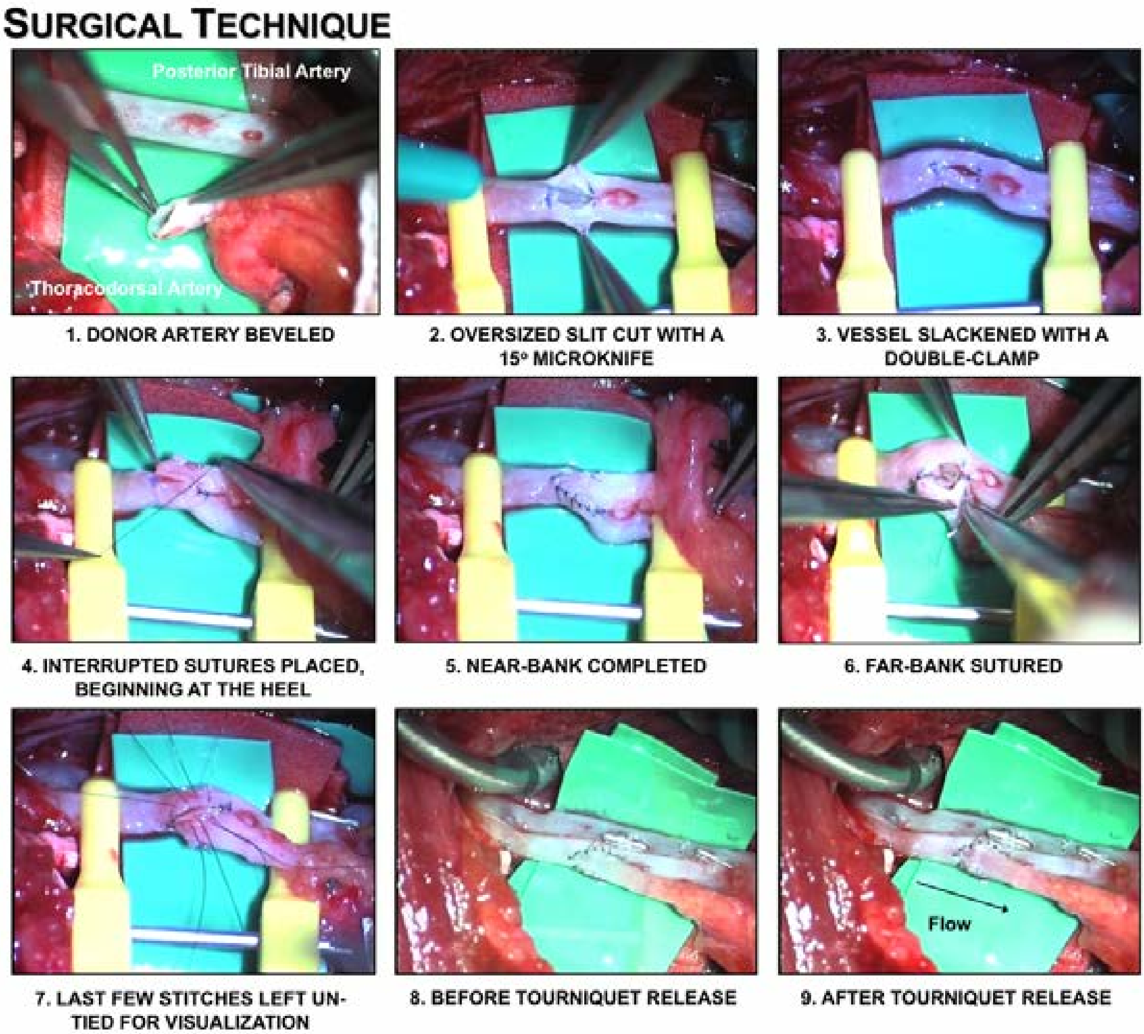

Figure 1-7: *A 3cm segment of a recipient artery is prepared. (1-1) A longitudinal slit is made using a 30 degree microknife, the clamps are then approximated to open the slit. (1-2) Beginning at the heel, interrupted sutures are placed sequentially, paying the vessel redundancy towards the toe. (1-4,5) On the far side, the suturing of the corners is done first terminating in the middle where the exposure is good(1-6). The final three sutures are left untied until all are in position. (1-7) The construct should consist of an optimally stretched donor vessel evenly distributed over the slit arteriotomy.*

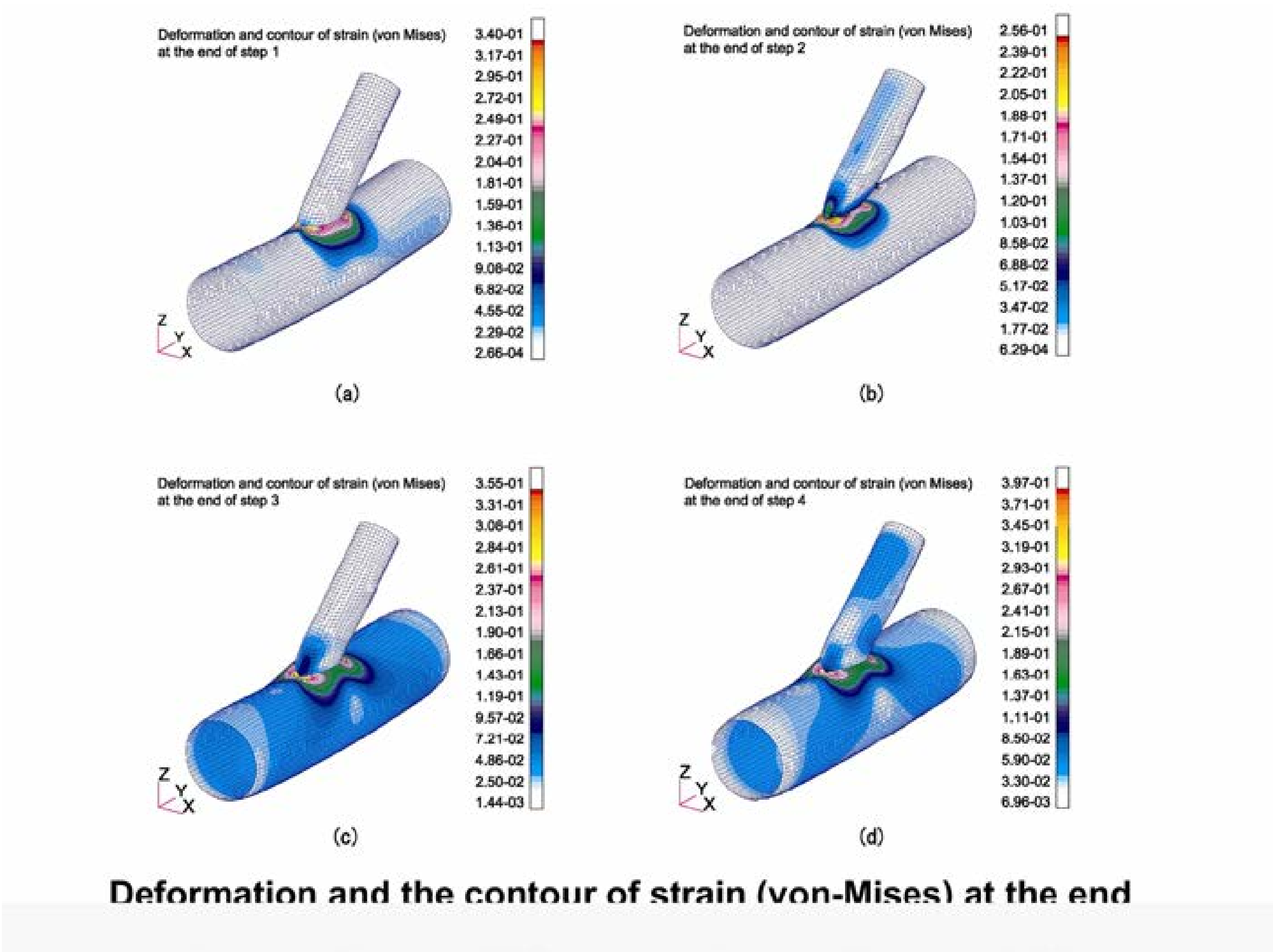

Figure 2: *Computer modeling of the end-to-side anastomosis showing stress and deformational forces at the anastomosis (caused by contraction of circular fibres, coupling effect, blood pressure) preventing closure of the slit. Maximal stress is seen at the heel and toe; hence care must be taken to prevent leak at these points.*

