JOURNAL OF RECONSTRUCTIVE MICROSURGERY

Official Journal of

The World Society for Reconstructive Microsurgery
The American Society for Peripheral Nerve
The Robotic Assisted Microsurgical and Endoscopic Society
The European Federation of Societies for Microsurgery

Manuscript Submission Center
All submissions to the *Journal of Reconstructive Microsurgery* should be made through the online submission center at
http://mc.manuscriptcentral.com/jrm

Thieme
New York · Stuttgart

Italian Society of Microsurgery (SIM) educational activities

The Italian Society of Microsurgery (http://www.microchirurgia.org/) offers its member a comprehensive educational program that spans from basic microsurgical training to clinical training. Starting with basic microsurgery courses, the student can go through an advanced microsurgery course in rats, a comprehensive and exciting flap course on cadavers and a perforator dissection technique course on pigs. Once the technical skills are mastered after these courses, clinical proficiency is pursued thanks to a funded fellowships that will expose the students to all fields of microsurgery.

Basic Microsurgery courses

All basic microsurgery courses of the society follow the standard guidelines developed over the years with the cooperation of our trainers and students. The student's progression is carefully taken care of in order to optimize proficiency and save animals in accordance to the 3R principle. Animal training comes only after all the techniques are mastered in a basic course – which does not necessarily need to include a living animal training -, in order to optimize the student's experience. Minimum 20 hours of training with at least the first 10 on non-animal models are the standard. A manual, edited by the Society, is provided to each participant.

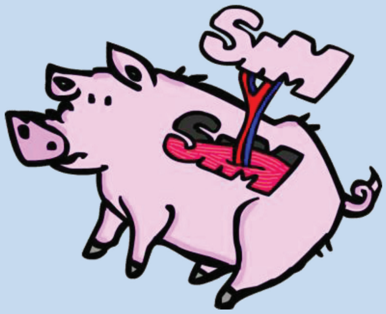
The 2018 courses are: **February** Udine and Torino; **March:** Varese and Milan; **April:** Naples; **May:** Parma; **September:** Bologna; **October:** Brescia; **November:** Bari; **December:** Pisa. http://www.microchirurgia.org/formazione-corso-base-microchirurgia.htm

Advanced Microsurgery course

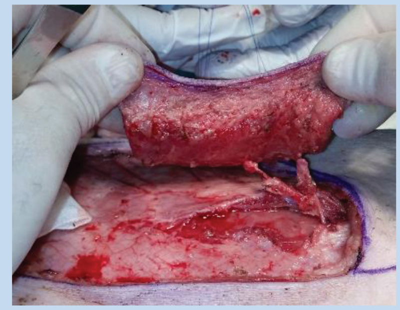
After having completed a basic course, the students can get access to the ***advanced course***: three full non-consecutive weeks over one year, for a total of 120 hours of hands-on training . The students do perform all type of microsurgical exercises on rats (18 different exercises are progressively done with a video demonstration) with the supervision of a master in microsurgical techniques. During the course, the students write a thesis that is defended during the final exam for their diploma.

Several tutors guide the students during their process. This advanced Course is also opened to foreigners that provide a certification of a basic course. A manual of exercises is also provided to each student. For more info surf to: http://www.microchirurgia.org/formazione-corso-avanzato-microchirurgia.htm

Perforator flaps dissection course on pigs



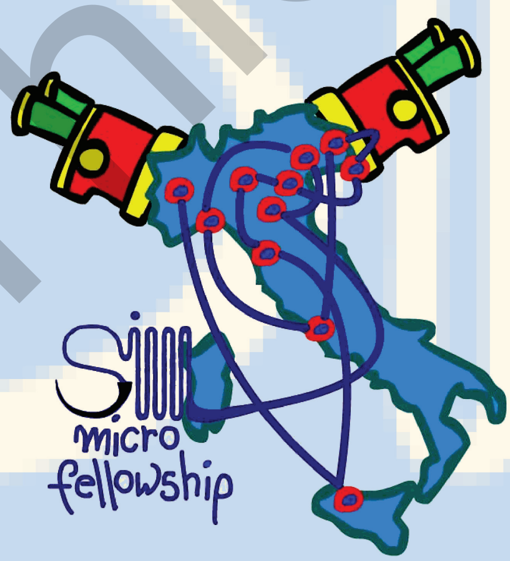
The ***perforator flap dissection course on pigs*** is specifically designed to provide two full days of surgical exposure to perforator dissection with close tuition by the society's instructors and develop perforator dissection skills on a living individual that has a similar anatomy to humans and allows immediate feedback by observing flap vascularization.
http://www.microchirurgia.org/formazione-corso-



Dissection Course on cadavers – flaps and peripheral nerve

Two cadaver courses are offered in Nice (France) and Alicante (Spain) on **flaps**, recipient and donor vessels and nerves and on peripheral nerve surgery respectively.
The most advanced teaching techniques are used and close tuition is provided to the students.
http://www.microchirurgia.org/formazione-corso-dissezione-chirurgica.htm

Fellowship with clinical exposure to microsurgery and hands-on training



The Microfellowship, funded by S&T, offers the recipients 10 weeks of advanced hands-on training in several well renowned microsurgical centers in Italy. Dedicate tuition is provided and the winners will deliver a presentation at the Society meeting on their experience.

http://www.microchirurgia.org/formazione-fellowship-clinica-italiana-microchirurgia.htm

ISSN 0743-684X

Journal of Reconstructive Microsurgery

 Journal of Reconstructive Microsurgery is published nine times a year in January, February, March, May, June, July, September, October, and November by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001.

Subscription and pricing information in €, US$, and Indian Rupees can be found online at **www.thieme.com/jrm/subscribe.**

Periodicals postage is paid at New York, NY and additional mailing offices. POSTMASTER: send changes of address to *Journal of Reconstructive Microsurgery*, Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001. Copies not received will be replaced upon written notification to the Publisher. Notification must be received within three months of issue date for U.S. subscribers, and within four months of issue date outside the United States.

Editorial comments should be sent to **journals@thieme.com.** Articles may be submitted to this journal on an open-access basis. For further information, please send an e-mail to openaccess@thieme.com. The content of this journal is available online at **www.thieme-connect.com/products.** Visit our Web site at **www.thieme.com** and the direct link to this journal at **www.thieme.com/jrm.**

Journal of Reconstructive Microsurgery is listed in *Current Contents/ ClinicalMedicine, EMBASE, Excerpta Medica, Index Medicus, MEDLINE, Research Alert, Scopus, and Scisearch*. Thieme Medical Publishers is a member of the Cross Ref initiative.

Volume 33, Supplement 1/2017

Journal of Reconstructive Microsurgery

Italian Society of Microsurgery
Current Concepts on Lower Extremity Reconstruction

Salvatore D'Arpa, MD, PhD and Francesco Moschella, MD

Editorial

S1 Introduction to the Current Concepts in Lower Extremity Reconstruction by the Italian Society for Microsurgery
Salvatore D'Arpa, MD, PhD, Francesco Moschella, MD

Review Articles

S3 Limb and Flap Salvage in Gustilo IIIC Injuries Treated by Vascular Repair and Emergency Free Flap Transfer
Zoran Marij Arnež, MD, PhD, Giovanni Papa, MD, PhD, Vittorio Ramella, MD, Federico Cesare Novati, MD, Uros Ahcan, MD, PhD, Chiara Stocco, MD

S8 Role of Negative Pressure Therapy as Damage Control in Soft Tissue Reconstruction for Open Tibial Fractures
Mario Cherubino, MD, FEBOPRAS, Luigi Valdatta, MD, FACS, Pierluigi Tos, MD, PhD, Salvatore D'Arpa, MD, PhD, Luigi Troisi, MD, Pellegatta Igor, MD, Federica Corradi, MD, Umraz Khan, MSc, FRCS

S14 Vascular Grafts and Flow-through Flaps for Microsurgical Lower Extremity Reconstruction
Francesca Toia, MD, PhD, Giovanni Zabbia, MD, PhD, Tiziana Roggio, MD, Roberto Pirrello, MD, Salvatore D'Arpa, MD, PhD, Adriana Cordova, MD

S20 Below Knee Stump Reconstruction with a Foot Fillet Flap
Pierluigi Tos, MD, PhD, Andrea Antonini, MD, Pierfrancesco Pugliese, MD, Bernardino Panero, MD, Davide Ciclamini, MD, Bruno Battiston, MD, PhD

S27 Muscle versus Fasciocutaneous Flap in Lower Limb Reconstruction: Is There a Best Option?
Mario Cherubino, MD, FEBORAS, Martina Corno, MD, Salvatore D'Arpa, MD, PhD, Pietro Di Summa, MD, PhD, Igor Pellegatta, MD, Luigi Valdatta, MD, FACS, Mario Ronga, MD

S34 Retrospective Analysis in Lower Limb Reconstruction: Propeller Perforator Flaps versus Free Flaps
Marta Cajozzo, MD, Francesca Toia, MD, PhD, Alessandro Innocenti, MD, Massimiliano Tripoli, MD, PhD, Giovanni Zabbia, MD, PhD, Salvatore D'Arpa, MD, PhD, Adriana Cordova, MD

S40 Achilles Region Soft-Tissue Defects: A Reconstructive Algorithm Based on a Series of 46 Cases
Marco Innocenti, MD, Alessandro Innocenti, MD, Serena Ghezzi, MD, Luca Delcroix, MD

Thieme
New York • Stuttgart

333 Seventh Avenue, New York, NY 10001, USA
Tel: +1(212) 584-4662

online www.thieme-connect.com/products

S48 The Propeller Concept Applied to Free Flaps and the Proposal of a "Clock Flap" Nomenclature
Andrea Antonini, MD, Carlo Rossello, MD, Carlo Salomone, MD, Giuliana Carrega, MD, Lamberto Felli, Giorgio Burastero, MD

Editorial

Introduction to the Current Concepts in Lower Extremity Reconstruction by the Italian Society for Microsurgery

Salvatore D'Arpa, MD, PhD[1,2] Francesco Moschella, MD[2]

[1] Department of Plastic and Reconstructive Surgery, Gent University Hospital, Gent, Belgium
[2] Division of Plastic, Reconstructive, and Cosmetic Surgery, Department of Surgical, Oncological, and Oral Sciences, University of Palerno, Palerno, Italy

J Reconstr Microsurg 2017;33:S1–S2.

We are proud to introduce the Journal of Reconstructive Microsurgery supplement, "Italian Society of Microsurgery: Current Concepts on Lower Extremity Reconstruction."

This is the inaugural issue of a series of supplements that will be published by the Italian Society of Microsurgery (SIM), an initiative introduced by our current President, Prof Francesco Moschella and the executive committee of the society.

Each supplement will follow our biannual symposium that is held during the year between two meetings and concentrates on a single topic. The supplement is published the year after the symposium and delivered to the members of the Society during the national meeting.

The topic described and discussed in the inaugural issue is lower limb reconstruction, a subject that can be well representative of the orthoplastic concept that joins together several members of the society.

This particular issue comes after 2016 Trieste's symposium, organized by Prof Arnez on lower limb reconstruction, with the contribution of Prof Tos, Prof Innocenti, Dr Cherubino, Dr Toia, Dr Caiozzo, and all other coauthors. We sincerely appreciate their efforts.

Selected aspects have been covered in this issue that reflect the attitude of the SIM towards modern lower limb reconstruction and its position on controversial issues.

The issue begins with the emergency treatment of open tibial fractures and the modern concept of negative pressure therapy in damage control surgery.

The use of vascular, arterial, and venous grafts, and flow-through flaps is described in the third article.

The fourth article discusses the *spare parts concept* in unsalvageable lower extremities and the technique and clinical applications of the foot fillet flap.

The fifth and sixth articles analyze the advantages and disadvantages of the use of muscle flaps versus fasciocutaneous flaps and propeller perforator flaps versus free flaps.

In the seventh article, an algorithm for reconstruction of the challenging Achilles region is described that provides useful indication on the use of free and pedicled flaps.

Lastly, the very modern concept of propeller perforator flaps harvested on free flaps to increase the surface to be covered is presented, together with a simple nomenclature proposal.

This issue is the result of a joint effort of the whole society. We are honored to serve as the Editors and would like to thank all the authors and the production team for their efforts.

Enjoy reading.

Address for correspondence Salvatore D'Arpa, MD, PhD, Adjunct Kliniekhoofd, Plastische Heelkunde, De Pintelaan 185 9000 Gent, Belgium (e-mail: Salvatore.DArpa@uzgent.be).

Issue Theme Italian Society of Microsurgery: Current Concepts on Lower Extremity Reconstruction; Guest Editors, Salvatore D'Arpa, MD, PhD, Francesco Moschella, MD

DOI https://doi.org/10.1055/s-0037-1606818.
ISSN 0743-684X.

Limb and Flap Salvage in Gustilo IIIC Injuries Treated by Vascular Repair and Emergency Free Flap Transfer

Zoran Marij Arnež, MD, PhD[1] Giovanni Papa, MD, PhD[1] Vittorio Ramella, MD[1]
Federico Cesare Novati, MD[1] Uros Ahcan, MD, PhD[2] Chiara Stocco, MD[1]

[1] Department of Plastic and Reconstructive Surgery, Universita degli Studi di Trieste Dipartimento di Scienze Mediche Chirurgiche e della Salute, Trieste, Friuli-Venezia Giulia, Italy
[2] Department of Plastic Surgery and Burns, Univerzitetni klinicny Center Ljubljana, Ljubljana, Slovenia

Address for correspondence Zoran Marij Arnež, MD, PhD, Department of Plastic and Reconstructive Surgery, Universita degli Studi di Trieste Dipartimento di Scienze Mediche Chirurgiche e della Salute, Trieste 34100, Friuli-Venezia Giulia, Italy (e-mail: zoran.arnez@asuits.sanita.fvg.it).

J Reconstr Microsurg 2017;33:S3–S7.

Abstract

Background Gustilo classification system defines IIIC fractures as open fractures associated with an arterial injury that requires repair. The aim of our study was to analyze the early outcome in terms of limb and flap salvage, early amputation, and early complication rate in patients with Gustilo IIIC open fractures treated in an emergency setup.
Methods We retrospectively reviewed 20 patients with Gustilo IIIC injuries treated by the "fix and flap" principle during the first surgical procedure in the first 24 hours after injury (emergency free flap transfer). All patients underwent surgery with radical debridement, wound irrigation, skeletal stabilization, vascular repair, and immediate free flap coverage.
Results In this study, 18 patients were men (90%) and 2 were women (10%). In all patients, a vascular repair was performed and in 17 cases (85%), the lower limb/foot was avascular and limb salvage was performed. Three patients had one vessels injured (15%) and 17 had two or three vessels injured (85%). In 9 out of 20 (45%), a revision surgery was needed for arterial (10%, 2 patients), arterial–venous (15%, 3 patients), and venous thrombosis (20%, 4 patients), while 4 patients required an early amputation (20%) and 1, a late one (5%). In three patients (15%), a flap loss occurred. Superficial infection occurred in seven cases (35%) and deep infection (osteomyelitis) in one (5%)
Conclusion A single-stage procedure performed in an emergency operating room could lead to an effective outcome with a high rate of limb salvage and satisfying long-term results.

Keywords
- emergency free flap
- lower limb
- microsurgical reconstruction
- Gustilo IIIC open tibial fracture

Approximately 15% of all fractures in adults are open tibial fractures (OTFs).[1] Vascular injuries in orthopaedic trauma are rare: they account for 1.6% in adults and 0.6% in pediatric patients.[2] Injuries to the vessels of the lower leg, in particular, to the popliteal artery and its trifurcation (anterior tibial artery and the tibioperoneal trunk) occur in 1.5 to 2.8% of tibial fractures[3] and a surgical repair of the popliteal artery, after knee dislocation, is required in 16 to 20% of cases.[4]

The Gustilo classification system defines IIIC fractures as open fractures associated with an arterial injury requiring repair,[5] resulting from high-energy traumas and presenting with vascular lesions and large soft tissue defects that have always been challenging for the surgeons to be treated at first place. Furthermore, their prognosis has been made even worse by a high rate of secondary complications (limb ischemia, osteomyelitis, compartment syndrome, etc.) leading

received
December 26, 2016
accepted after revision
April 29, 2017

DOI https://doi.org/10.1055/s-0037-1603737.
ISSN 0743-684X.

to potential secondary amputation. Despite microvascular reconstruction and technical innovations, the management of Gustilo IIIC injuries represents a challenge even for expert surgeons since an immediate decision between limb salvage and primary amputation is required. Treatment of Gustilo IIIC injuries is by rule interdisciplinary in between orthopaedic and plastic surgeons.