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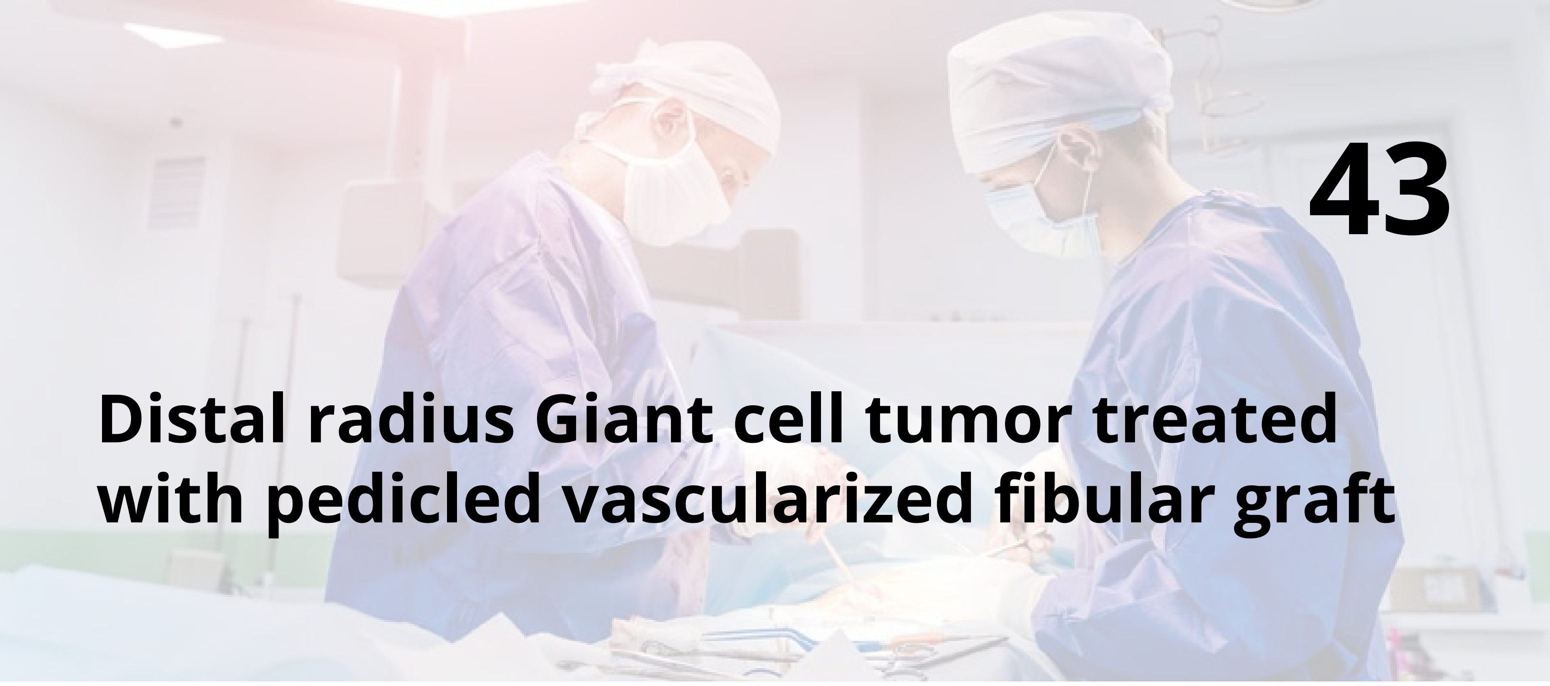

43

Distal radius Giant cell tumor treated with pedicled vascularized fibular graft

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Introduction

During the late decades the use of bone grafts in orthopaedic surgery is gaining ground, especially the autografts. The wide use of bone autografts has been combined with the scientific and technological advances in our science. For these reasons bone grafts are used in many cases as trauma, non-unions, tumors, osteonecrosis etc [1,2,4,5]. There is a debate between non-vascularized bone grafts and vascularized ones. According to the writer's opinion, vascularized bone grafts are placed with intact vascularity, meaning they are viable for the very first minute as well as capable of preserving their mechanical strength and structural integrity. They are also incorporated via primary or secondary bone healing and not via the "creeping substitution" procedure that happens to non-vascularized grafts. Consequently, the use of vascularized grafts is in favor in certain cases such us traumatic bone loss, tumor resection, osteomyelitis, infected or persistent non-unions and osteonecrosis[8].

The free vascularized fibular bone graft (FVFG) is the most widely used graft used for large (>6cm) bone defects. There are many reasons for this preference including but not limited to the easy accessibility of fibula, the minimal consequences on weight bearing of the foot due to the fact that the fibula bears only 15 percent of axial load[9], the well known vascular anatomy [6,10] of this certain region aw well as the low number of post-op donor site related complications.

In this chapter we describe the technique of receiving a free pedicled vascularized fibular bone graft to fill bone defects after excision of giant cell tumor of the distal radius. At first the procedure of receiving the bone graft will be described in details and afterwards the different ways of treatment will be presented, based on the anatomy, location and staging of the giant cell tumor.

Surgical technique

The whole procedure is being performed under general anesthesiacombined with nerve block anesthesia of upper limb mainly for postoperative analgesia. The best option is working with two different surgical teams, one who makes the tumor excision and the graft implantation, stabilization and vessel anastomoses and a second one for receiving and preparing the vascularized fibular graft. The patient is placed supine on the surgical table placing a sand or liquid bag under the buttock of the limb that will be the fibular donor site in order to maintain it in slight internal rotation.

Fibular graft harvestingtechnique

The first step is the decision which extremity to use for fibular graft. The writer prefers the contralateral leg for fibular harvesting because is much more convenient for two surgical groups to operate simultaneously. However, preoperative planning should exclude peripheral vascular disease, deep venous thrombosis as well as previous trauma/damages of blood vessels of the affected limb. If everything is normal, then the extremity is suitable for the procedure and be chosen. We do not exsanguinate the limb with Esmarch bandage but we prefer to hold it for five minutes in an upright position (during disinfection) and right after to inflate the tourniquet to 350 mmHg.

A strait line is drawn over the lateral aspect of the fibular starting from fibular head and ending at the very distal tip of lateral malleolus. To maintain the stability of ankle and knee as well as to include the artery nutrient foramen of fibular me mark on that line two certain points. The first is 10cm proximal to the distal malleolus end and the other is 10cm distal to the fibular head. Usually the incision is located between these two points (Fig.1).

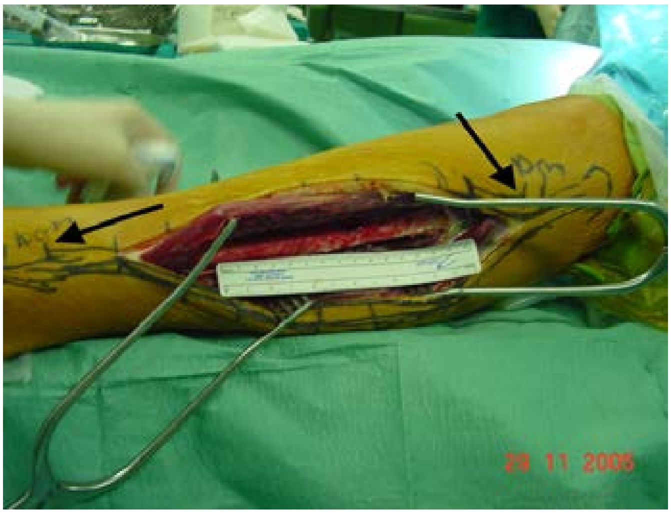

Figure 1. *The surgeon marks the two points that are 10cm away (arrows) from fibular head and tip of lateral malleolus. Usually the incision is located between these two points. The maximum located between these two points. The maximum length of the harvesting graft is 13 to 15 cm*

The author prefers the formation of full thickness flaps and right after the incision of the lateral compartment fascia in line with the skin incision. The peroneal muscles are elevated anteriorly off the posterior intermuscular septum. The peroneal muscles are then detached with Metzenbaum scissors from the lateral aspect of the fibula until the anterior intermuscular septum is clearly visible all along the segment of the fibula that will be harvested. At that point is crucial the surgeon to preserve the periosteal blood supply. In order not to affect it, it is preferable to retain a 2mm layer of muscle giving to the graft the final marble-like appearance (Fig.2).