The role of the plastic surgeon is, other than performing surgical debridement of soft tissues, to evaluate the vascular tree of the injured limb (to assess if the lower limb is ischemic), to decide what type of vascular repair should be needed (arterial anastomosis, vein graft), to select the appropriate recipient vessels and the type of anastomosis (end-to-end, end-to-side), as well as planning the soft tissue reconstruction,[6] as a superficial evaluation can lead to disastrous outcomes (amputation). For this reason, it is mandatory to establish which and how many vessels are injured and which and how many are preserved. Gustilo IIIC classification does not differentiate between injury of one, two, or three lower leg arteries, and since this being of critical importance, it should be taken into account.[7] Khan et al suggested a new classification of Gustilo IIIB fractures, which proposes inclusion of a special subunit for IIIB defects with vascular damage to a single artery, thus reserving Gustilo IIIC type fractures/defects only for injuries with avascular limb/foot.[7]

Many articles[8,9] outline the advantages of early microsurgical reconstruction of open fractures, and it is well recognized nowadays that a combined management is required even if the timing of the reconstruction has changed; moreover, the British Orthopedic Association/British Association of Plastic, Reconstructive and Aesthetic Surgeons guidelines for management of OTFs underline the appropriate criteria and approach to these type of fractures.

The aim of our study was to analyze the early outcome (in terms of limb and flap salvage, primary or secondary wound healing, early amputation rate, and early complication rate) in patients with Gustilo IIIC OTF treated by a combined orthopaedic/plastic surgery approach by the “fix and flap” principle in an emergency setup.

Methods

The retrospective study was performed in two tertiary referral centers (Ljubljana and Trieste) for complex limb

Table 1 Patient demographics

Patient		Age (y)	Gender (M/F)	Cause of injury	Injury level	Defect size	Avascular foot (Y/N)	Bone fixation	Vascular injury	Free flap	Anastomosis revision	Limb amputation after vascular repair
1	B.V.	47	M	Hit by a vehicle	M3/L3	Large	Y	Plate	PTA (vein graft)–ATA	LD	None	Late amputation
2	B.M.	45	M	Fall	L3	Large	N	Plate	PTA (vein graft)	LD	None	None
3	B.J.	9	F	Heavy object falling trauma	Foot	Large	Y	K-wires	PTA–ATA	LD	AT–VT	Early amputation
4	T.M.	25	M	MVA	U3	Large	Y	External fixation	POP	LD	AT	Early amputation
5	S.R.	16	M	MVA	Ankle	Large	Y	K-wires	PTA–ATA	LD	None	None
6	B.S.	51	M	Fall	L3	Large	Y	Plate	PTA (vein graft)–ATA	Scapular	None	None
7	J.Z.	30	M	MVA	U3	Large	Y	External fixation	PTA–ATA	LD	VT	None
8	J.S.	20	M	Lawn mover	L3	Large	Y	Plate	PTA–ATA	LD	AT–VT	Early amputation
9	V.J.	11	M	MVA	L3	Large	Y	External fixation	PTA–ATA	LD	VT	Early amputation
10	G.F.	46	M	Heavy object falling trauma	Foot	Large	Y	K-wires	PTA–ATA	LD	None	None
11	S.V.	32	M	Lawn mover	L3	Large	N	External fixation	PTA (vein graft)	LD	None	None
12	K.B.	34	M	Heavy object falling trauma	Foot	Large	N	External fixation	ATA (vein graft)	LD	None	None
13	K.L.	46	M	MVA	L3	Medium	Y	Plate	PTA–ATA (flow through)	RF	AT	None
14	S.P.	65	M	Skiing	U3	Large	Y	External fixation	POP	RA	AT–VT	None
15	S.M.	17	M	Pedestrian hit by a car	L3/ankle	Medium	Y	Arthrodesis and K-wires	PTA–ATA	Gracilis	None	None
16	Z.J.	42	M	Accidental fall	L3	Small	Y	External fixation	PTA–ATA	Gracilis	None	None
17	P.M.	18	F	MVA	U3/M3	Large	Y	External fixation	POP (vein graft)	LD	VT	None
18	O.S.	30	M	MVA	M3	Small	Y	External fixation	PTA (vein graft)–ATA (vein graft)	Gracilis	None	None
19	D.J.	49	M	MVA	L3	Large	Y	External fixation	PTA–ATA	LD	None	None
20	B.M.	16	M	MVA	M3/L3	Medium	Y	External fixation	PTA (vein graft)–ATA (flow through)	ALT	None	None

Abbreviations: ALT, anterolateral thigh; AT, arterial thrombosis; ATA, anterior tibial artery; LD, latissimus dorsi; MVA, motor vehicle accident; PTA, posterior tibial artery; RA, rectus abdominis; RF, radial forearm; U3/M3/L3, upper/middle/lower third of the limb; VT, venous thrombosis.

reconstruction, where charts and photo documentation of all patients with Gustilo IIIC injuries, treated by the “fix and flap” principle during the first surgical procedure within 24 hours after injury (emergency free flap transfer) operated by the senior author from 1984 to 2016, were examined.

Total 20 patients fulfilled the inclusion criteria (open fractures of the lower leg/foot, vascular injury requiring repair [►**Table 1**]) and all the open fractures of the lower leg without vascular injury were excluded. All patients were treated according to the same protocol: resuscitation was performed following the Advanced Trauma Life Support guidelines,[10] all patients were given tetanus prophylaxis and broad-spectrum antibiotics (cefazolin 1 g three times a day and gentamycin 800 mg twice a day during the first 72 hours) and low-molecular-weight heparin until discharged. All patients underwent emergency surgery within 24 hours from injury, following the “fix and flaps” principles[11] with radical debridement, copious wound irrigation, skeletal stabilization, vascular repair, and immediate free flap coverage. The vascular injury was confirmed by surgical exploration of the zone of injury (most often), by Doppler ultrasound, or by on-table angiography (rarely) and the concomitant injuries were treated and documented as well as the number of secondary procedures required. After the operation, the patients were transferred to the plastic surgery semi-intensive care for flap monitoring or to the intensive care unit (polytraumatized patients) and in all cases, the plastic surgeons were responsible for the patient follow-up during the wound-healing period (14 days after injury), when all sutures were removed and when all skin grafts should have been healed, while orthopaedic surgeons were responsible for the patient during the bone-healing period.

Fig. 1 Above left: patient with motor vehicle accident of lower limb treated with a single-stage latissimus dorsi free flap. Above right, below left, and below right: follow-up at 2 years.

Results

We reviewed 20 patients with 20 Gustilo IIIC open fractures and all the patients were followed up until the end of their clinical course. Eighteen were men (90%) and 2 were women (10%) with a mean age of 32 years (9–65 years). The most common cause of injury was a motor vehicle accident while the mean hospital stay was 14 days (7–56 days). The tibial fractures were classified according to the location of major fracture fragments.[12] The mean operative time was 8 hours (5 hours and 50 minutes—13 hours). In all patients, a vascular repair was performed: in 17 cases (85%), the lower limb/foot was avascular and a limb salvage was performed; 3 patients had one vessels injured (15%) and 17 had two or three vessels injured (85%). Overall 37 vessels were injured in 20 patients, 9 of which were repaired with a reverse saphenous vein graft and 28 with a direct suture. In two patients, revascularization was performed via a “flow-through” free flap (one anterolateral thigh [ALT] flap and one radial forearm flap). In all patients, an emergency free flap was used to cover the soft tissue defects at the time of the first surgical debridement, bone stabilization, and vascular repair: 13 patients had a latissimus; 3, a gracilis; 1, an ALT; 1, a scapular; 1, a rectus abdominis; and 1, a radial forearm free flap (►**Figs. 1** and **2**). In 9 out of 20 (45%) patients, a revision surgery was needed for arterial (10%, 2 patients), arterial–venous thrombosis (15%, 3 patients), and venous thrombosis (20%, 4 patients), while 4 patients required an early amputation (20%) and 1 a late one (5%). In three patients (15%), a flap loss occurred. In patients with early lower leg amputations, the free flap was used to cover the amputation stump; thus, preventing a more proximal amputation. Superficial infection occurred in seven cases (35%) but only one (5%) deep infection (osteomyelitis) was recorded. One polytraumatized patient died of respiratory distress syndrome.

Discussion

Gustilo IIIC OTF are not very common, but they can cause high morbidity rates and multiple complications.[13] Historically, these complex injuries resulted in a very high amputation rate (around 80%)[14] even if recent advances in trauma management, bone fixation, vascular repair, microsurgical skills, and knowledge about appropriate use of antibiotics have improved the outcome of Gustilo IIIC OTF, they still represents a complex challenge. Our rate of early amputation (20%) is comparable to those of 16.6% reported by Soni et al,[15] 17% by Segal et al,[16] and 21% by Brinker and Bailey.[17]

Treatment of Gustilo IIIC OTF requires an early decision about limb reconstruction or amputation based on

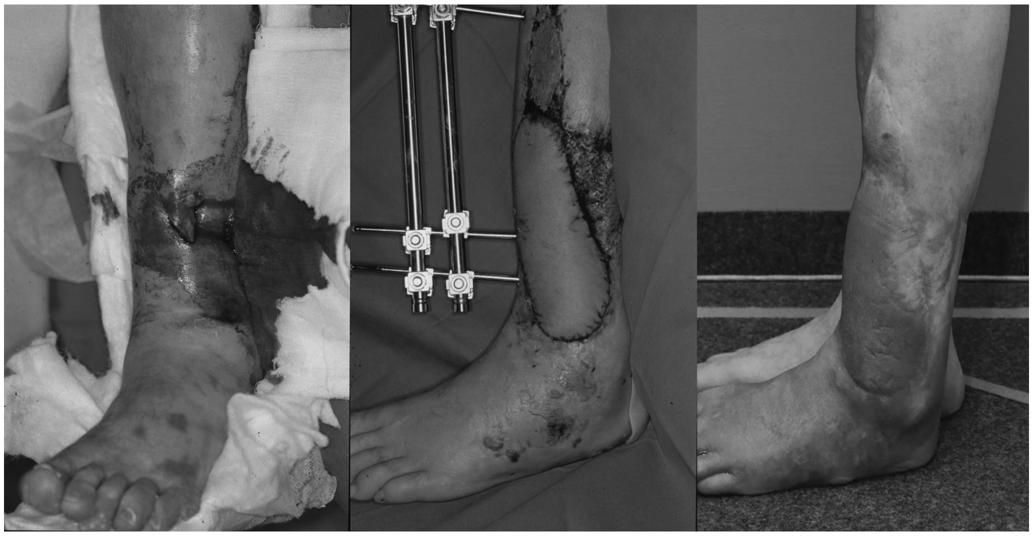


Fig. 2 Avascular foot after trauma, treated with a radial forearm flow-through free flap. Early postoperative result and follow-up at 18 years.

predictions of expected outcome both for the limb and for the patient: a primary amputation is considered as a valid option in those patients when the limb ischemia time exceeds 4 to 6 hours of warm ischemia, those with muscle loss affecting more than two lower compartments and those with bone loss involving more than one-third of the length of the tibia.[18] Secondary amputations can be expected in 5.5 to 28% of Gustilo IIIC OTF[19,20] and they were reported to represent the 10.2% of patients by Seligson et al,[21] 28% by Alexander et al,[22] 19.4% by Lin et al[23] but only 5.5% by Soni et al.[15] In our series, only one patient underwent secondary amputation (5%). According to McNutt et al,[24] the main reasons for secondary amputation included extensive muscle necrosis, infection, delayed revascularization, distal thrombosis, and lack of adequate collateral blood flow. The patient who, in our series, underwent secondary amputation developed chronic osteomyelitis and refused further surgical procedures. In three patients (15%), a flap loss occurred due to vascular (arterial or venous) thrombosis, even if the anastomoses were placed proximally and far from the zone of injury, probably due to the extended unrecognized endothelial damage of the recipient vessel not correctly evaluated at first place and a second free flap was used later to provide coverage. Superficial infection occurred in seven cases (35%), in agreement with the literature (many authors have reported a higher infection rate in Gustilo IIIC compared with IIIA and B).[25] The reason, in our patients, was most often nosocomial infection in the areas covered by split thickness skin grafts. There was only one deep infection resulting in an osteomyelitis and a secondary amputation, which speaks favorably of the quality of the debridement and in favor of immediate wound closure by emergency free flap transfer. Laser-assisted indocyanine green angiography has recently been introduced in the reconstruction of Gustilo IIIB open lower limb fractures to detect areas of poor vascularity or necrosis of superficial and deep tissues to facilitate accurate surgical debridement in a single or more surgical sessions and prevent complications such as secondary healing and deep infections.[26] Further studies should be necessary to apply and evaluate this technique in Gustilo IIIC injuries where clear separation of tissue necrosis (completely avascular tissue) from the areas of reperfusion injury often represents a problem.

Conclusion

In conclusion, our series of patients with Gustilo IIIC injuries treated with a single-stage reconstruction including debridement, bone fixation, vascular repair, and soft tissue cover by a free flap, performed by experienced surgeons using an orthoplastic approach, in an emergency setting, could lead to efficient outcomes in few operating procedures, low rate of deep infection, and a moderate rate of superficial infection. As expected, the complication rates of treatment of Gustilo IIIC injuries were higher compared with nonischemic fractures (with smaller zones of injury); however, a high rate of limb/flap salvage was observed.

References

1 Aslan A, Uysal E, Ozmeriç A. A staged surgical treatment outcome of type 3 open tibial fractures. ISRN Orthop 2014;2014:721041
2 Barmparas G, Inaba K, Talving P, et al. Pediatric vs adult vascular trauma: a National Trauma Databank review. J Pediatr Surg 2010; 45(07):1404–1412
3 Caudle RJ, Stern PJ. Severe open fractures of the tibia. J Bone Joint Surg Am 1987;69(06):801–807
4 Mullenix PS, Steele SR, Andersen CA, Starnes BW, Salim A, Martin MJ. Limb salvage and outcomes among patients with traumatic popliteal vascular injury: an analysis of the National Trauma Data Bank. J Vasc Surg 2006;44(01):94–100
5 Gustilo RB, Mendoza RM, Williams DN. Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. J Trauma 1984;24(08):742–746
6 Park S, Han SH, Lee TJ. Algorithm for recipient vessel selection in free tissue transfer to the lower extremity. Plast Reconstr Surg 1999;103(07):1937–1948

7 Chummun S, Wigglesworth TA, Young K, et al. Does vascular injury affect the outcome of open tibial fractures? Plast Reconstr Surg 2013;131(02):303–309
8 Godina M. Early microsurgical reconstruction of complex trauma of the extremities. Plast Reconstr Surg 1986;78(03):285–292
9 Arnez ZM. Immediate reconstruction of the lower extremity–an update. Clin Plast Surg 1991;18(03):449–457
10 ATLS Subcommittee; American College of Surgeons' Committee on Trauma; International ATLS working group. Advanced trauma life support (ATLS®): the ninth edition. J Trauma Acute Care Surg 2013;74(05):1363–1366
11 Gopal S, Majumder S, Batchelor AG, Knight SL, De Boer P, Smith RM. Fix and flap: the radical orthopaedic and plastic treatment of severe open fractures of the tibia. J Bone Joint Surg Br 2000;82(07):959–966
12 Veliskakis KP. Primary internal fixation in open fractures of the tibal shaft; the problem of wound healing. J Bone Joint Surg Br 1959;41-B(02):342–354
13 Saddawi-Konefka D, Kim HM, Chung KC. A systematic review of outcomes and complications of reconstruction and amputation for type IIIB and IIIC fractures of the tibia. Plast Reconstr Surg 2008;122(06):1796–1805
14 Flint LM, Richardson JD. Arterial injuries with lower extremity fracture. Surgery 1983;93(1 Pt 1):5–8
15 Soni A, Tzafetta K, Knight S, Giannoudis PV. Gustilo IIIC fractures in the lower limb: our 15-year experience. J Bone Joint Surg Br 2012;94(05):698–703
16 Segal D, Brenner M, Gorczyca J. Tibial fractures with infrapopliteal arterial injuries. J Orthop Trauma 1987;1(02):160–169
17 Brinker MR, Bailey DE Jr. Fracture healing in tibia fractures with an associated vascular injury. J Trauma 1997;42(01):11–19
18 BAPRAS/BOA. Standards for the Management of Open Fractures of the Lower Limb. London, UK: Royal Society of Medicine Press Ltd; 2009
19 Durham RM, Mistry BM, Mazuski JE, Shapiro M, Jacobs D. Outcome and utility of scoring systems in the management of the mangled extremity. Am J Surg 1996;172(05):569–573, discussion 573–574
20 Hoogendoorn JM, van der Werken C. Grade III open tibial fractures: functional outcome and quality of life in amputees versus patients with successful reconstruction. Injury 2001;32(04): 329–334
21 Seligson D, Ostermann PA, Henry SL, Wolley T. The management of open fractures associated with arterial injury requiring vascular repair. J Trauma 1994;37(06):938–940
22 Alexander JJ, Piotrowski JJ, Graham D, Franceschi D, King T. Outcome of complex vascular and orthopedic injuries of the lower extremity. Am J Surg 1991;162(02):111–116
23 Lin CH, Wei FC, Levin LS, Su JI, Yeh WL. The functional outcome of lower-extremity fractures with vascular injury. J Trauma 1997; 43(03):480–485
24 McNutt R, Seabrook GR, Schmitt DD, Aprahamian C, Bandyk DF, Towne JB. Blunt tibial artery trauma: predicting the irretrievable extremity. J Trauma 1989;29(12):1624–1627
25 Pollak AN, Jones AL, Castillo RC, Bosse MJ, MacKenzie EJ; LEAP Study Group. The relationship between time to surgical debridement and incidence of infection after open high-energy lower extremity trauma. J Bone Joint Surg Am 2010;92(01):7–15
26 Koshimune S, Shinaoka A, Ota T, Onoda S, Kimata Y. Laser-assisted indocyanine green angiography aids in the reconstruction of Gustilo grade IIIB open lower-limb fractures. J Reconstr Microsurg 2017;33(02):143–150

Role of Negative Pressure Therapy as Damage Control in Soft Tissue Reconstruction for Open Tibial Fractures

Mario Cherubino, MD, FEBOPRAS[1] Luigi Valdatta, MD, FACS[1] Pierluigi Tos, MD, PhD[2]
Salvatore D'Arpa, MD, PhD[3,4] Luigi Troisi, MD[5] Pellegatta Igor, MD[1] Federica Corradi, MD[1]
Umraz Khan, MSc, FRCS[5]

[1] Department of Biotechnology and Life Sciences, Division of Plastic and Reconstructive Surgery, University of Insubria, Varese, Italy
[2] Department of Orthopaedics and Traumatology for Hand, ASST Gaetano Pini, Milan, Italy
[3] Department of Plastic and Reconstructive Surgery, Ghent University Hospital, Gent, Belgium
[4] Division of Plastic and Reconstructive Surgery, Department of Surgical, Oncological and Oral Sciences, University of Palermo, Palermo, Italy
[5] Department of Plastic and Reconstructive Surgery, Southmead Hospital, North Bristol NHS Trust, Bristol, United Kingdom

J Reconstr Microsurg 2017;33:S8–S13.

Address for correspondence Mario Cherubino, MD, FEBOPRAS, Department of Biotechnology and Life Sciences (DBSV), Division of Plastic and Reconstructive Surgery, University of Insubria, ASST Sette Laghi, Viale Borri 57, 21100 VA, Italy (e-mail: mario.cherubino@gmail.com).

Abstract

The concept of damage control orthopaedics (DCO) is a strategy that focuses on managing orthopaedic injuries in polytrauma patients who are in an unstable physiological state. The concept of DCO is an extension of damage control surgery or damage limitation surgery (DCS/DLS). Recently, it has become clear that certain patients, following extensive soft tissue trauma, could benefit from the idea of DCS. In the management of severe lower extremity trauma with exposed fracture sites, aggressive early wound excision debridement, early internal fixation, and vascularized wound coverage within a few days after trauma were proposed. A negative-pressure dressing can be easily and rapidly applied to obtain a temporary closure between surgical stages. While negative pressure wound therapy (NPWT) has clear indications in the management of chronic wounds, its applications in the acute setting in victims of polytrauma are uneven. We conducted a review of the current clinical literature to evaluate the role of NPWT in this field, which points out that the negative pressure, applied immediately after the first debridement, seems to be an optimal bridge to the final reconstruction up to 7 days.

Keywords
- damage control
- negative pressure wound therapy
- limb trauma
- soft tissue
- microsurgical reconstruction

The concept of damage control orthopaedics (DCO) is a strategy that focuses on managing orthopaedic injuries in polytrauma patients who are in an unstable physiological state.[1–3] The basis of DCO depends upon controlling hemorrhage by temporarily stabilizing the fractured skeleton. The concept of DCO is an extension of damage control surgery or damage limitation surgery (DCS/DLS). Recently, it has become clear that certain patients following extensive soft tissue trauma could benefit from the spirit of DCS. In the management of severe lower extremity trauma with exposed fracture sites, aggressive early wound excision debridement, early internal fixation, and vascularized wound coverage within a few days after trauma were proposed by some.[4,5] This then led some to propose the concept of "fix and flap,"[6] leading to an early internal fixation of the bone stump and flap reconstruction at the same time to improve outcomes. Free tissue transfer is often indicated in severe open tibial fractures.[7–9] The idea of undertaken emergency free flap surgery has been debated as an extrapolation of the "fix and flap" idea to deliver early total care (ETC). However, the latter may result in the untimely

received
July 26, 2017
accepted
July 31, 2017

DOI https://doi.org/10.1055/s-0037-1606542.
ISSN 0743-684X.

execution of "fix and flap," because a clear necrosis of the damaged soft tissue could not be determined. Furthermore, in cases of polytrauma, ETC may not be possible. To avoid a "second hit" to the patient following severe trauma, it is suggested that complex surgery should be delayed to improve survival.[10] In these cases, negative pressure wound therapy (NPWT) may be an adjunct to DLS in the context of polytrauma. Early, acute total care relies on the availability of a specialized team.[11] The latter may be unavailable. A negative-pressure dressing can be easily and rapidly applied to obtain a temporary closure between surgical stages.[12] The role of NPWT includes prevention of bacterial contaminations and infections (only 18% of infections are caused by the initial contamination, while the largest part is due to nosocomial microorganisms[13]), decrease of edema and limb circumference, and reduction of wound surface. The clinical indications of NPWT in the management of chronic wounds have established as a good standard, while its applications in the acute setting in victims of polytrauma are patchy. We conducted a review of the current clinical literature to evaluate the role of NPWT in this field. In particular, we focused our work on open fractures.

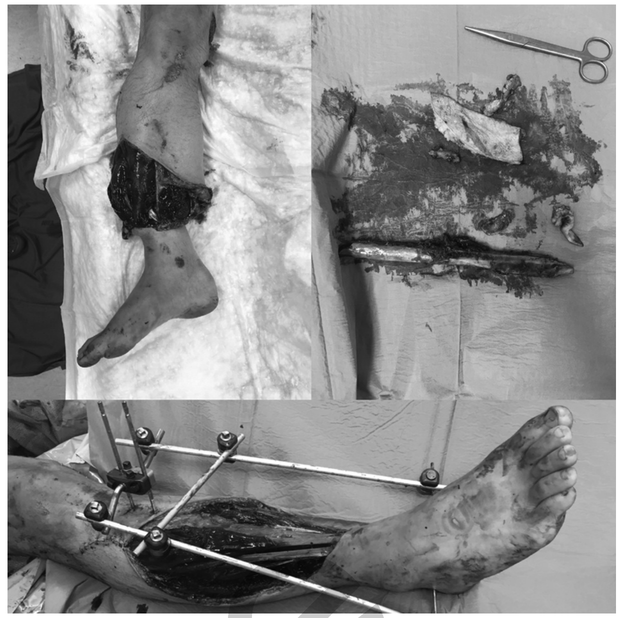


Fig. 1 Damage control. A Gustillo III C fracture of the lower extremity. (**A**) Aspect of the lower extremity at the ER before the debridement. (**B**) The portion of the soft tissues removed and the metaphysis of the peroneal bone that was disrupted and contaminated. (**C**) The temporally external fixation for bone alignment and after the first debridement ready for negative pressure therapy. ER, emergency room.

Before Negative Pressure: Fix and Flap

In 2000, Gopal et al[4,6] published a retrospective review of 80 patients who had suffered a Gustilo IIIb (94%) or IIIc (6%) open fracture of the tibia after trauma. Patients immediately treated by radical debridement, fracture stabilization and early cover, with a vascularized muscle flap, were reported to have the best outcome. These authors favored internal fixation over external fixation. Similar results were obtained by Hertel et al.[14] A significant reduction in the number of surgeries and time to union was achieved in case of soft tissue reconstruction in the first 4 days. Despite these advocates, ETC could not be prescribed in all cases because of the polytraumatic conditions of the patients or the necessity of transfer in selected canters (►**Fig. 1**).

The Introduction of Negative Pressure Wound Therapy and Damage Control Theory

New strategies have been consequently adopted by other authors to face up against the problems related to the impossibility of performing an early definitive surgical treatment.

Some patients (with thoracic, abdominal, and head injuries or high-injury severity score), not only appeared not to benefit from early total care, but also extended operative procedures (> 6 h) during the emergency phase, were associated with an adverse outcome.[15] This has been related to a massive systemic inflammatory response with high levels of IL-6, microvascular damage, widespread interstitial edema, and multiorgan failure.[16] In these patients, DLO/DLS allows delay of definitive management until the patient has been stabilized (not before 6–8 days). In this way, an inappropriate "second hit" to the metabolism of the patient is avoided.[17]

This concept can be extended to soft tissue reconstruction and we might term it "damage limitation plastic surgery." To bridge DCO and definitive treatment, NPTW has been introduced to provide temporary coverage. Immediately after the debridement, the negative pressure could be applied on all the traumatic wounds. The use of negative pressure therapy in the management of limb trauma has become more and more common. The rationale behind the NPWT is acceleration of wound healing by (1) reduction of edema with increased blood flow, oxygen, and nutrient supply and toxins outflow; (2) decrease of number of bacteria; and (3) growth of soft tissue around the injury.[18]

Similar results were reported by Kushagra Sinha et al.[19] Patients with open musculoskeletal traumatic injuries were selected and a prospective, randomized study was designed. The authors aimed at comparing negative pressure and standard therapies for the upper and lower limbs and finding that granulation led to a mean decrease of 26.66% of wound extension with less inflammation and fibrosis when vacuum therapy was used. Also, reduction of bacterial growth and augmentation of blood flow and oxygenation were observed.

However, there is no general agreement on these findings. The use of NPTW in the temporary treatment of soft tissue injuries was also analyzed by Dedmond et al[20] in a retrospective study involving 49 patients with type III open tibial fractures. They also initially thought that the application of NPWT could reduce the rate of infections by isolating the wound from the nosocomial environment. In contrast, results demonstrated that the rate of infections was similar to conventional dressings, such as antibiotic-impregnated medications.

The same concepts were resumed in a later review[21] in which 11 clinical studies on the use of negative pressure in acute traumatic injuries of lower extremities were evaluated. Constant or intermittent negative pressure was applied after debridement of necrotic tissues and covered all vital structures such as vessels and nerves. Results were equivalent to standard medications and wound coverage techniques, while necessity of complex reconstructions was reduced due to reduction of hematoma and improvement of soft tissue healing.[22] However, in these articles, wound debridement was not standardized and the studies compeered all Gustillo class III a and b/c. In contrast with the study by Dedmond et al,[20] the reduction in infections with the use of NPWT was clearly demonstrated by a level-I randomized study by Stannard et al[23] that attested a one-fifth reduction in infections for patients treated with negative pressure, when the latter were compared with patients who underwent wet-to-dry dressings. Also, a trend toward a reduction in bacterial contamination seemed to be present (►**Fig. 2**).

Negative Pressure Therapy in Military Field

In the military field, where both ETC and secondary intention closure are not suitable, NPWT has improved the management of high-energy injuries. Because of great contamination, difficulties in reaching the hospital and severe systemic conditions, it turned out to be the best strategy by permitting successful delayed wound closure in an insecure environment. Another study reports a retrospective examination of 88 soft tissue wounds in 77 patients treated in a military trauma center in Balad, Iraq. Lower extremity injuries represented 44% and were covered within 24 hours with NPWT for 2 to 4 days before definitive treatment with 0% of wound infections or complications.

Ideal Timing

Steiert et al[10] focused their attention on timing in the management of traumatized extremities, evaluating the outcomes of delayed flap, using negative pressure as temporary treatment.

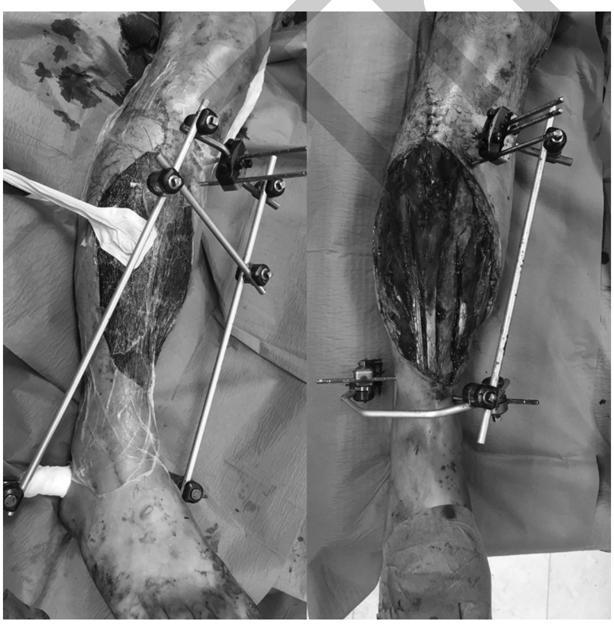


Fig. 2 The soft tissue damage control. (**A**) The negative pressure was applied immediately after the first debridement. (**B**) The wound bed after 5 days of negative pressure, ready for the final coverage. A microsurgical reconstruction was performed with an ALT flap. ALT, anterolateral thigh flap.

They considered 43 open fractures classified as Gustilo III b/c. According to this study, Steiert et al were able to obtain comparable results between delayed definitive closure (3–90 days) and early reconstruction within 72 hours. It is important to point out that negative pressure was applied immediately after fracture stabilization and debridement.

Herscovici et al[24] published a nonrandomized clinical study of 21 patients with 21 high-energy soft tissue wounds of the lower and upper limb. The device was maintained for 19.3 days (5–84) to reduce the number of flaps, and good results were accomplished. Another study[25] investigated whether negative pressure could permit a delay in flap reconstruction without an increase in infections or not. Patients treated within 7 days and those treated at 7 days or more after injury, while bridging the time elapsed with NPWT, were compared. The study concluded that although negative-pressure dressings represented an excellent dressing, soft tissue coverage post 7 days was accompanied by a higher nosocomial infection rate.[26,27]

Stannard considered all these findings and published a review in 2010, in which he stated that the best treatment for soft tissue loss associated with open fractures was radical debridement and soft tissue coverage as soon as the patient's condition allowed it.[23]

In 2011, a retrospective review considered the impact of delayed free-flap reconstruction, of prolonged hardware exposure, of preexisting wound infection and the role of NPWT on the outcome of open lower limb injuries. One hundred five free flaps were performed and compared with patients treated within 3 days from injury; the ones who underwent delayed reconstruction beyond 7 days had higher rates of preflap wound infection, flap reoperation, venous thrombosis, flap hematoma, deep metal infection, and osteomyelitis. Preflap tissue infection, in particular, independently predicts an adverse flap and skeletal reconstruction outcome. Nonetheless, no significant differences in number of flap failures, fracture nonunions, and weight bearing capacity subsisted between the two groups. When internal fixators were exposed, an elevated flap failure rate was observed even in patients treated after only 24 hours; also, full weight bearing capacity was reduced. When the exposure lasted more than 7 days, higher rates of osteomyelitis, flap takebacks and failures were observed. In conclusion, although flap reoperations and venous thrombosis are reduced by vacuum therapy, soft tissue coverage within 3 days or immediately following fracture fixation has better outcomes than delayed flaps after NPWT. When this is not possible, soft tissue reconstruction should be performed within 7 days, as further delays lead to serious short- and long-term complications[28,29] (►**Fig. 3**).

Comparison of Three Techniques

A comparison of primary and delayed wound closure in severe open tibial fractures has been recently performed to investigate[30] the best treatment for type III open tibial fractures. Patients involved in this study were divided into three groups: one group underwent internal fixation and primary closure; a second cohort was treated with internal fixation and delayed closure (within 2 weeks) using NWPT as

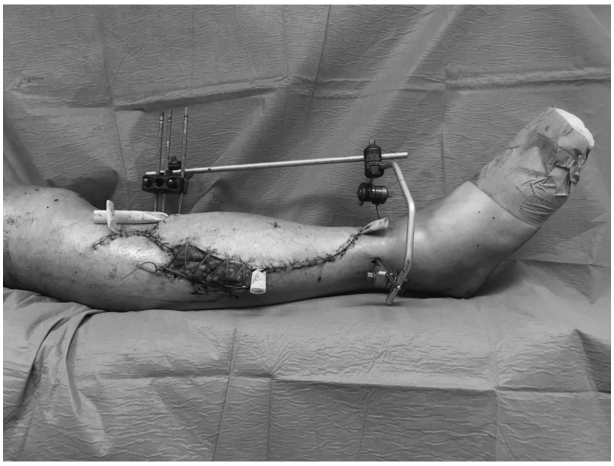


Fig. 3 The immediate postop of the microsurgical reconstruction of the lower extremity with an ALT flap. ALT, anterolateral thigh flap.

temporary treatment; and the third group received external fixation and NPWT. In the first group, negative pressure was also applied as an aid for primary closure to reduce the edema. The wounds treated with primary closure were smaller and less complex than the others. For this reason, infections (18.5 vs. 27.3%), osteomyelitis (11.1 vs. 18.2%), and amputations (3.7 vs. 13.6%) were all lower in this group, although the difference was not significant. No significant differences were found between the two groups treated with internal fixation and the patients treated with external fixation. Infection rates (10 vs. 32%), osteomyelitis (10 vs. 18%), and amputations (5 vs. 11%) were lower in patients who received wound coverage within 7 days compared with 7 days after injury (►**Fig. 4**).

Evidence-Based Recommendations

In a review, published in 2011, evidence-based recommendations on application of negative pressure on open fractures and soft tissues defects were collected.[12] According to the authors, negative pressure may be used when primary closure is not possible, after a well-performed debridement, or as a temporary dressing between serial debridements. Negative pressure may reduce the necessity for immediate or early closure: in some studies, the outcomes of delayed treatment associated with vacuum therapy are similar to those associated with early reconstruction.[20] It is also possible that being a closed system, NPWT might avoid bacterial colonization.