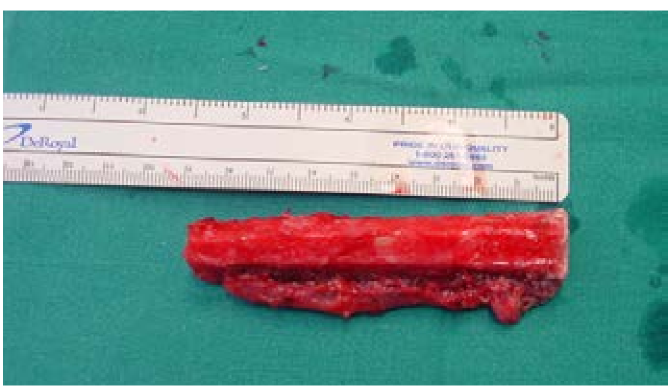

Figure 2. *Marble-like appearance of the graft due to the remaining 2mm of muscle attachment in order not to disturb the periosteal blood supply.*

The anterior intermuscular septum in then incised and the anterior tibia compartment musclesare exposed. Those muscles are reflected from fibular and the surgeon now could recognize the interosseous membrane. There are no nutrient vessels of the fibula on that surface, therefore there is no danger in reflecting the anterior tibia muscles off the fibula. Before the incision of the interosseous membrane care should be taken to recognize and protect the anterior tibial artery and the profundus peroneal nerve. The interosseous membrane is divided along the entire length of the proposed graft and for confirmation, that is adequate incised, palpation of tibia and fibula could be of benefit. Right after that, the surgeon incises the posterior intermuscular septum exposing the posterior to fibula muscle, which are the soleus proximally and the flexor hallucis longus distally. The pedicle is directly under this muscle and excessive care must be taken in order no to damage or cut the peroneal vessels while releasing fibula from these muscles. Once the peroneal vessel pedicle is identified both proximally and distally, it is well protected by malleable retractors before the osteotomy performed. After the above mentioned measures for vessel protection have been taken, the surgeon checks once more the distal and proximal sites of osteotomy to ensure that at least 10cm of distal and 10cm of proximal fibula are remaining after the osteotomy and if so, performs the osteotomy with an oscillating saw. To avoid thermal osteonecrosis arising from oscillating cut the point of osteotomy is constantly washed with cold saline solution. The distal bone cut is performed first followed by the proximal one. During the proximal osteotomy care should be taken to protect the superficial peroneal nerve. Right after the osteotomies the peroneal vessels are ligated distally (usually with hemoclips) followed by dissection of the pedicle from the surrounding muscles. As the procedure comes proximally it is beneficial to ensure a pedicle length of 5 cm and then to ligate the pedicle and cut it (Fig.3).

Figure 3. *Identifying and dissect vessel pedicle from the surrounding muscle tissues.*

The graft is transferred to a back table with great care to be prepared for implantation, i.e. injection of heparinized solution, microsurgical dissection of the ends of pedicle and selection of one out of two veins that will be used as outflow vessel, possible repair of any leak of the major vessels [7].

At the end the tourniquet is deflated, the wound is irrigated and any possible bleeding is getting under control. After that, the surgical team closes the wound using a drainage for one day.

Excision of a distal radius giant cell tumor grade II with preserving the articular surface of radius

The Giant cell tumor is a benign tumor with a potential for aggressive behavior and ability for metastasis. Giant cell tumors are rare tumor and usually near joint in young adults. The classification of these tumor was made by Campanacci based on radiological appearance and having three stages [11].

In our case we treated a grade II giant cell tumor of distal radius without break of the bone cortex despite the thinning parts of the cortex to some extent (Fig.4).

Figure 4. *A type II giant cell tumor of distal radius. *The cortex was getting thinner but not broken. (Red arrows) the K-wires are placed to identify the margins of surgical excision of the tumor.*

The author always asks for MRI examination of the affected part (Fig.5) as well as CT of thorax and abdomen to investigate the rare possibility of metastasis. Being these examinations normal(without pathological signs), the universal golden standard for bone giant cell tumor is the surgical resection.

Figure 5. *MRI of the affected part is always a part of the tumor investigation protocol*

The patient is placed supine under general anesthesia and regional nerve block of the upper limb (as stated before). The arm is partially exsanguinated by holding it upright while the arm is being disinfected and then the tourniquet is inflated to 270 mmHg. The forearm is placed over a hand table and care is taken for the accessibility of C-arm in order to have images during the operation. The dorsal approach is chosen and a straight line is drawn centered over the third metacarpal. The extensor retinaculum is incised along with the third compartment and the extensor pollicis longus is mobilized. The fourth compartment and the extensor muscle are the subperiosteal elevated and detached from the radius. The same procedure is followed also for the second compartment.

At that point the surgeon marks with the use of kirschner-wires and help of image intensifier the resection points of the tumor taking in account to excise the whole tumor in clear margins leaving behind the healthy articular surface (Fig.4). It is very crucial to maintain the function of the wrist, especially in those case that the patient is quite young (the majority of giant cell tumors).

As soon as the resection margins are established, the surgeon measures the length of the bone to be excised and performs the distal and proximal osteotomy by an oscillating saw. During the osteotomies bones are washed with sterile solution to avoid thermal osteonecrosis. Having the osteotomies performed the resected part of distal radius is removed and sent for biopsy (Fig.6).

Figure 6. *The resected tumor will be send for biopsy to confirm diagnosis. The measurement of the resected bone is crucial to define the length of the harvested fibular graft.*

Next to that, the surgeon identifies and prepares the radial artery and the concomitant veins for the anastomoses with the fibular graft. The radial artery and one vein are ligated and cut prepared for the upcoming end to end anastomosis with peroneal artery and vein respectively. Having measured the length of the resected part of the radius (Fig.6) we prepare a fibular graft at the same size in order to maintain the lengths of the radius and do not affect the function of the wrist (Fig.7).

Figure 7. *Having measured the resected bone the surgeon defines how long fibular graft is going to be harvested.*

Thereafter the free pedicled fibular graft with the appropriate length is placed in place with the distal past of fibular facing the proximal end of radius. Now it is time for osteosynthesis of the fibular graft and the radial epiphysis. For that purpose, an anatomical π-shaped plate is chosen using four screws at the epiphysis and other four at the fibular graft to achieve a very stable osteosythesis (Fig.8 and 9a,9b).

Figure 8. *A π-shaped plate is applied and contoured in order to stabilize the radial epiphysis with the intercalated fibular graft*

The next step is to stabilize the graft with the radius diaphysis using dorsally a conventional LC-DCP plate and screws. Using three screws (six cortex) in both side is considered stable enough (Fig. 9a, 9b).

Figure 9a. *Final stable osteosynthesis using also a LC-DCP plate.*

Note: the fibular graft is supported along all his length by a plate to avoid the possibility of a graft fracture between the two plates.

Figure 9b. *Final stable osteosynthesis using also a LC-DCP plate.*

Note: the fibular graft is supported along all his length by a plate to avoid the possibility of a graft fracture between the two plates.
The placement of the plates or screws, as well as the quality and stability of osteosynthesis is checked under fluoroscopy.
As soon as the osteosynthesis comes to an end, the vessel anastomosis is time to take part. First we anastomose the one peroneal vein with the radial one and right after that the surgeon performs the arterial anastomosis with the use of 8-0 nylon monofilament suture. Simple interrupted stitches are preferred over a running one. At that time the tourniquet could be deflated to note the quality of anastomoses and in case of leaks further stitches are being placed. Any other bleeding is addressed and the wound is closed with a drainage for 24 hours. The author prefers to use a splint for a couple o weeks for better soft tissue healing and pain alleviation.
Postoperatively the patient is given low molecular weight heparin (LMWH) in combination with acetylsalicylic acid for one month. The drains are removed on the first post-op day and the average hospital stay is three days.

Excision of a distal radius giant cell tumor grade III with wrist arthrodesis

In cases suffering from giant cell tumor grade III the bone cortex/articular surface is obliterated and extension of the tumor into the soft tissues is a fact that needs also treatment. In this chapter the author describes the treatment method of a distal radius giant cell tumor that breaks the distal articular surface, distal radioulnar joint and the palmar cortex of radius (Fig. 10 to 13).

Figure 10. *A type III distal radius giant cell tumor that penetrates distal radial articular surface as well as distal radioulnar joint.*

Figure 11. *A type III distal radius giant cell tumor that penetrates also the palmar cortex of the radius.*

Figure 12. *MRI of the wrist to evaluate in details the anatomy of the tumor and plan the optimal treatment*

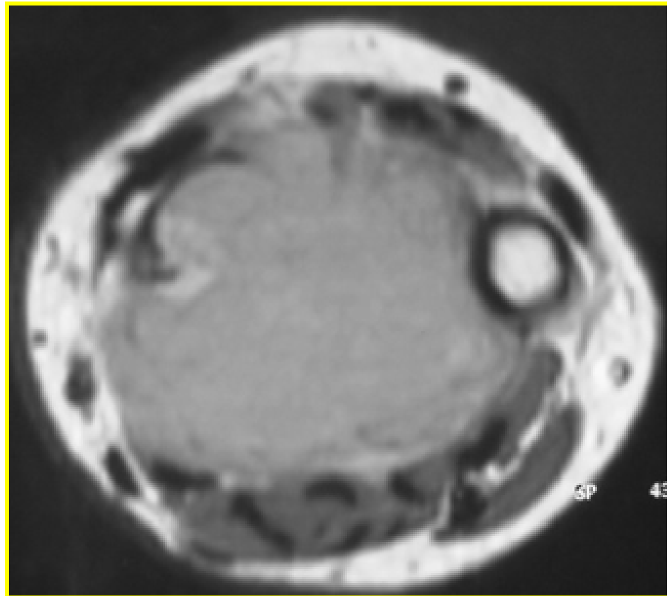

Figure 13. *MRI of the wrist to evaluate in details the anatomy of the tumor and plan the optimal treatment*

The chosen treatment is excision of the distal radius along with the first carpal row and distal ulnar thirdexcision, performing wrist arthrodesis with intercalation of the free pedicled vascularized fibular graft.