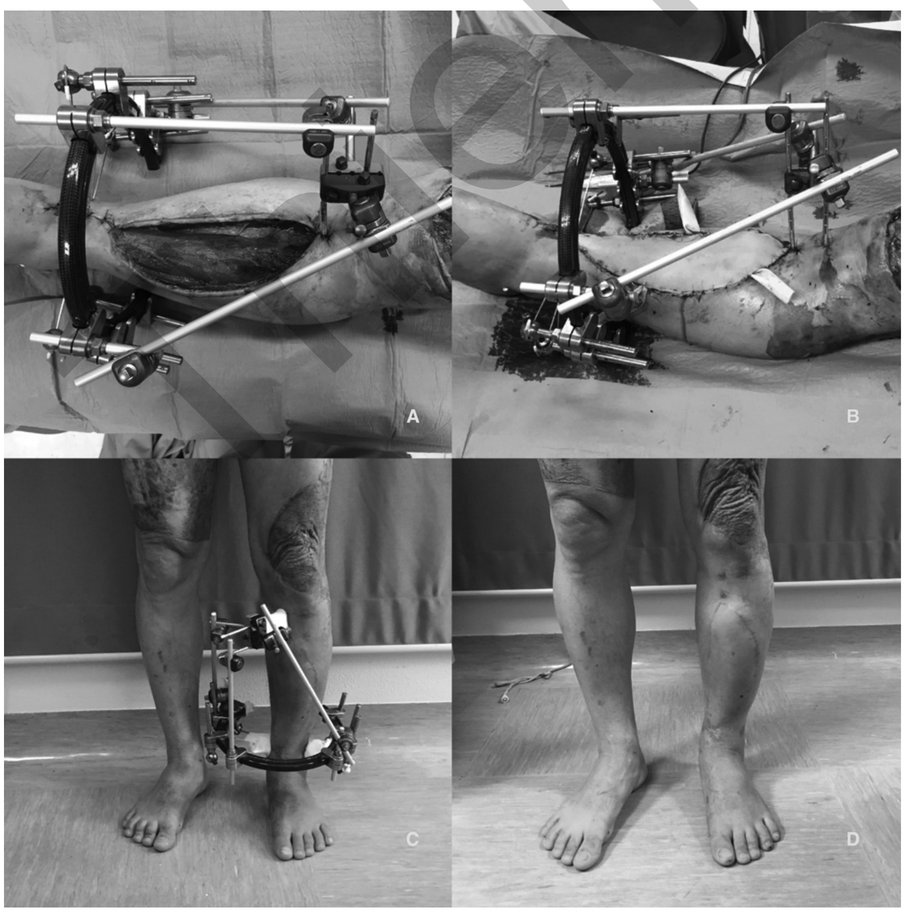


Fig. 4 (A) Aspect of the wound bed after 6 days of negative pressure therapy. There is an evidence of a small necrosis of the tibial anterior muscle that was not evident after the first debridement. (B) Reconstruction of the lower extremity with an ALT flap. (C) Aspect of the leg after several weeks the patient can walk and follow the FKT therapy with the external fixator due to healing of the soft tissue. (D) Final result after 1 year. ALT, anterolateral thigh flap; FKT, kinesiotherapy.

Complications of Negative Pressure Use

The rate of complications of NWPT reported in the current literature is low.[31] These include temporary skin rash (that actually is avoided if the sponge fits precisely the wound area) and bleeding from wound bed. To minimize the risk of bleeding, exposed vessels must be protected. In addition, the careful monitoring of anticoagulation therapies and the use of proper negative pressure pumps are required. Overall, the complication rate remains low.[32,33]

Conclusion

Since the study by Godina[4] in 1986, the recommendation for Grade IIIb tibia fractures has been early (within 72 hours) bony stabilization and soft tissue reconstruction. This duration is challenging to achieve. Nowadays, the limit of 72 hours is not "mandatory" anymore because the negative pressure can help in delaying the microsurgical reconstruction, reducing the edema, and improving the receiving wound bed. The negative pressure can be applied immediately after the first debridement of the traumatic wounds and can be used to bridge between several debridements until the final reconstruction. The negative pressure, compared with standard of care dressing, has the ability to improve the receiving bed. Although a systematic analysis of the literature and better-designed studies are still required to comfort this statement, with our review, we can say that it could be extended with NPWT up to 7 days before the final microsurgical reconstruction, with a reasonable risk if compared with poor clinical conditions. Instead, after 7 days, an excessive number of complications, such as higher levels of osteomyelitis, wound and metal wear infections, and flap takebacks and failure might occur because open wounds seem to be colonized with potentially pathogenic organisms after 7 days. This concept is termed "damage limitation plastic surgery" or "damage control soft tissue reconstruction."

References

1 Giannoudis PV, Giannoudi M, Stavlas P. Damage control orthopaedics: lessons learned. Injury 2009;40(Suppl 4):S47–S52
2 Jain S, Dharap SB, Gore MA. Early prediction of outcome in very severe closed head injury. Injury 2008;39(05):598–603
3 Doody O, Given MF, Lyon SM. Extremities–indications and techniques for treatment of extremity vascular injuries. Injury 2008; 39(11):1295–1303
4 Godina M. Early microsurgical reconstruction of complex trauma of the extremities. Plast Reconstr Surg 1986;78(03):285–292
5 Byrd HS, Spicer TE, Cierney G III. Management of open tibial fractures. Plast Reconstr Surg 1985;76(05):719–730
6 Gopal S, Majumder S, Batchelor AG, Knight SL, De Boer P, Smith RM. Fix and flap: the radical orthopaedic and plastic treatment of severe open fractures of the tibia. J Bone Joint Surg Br 2000;82 (07):959–966
7 Gustilo RB, Mendoza RM, Williams DN. Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. J Trauma 1984;24(08):742–746
8 Lange RH, Bach AW, Hansen ST Jr, Johansen KH. Open tibial fractures with associated vascular injuries: prognosis for limb salvage. J Trauma 1985;25(03):203–208
9 Howe HR Jr, Poole GV Jr, Hansen KJ, et al. Salvage of lower extremities following combined orthopedic and vascular trauma. A predictive salvage index. Am Surg 1987;53(04):205–208
10 Steiert AE, Gohritz A, Schreiber TC, Krettek C, Vogt PM. Delayed flap coverage of open extremity fractures after previous vacuum-assisted closure (VAC) therapy - worse or worth? J Plast Reconstr Aesthet Surg 2009;62(05):675–683
11 Schlatterer DR, Hirschfeld AG, Webb LX. Negative pressure wound therapy in grade IIIB tibial fractures: fewer infections and fewer flap procedures? Clin Orthop Relat Res 2015;473(05):1802–1811
12 Krug E, Berg L, Lee C, et al; International Expert Panel on Negative Pressure Wound Therapy [NPWT-EP]. Evidence-based recommendations for the use of negative pressure wound therapy in traumatic wounds and reconstructive surgery: steps towards an international consensus. Injury 2011;42(Suppl 1):S1–S12
13 Patzakis MJ, Bains RS, Lee J, et al. Prospective, randomized, double-blind study comparing single-agent antibiotic therapy, ciprofloxacin, to combination antibiotic therapy in open fracture wounds. J Orthop Trauma 2000;14(08):529–533
14 Hertel R, Lambert SM, Müller S, Ballmer FT, Ganz R. On the timing of soft-tissue reconstruction for open fractures of the lower leg. Arch Orthop Trauma Surg 1999;119(01):(02):7–12
15 Pape HC, Pfeifer R. Safe definitive orthopaedic surgery (SDS): repeated assessment for tapered application of Early Definitive Care and Damage Control?: an inclusive view of recent advances in polytrauma management Injury 2015;46(01):1–3
16 Ogura H, Tanaka H, Koh T, et al. Priming, second-hit priming, and apoptosis in leukocytes from trauma patients. J Trauma 1999;46 (05):774–781; discussion, 781–783
17 Hildebrand F, Giannoudis P, Kretteck C, Pape H-C. Damage control: extremities. Injury 2004;35(07):678–689
18 DeFranzo AJ, Argenta LC, Marks MW, et al. The use of vacuum-assisted closure therapy for the treatment of lower-extremity wounds with exposed bone. Plast Reconstr Surg 2001;108(05):1184–1191
19 Sinha K, Chauhan VD, Maheshwari R, Chauhan N, Rajan M, Agrawal A. Vacuum assisted closure therapy versus standard wound therapy for open musculoskeletal injuries. Adv Orthop 2013;2013:245940
20 Dedmond BT, Kortesis B, Punger K, et al. The use of negative-pressure wound therapy (NPWT) in the temporary treatment of soft-tissue injuries associated with high-energy open tibial shaft fractures. J Orthop Trauma 2007;21(01):11–17
21 Kanakaris NK, Thanasas C, Keramaris N, Kontakis G, Granick MS, Giannoudis PV. The efficacy of negative pressure wound therapy in the management of lower extremity trauma: review of clinical evidence. Injury 2007;38(05, Suppl 5):S9–S18
22 Parrett BM, Matros E, Pribaz JJ, Orgill DP. Lower extremity trauma: trends in the management of soft-tissue reconstruction of open tibia-fibula fractures. Plast Reconstr Surg 2006;117(04):1315–1322; discussion, 1323–1324
23 Stannard JP, Singanamala N, Volgas DA. Fix and flap in the era of vacuum suction devices: What do we know in terms of evidence based medicine? Injury 2010;41(08):780–786
24 Herscovici D Jr, Sanders RW, Scaduto JM, Infante A, DiPasquale T. Vacuum-assisted wound closure (VAC therapy) for the management of patients with high-energy soft tissue injuries. J Orthop Trauma 2003;17(10):683–688
25 Bhattacharyya T, Mehta P, Smith M, Pomahac B. Routine use of wound vacuum-assisted closure does not allow coverage delay for open tibia fractures. Plast Reconstr Surg 2008;121(04):1263–1266
26 Ostermann PA, Henry SL, Seligson D. Timing of wound closure in severe compound fractures. Orthopedics 1994;17(05):397–399
27 Breugem CC, Strackee SD. Is there evidence-based guidance for timing of soft tissue coverage of grade III B tibia fractures? Int J Low Extrem Wounds 2006;5(04):261–270
28 Liu DS, Sofiadellis F, Ashton M, MacGill K, Webb A. Early soft tissue coverage and negative pressure wound therapy optimises patient outcomes in lower limb trauma. Injury 2012;43(06):772–778

29 Hou Z, Irgit K, Strohecker KA, et al. Delayed flap reconstruction with vacuum-assisted closure management of the open IIIB tibial fracture. J Trauma 2011;71(06):1705–1708
30 Wei SJ, Cai XH, Wang HS, Qi BW, Yu AX. A comparison of primary and delayed wound closure in severe open tibial fractures initially treated with internal fixation and vacuum-assisted wound coverage: a case-controlled study. Int J Surg 2014;12(07):688–694
31 Webb LX. New techniques in wound management: vacuum-assisted wound closure. J Am Acad Orthop Surg 2002;10(05):303–311
32 Argenta LC, Morykwas MJ, Marks MW, DeFranzo AJ, Molnar JA, David LR. Vacuum-assisted closure: state of clinic art. Plast Reconstr Surg 2006;117(7, Suppl)127S–142S
33 Gwan-Nulla DN, Casal RS. Toxic shock syndrome associated with the use of the vacuum-assisted closure device. Ann Plast Surg 2001;47(05):552–554

Vascular Grafts and Flow-through Flaps for Microsurgical Lower Extremity Reconstruction

Francesca Toia, MD, PhD[1] Giovanni Zabbia, MD, PhD[1] Tiziana Roggio, MD[1] Roberto Pirrello, MD[1] Salvatore D'Arpa, MD, PhD[1,2] Adriana Cordova, MD[1]

[1] Division of Plastic and Reconstructive Surgery, Department of Surgical, Oncological and Oral Sciences, University of Palermo, Palermo, Italy
[2] Department of Plastic and Reconstructive Surgery, Gent University Hospital, Gent, Belgium

Address for correspondence Salvatore D'Arpa, MD, PhD, Division of Plastic and Reconstructive Surgery, Department of Surgical, Oncological and Oral Sciences, University of Palermo, Via del Vespro, 129, Palermo, Italy (e-mail: info.turidarpa@gmail.com).

J Reconstr Microsurg 2017;33:S14–S19.

Abstract

Background The use of vascular grafts is indicated in case of insufficient pedicle length or for complex defects involving both soft tissues and vessels. Venous grafts (for both venous and arterial reconstructions) and arterial grafts (arterial reconstruction) can be used. This study retrospectively evaluated the needs for vascular reconstruction and its results in a clinical series of lower limb reconstructions with microsurgical free flaps.

Materials and Methods From 2010 to 2015, a total of 16 vascular grafts or flow-through flaps were used in 12 patients out of a total of 150 patients undergoing microsurgical reconstruction (8%). Arterial reconstruction was performed in seven cases (six flow-through flaps, one arterial graft), combined arterial and venous reconstruction in four cases (three vein grafts, one combined venous/arterial graft), and venous reconstruction in one case (one venous graft). The rate of complications and donor-site morbidity related to vascular graft harvest were evaluated.

Results Reconstruction was successful in all cases, despite an overall complication rate of 17 and 8% of surgical revision. Donor-site morbidity, subjectively evaluated, was minimal with respect to functional deficits and aesthetic outcome. Indications for the different types of grafts are discussed.

Conclusion The use of vascular grafts is needed in a relevant percentage of microsurgical reconstruction cases. Venous and arterial vascular grafts, transient arteriovenous fistulas, and "flow-through" microsurgical flaps showed a safe reconstruction comparable to microsurgical reconstructions without the use of grafts. Donor-site morbidity secondary to vascular graft harvest is minimal, and in almost 70% of cases no additional scars are needed.

Keywords
- vascular grafts
- lower limb reconstruction
- microsurgery

Selection of recipient vessels is crucial for the success of a microsurgical reconstruction. Recipient vessels must be healthy and out of the zone of injury: to achieve this, a long vascular pedicle of the microsurgical flap—and eventually a vascular graft—may be required to comfortably reach them.

The use of vascular grafts is indicated in cases of insufficient pedicle length or of complex defects involving both soft tissues and vessels. Autologous vascular grafts or artificial grafts are the two main options; autologous vascular grafts are most commonly used, as they have lower thrombotic risk and provide higher success rates.[1]

Venous or arterial grafts may be used. Venous grafts are more commonly used and are indicated for the reconstruction of a vein or an artery, while arterial grafts are less

received
July 14, 2017
accepted after revision
August 1, 2017

DOI https://doi.org/10.1055/s-0037-1606560.
ISSN 0743-684X.

commonly used and indicated for the reconstruction of an artery.[2,3] In some selected cases, an arterial and venous defect can be reconstructed by means of a "flow-through" microsurgical flap, or by the use of a venous loop for the creation of a temporary arteriovenous fistula.[4,5]

The purpose of this study was to retrospectively evaluate the need for venous and arterial reconstruction and its results in a clinical series of free microsurgical transfers for lower limb reconstruction, operated at two reconstructive surgery centers: the University of Palermo (Italy) and the University of Gent (Belgium).

Materials and Methods

From 2010 to 2015, a total of 16 vascular grafts or flow-through flaps were used in 12 patients out of a total of 150 patients undergoing microsurgical reconstruction of the lower limb (8%), due to a combined soft tissues and vascular defect. Seven patients were men and five patients were women. Mean age was 49 years (range: 28–72). Data on comorbidities (diabetes, obesity, and hypertension) and smoking habit were extrapolated: four patients were active smokers and two patients were diabetic. In all, but one, cases, the etiology of the defect was traumatic. Only one patient had an associated tibial fracture. In seven patients, vascular grafts were used for the reconstruction of a leg defect; in four patients, vascular grafts were used for the reconstruction of a foot defect; and in one patient, vascular graft was used for the reconstruction of a knee defect. The flaps used for reconstruction were as follows: anterolateral thigh (ALT) flap (six cases), vastus lateralis muscle flap (two cases), peroneal artery perforator flap (one case), superficial circumflex iliac artery perforator flap (one case), vastus lateralis and rectus femoris chimeric flap (one case), and thoracodorsal artery perforator flap (one case).

Arterial reconstruction alone was performed in seven cases, combined arterial and venous reconstruction in four cases, and venous reconstruction alone in one case. Arterial reconstruction was accomplished by means of a flow-through flap in six cases (►**Fig. 1–3**), and of an arterial graft in one case (►**Figs. 4–6**). Combined arterial and venous reconstruction was accomplished by means of venous grafts in three cases (two of which was an arteriovenous temporary loop; ►**Figs. 7** and **8**), and of a combined arterial and venous graft in one case (►**Fig. 9**), while venous reconstruction was accomplished by means of a vein graft in one case. Vascular grafts or flow-through flaps were mainly used to lengthen the pedicle, with the exception of patient no. 10, in which the flow-through flap was also used to revascularize the limb. The average length of the vascular defect was 6 cm (range: 2–20). Detailed data for each patient are shown in ►**Table 1**.

Postoperatively, all patients received thromboembolic prophylaxis with low-molecular-weight heparin. Full weight-bearing ambulation was allowed at 3 weeks postoperatively in all but one patient (patient no. 10, associated with tibial fracture).

Median postoperative follow-up was 13 months (range: 5–24 months). The success rate of reconstruction and the

Fig. 1 Flow-through anterolateral thigh flap for leg reconstruction after trauma.

Fig. 2 Flap inset: flow-through arterial reconstruction of the posterior tibialis vessels, with an additional venous anastomosis on the great saphenous vein.

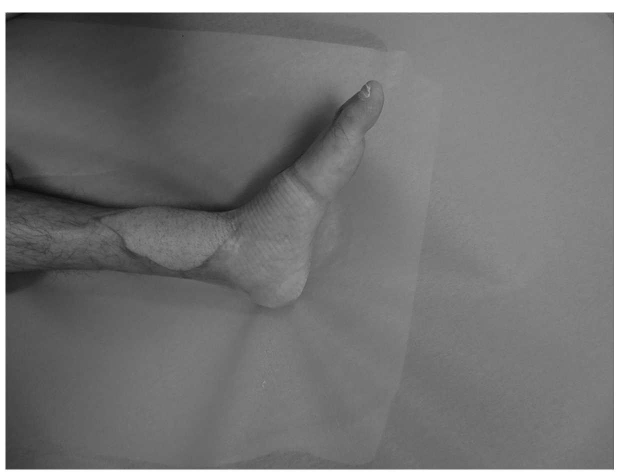


Fig. 3 Six months postoperative result.

Fig. 4 Bipedicled anterolateral thigh flap for heel reconstruction after division of the perforator bifurcation to leave the muscle intact.

Fig. 5 Flap inset. One of the pedicles was anastomosed to the distal stump of the posterior tibial artery (green contrast, left), while the other pedicle was anastomosed, with interposition of a descending branch of the lateral circumflex femoral artery graft, to the proximal stump of the posterior tibial artery and its comitant vein (green contrasts, right). The sensory nerve was sutured end to side to the tibial nerve.

Fig. 6 Three months postoperative result.

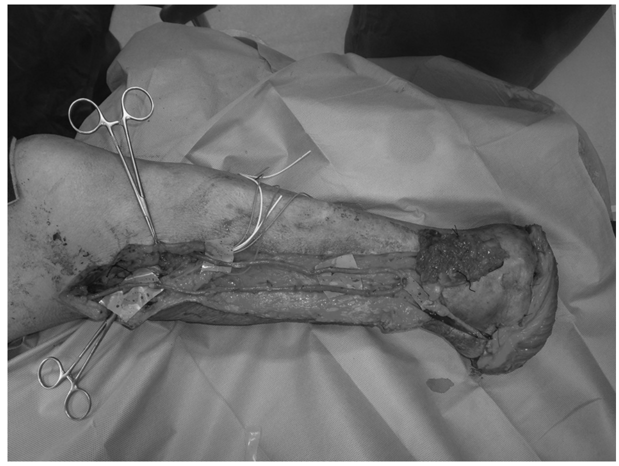


Fig. 7 Chimeric vastus lateralis–rectus femoris flap for forefoot reconstruction. The flap was anastomosed to the popliteal vessels (end to side) with interposition of a long great saphenous vein loop. This picture shows the arteriovenous loop before division.

Fig. 8 Same case as in ►**Fig. 7**, after arteriovenous loop division and anastomosis to the flap pedicle.

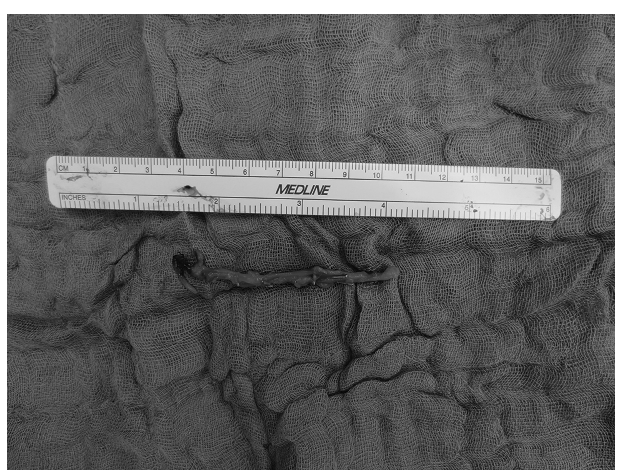


Fig. 9 Combined arterial/venous graft from the descending branch of the lateral circumflex femoral artery and vein.

Table 1 Detailed patients' data

Case (*n*)	Sex/Age	Comorbidities/ smoking	Defect	Defect etiology	Microsurgical flap	Vascular graft type	Donors vessels	Recipient vessels	Graft length (cm)
1	M/55	Smoker	Leg	Traumatic	Vastus lateralis	Venous pro vein	Great saphenous vein	Posterior tibialis vessels	7
2	F/30		Foot	Traumatic	ALT	Venous pro artery Venous pro vein	Dorsal foot vein Great saphenous vein	Posterior tibialis artery Posterior tibialis vein	4 4
3	F/56		Leg	Traumatic	Vastus lateralis	Arteriove-nous temporary loop	Great saphenous vein	Popliteal vessels	20
4	F/60	Hypertension, obesity	Leg	Traumatic	ALT flow-through	Arterial	dbLCFA	Posterior tibialis artery	4
5	M/42	Smoker	Heel	Traumatic	ALT, bipedicled	Arterial	dbLCFA	Posterior tibialis vessels	7.5
6	M/28	Smoker	Leg	Traumatic	Peroneal artery perforator, flow-through	Arterial	Peroneal artery	Dorsalis pedis artery	2
7	M/29		Leg	Traumatic	ALT, flow-through	Arterial	dbLCFA	Posterior tibialis artery	3
8	M/53	Smoker	Heel	Traumatic	TDAP flow-through	Arterial	Thoraco-dorsal artery	Dorsalis pedis artery	3
9	M/64	Diabetes	Forefoot	Diabetic foot	Vastus lateralis-rectus femoris chimeric flap	Arteriove-nous temporary loop	Great saphenous vein	Popliteal artery and great saphenous vein	20
10	M/36		Tibia Gustilo IIIC fracture	Traumatic	ALT flow-through	Arterial	dbLCFA	Anterior tibialis vessels	8
11	F/72	Hypertension	Knee	Traumatic	SCIAP	Arterial venous	DIEA/V	dbLCFA	6
12	F/67	Diabetes	Leg	Traumatic	ALT flow-through	Arterial	dbLCFA	Posterior tibialis artery	2

Abbreviations: ALT, anterolateral thigh; DIEA, deep inferior epigastric artery; dbLCFA, descending branch of the lateral circumflex femoral artery; pro vein, used for venous reconstruction; pro artery, used for arterial reconstruction; SCIAP, superficial circumflex iliac artery perforator; TDAP, thoracodorsal artery perforator; V, vein.

incidence of intra- and early postoperative complications were recorded, together with the need for secondary surgery. Donor-site morbidity was subjectively evaluated by patients and surgeons with regard to the presence of accessory scars and functional deficits.

Results

Reconstruction was successful in all cases. Overall complication rate was 17%. One patient required surgical revision due to a venous thrombosis related to dislocation of the fracture; this complication was solved but resulted in a partial flap necrosis. In one case, there was a dehiscence of the wound, solved with conservative treatment.

The donor-site morbidity related to vascular reconstruction, subjectively evaluated, was minimal: all patients were satisfied with the aesthetic result and scars appearance. In only four cases (33%), harvesting of the vascular grafts yielded accessory scars. No vascular or functional deficit related to the vascular graft harvest was recorded.

Discussion

Reconstruction of a vascular defect is necessary in a relevant percentage of microsurgical reconstruction cases (8% in this case series). Success rates are comparable to that of microsurgical reconstructions without the use of grafts.[2,6,7]

In this case study, despite a 17% of overall complication rate, reconstruction was successful in all cases (100%) and only one patient required reexploration for venous thrombosis (8%). These data provide evidence in support of the safety of vascular grafts in reconstructive microsurgery, which are generally considered to have a higher thrombotic risk.[7] Also, in our series, no vascular or functional deficit resulted from vascular grafts harvest. Additional scars were not needed in two-thirds 67%) of patients.

Vascular grafts (venous) have been described for the first time in 1969.[8] Venous reconstruction can be performed using venous grafts, whereas arterial reconstruction can be performed using venous or arterial grafts. Historically, vein grafts have been most commonly used.[2,7] Recently, several authors have supported the superiority of arterial vascular grafts compared with venous grafts in the reconstruction of arterial defects based on higher long-term patency rates.[9–13] The greatest evidence comes from studies performed on patients undergoing aortocoronary by-pass revascularization[9–11,14,15]: Webb et al[10] have postulated that radial artery bypasses, compared with great saphenous vein grafts, showed a flow-mediated dilation 5 years postoperatively, and Collins et al[9] showed a higher percentage of patency of radial arteries and internal mammary arterial grafts compared with great saphenous vein grafts 5 years after surgery. Slevin et al[15] have also shown that arterial grafts yield a lower incidence of myocardial infarction, lower reoperation rates, and longer survival rates. Other authors,[16–18] however, have shown comparable graft patency rates between radial artery and great saphenous vein grafts.

The use of arterial grafts has also become widespread in reconstructive microsurgery, mainly in the field of reconstruction with microsurgical flaps,[11–13,19–22] and also in other fields, such as cavernous arterial insufficiency,[23] although available literature is more limited compared with that on venous grafts.

Arterial grafts have several advantages over venous grafts: they are easier to handle, have a more predictable branching pattern, and do not tend to collapse during anastomosis; moreover, they generally provide better caliber match, develop less intimal hyperplasia, and seem to provide higher long-term patency rates.[10,12,19] Also, clinical and experimental studies have shown that size mismatch in vein grafts is responsible for a higher thrombotic risk.[22–25]

He et al[26] classified arterial grafts in to three types, based on experimental studies on vasoreactivity and anatomical, physiological, and embryological considerations:

- Type 1: somatic arteries with low spasticity (e.g., internal mammary artery, inferior epigastric artery, subscapular system, lateral circumflex femoral system).
- Type 2: splanchnic arteries (spastic).
- Type 3: arteries of the limbs (spastic).

Type 1 arteries show greater endothelial activity and release more nitric oxide and other relaxing agents, while type 2 and 3 arteries show greater reactivity to vasoconstrictors. Type 1 arteries are most commonly used. Various authors recommended the use of the inferior epigastric artery,[20,22] the lateral circumflex femoral artery,[3] the subscapular artery system,[11,13,21] or the superficial temporal artery.[11]

In our study, vascular reconstruction was performed with the only aim of lengthening the pedicle in all but one case, in which a flow-through flap was used to simultaneously revascularize the limb. The type of vascular reconstruction was dependent on type, location, and length of the vascular defect. When the vascular defect was located in the same area of the soft-tissue defect, vein defects were reconstructed with a vein graft and arterial defects were reconstructed with a flow-through flap, which allowed to reconstruct the various components with a single transplant. Also, flow-through flaps allow to have the number of "pre-flap" anastomoses unchanged compared with conventional flap transfer and additional donor sites were avoided in 67% of cases.

When the vascular defect was located away from the soft-tissue defect, an arterial or combined arterial/venous graft was harvested from the deep inferior epigastric vessels or from the descending branch of the lateral circumflex femoral vessels if the defect measured less than 9 cm. For defects longer than 9 cm, a long great saphenous vein graft was preferred to create a temporary arteriovenous loop. Temporary arteriovenous loops allow delaying of flap transfer in case of any doubt on recipient vessels' reliability and decrease the number of anastomoses per surgery.[26] Potential disadvantages are related to the possible discrepancy in vessel's caliber and to the use of superficial veins, sometimes thickened and damaged. Furthermore, the two segments used for arterial and venous reconstruction are not held together as in a combined arterial and venous graft, which may facilitate twisting, kinking, or malpositioning. For this reason, Zenn et al recommended the use of grafts from the descending lateral femoral circumflex artery and vein.[3] In the literature, their use is mainly reported in limb reconstructions.[26–28]

When a vein graft is needed, the great saphenous vein is the vessel most frequently used. The use of large caliber conduits is preferable whenever possible, as flow is directly proportional to caliber.[27] In this case study, the great saphenous vein was used in two cases (17%).

Limitations of this study include a small sample size and its retrospective nature. Due to the small sample size, the role of patient characteristics and defect etiology was not evaluated. Further studies are needed to provide stronger evidence for clinical recommendations and treatment algorithms.

Conclusion

The use of vascular grafts is needed in a relevant percentage of microsurgical reconstruction cases (8% in this case series). Vascular grafts are a safe reconstructive option, with a success rate that is similar to that of microsurgical reconstructions without the use of grafts.

Venous reconstruction is performed using venous grafts, whereas arterial reconstruction may be performed using venous or arterial grafts. Arterial grafts are a safe reconstructive option for arterial reconstruction. Flow-through flaps and venous loops are a useful option in selected cases of simultaneous arterial and venous reconstruction.

Donor-site morbidity secondary to vascular graft harvest is minimal, and in almost two-thirds of cases no additional scars are needed.

Conflict of Interest
No conflict of interest exists for none of the authors.

Funding
The authors received no financial support for this study.

References

1 Uhl C, Grosch C, Hock C, Töpel I, Steinbauer M. Comparison of long-term outcomes of heparin bonded polytetrafluoroethylene and autologous vein below knee femoropopliteal bypasses in patients with critical limb ischaemia. Eur J Vasc Endovasc Surg 2017;54(02):203–211
2 Nelson JA, Fischer JP, Grover R, et al. Vein grafting your way out of trouble: Examining the utility and efficacy of vein grafts in microsurgery. J Plast Reconstr Aesthet Surg 2015;68(06):830–836
3 Zenn MR, Pribaz J, Walsh M. Use of the descending lateral femoral circumflex artery and vein for vascular grafting: a better alternative to an arteriovenous loop. Plast Reconstr Surg 2010;126(01): 140–142
4 Qing L, Wu P, Liang J, Yu F, Wang C, Tang J. Use of flow-through Anterolateral Thigh Perforator flaps in reconstruction of complex extremity defects. J Reconstr Microsurg 2015;31(08):571–578
5 Cavadas PC. Arteriovenous vascular loops in free flap reconstruction of the extremities. Plast Reconstr Surg 2008;121(02):514–520
6 Bayramiçli M, Tetik C, Sönmez A, Gürünlüoğlu R, Baltaci F. Reliability of primary vein grafts in lower extremity free tissue transfers. Ann Plast Surg 2002;48(01):21–29
7 Furr MC, Cannady S, Wax MK. Interposition vein grafts in microvascular head and neck reconstruction. Laryngoscope 2011;121(04): 707–711
8 Crowell RM, Yasargil MG. Experimental microvascular autografting. Technical note. J Neurosurg 1969;31(01):101–104
9 Collins P, Webb CM, Chong CF, Moat NE; Radial Artery Versus Saphenous Vein Patency (RSVP) Trial Investigators. Radial artery versus saphenous vein patency randomized trial: five-year angiographic follow-up. Circulation 2008;117(22):2859–2864
10 Webb CM, Moat NE, Chong CF, Collins P. Vascular reactivity and flow characteristics of radial artery and long saphenous vein coronary bypass grafts: a 5-year follow-up. Circulation 2010;122(09): 861–867
11 Godina M. Arterial autografts in microvascular surgery. Plast Reconstr Surg 1986;78(03):293–294
12 Masden DL, Seruya M, Higgins JP. A systematic review of the outcomes of distal upper extremity bypass surgery with arterial and venous conduits. J Hand Surg Am 2012;37(11):2362–2367
13 Masden DL, McClinton MA. Arterial conduits for distal upper extremity bypass. J Hand Surg Am 2013;38(03):572–577
14 Desai ND, Naylor CD, Kiss A, et al; Radial Artery Patency Study Investigators. Impact of patient and target-vessel characteristics on arterial and venous bypass graft patency: insight from a randomized trial. Circulation 2007;115(06):684–691
15 Slevin M, Bontas E. Arterial graft failure. In: Coronary Graft Failure. Switzerland: Springer International Publishing; 2016: 235–265
16 Hata M, Yoshitake I, Wakui S, et al. Long-term patency rate for radial artery vs. saphenous vein grafts using same-patient materials. Circ J 2011;75(06):1373–1377
17 Goldman S, Sethi GK, Holman W, et al. Radial artery grafts vs saphenous vein grafts in coronary artery bypass surgery: a randomized trial. JAMA 2011;305(02):167–174
18 Hayward PA, Hare DL, Gordon I, Buxton BF. Effect of radial artery or saphenous vein conduit for the second graft on 6-year clinical outcome after coronary artery bypass grafting. Results of a randomised trial. Eur J Cardiothorac Surg 2008;34(01):113–117
19 McClinton MA. Reconstruction for ulnar artery aneurysm at the wrist. J Hand Surg Am 2011;36(02):328–332
20 Smith HE, Dirks M, Patterson RB. Hypothenar hammer syndrome: Distal ulnar artery reconstruction with autologous inferior epigastric artery. J Vasc Surg 2004;40(06):1238–1242
21 Valnicek SM, Mosher M, Hopkins JK, Rockwell WB. The subscapular arterial tree as a source of microvascular arterial grafts. Plast Reconstr Surg 2004;113(07):2001–2005
22 Rockwell WB, Smith SM, Tolliston T, Valnicek SM. Arterial conduits for extremity microvascular bypass surgery. Plast Reconstr Surg 2003;112(03):829–834
23 Munarriz R, Uberoi J, Fantini G, Martinez D, Lee C. Microvascular arterial bypass surgery: long-term outcomes using validated instruments. J Urol 2009;182(02):643–648
24 Harris JR, Seikaly H, Calhoun K, Daugherty E. Effect of diameter of microvascular interposition vein grafts on vessel patency and free flap survival in the rat model. J Otolaryngol 1999;28(03):152–157
25 Zhang F, Ho PR, Chin BT, Ozek C, Buncke HJ, Lineaweaver WC. Effect of vein grafting on the survival of microvascularly transplanted muscle flaps. Microsurgery 1996;17(09):512–516
26 He GW. Arterial grafts: clinical classification and pharmacological management. Ann Cardiothorac Surg 2013;2(04):507–518
27 Lin CH, Mardini S, Lin YT, Yeh JT, Wei FC, Chen HC. Sixty-five clinical cases of free tissue transfer using long arteriovenous fistulas or vein grafts. J Trauma 2004;56(05):1107–1117
28 Murphy GJ, White SA, Knight AJ, Doughman T, Nicholson ML. Long-term results of arteriovenous fistulas using transposed autologous basilic vein. Br J Surg 2000;87(06):819–823

Below Knee Stump Reconstruction with a Foot Fillet Flap

Pierluigi Tos, MD, PhD[1] Andrea Antonini, MD[2] Pierfrancesco Pugliese, MD[3] Bernardino Panero, MD[3] Davide Ciclamini, MD[3] Bruno Battiston, MD, PhD[3]

[1] UOC Hand Surgery and Reconstructive Microsurgery Unit, ASST G Pini-CTO, Milano, Italy
[2] UOC Septic Orthopaedics Unit, ASL II Savonese, Savona, Italy
[3] UOC Orthopaedics and Traumatology, Hand Surgery and Microsurgery, AOU City of Health and Science, Torino, Italy

Address for correspondence Pierluigi Tos, MD, PhD, UOC Hand Surgery and Reconstructive Microsurgery Unit, ASST G Pini-CTO, Piazza Cardinale Andrea Ferrari, 1, 20122 Milano, Italy (e-mail: pierluigi.tos@unito.it).