The patient is supine on surgical table under general anesthesia combined with regional nerve block. The same exsanguination procedure (as described above) is followed and the tourniquet is inflated to 270 mmHg. The forearm is placed over a hand table allowing place and accessibility for C-arm imaging during the operation.

A strait line is drawn on the dorsal part of the forearm centered over the third metacarpal. The dorsal approach to the wrist is the same as stated in the previous paragraph. However, in this case, a wide elevation of ulnar muscle off ulna is mandatory as the distal part of the ulna should be removed. As the muscle detaching from radius and ulna is finished, the surgeon marks the proximal site of radial and ulna osteotomy using a K-wire and fluoroscopy and measures the length from the radial osteotomy site to capitate for preparing the appropriate length of fibular graft. Then, heproceeds to the two osteotomies, removing the distal radius and ulna. As a typical part of this procedure the radial osteotomised region is constantly washed with sterile normal saline to avoid thermal osteonecrosis of the bone at this point. Ideally the distal part of the radius should be removed en-bloc with the supinator quadratous, the DRUJ and the distal third of the ulna. By this procedure the possibility of tumor local relapse is eliminated. Next step is the first carpal row (scaphoid, lunate, triquertum) excision. Furthermore, it seems to be advised to decorticate the proximal pole of capitate with a ronguer or a burr to help union (desis) of the intercalated graft with capitate and achieve stable wrist arthrodesis.

Having the tumor excision completed, the surgeon prepares the radial artery and the concomitant veins. Then, as described in the previous section, ligates the radial artery and one vein for being prepared for the upcoming anastomoses with the intercalated vascularized fibular graft.

The appropriate-length fibular graft is placed in the empty space the radius removal creates (Fig. 14), with the distal part of the fibula facing the radius stump and the proximal part of the tibia facing the capitate. The fixation of fibular graft is made either with one-prebended special wrist arthrodesis plate or a single LC-DCP plate (that will be bended) placing three screws to the third metacarpal, one to capitate and three to in the fibular graft and finally three to the radial stump.

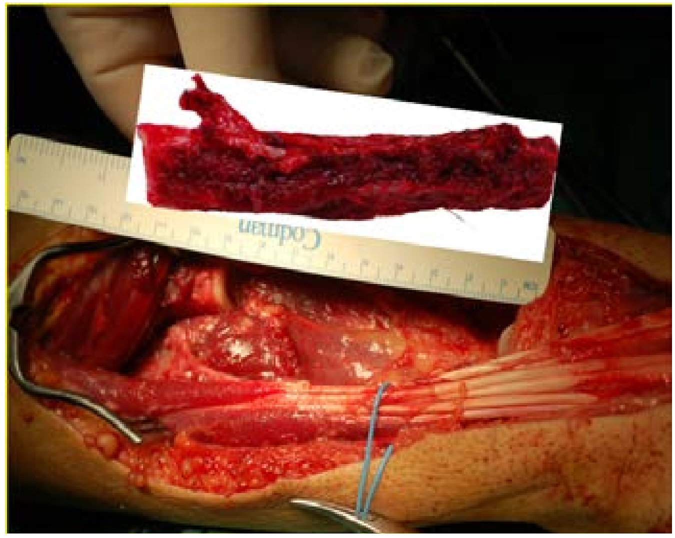

Figure 14. *The surgeon measures the distance between the radial cut and proximal pole of capitate in order to harvest the correct size of fibular graft. This ensures the preservation of the arm length.*

If there is no long-enough available plate for these osteosynthesis, the author uses the technique of "plate overlapping" that combines the placement of screw through two plates, that are overlapped each other to some extend (Fig. 15a and 15b).

Figure 15. *Final osteosynthesis/arthrodesis using two plates and the overlapping technique*

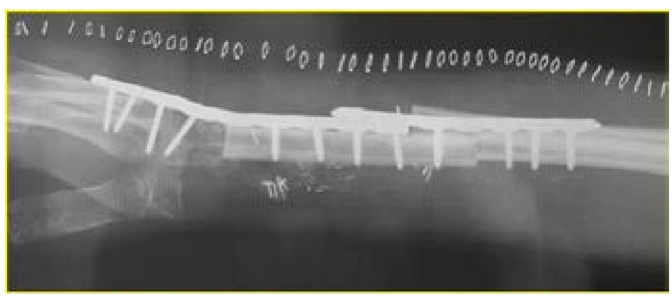

Figure 16. *Three screws are placed to the third metacarpal, one to capitate five to the fibulargraft and three to the radius stump.*

Note: as there was not available an adequate long enough plate for this procedure, the surgeon used two different plates with overlapping parts (two screws are placed through both plates) to support the entire length of the graft, minimizing the fracture risk.

By this technique the graft is supported by a plate to all its length minimizing the risk of a fracture at the area between two different not overlapped plates.

Having made the osteosynthesis and checked it with fluoroscopy, vessels anastomoses should take place. The peroneal vein is anastomosed with one radial vein and the peroneal artery with the radial artery. The author prefers end to end anastomosis, as described in the previous sub-chapter. Finally,the tourniquet could be deflated to note the quality of anastomoses and in case of leaks further stitches are being placed. The wound is well irrigated and washed out and hemostasis is carried out when needed. The trauma is closed with one drainage and a thermoplastic splinter is placed to alleviate the pain and help the recovery of soft tissues. The drainage is removed after 24-48 hours.

Postoperatively the patient follows the same anti-thrombotic protocol of giving both low molecular weight heparin (LMWH) and acetylsalicylic acid for one month.The average hospitalization is around 4 days. The splint is removed usually in six weeks and the arm is protected for heavy duties for at least three months.

Complications of FVFG donor/recipient site

As in every orthopedic operation complications can occur acutely, sub-acutely or delayed. The most usual early complications are the excessive bleeding (due to poor hemostasis or poor anastomosis technique), thrombosis of the graft pedicle as well as compartment syndrome at the donor site usually occurred after poor hemostasis of that area (for that reason it is advised to to close the deep fascia too tightly).

Non-unions and fracture of the graft are late complication that usually need a re-operation. There are noticed muscle weakness at the donor site especially as regards the extensor hallucislongus muscle as well as valgus deformity of the talus. To avoid this deformity, it is very crucial the residual fibular bone to be around 10cm.

Conclusion

Free vascularized fibular graft is a very reliable solution for a wide variety of orthopaedic issues and gives alternatives to the surgeon in cases that really there is no too many options to choose. It provides immediate structural support as well as osteoconductive, osteoinductive and osteogenic properties that make this type of graft one of the most widely used vascularized graft in orthopaedic, due to the quite good to excellent results [3,6].

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44

Importance of dissection in the formation of microsurgical technique.

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Learning to dissect well is an important step in the training of microsurgical technique: dissection under a microscope is an integral part of microsurgical technique, it partly conditions the success of a surgical intervention. In addition, varying the dissection exercises allows you to acquire good dexterity.

Key words: dissection - microsurgery - dexterity - training

When we speak of microsurgical training, this very often implies learning the technique of microsurgical anastomosis but the stage which precedes anastomosis and which consists of the preparation of the vessel, the lymphatic, the nerve or of an organ for example, is also a very important step. It is an integral part of microsurgical technique and partly conditions its success.

From our experience, the dissection step seems to us as important as learning the suturing technique - this step should not be overlooked. Poor dissection can compromise the rest of the operative technique.
Besides, in addition to learning to dissect well, the dissection exercise is an excellent way to acquire great dexterity, very useful in microsurgery but also for all surgeries.

In this article, the basic principles of dissection as we teach them will be discussed, and then we will see what are the main mistakes not to make as well as the consequences of these mistakes.