J Reconstr Microsurg 2017;33:S20–S26.

Abstract

Background The "spare parts" approach to the reconstruction of below knee amputation, applied in acute trauma patients, can also be employed in elective surgery, ensuring knee salvage and a sensitive stump and enabling tissue harvesting without further donor-site morbidity.

Methods We present a series of eight cases, where leg amputation due to trauma or its sequelae was followed by reconstruction with skin or a composite flap from the foot. An osteocutaneous flap was used in two emergency patients with below knee amputation, where it allowed stump elongation and knee coverage, and in five secondary procedures, where it provided both stump length and sensitive skin coverage. The skin of the foot was used in one case to cover the tibial stump. Fixation was accomplished with 2-mm Kirschner wires in the emergency patients and with an external fixator ($n = 5$) or by internal fixation ($n = 1$) in the elective procedures. Any complications were minor. Secondary compression with an external fixator was required in one emergency patient due to delayed bone healing.

Results All knees healed. Sensibility was restored in all patients with a posterior tibial nerve suture (S4) and was well preserved in those without nerve coaptation. No patients reported problems with the prosthesis at a minimum follow-up of 3 years. Knee flexion and extension were comparable to those of the contralateral limb.

Conclusion The "spare parts" concept is a reliable approach to tibial stump reconstruction. External fixation in elective procedures allowed immediate weight bearing and bone healing. In emergency patients, rapid fixation with wires provided satisfactory results.

Keywords
- fillet flap
- spare parts
- below knee stump reconstruction
- lower limb replantation

Traumatic amputation or devascularization of the lower leg is ideally treated by replantation or revascularization using a microsurgery technique. Diffuse soft-tissue injury or multiple fractures in the amputated portion may, however, make these approaches unfeasible. Yet, tissue from amputated or nonsalvageable limbs can be used to reconstruct complex defects resulting from tumor or trauma.[1,2] This is the "spare parts" concept described by Russell et al[3] and Frykman and Jobe,[4] who used undamaged portions of the amputated limb to reconstruct a below knee amputation (BKA) in an acute trauma patient. In this framework, the fillet flap involves axial pattern flaps that can function as composite tissue transfers. An extension of the principle is the foot fillet flap,[5–10] a soft-tissue envelope collected from the foot that is supplied by the dorsal

received
June 20, 2017
accepted after revision
July 31, 2017

DOI https://doi.org/10.1055/s-0037-1606538.
ISSN 0743-684X.

artery of the foot, the posterior tibial artery, or both, which can be raised as a pedicle or a free flap. It is a valuable reconstruction strategy for major defects that exploits viable tissue adjacent to the defect and allows flap harvesting without additional donor-site morbidity. Amputation closure requires preservation of knee joint function, adequate tibial length for prosthesis application, and healthy soft-tissue coverage. However, sufficient viable soft tissue may not be available for closing the stump at the desired level.

BKA is associated with faster rehabilitation[4] and a more natural gait (through a greater control over the swing phase of ambulation), and allows greater physical activity compared with above knee amputation (AKA). In severe injuries involving extensive lower limb soft-tissue trauma, the foot is frequently distal to the injured area and may escape the crushing/torsion forces of the traumatic event, with preservation of perfusion and sensation. The distal limb thus affords a potential source of soft tissue for BKA.[6] Reconstruction of the BKA stump with an island pedicle or a free foot fillet flap not only allows preserving adequate tibial length for prosthesis fitting but also avoids further donor-site morbidity, providing a sturdy and sensate weight-bearing tissue that enables ambulation without excessive energy expenditure.[7] We present our experience in knee joint salvage with fillet flap reconstruction and review the literature.

Methods

From 2006 to 2015, eight patients underwent a fillet flap procedure. Their data were obtained from a chart review and clinical reevaluation. The parameters recorded included age, gender, indication for the fillet flap, medical history, defect size and location, donor site, and clinical success rate, defined as satisfactory defect coverage by the flap. Documented complications included flap loss, partial flap necrosis, wound infection, revision of anastomoses, flap revision, bone nonunion, and clinical failure. The case series is reported in ►**Table 1**.

Two of the eight patients received emergency BKA, where a composite osteocutaneous flap collected from the foot allowed stump elongation and coverage. The other six cases were secondary procedures after the failure of previous operations performed to treat the sequelae of trauma (infection, complication of lengthening). Of the secondary procedures, five involved a pedicle osteocutaneous flap providing both stump length and sensitive skin coverage, whereas in the sixth case only the skin of the foot was available to cover the BKA stump. Microsurgical sutures were required in cases 3, 5, and 6 to address problems of venous flow or, as in case 3, to ensure also the blood supply. When the vascular pedicle of the flap was long, special attention was devoted to avoid kinking and compression.

Fixation to achieve bone healing between the calcaneus and the tibia was accomplished with 2-mm Kirschner wires in the two emergency patients, and with an external fixator ($n = 5$) or by internal fixation ($n = 1$) in the elective procedures. The external fixator was chosen because it affords immediate weight bearing.

Results

The results and complications of our eight cases are summarized in ►**Table 1**. All knees healed. Any complications were minor. Nonunion in one emergency patient was managed by external fixation, which achieves healing by simple compression. Knee joint flexion and extension were comparable to those of the contralateral limb: extension was always complete and flexion was more than 100 degrees. Sensibility of the sutured tibial nerve was always S4 (complete recovery; British Medical Research Council grading system) and sensation of the pedicle graft was unchanged after surgery. No late ulceration or problems with the prosthesis were reported at a follow-up of at least 3 years.

The history of patient 3 (secondary procedure) and of patient 7 (emergency procedure) is summarized in ►**Fig. 1** and ►**Fig. 2**, respectively.

Discussion

The fillet flap is a valuable tool to preserve stump length in leg amputation, both in emergency and in secondary procedures. However, the indications for lower extremity replantation are limited.[11] When replantation is unfeasible, the amputation often needs to be revised to maximize stump length and ensure adequate soft-tissue coverage for the prosthesis. The respective cost of limb salvage and amputation has been examined by Chung and coworkers,[12] who concluded that the latter option is more expensive. The aforementioned considerations suggest that the issue requires careful evaluation. "Spare parts" surgery permits preserving bone length and knee function, providing sensate soft tissue around the bone and avoiding AKA. The use of vascularized composite tissue obtained from viable portions of the amputated lower extremity, such as plantar skin, is a valuable approach that not only avoids donor site morbidity but also provides sturdy, sensate coverage.[2] The advantages of the "spare parts" approach for BKA stump reconstruction are obvious. The key goals of stump reconstruction are to preserve sufficient bone length and to provide good soft-tissue coverage, as they are preconditions for satisfactory knee function and prosthesis support; in addition, the skin harvested from the sole of the foot is the most natural and suitable tissue for weight bearing and the unique structure of the heel pad is capable of absorbing shear forces very efficiently. Good sensory recovery of the weight-bearing area is possible if the nerve repair is successful.[7] The septa prevent transmission of shear forces to the soft tissue during ambulation with the prosthesis; innervated plantar skin provides proprioceptive feedback and reduces prosthesis-related complications, such as ulcers and painful neuromas, improving compliance.[6,10]

The importance of preserving functional length in an amputated limb cannot be overstated. Ambulation with a BKA has been calculated to involve a lower energy expenditure compared with AKA, approximately 10% greater than normal for the former patients, more than 15% for younger AKA patients, and 25% and greater for older AKA patients.[13,14]

A variety of reconstruction techniques have been devised to achieve BKA stump coverage. The pedicle or free fillet flap has

Table 1 Cases series

Patient no., age and gender (M/F)	Lesions	Cause	Technique	Comorbidity and complicating factors	Bone fixation	Healing/Days without weight bearing	Knee extension/ flexion at 6 mo	Complications
1 71 y M	Fracture, ischemic loss of the extensor compartment	Motor plow	Calcaneus fillet flap pedicled on PT vessels + nerve	Diabetes, anxious depressive syndrome, sacral pressure sore *Stenotrophomonas maltophilia* infection	External fixation	40/60	0–110°	No
2 52 y F	Fracture, loss of the extensor compartment, numb foot Full-thickness knee skin necrosis Knee stiffness	Traffic accident	Plantar fillet flap pedicled on PT vessels + nerve	Endovascular popliteal revascularization for ischemia	–	–	0–120°	Minor skin necrosis
3 47 y M	Chronic multiple MRSA tibial osteomyelitis	Traffic accident	Calcaneus fillet flap “pedicled” on tibial nerve and microsurgical anastomosis of distal PT artery + 1 comitant vein on proximal PT vessels	Failure of two previous radical debridement procedures and distraction osteogenesis No bone regeneration and persistent infection	External fixation	55/70	0–110°	No
4 64 y M	Chronic CM4 right tibia osteomyelitis since age 37 y	Traffic accident	Calcaneus sole fillet flap pedicled on posterior tibial vessels and tibial nerve	Chronic ulcer, impaired morphology, and function Polymicrobial infection (*E. coli* + *M. morganii* + *E. faecalis*) Posterior leg skin not reliable for stump closure (grafts and secondary healing scars with massive inflammation and edema)	External fixation	45/90	0–110°	Minimal distress of flap margin healed by secondary intention without additional surgery
5 37 y F	Fracture	Traffic accident	Calcaneus fillet flap with complete foot skin extension pedicled on Tibial nerve, AT artery and 1 only viable comitant vein + PT artery anastomosis on common tibioperoneal artery (previous by-pass level)	Saphenous vein by-pass revascularization Fractures Grade I calcaneal pressure sore. Polymicrobial infection w/ by-pass rupture (*Klebsiella*, *Aeromonas*...)	External fixation	90/150	0–110°	Massive skin necrosis due to insufficient venous drainage treated with skin graft. Difficult healing of graft donor site and calcaneal pressure ulcer
6 56 y F	Osteomyelitis of the tibia after Gustilo IIIC fracture	Car accident	Calcaneus pedicle flap on PT artery + supplementary microsurgical vein	Diabetes	Plate and screw	80	0–110°	Initial skin margin deepithelization
7 30 y M	Traumatic leg amputation	Motorcycle accident	Emergency—calcaneus and skin composite free flap PT artery on popliteal artery PT nerve on sciatic nerve	–	4 Kirschner wires	80 days	0–120°	No
8 35 y M	Traumatic leg amputation	Motorcycle accident	Emergency calcaneus and skin composite free flap PT artery on popliteal artery PT nerve on sciatic nerve	–	3 Kirschner wires	180	0–120°	Nonunion, secondary surgery with external fixation/compression

Abbreviations: AT, anterior tibial; CM, Cierny–Mader; *E. coli, Escherichia coli*; *E. faecalis, Enterococcus faecalis; M. morganii,* Morganella morganii; MRSA, methicillin-resistant *Staphylococcus aureus*; PT, posterior tibial.

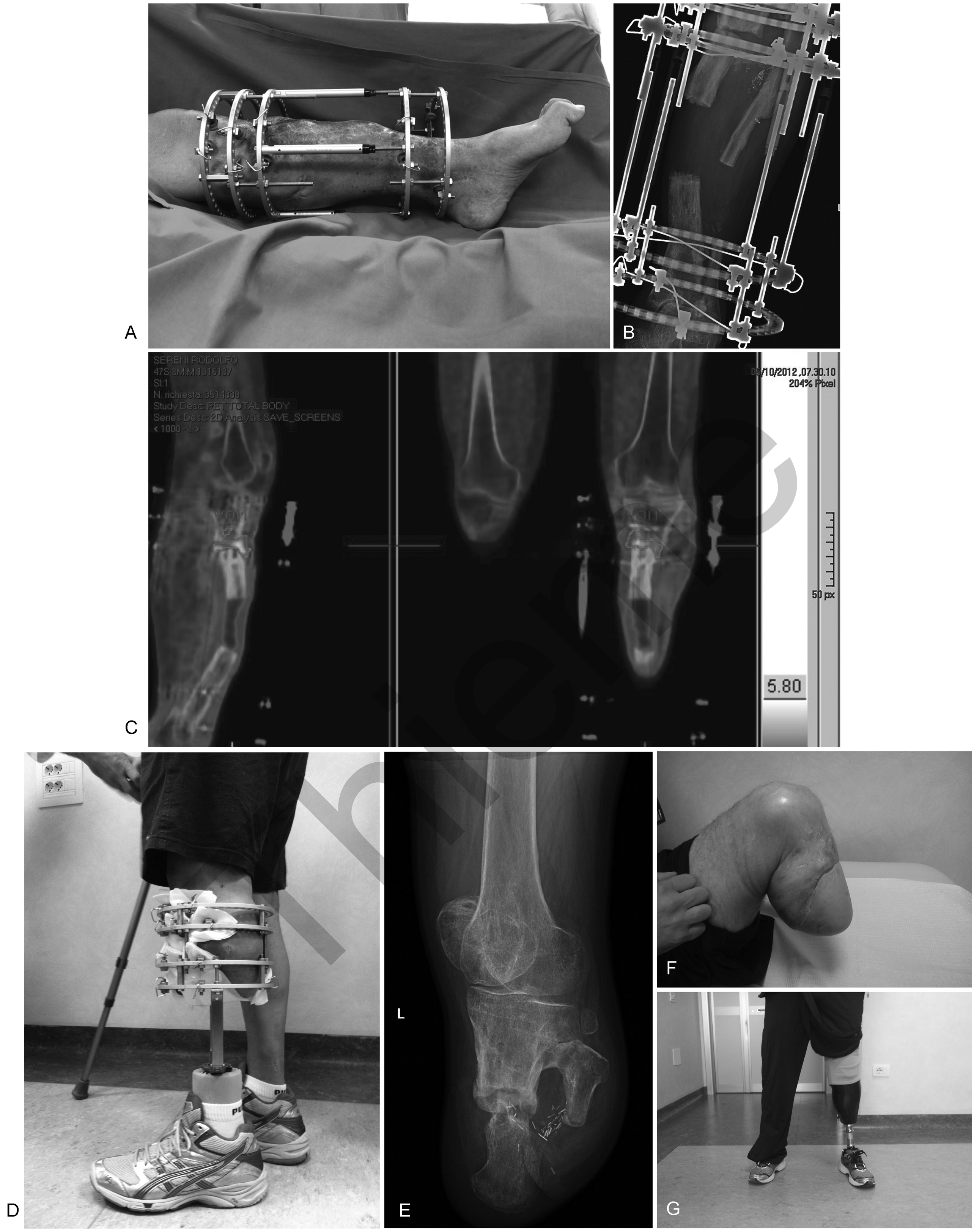


Fig. 1 Case 3: Failure of distal-to-proximal distraction osteogenesis in a patient with tibial osteomyelitis. Dystrophic skin (**A**), absence of regenerated bone, nonunion of docking site (**B**), and persistent infection in the PET scan (**C**) provided the indication for above knee amputation. The calcaneus fillet flap (**D**) (tibial nerve preserved, posterior tibial artery, and comitant vein shortened and sutured) was stabilized to the tibial stump with a circular external fixator to which a prosthetic foot was applied, to keep the patient walking during the bone healing period; (**E**) 40 days after the operation, the external fixator was removed and the bone had healed; (**F**) a month later, the edema was resolving and correct stump size and morphology were obtained; (**G**) the patient standing wearing his prosthesis.