Fundamentals of microsurgical dissection:
Dissection is above all learning to respect all tissues (vessels, nerves, muscles, lymphatics).
It is to isolate, to separate the elements that interest us with delicacy but efficiency.
For this it is necessary to have a perfect vision under the microscope and to have a fine and precise gesture.

How to dissect a vessel and with what instruments? :
First, the microscope setting must be perfect, the vision must be perfectly clear. Each gesture must be done under complete vision control.
In order to avoid physiological tremor, the operator should be comfortably seated, with the forearms if possible resting on the operating table, or at least the ulnar edge of the hands should rest on something. No tension should be felt, whether in the lower back, cervical or hands. The instruments must be held between the thumb and forefinger (Fig. 1);
The dissection must be performed with non-contending instruments. We recommend the use of forceps known as watchmaker's forceps not too fine and in perfect working order (Dumont forceps n ° 3) as well as a pair of scissors with blunt tips. (Fig. 1)

Fig.1: *Holding instruments between thumb and forefinger (fine forceps and pair of scissors with curved blades and blunt tips).*

The manipulation of a vessel is done by taking it by its adventicia with the forceps and separating it from adjacent tissues using the pair of scissors. In no way should the vessel be pinched. We are used to using a pair of scissors with curved blades so that we can see precisely the extremities of the blades and the tissue that will be cut. (Fig. 2)

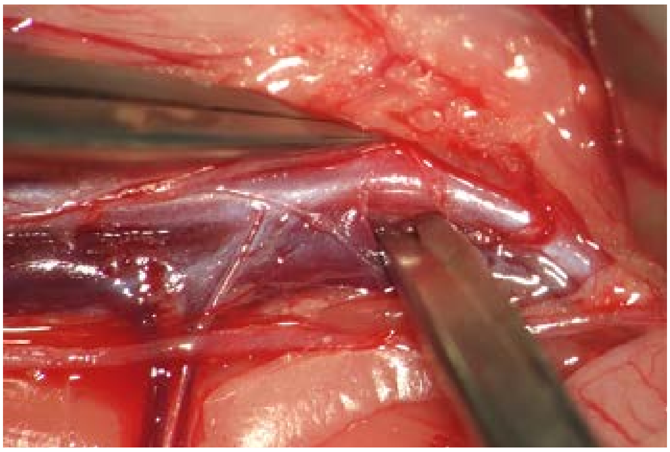


Fig. 2 : *Dissection of the abdominal aorta of the rat: The forceps hold the adventitia of the aorta and pull the vessel away from the vena cava. Scissor separates the aorta from the vena cava. The use of saline during all the time of the dissection helps protect the tissues from dehydration.*

The vessel must be perfectly prepared for several centimeters, free from all adhesions, the fat must be removed, the collateral branches dissected before being bound or electrocoagulated. However, we take care to leave the adventitia well on the vessel so as not to weaken it. (Fig. 3)

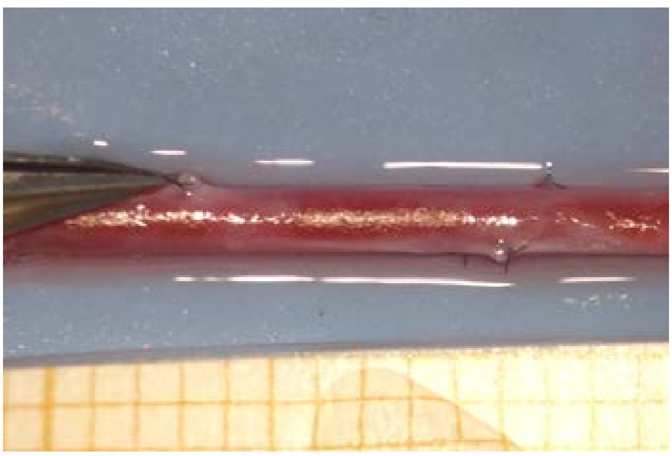


Fig. 3: *completely free vessel, ligated collateral branches.*

What are the main mistakes to avoid:
First of all, the use of unsuitable or damaged instruments: forceps with damaged extremities, a pair of scissors with pointed extremities favor the creation of wounds.

Dissection with two forceps is also to be avoided, although apparently it seems less dangerous than using scissors. It is indeed more of a dilaceration than a dissection which risks generating spasms of the vessels and / or irreversible lesions of the vascular walls or even tears in the walls. (Photo 4)

Fig. 4: *Forcep tip damaged and scissors with pointed ends*

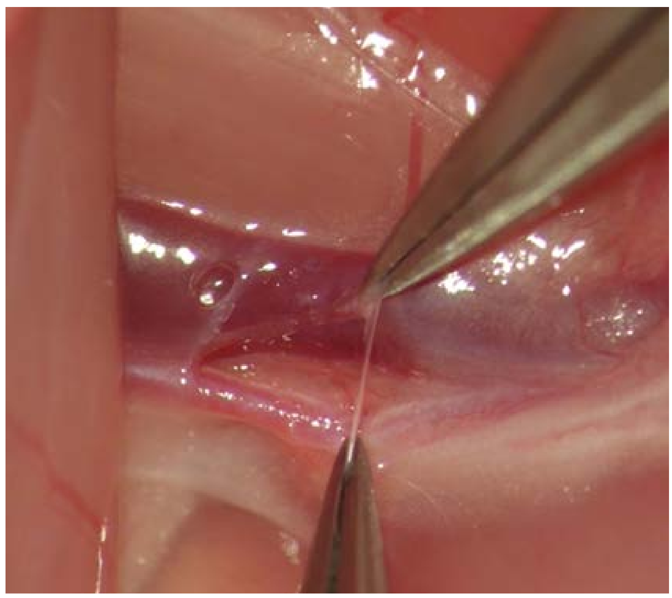


Fig. 5 : *Dilaceration with 2 forceps*

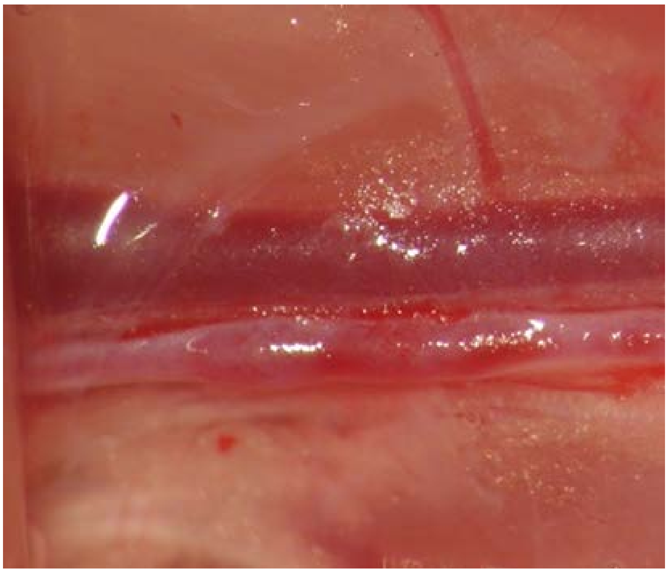


Fig. 6: *Arterial spasm due to laceration*

Do a minima dissection, too short, an insufficient preparation on the pretext of saving time or avoiding damaging the vessel is not a very good idea. Indeed, if the dissection is insufficient the risks are among others:

- To have a clamp that does not sufficiently tighten the vessel if there is fat remaining causing the vessel's dropping,
- To have permanent bleeding if a collateral branch has not been linked between the end of the vessel and the clamp. This bleeding can lead to an intraluminal thrombus which will cause the failure of the anastomosis technique,
- Not having enough space and being very embarrassed to perform the anastomosis (Fig. 5)

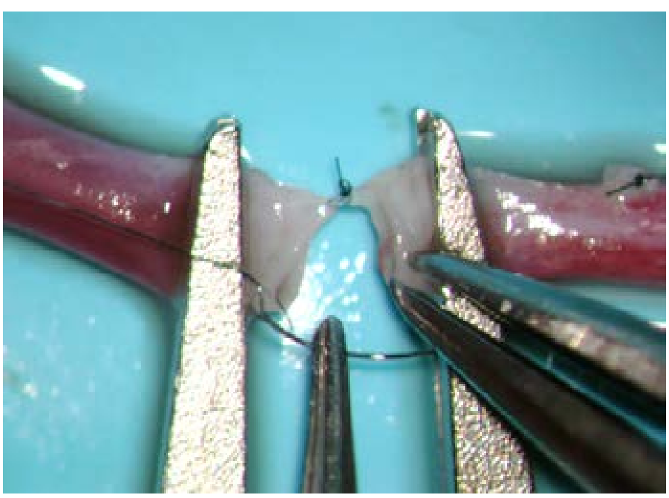


Fig. 5 *:Difficulties for anastomosis, clamps being too close together because of insufficient dissection*

Benefits of varying dissection exercises:

If at first it is entirely possible to learn the basic gestures on inert tissue (chicken leg for example), performing exercises on the laboratory animal is still essential to this day to allow to understand all the factors related to the dissection of living tissue: plasticity, the behavior of different tissues, spasm, hemorrhage or even more or less significant adhesions.