Fig. 2 **Case 7**: (**A, B**) Right leg amputation. Replantation was not indicated due to the avulsion injury and the time elapsed since the lesion. The tibial bone stump was too short for a functional leg amputation (only 4 cm of proximal tibia and insufficient skin to cover the stump). The indication would have been for an above knee amputation if an emergency fillet free flap had not been performed. (**C, D**) Intraoperative preparation of the composite flap on a table; the anterior part of the foot was detached and the calcaneus, the skin, a posterior tibial pedicle, and the nerve were harvested from the leg; (**E, F**) postoperative clinical and radiological results with good stump axis and length; (**G, H, I**) clinical and radiological outcome at 1 year. (**J,K**) final result with the prosthesis.

Fig. 2 (*Continued*)

been reported to have satisfactory long-term outcomes.[5–10] Despite major advances in the design and adaptability of lower extremity prostheses, preservation of an intact knee joint remains a key functional advantage to the patient. The proprioceptive input, the more normal gait pattern, including the ability to change cadence, and the lower energy expenditure involved in walking compared with AKA are major functional assets.

In our series, BKA was ensured in patients who, through knee amputation or AKA, would have required closing the wound with local tissue. The "spare parts" approach allowed preserving the below knee stump, adding length where necessary, and closing the wound with innervated soft tissue.

Five of our patients were managed with a pedicle fillet flap, with the advantage that no microvascular anastomosis was required and that normal sensation was provided by the preserved tibial nerve and/or the deep peroneal nerve. The vessels were laid in a loop within the stump soft tissue, to avoid kinking or compression. A supplementary vein anastomosis was required in three cases. In the two emergency patients, who were managed with free flaps, the tibial nerve was sutured to the proximal sciatic nerve to ensure good sensation. In the patients in whom the calcaneus was used, the heel at the end of the stump provided an efficient natural weight-bearing surface.

Pedicle plantar flaps are reliable and ensure excellent mechanical stability and almost normal sensibility to the stump, providing early weight bearing, better proprioceptive feedback during gait training, and reduction in prosthesis-related complications such as ulceration, neuroma, and pain. Technical difficulties include placement of the redundant neurovascular bundle in the distal thigh or under the flap. The unique structure of the heel pad has obvious advantages in terms of durability of the stump coverage.[6] Theoretically, long pedicles may kink and interfere with the blood flow when they are wrapped around the stump; in practice, however, the high pressure and flow ensure patency and prevent kinking. This may not apply to venous drainage: in such cases, the pedicle fillet flap should be converted to a free fillet flap.

With regard to bone fixation, we believe that in the emergency setting a rapid and easy procedure can help reduce the operating times. In programed procedures, external bone fixation enables immediate weight bearing, facilitating and shortening the rehabilitation period. Although internal fixation has also been described, we feel that in patients with infection, external fixation carries a lower risk of complications. Of the 12 published reports on the topic,[1–10,12,15] only 1 describes a large series of below knee salvaged limbs.

Conclusion

Our data and the literature review demonstrate that the fillet flap is a valuable approach to complex stump reconstructions. The plantar fillet flap should always be considered in case of lower leg amputation, because it may be critical in preserving stump length, besides avoiding donor-site morbidity.

When the amputation is inevitable but the foot vascular supply is preserved, the pedicle foot fillet flap should be considered, as it can preserve leg length or enable conversion of an amputation above the knee to one below the knee. This involves reduced energy expenditure and enhanced ease of ambulation compared with a more proximal amputation. The pedicle fillet flap does not require microvascular anastomoses, avoiding their possible complications while preserving sensation through an intact nerve. Conversion to a free flap is a good option when the clinical situation does not allow maintaining a viable pedicle.

Conflict of Interest
None.

References

1 Colen SR, Romita MC, Godfrey NV, Shaw WW. Salvage replantation. Clin Plast Surg 1983;10(01):125–131
2 Jupiter JB, Tsai TM, Kleinert HE. Salvage replantation of lower limb amputations. Plast Reconstr Surg 1982;69(01):1–8
3 Russell RC, Vitale V, Zook EC. Extremity reconstruction using the “fillet of sole” flap. Ann Plast Surg 1986;17(01):65–72
4 Frykman GK, Jobe CM. Amputation salvage with microvascular free flap from the amputated extremity. J Trauma 1987;27(03):326–329
5 Küntscher MV, Erdmann D, Homann HH, Steinau HU, Levin SL, Germann G. The concept of fillet flaps: classification, indications, and analysis of their clinical value. Plast Reconstr Surg 2001;108(04):885–896
6 Ghali S, Harris PA, Khan U, Pearse M, Nanchahal J. Leg length preservation with pedicled fillet of foot flaps after traumatic amputations. Plast Reconstr Surg 2005;115(02):498–505
7 Chiang YC, Wei FC, Wang JW, Chen WS. Reconstruction of below-knee stump using the salvaged foot fillet flap. Plast Reconstr Surg 1995;96(03):731–738
8 Tran NV, Evans GR, Kroll SS, et al. Free filet extremity flap: indications and options for reconstruction. Plast Reconstr Surg 2000;105(01):99–104
9 Hidalgo DA, Shaw WW. Dorsalis pedis and “foot fillet” free flaps. In: Microsurgery in Trauma. Mount Kisco, NY: Futura Publishing Company; 1987
10 Laporta R, Atzeni M, Longo B, Santanelli di Pompeo F. Double free fillet foot flap: sole of foot and dorsalis pedis in severe bilateral lower extremity trauma, a 10-year follow-up case report. Case Reports Plast Surg Hand Surg 2016;3(01):62–65
11 Battiston B, Tos P, Pontini I, Ferrero S. Lower limb replantations: indications and a new scoring system. Microsurgery 2002;22(05):187–192
12 Chung KC, Saddawi-Konefka D, Haase SC, Kaul G, Kaul G. A cost-utility analysis of amputation versus salvage for Gustilo type IIIB and IIIC open tibial fractures. Plast Reconstr Surg 2009;124(06):1965–1973
13 Pribaz JJ, Morris DJ, Barrall D, Eriksson E. Double fillet of foot free flaps for emergency leg and hand coverage with ultimate great toe to thumb transfer. Plast Reconstr Surg 1993;91(06):1151–1153
14 Waters RL, Perry J, Antonelli D, Hislop H. Energy cost of walking of amputees: the influence of level of amputation. J Bone Joint Surg Am 1976;58(01):42–46
15 Kayikçioğlu A, Ağaoğlu G, Nasir S, Keçik A. Crossover replantation and fillet flap coverage of the stump after ectopic implantation: a case of bilateral leg amputation. Plast Reconstr Surg 2000;106(04):868–873

Muscle versus Fasciocutaneous Flap in Lower Limb Reconstruction: Is There a Best Option?

Mario Cherubino, MD, FEBORAS[1] Martina Corno, MD[1] Salvatore D'Arpa, MD, PhD[2,3] Pietro Di Summa, MD, PhD[4] Igor Pellegatta, MD[1] Luigi Valdatta, MD, FACS[1] Mario Ronga, MD[5]

[1] Division of Plastic and Reconstructive Surgery, Department of Biotechnology and Life Sciences (DBSV), University of Insubria, Varese, Italy
[2] Department of Plastic and Reconstructive Surgery, Ghent University Hospital, Gent, Belgium
[3] Division of Plastic and Reconstructive Surgery, Department of Surgical, Oncological and Oral Sciences, University of Palermo, Palermo, Italy
[4] Department of Plastic, Reconstructive and Hand Surgery, University Hospital of Lausanne (CHUV), Lausanne, Switzerland
[5] Department of Medicine and Health Sciences "Vincenzo Tiberio," University of Molise, Campobasso, Italy

Address for correspondence Mario Cherubino, MD, Division of Plastic and Reconstructive Surgery, Department of Biotechnology and Life Sciences (DBSV), University of Insubria, ASST Sette Laghi, Varese, Italy (e-mail: chirplas@gmail.com; mario.cherubino@gmail.com).

J Reconstr Microsurg 2017;33:S27–S33.

Abstract

Soft tissue defects of the lower extremity that expose underlying bones, joints, and tendons pose challenging problems and generally require free tissue transfer for a successful reconstruction. Historically, muscle flaps were the gold standard choice for lower limb reconstruction. To obviate the unpredictable appearance and high donor-site morbidity of muscle flaps, fasciocutaneous flaps were introduced. Recently, perforator flaps, such as the anterolateral thigh flap, gained a leading role in the reconstructive scenario. There is growing evidence in the literature supporting that fasciocutaneous and perforator flaps are comparable to muscle flaps in terms of flap survival, postoperative infection, osteomyelitis, bone union, and ambulation. With the advances of knowledge in perforator anatomy and their mapping, a new era of lower limb reconstruction has begun. Propeller flap could be raised on any suitable perforator vessel and, without the aid of microsurgical anastomosis, used to restore small- to middle-sized soft tissue defects. In this review, we intend to analyze pros and cons of muscle and fasciocutaneous free flaps and the applicability of the propeller flaps in lower limb reconstruction.

Keywords
- ► lower limb reconstruction
- ► free flaps
- ► muscle flaps
- ► fasciocutaneous flaps

Soft tissue defects of the lower extremity that expose underlying bones, joints, and tendons pose challenging problems and generally require free tissue transfer for a successful reconstruction. The lower limb fulfills to the peculiar tasks which are weight-bearing and locomotion functions and obviously plays an important role in the aesthetic appearance and social acceptance of a person. Historically, such goals were pursued employing muscle flaps harvested from the latissimus dorsi or transverse abdominis muscles.[1–3] Lately, free and pedicled muscle flaps, such as the soleus, gastrocnemius, and free gracilis flap or free serratus anterior, were described and became the mainstay of lower limb reconstruction. To obviate the unpredictable appearance and high donor-site morbidity of muscle flaps,[4] fasciocutaneous flaps were introduced. Recently, perforator flaps, such as the anterolateral thigh (ALT) flap, gained a leading role in the reconstructive scenario.[5–7] There is growing evidence in the literature supporting that fasciocutaneous and perforator flaps perform similarly to muscle flaps in terms of flap survival, postoperative infection, osteomyelitis, bone union, and ambulation.[8] Furthermore, in the patients who underwent a lower traumas, fasciocutaneous flaps allow to spare

received
June 19, 2017
accepted after revision
August 2, 2017

DOI https://doi.org/10.1055/s-0037-1606559.
ISSN 0743-684X.

core muscles that would be critical to rehabilitation.[9] With the advances of knowledge in perforator anatomy and their mapping, a new era of lower limb reconstruction has begun. Propeller flap could be raised on any suitable perforator vessel and, without the aid of microsurgical anastomosis, used to restore small- to middle-sized soft tissue defects.[10–12] In this review, we intend to analyze the pros and cons of muscle and fasciocutaneous flaps in lower limb reconstruction.

Materials and Methods

A systematic review of the literature was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) depicting the article selection process following PRISMA guidelines analyses statement (►**Fig. 1**). Two independent researchers performed a literature search on June 29, 2017, using the PubMed/MEDLINE and EMBASE electronic database. The following search phrases were used on to identify articles: "muscle flap," "fasciocutaneous flap," and "lower limb reconstruction and free flaps." Studies in English and French languages published between January 1, 1978, and May 2017 were considered eligible if they had described original clinical studies of patients who underwent a muscle or fasciocutaneous flap for trauma of lower extremity. Citation cross-referencing of resulting studies was then performed. We excluded review articles, nonclinical articles, studies reporting recipient sites other than lower extremities, or those lacking patient follow-up. We excluded patients from studies for which the recipient site could not be determined. We did not include duplicates of patients appearing in more than one published study. Any disagreement regarding inclusion was resolved by consensus review.

►**Fig. 1** outlines the search algorithm. To summarize, the initial database search yielded 1,984 studies. After general exclusion criteria were applied (i.e., removal of nonclinical, review, redundant, and non-English or French articles), 234 articles remained. Title and abstract review and assessment of relevance resulted in exclusion of 95 additional articles. Forty-one articles were read thoroughly and assessed using specific criteria, and 3 unique articles were added following citation cross-referencing. This yielded 44 studies that met all search criteria.

The following data were collected and recorded from each individual study: year of publication, study design, subjects (total number, gender, mean age, age range, and smoking status), orthopaedic pathology, number and type of prior surgical treatments, duration of follow-up, union rate, range of motion, and complications. Additional comorbidities that may affect union rate including diabetes or immunosuppressant medication use were not consistently reported throughout the literature, and therefore, these data were not collected. Similarly, recipient vessel choices were rarely reported and these data were not collected.

Results and Discussion

Lower extremity soft tissue defects, whatever the etiology is traumatic or infectious, are often associated with segmental bone defects or exposed hardware. The soft tissue damage may progressively aggravate and extend beyond the initial lesion and sometimes could lead to limb amputation. Savage rate and functional rehabilitation have dramatically

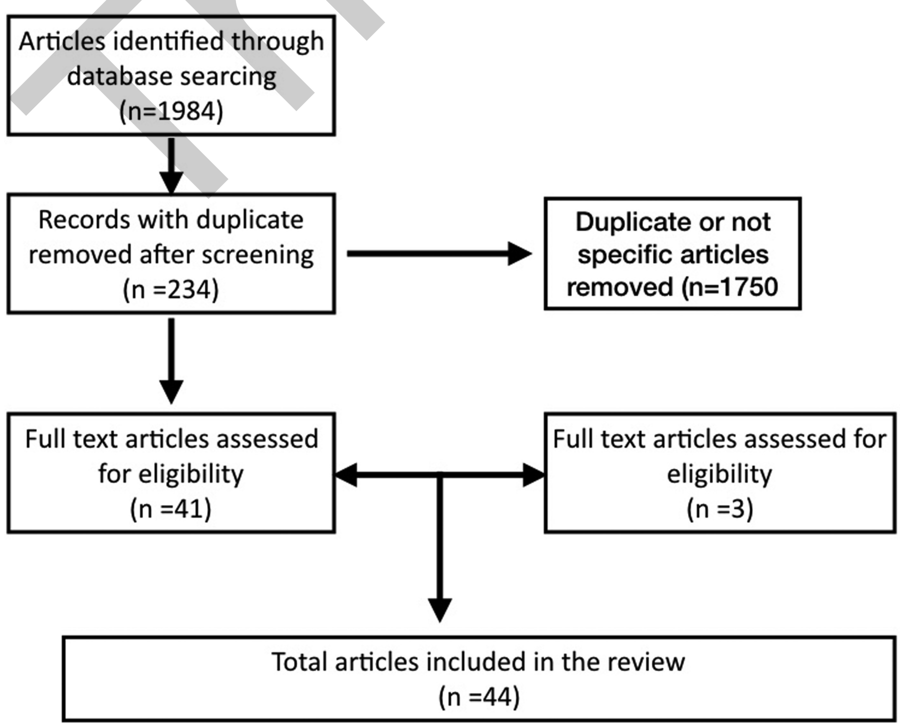


Fig. 1 Flow chart depicting the article selection process.

improved because of the advent of microsurgical techniques. There is general agreement that microsurgery provides the optimal treatment for extensive soft tissue defects, where large exposures of vascular and nervous structures and bone are involved. However, timing of these procedures is still a matter of controversy. Following the pioneering work of Godina,[13] many authors advocate immediate soft tissue coverage after aggressive debridement and bone stabilization, ideally within the first 72 hours. This strategy aims at preventing tissue fibrosis, infection, and tissue edema which may complicate reconstruction.[14] In a high-energy trauma, the wound is often associated with other injuries that could preclude or significantly delay complex extremity reconstruction. Moreover, early total care has been found to increase the risk of postoperative complications and reduces the chances for a correct assessment of the extent of the soft tissue defect, since in the acute setting, the exact tissue damage is difficult to evaluate. This has led to the concept of "damage control orthopaedics (DCO)," which combines primary temporary fixation and secondary definitive management to protect critically ill patients from a "second hit" by a lengthy and stressful operation.[15,16] Anyway, an appropriate surgical debridement is mandatory in the primary treatment phase. The DCO principle could be applied at the soft tissue damage. Negative pressure wound therapy (NPWT) after bone stabilization, besides delaying ultimate wound coverage, produces favorable conditions for later flap reconstruction. First, it reduces tissue edema, diminishing the circumference of the extremity, and thus, decreasing the wound surface. Second, it promotes profuse granulation, increasing microcirculation, and thus, improving local conditions in devitalized and infected tissues. In a study by Steiert et al, it was demonstrated that delaying lower limb soft tissue reconstruction beyond the traditional limit of 72 hours with the aid of negative pressure therapy yields similar results to those of immediate reconstruction.[17] The authors, therefore, believe that inserting NPWT in the management of complex extremity wounds provides several advantages since it reduces the necessity for lengthy, exhausting, and potentially harmful operations in the early posttraumatic phase and allows for an accurate and tailored flap reconstruction.