Varying the dissection exercises makes it possible to refine the gestures, to better perceive the many difficulties and to learn how to overcome them. Thus, dissection of a rat aorta will be different from a dissection of femoral vessels or even of an organ such as the kidney for example.

Releasing the aorta from all of its adhesions is first of all finding the cleavage plane between the aorta and the vena cava without making a wound in the vena cava – It's also to identify, dissect and ligate all the collateral branches.

In the dissection of the femoral vessels it will be especially a question of avoiding the spasm, of these vessels which are about 0.8 mm in diameter.

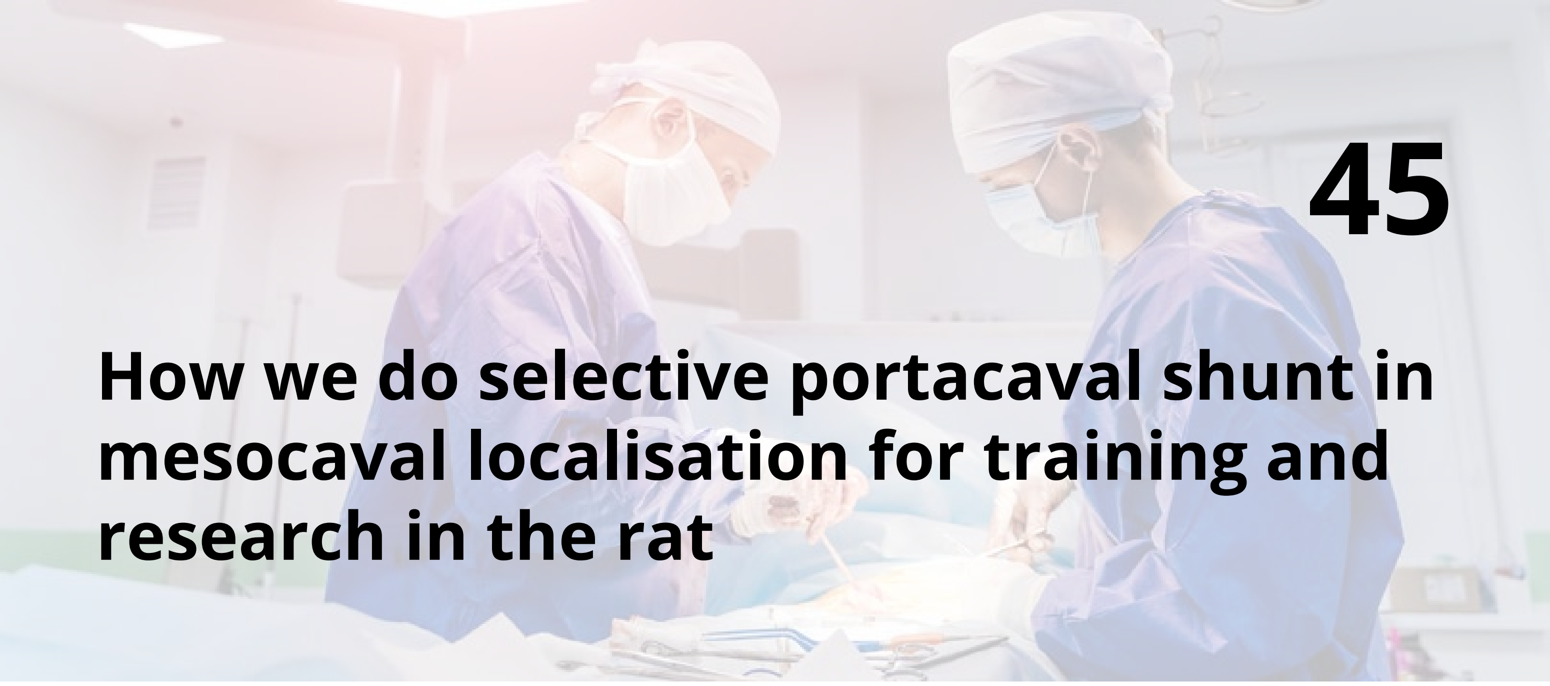
To release an organ like the kidney is to remove all the fat that protects it, fat that is generally accompanied by very many neo-vessels that bleed easily.

And to finish in the learning curve, there is an exercise in style that requires patience and great precision. It is a question of resuming a microsurgical technique after a fortnight of post-operative days when very many adhesions have formed accompanied by neo-vessels. This exercise, carried out under certain conditions, of course in full compliance with

animal experimentation regulations, is an exercise that prepares in particular for tumor excision surgeries.
Thus, over time and by increasing the difficulties during the training sessions, the student will obtain a certain ease, will take insurance and will be able to react in the face of certain difficulties such as for example in case of hemorrhage .

Conclusion

Mastering the dissection technique under the microscope requires many hours of laboratory training, in our opinion more than thirty sessions are necessary. Varying the exercises will make it easier to detect the different anatomical traps in all future situations in surgery and will make to develop both mastery of tactile perception and visual perception.



45

How we do selective portacaval shunt in mesocaval localisation for training and research in the rat

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Introduction

Various techniques and localizations are known for artificial porto-systemic shunts in the clinical practice of portal hypertension, when other therapeutical ways are not effective, or as a supportive tool in liver transplantation or small-for-size grafting [1,2]. Numerous portacaval shunt models were developed in rats, rabbits, dogs, pigs or even using simulation models: Lee-type end-to-side anastomosis, side-to-side version, interpositioned H-graft methods, selective portacaval shunt models (e.g., distal splenorenal, mesocaval portacaval) [3-7].

In this chapter we describe a refined microsurgical model for selective portacaval shunt in the rat, in which the rostral mesenteric vein is sutured to the caudal caval vein with end-to-side anastomosis technique, while the other main branch of the portal vein (gastrosplenic vein) is left intact [8,9].

Operative technique

1. *Incision and exploration:* To explore the portal and suprarenal region of the caval vein a median laparotomy is recommended. The correct positioning of the retractors is important for the better exploration, but avoiding stretching and allowing free breathing. The intestinal loops are gently antepositioned toward the left side, and covered with wet textile (physiological saline solution, body temperature).
2. *Dissection:* Using Q-tips the retroperitoneal space is opened, and the two renal veins connecting to a caudal caval vein (CCV) are identified. Proximally to that we can find the portal vein (PV) and the the bifurcation of the rostral mesenteric vein (rMV) and gastrosplenic vein. Depending on the size of the rat various amount of fat can be found in the mesentery and retroperitoneum, thus gentile dissection is required to identify the vessels.
3. *Preparation for anastomosis* (Figure 1): The rMV is ligated (8/0) as proximally as possible, and three microvascular clamps are applied. One distally on the rMV, and the other two are applied on the CCV. The rMV is cut distally from the ligature and positioned above the left renal vein. A venotomy is made on the lateral side of the CCV. The venotomy size has to be equal to the rMV's diameter. Irrigating the lumen with heparinized physiological saline solution (10%) is necessary.

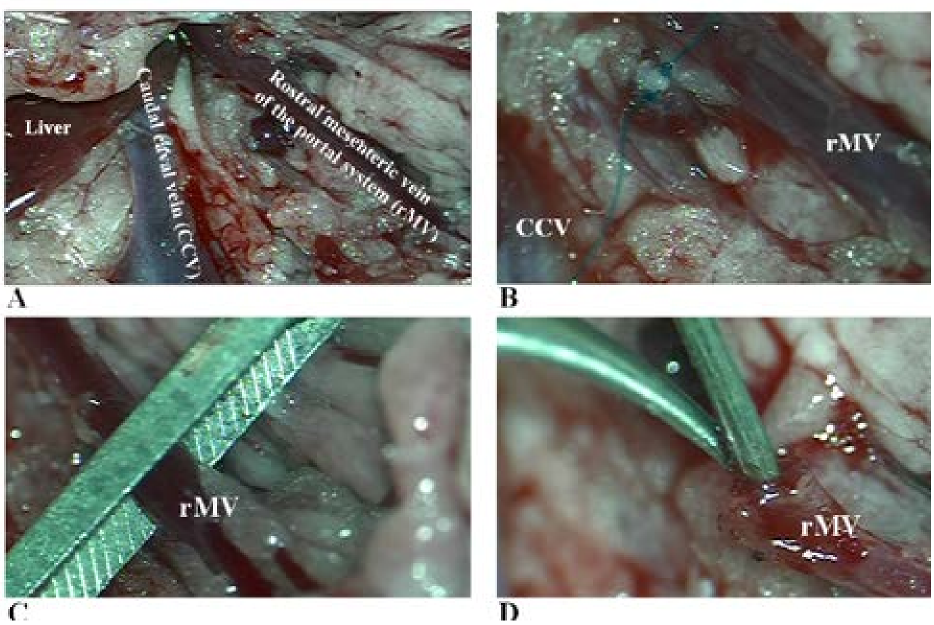

Figure 1. *Main steps of the operative technique I [8,9]: (A,B) After completing median laparotomy and anteposition of intestinal loops, gentle preparation and mobilization of the caudal caval vein (CCV) and the portal vein (PV) together with its main branches. (C) Aplying of atraumatic clips on the distal part of the rostral mesenteric vein (rMV) and ligating its proximal part, (D) venotomy and flushing the lumen with heparinized physiological saline solution. Magnification: 16X in A, 25X in B, C, D.*

4. *Suturing the anastomosis* (Figure 2): For taking stitches a 10/0 polyamide monofilament thread with serosa/taper needle is used. The back wall of the anastomosis can be sutured with a continuous suture or simple stitches using "one-way up" technique. The front wall is connected with 6-7 interrupted stitches. It limits the extent of possible stenosis.
5. *Bleeding control and patency test*: If the stitches were correctly applied minimal bleeding should occur. All branches of the anastomosis should be tested for patency. The double occlusion test is recommended.

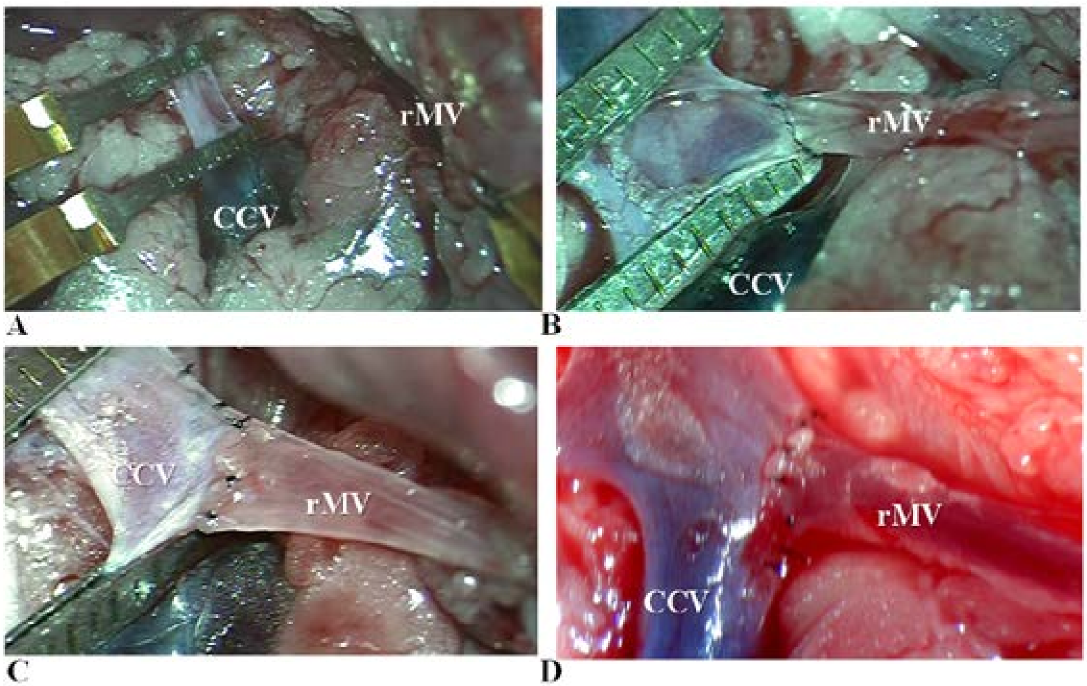

Figure 2. *Main steps of the operative technique II [8,9]: (A) applying proximally and distally positioned clips on the caudal caval vein (above the renal veins), venotomy on the lateral side (approximately with equal size of the rostral mesenteric vein's circumference), (B) flushing the lumen with heparinized physiological saline solution, positioning the rostral mesenteric vein's distal cut-end to the caudal caval vein (minimizing stretching and torquing), continuous suture line on the posterior wall of the anastomosis, (C) simple interrupted stitches on the front wall of the anastomosis, and finally, (D) removal of the clips (order: 1. distal and 2. proximal clip from the caudal caval vein, 3. distal clip from the rostral mesenteric vein). Magnification: 16X in A, 25X in B, C, D.*

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Performing various arterio-venous shunts for training and research in the rat

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Introduction

To study pathophysiology of the fistulas and related disorders various arterio-venous (AV) shunts models are known in rodents, such as aortocaval model, AV shunts in the femoral and carotid region, tail model [1-6]. Many of these shunt models can be applied to microsurgical training as well, dominantly in advanced level [7-9]. In this chapter we describe how we do arterio-venous fistulas (1) between the femoral artery and the superficial inferior epigastric vein, (2) between the saphenous artery and the medial saphenous vein, and (3) between the common carotid artery and the external jugular vein in the rat for training or research.

Operative techniques

End-to-side arterio-venous fistula in the femoral region

This anastomosis is performed between the femoral artery and the superficial inferior epigastric vein (SIEV) (Figure 1). The average diameter of the femoral artery in adult Wistar rats is about 0.5-1.0 mm, and 0.25-0.5 mm for the SIEV.

1. *Incision and exploration:* A 2-cm long skin incision is made just below the level of the inguinal ligament. The fatty tissue beneath the skin contains several small vessels which can cause bleeding. Therefore, it is important to continue the dissection as close as possible to the medial skin edge, toward the deeper layers where the femoral vessels can be found.
2. *Dissection:* The SIEV is the first side branch of the femoral vein proximally from the saphenous artery. The proximal and distal end of the femoral artery is clamped down, and the proximal end of the SIEV, where it meets the femoral vein. The SIEV is dissected from the superficial inferior epigastric artery.
3. *Preparation for anastomosis:* The adventitia of the femoral artery is removed from the site of the anastomosis, and the distal end of the SIEV is ligated distally, and then cut at 90° degree. A 26-G cannula is used to dilate the lumen of the vein and also for flushing with heparinized saline solution. This allows the operator to easily connect the vessel ends, since there is no notable diameter difference between the vein and the artery here. A stitch is placed into the side of the femoral artery, not reaching the lumen. This stitch is pulled and a small portion of the artery is then cut off. This creates an orifice which can be used for the end-to-side anastomosis. It is also dilated and washed using the 26-G cannula. The distal end of the SIEV is rotated towards the arterial orifice. The vein has to be protected from any rotation, because it can cause thrombosis later. In order to make sure that the vein is not rotated the vessel should be flattened using the belly of a curved forceps.
4. *Suturing the anastomosis:* For taking stitches a 10/0 polyamide monofilament thread with serosa/taper needle is used. Two positioning stitches were used to hold the vessels together. These divides the anastomoses into two sides. First the lower side is sutured. A suture is placed in the middle of the lower side and then two additional stitches are placed on both sides of the middle suture (halving technique). The upper wall is sutured in this same manner. The most important tip is that always suture from the venous wall towards the arterial wall. This enables the operator to control the amount venous tissue which is sutured into the anastomosis without stenosis.
5. *Bleeding control:* Once the anastomoses were finished, the clamps are removed in a specific order. First the venous clamp is removed. So it does not cause bleed-

ing because the venous pressure is not high enough to create a retrograde flow from the femoral vein to the anastomosis through the SIEV. The second clamp to be removed is the distal femoral clamp. The removal of this clamp results in a retrograde arterial blood flow. This helps to see if the anastomoses have severe problem or not. The bleeding should stop within a few second, if not, additional stitches are needed. If the bleeding was finally stopped the proximal clip is removed as well. This puts a much higher pressure on the anastomosis, which usually causes a new bleeding. Normally after a few second the bleeding stops again from the punctured holes and the fistula can be tested.

6. *Patency test:* By closing the SIEV dark red venous blood flows through the femoral vein. If the fistula is opened the flowing blood turns to a much lighter red color, which is a proof that the anastomosis is working. The flow distal to the anastomosis is tested with the double occlusion test. For this two forceps are needed. With one forceps the vessel is closed proximally and using the other one for pushing the blood out from the vessel lumen to distal direction. This gives us an empty bloodless vessel section between the two forceps. Then the proximal forceps is opened and the operator can examine how fast the empty section fills up with blood. This can give valuable information about the patency of the fistula.

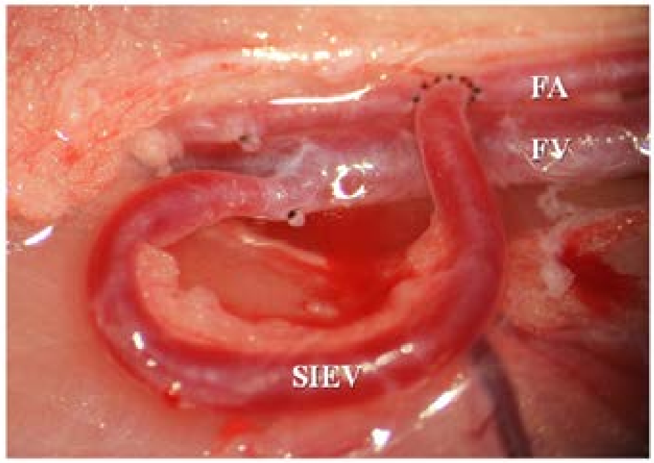

Figure 1. *Intraoperative photo of the arterio-venous fistula. FA: femoral artery, FV: femoral vein, SIEV: superficial inferior epigastric vein. M: 16X*

End-to-side saphenous arterio-venous fistula

This type of anastomosis is performed between the saphenous artery and the medial saphenous vein [10,11] (Figure 2). These vessels are approximately equal in diameter, which is about 0.5-0.6 mm in adult Wistar rats. The previously mentioned steps are mostly the same in this case as well.

1. *Incision and exploration:* Made at the lower medial region of the thigh above the gracilis muscle. Here the skin and the subcutaneous fat are very thin, and so it is very easy to cut into the vessels beneath. In this region the vessels don't branch and they are quite straight, superficial and easily accessible.
2. *Dissection:* Using two forceps the vessels can be easily separated from each other and from the surrounding tissues.
3. *Preparation for anastomosis:* The vessels

are clamped down proximally and distally to stop the flow. The artery and the vein are clamped simultaneously with microvascular clamps. The vein is distally ligated and cut and a hole is made on the medial surface of the artery by the same way as it was written before. The proximal end of the saphenous vein is cut in a 45° degree angle, which can be achieved by inserting one jaw of the microsurgical scissors, and cut the wall of the vein as deep as wide the vessel is.

4. *Suturing the anastomosis:* For taking stitches a 10/0 polyamide monofilament thread with serosa/taper needle is used. Two positioning corner sutures are placed into the vessel, and continuous suture lines are prepared. Since the lower wall cannot be reached from beneath, if interrupted stitches are used, the "one-way up" technique is recommended. It is very important not to over-tighten the suture because it would narrow the anastomosis.
5. *Bleeding control:* The distal clip is removed first and the anastomosis is checked for bleeding spots. If the bleeding stops the proximal clip can also be removed. The bleeding generally stops within a few seconds. If the bleeding is originated from a punctured hole, the proximal clip should be placed on the vessel again for a few seconds, allowing the blood to plug the small channel in the vessel wall. In our experience hot saline solution can be quite damaging for these small vessels.
6. *Patency test:* The distal end of the artery and also the saphenous vein have to be tested for patency. The double occlusion test is recommended.

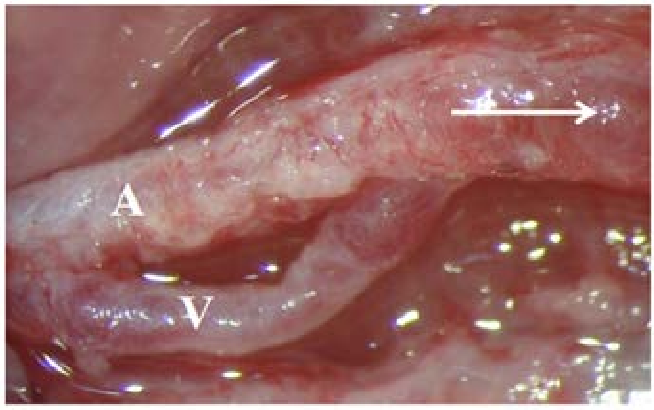

Figure 2. *Macroscopic picture of the end-to-side saphenous arterio-venous fistula 8 weeks after surgery [11]. A: saphenous artery, V: medial saphenous vein, white arrow: direction of flow. M: 40X*

End-to-end carotid-jugular fistula

This kind of anastomosis is performed between the common carotid artery and the external jugular vein [12] (Figure 3). The average diameter of these vessels is about 1 and 1.5 mm, respectively, in adult Wistar rats.

1. *Incision and exploration:* The head is turned to the contralateral side. This allows a much better view of the surgical field. A 1.5-cm oblique incision is made at the lower part of the neck just above the right clavicula and the sternal notch.
2. *Dissection:* The dissection of the cervical soft tissue should be done directly above the clavicula to avoid the injury of salivary glands. The dissection should be started medially to avoid an accidental injury of the vein in the lateral part of the incision. The vessels should be gently isolated, the vein is isolated carefully to its large tributaries i.e. for about 7 mm above the clavicle. It is enough to isolate the common carotid artery for 10-12 mm above clavicula, there is no need to reach the bifurcation of the artery which reduces the risk of bleeding by unnecessary excessive and

deep dissection.

3. *Preparation for anastomosis:* The artery should be ligated as distal as possible; it is enough to ligate the EJV just under the tributaries. It is important to mention that the unilateral carotid ligation in rats is almost innocuous as opposed to humans. Both vessels are clamped proximally with microsurgical clamps. It is recommended to control the artery using two clamps since the spontaneous release of the arterial clamp is life threatening. Artery and vein diameters are different, so the EJV should be cut perpendicular under the ligation and the artery should be cut at a 45-degree angle medially and obliquely so that the artery diameter matched to the diameter of the vein. It is important not to forget to irrigate the proximal lumens of CCA and EJV with sodium-heparin solution (10 U/ml).
4. *Suturing the anastomosis:* The golden tip in the construction of all microsurgical anastomoses is to do it tension-free. An end-to-end anastomosis was constructed in front of the sternocleidomastoid muscle between the proximal ends of artery and vein using 10-0 polyamide suture material with serosa/taper needle. Several techniques can be used for this anastomosis. The one we used in our studies was continuous suture. Two stay stitches would be used here, first stay stitch is placed at the lateral edge of the anastomosis, and second stay stitch is placed at 180^{o} angle from the first one. The anterior wall is stitched continuously using the first thread up to the second stay stitch then the first thread would be knotted with the second stay stitch. The anastomosis can now be flipped, and the posterior wall is stitched continuously using the second thread up to the first stay stitch then the second thread would be knotted with the first stitch. The continuous suture needs a good experience and a sense of anastomosis since it is easy to constrict the anastomosis by tight knots.
5. *Bleeding control and patency test:* After completing the anastomosis the venous clamp could be opened to check the bleeding with low-pressure (venous pressure is lower than arterial pressure), then the arterial clamps could be opened. A gentle compress of the anastomosis for a few seconds helps in bleeding control. The patency of the anastomosis is tested by the same way as described previously.
6. *Special note:* The postoperative neurological examination may show dropping of the upper eyelid, partial ptosis, as a part of the Horner syndrome (a known complication of carotid artery surgery in humans and rats) [13].

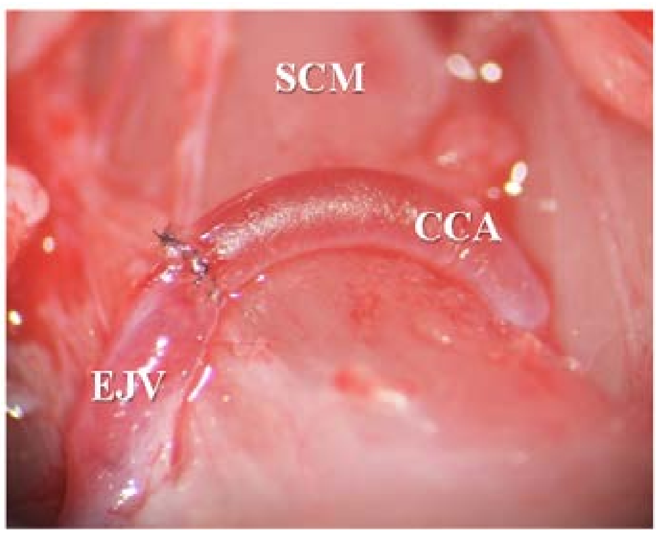

Figure 3. *Intraoperative photo of the carotid-jugular fistula [12]. SCM: sternocleidomastoid muscle, CCA: common carotid artery, EJV: external jugular vein. M: 16X*

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