After fracture stabilization of Gustilo grade IIIB–C injuries, soft tissue defects still remain the main concern due to their large extent or their susceptibility to break down and expose hardware. Vascularity, cellularity, and immunologic properties contribute to wound and fracture healing.[5]

Before the introduction of perforator skin flaps, muscle flaps with split-thickness skin grafts (STSG) or musculocutaneous flaps in which the whole functional muscle unit is harvested were used. Muscle flaps were often selected for the management of these wounds because they had been proved to display a more rapid rate of wound and fracture healing[18–20] and also some increased antimicrobial properties[21–24] thanks to their rich blood supply. They have also been shown to promote bone repair secondary to a greater provision of osteogenic mesenchymal stem cells and bone anabolism such as interleukine-6 and fibroblast grow factor-2.[25–27] Beyond these experimental studies, muscle flap presented the advantage of being able to obliterate easily the dead space and conform well to the unique contour of the lower extremity. However, muscular atrophy occurs with several months and is virtually unpredictable. It is well known, indeed, that muscle flaps require several revision surgeries to obtain an acceptable cosmetic appearance (►**Fig. 2**).

Fasciocutaneous Flaps

Recently, fasciocutaneous and perforator flaps have been gaining popularity, as they offer certain advantages over muscle flaps: they provide a more "like-to-like" tissue for several versatile reconstructive options, present a high reported success rate,[5,9,28–30] and spare core and accessory muscles essential for rehabilitation.[5,9,28,29] Regarding the ability of fasciocutaneous flaps to establish an adequate blood supply to bring sufficient antibiotics to the infectious focus, Salgado et al performed an experimental study on animal models of osteomyelitis in which they demonstrated that muscle or nonmuscle–axial flaps provide equally viable options, provided an adequate surgical debridement.[31] Moreover, in the acute setting as well as in the chronically infected nonunion, the bone union time was found equivalent to both flap types, but a faster return to weight bearing was noted after a fasciocutaneous reconstruction.[32] Another benefit of fasciocutaneous and perforator flaps over muscle flaps is the relative ease of elevation when a secondary procedure, such as bone grafting, tenolysis, tendons repairs, and delayed nerve grafting, is required. Particularly, we have noted a peculiarity of fasciocutaneous flaps that

Fig. 2 The muscle free flaps in lower extremities reconstructions. An acceptable functional and cosmetic appearance can be achieved, even if the muscle flaps are a big flap. However, the muscular atrophy is unpredictable and the donor-site morbidity makes the muscular flaps a second choice. (**A**) Latissimus dorsi flap and a serratus flap for a significant soft tissue defect. The defect at the trauma; (**B**) a third flap, a fasciocutaneous sural flap was used to repairs the calcaneus defect. (**C, D**) The cosmetic appearance and function after 5 years of follow-up.

differentiates them from muscle flaps. Fasciocutaneous flaps, indeed, experience a reorganization of their vascular tree, incorporating blood vessels from the surrounding tissue. Muscle flaps, conversely, cling on their original axial artery, with no revascularization from their periphery (►**Fig. 3**). For these reasons, when a re-elevation or exploration of a muscle flap is required, we strongly recommend to place incisions along the scars of the previous reconstruction and avoid any main artery division, to prevent partial flap necrosis (►**Fig. 4**). Finally, if contouring is required, skin flaps might be easily contoured with liposuction,[33] while muscle flaps require tangential excision of the muscle and reapplication of a skin graft.

If it is true that fasciocutaneous flaps present a more predictable appearance since they do not undergo significant atrophy, it is also true that their draping and tailoring to the soft tissue defect is not so plain. It is not so uncommon to perform at least one revision surgery even after a fasciocutaneous reconstruction.[32] A bulky appearance might occur especially when the pretibial area, ankle, or foot are affected. To attain an acceptable thickness for functional and aesthetic outcomes, many authors recommend performing a meticulous thinning of the flap[34,35] or to harvest an ultrathin suprafascial flap. However, in the western obese patients, the subcutaneous tissue is too thick even after thinning procedures and a small bulky cuff linger around the perforators[36] leading to contour deformity (►**Fig. 5**).

Among fasciocutaneous flaps, the ALT flap, first reported by Song et al,[37] represents a valuable option for soft tissue reconstructions. Its use has been established especially for head and neck region and only recently has been described also for the lower extremity.[38] The peculiarity of the ALT flap that made it so attractive for so many different reconstructions resides in the wealth of tissue provided from the ALT area (i.e., skin, subcutaneous tissue, fascia, muscle, nerve). Taken as a perforator skin flap, the ALT flap provides supple and pliable soft tissue coverage for reconstruction of thin skin areas and leaves the muscle essentially intact, minimizing donor-site morbidity.[39] Conversely, if the muscle is needed to fill in the dead space, a small cuff of vastus lateralis muscle can be harvested and tailored to the defect.[39] Moreover, a real chimeric flap could be harvest, using the different branches of the inferior circumflex lateral femoral vessels to allow a three-

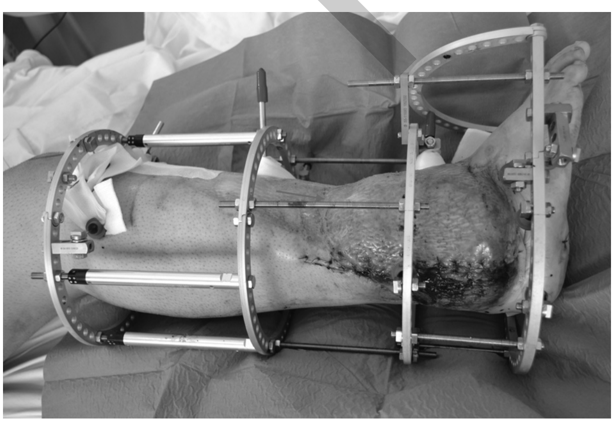


Fig. 3 The vascular pattern of the muscle flap. After 6 months from the microsurgical reconstruction, because of an infection of the distal epiphysis of the tibia, a lateral approach through a previous latissimus dorsi flap was made to reach the infected bone. Three days after surgery, the necrosis of the peripheral component of the muscle shows the importance of the vascular pedicle as to maintain the vitality of the whole flap. The arrow shows the position of the anastomosis on the anterior tibial artery and vein.

Fig. 4 The approach to the bone under a muscle flap. Re-elevation of the muscle for exploration of a bone fracture. The incisions are along the scars of the previous reconstruction to avoid any main artery division, to prevent partial flap necrosis. (**A**) The incision on the flap margins and (**B**) the secondary fixation with a bone plate.

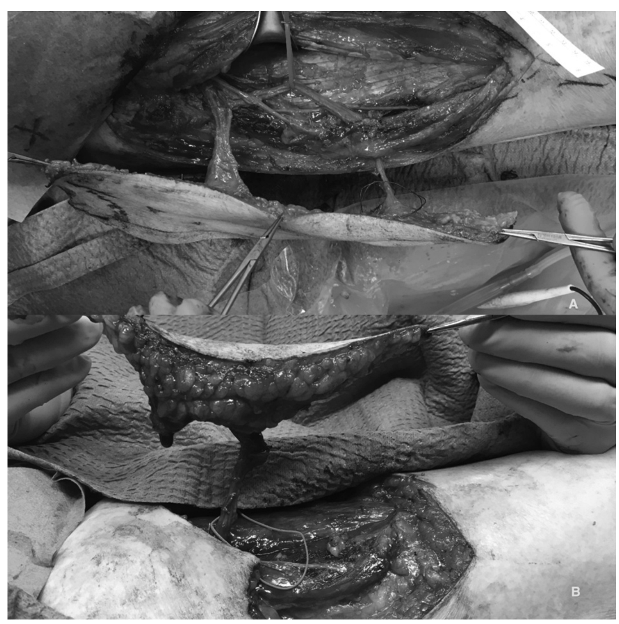


Fig. 5 The suprafascial dissection. (**A**) A suprafascial anterolateral flap in a male slim patient, a very thin flap can be raised easily. (**B**) In the western obese patients, the subcutaneous tissue of the thigh is too thick, in particular, in female patients. Because of this, the harvesting of the flap could be very difficult. Moreover, even after thinning procedures, a small bulky cuff lingers around the perforators persist.

dimensional reconstruction if needed.[40] The color and texture of the anterolateral skin is good for lower extremity reconstruction and indisputably much better compared with skin grafted muscle. It offers a long vascular pedicle which is of paramount importance since microvascular anastomosis should be performed far away from the traumatized area. Any vein graft should be avoided as much as possible since its use in lower extremity reconstruction increases the complication rate as much as fivefold.[2,5] According to the literature, survival and complication rates of fasciocutaneous ALT flaps and muscle flaps are comparable.[5,6,8,32,35,38,41]

The treatment choice for soft tissue defects of the lower extremity depends on the size and location of the wound, besides its cause.[42,43] When a functional transfer is desirable, a muscle flap is the only reasonable reconstruction. Conversely, in the presence of osteomyelitis, exposed hardware, or open fracture, both fasciocutaneous and muscle flap are feasible options.

Proximal third injuries can often be addressed by transposing local muscle flaps such as the gastrocnemius or tibialis anterior muscles. Particularly, the medial gastrocnemius muscle flap is considered a good option to cover the proximal tibia. However, the propeller flaps based on the perforators of the deep femoral artery may be good alternatives to cover the patella region since they provide thin and pliable skin coverage. Innocenti et al reported a new chimeric pedicled flap based on the medial sural artery and consisting of a musculocutaneous medial gastrocnemius flap where the skin paddle is raised according to the principles of propeller flaps and oriented in a different direction.[44] This union of a propeller plus muscle flap shows the potentiality of both flaps. When a pedicle gastrocnemius muscle is selected, we recommend not to overlook a little ingenuity and namely to interrupt the motor nervous branch to the muscle to prevent twitching of the flap during walking and allow for its prompt atrophy. Reconstruction of small distal-third wounds might be accomplished using local muscle flaps such as the reverse or distally based soleus flap or, in the case of the lateral malleolar region, with a distally or proximally based peroneus brevis muscle flap.[45,46] Conversely, large distal tibial defects often require a free tissue transfers. A musculocutaneous ALT flap can be used for large, bone exposed areas and for weight-bearing areas.[39] The plantar surface, indeed, requires a tissue that can withstand repetition of walking and prevent shearing planes that would cause instability with mobilization. For these reasons, a muscle flap is generally preferred over a fasciocutaneous flap for the reconstruction of the sole or heel pad. A fasciocutaneous ALT flap can be used in cases where a thin flap is required, such as the dorsum of the foot or posterior aspect of the ankle. In these cases, a very thin flap is needed, and a suprafascial dissection is suggested thinning the ALT flap. Conversely, when dealing with obese patients and in women, the dissection around the pedicle in the suprafascial plane may represent a difficult procedure and the risk of damaging the perforator limits the ability to thin the flap. In such situations, generally, the surgeon prefers to thin only the periphery of the flap and thereby resulting in a pyramid shape flap.

To reconstruct lower limb regions substantially devoid of subcutaneous tissue, such as the ankle and dorsum of the foot, we propose a variation of the ALT flap, called the sandwich fascial ALT flap. The ALT flap is harvested as a composite flap including the superficial fascia, the subscarpal fat, and the deep fascia. At the recipient site, the flap is inset with the deep fascia facing out and a STSG is used to cover the deep fascia and pedicle. With this method, a very thin and consistent reconstruction could be accomplished in a single-stage procedure. The ability to use the ALT as a vascularized fascial flap, without skin or muscle, was first documented by Koshima et al[47] for the reconstruction of an abdominal defect. Despite its description more than 20 years ago, little literature exists on the application of the fascia-only ALT flap, and mainly concerns its employ in oral or dorsal hand reconstruction.[48–50] Recently, the ALT flap as vascularized fascial flap has been proposed also for lower extremity reconstruction.[51,52] We believe that the fascia-only variation presents three major advantages over other muscle or fasciocutaneous flaps. First, it atrophies less than other muscle flaps and adapts more easily to the geometry of defect than common fasciocutaneous flaps. Second, its stable and predictable appearance over time abate the need for secondary procedures.[52] Third, donor-site incisions result in consistent straight-line scars, regardless of the size of the flap, since no skin island is harvested. With regard to the aesthetic appearance, a comparative photographic study by Fox et al showed that grafting the fascial surface of the flap with a sheet skin graft assures cosmetic outcomes comparable to that of fasciocutaneous flaps[52] (►**Fig. 6**).

Fig. 6 Sandwich fascial flap. To reconstruct lower limb regions substantially devoid of subcutaneous tissue, such as the ankle and dorsum of the foot, we propose a superficial fascial flap, covered with a split-thickness skin graft. (**A**) The flap harvest. A real thin ALT flap can be harvest from any patient. (**B**) The flap after 4 weeks; (**C**) the final result after the complete heal of the skin graft. The patient is able to wear normal shoes without any secondary procedure of debulking. ALT, anterolateral thigh.

Conclusion

Soft tissue defects of the lower extremity represent a challenging problem that requires a multidisciplinary approach involving both the reconstructive and orthopaedic surgeons. A thorough evaluation of the patient and his wound should be undertaken and the risks and chances of the reconstructive procedure should be discussed. Whenever an immediate reconstruction could not be proposed, a damage control strategy with the aid of negative pressure therapy should be set up.

With this article, we cannot say that exist a really better solution for the treatment of the lower limb reconstruction, however, the choice of a free tissue transfer should be relegated to the experienced surgeon independently from the result. Both techniques are equal in terms of efficiency. However, the muscle flaps have their clear disadvantages in terms of donor-site morbidity. Beyond the well-known muscle flaps, we encourage to take into account new reconstructive solutions such as the fasciocutaneous ALT flap, propeller flaps, and the sandwich fascial ALT flap, especially when a thin and pliable skin coverage is required. These flaps, even if their limitations are to be probed yet, offer the opportunity to treat in a single stage and with a less invasive procedure complex soft tissue defects such as those involving the lower limb.

Conflict of Interest
The authors have no conflict of interest to report.

Acknowledgments
None.

References

1 Yaremchuk MJ, Brumback RJ, Manson PN, Burgess AR, Poka A, Weiland AJ. Acute and definitive management of traumatic osteocutaneous defects of the lower extremity. Plast Reconstr Surg 1987;80(01):1–14
2 Khouri RK, Shaw WW. Reconstruction of the lower extremity with microvascular free flaps: a 10-year experience with 304 consecutive cases. J Trauma 1989;29(08):1086–1094
3 Melissinos EG, Parks DH. Post-trauma reconstruction with free tissue transfer–analysis of 442 consecutive cases. J Trauma 1989; 29(08):1095–1102, discussion 1102–1103
4 Ohjimi H, Taniguchi Y, Kawano K, Kinoshita K, Manabe T. A comparison of thinning and conventional free-flap transfers to the lower extremity. Plast Reconstr Surg 2000;105(02):558–566
5 Yildirim S, Gideroğlu K, Aköz T. Anterolateral thigh flap: ideal free flap choice for lower extremity soft-tissue reconstruction. J Reconstr Microsurg 2003;19(04):225–233
6 Ozkan O, Coşkunfirat OK, Ozgentaş HE. The use of free anterolateral thigh flap for reconstructing soft tissue defects of the lower extremities. Ann Plast Surg 2004;53(05):455–461
7 Masia J, Moscatiello F, Pons G, Fernandez M, Lopez S, Serret P. Our experience in lower limb reconstruction with perforator flaps. Ann Plast Surg 2007;58(05):507–512
8 Yazar S, Lin CH, Lin YT, Ulusal AE, Wei FC. Outcome comparison between free muscle and free fasciocutaneous flaps for reconstruction of distal third and ankle traumatic open tibial fractures. Plast Reconstr Surg 2006;117(07):2468–2475, discussion 2476–2477
9 Sabino J, Polfer E, Tintle S, et al. A decade of conflict: flap coverage options and outcomes in traumatic war-related extremity reconstruction. Plast Reconstr Surg 2015;135(03):895–902
10 Schaverien MV, Hamilton SA, Fairburn N, Rao P, Quaba AA. Lower limb reconstruction using the islanded posterior tibial artery perforator flap. Plast Reconstr Surg 2010;125(06): 1735–1743
11 Lu TC, Lin CH, Lin CH, Lin YT, Chen RF, Wei FC. Versatility of the pedicled peroneal artery perforator flaps for soft-tissue coverage of the lower leg and foot defects. J Plast Reconstr Aesthet Surg 2011;64(03):386–393
12 Hallock GG. A paradigm shift in flap selection protocols for zones of the lower extremity using perforator flaps. J Reconstr Microsurg 2013;29(04):233–240
13 Godina M. Early microsurgical reconstruction of complex trauma of the extremities. Plast Reconstr Surg 1986;78(03):285–292
14 Heller L, Levin LS. Lower extremity microsurgical reconstruction. Plast Reconstr Surg 2001;108(04):1029–1041, quiz 1042
15 Roberts CS, Pape HC, Jones AL, Malkani AL, Rodriguez JL, Giannoudis PV. Damage control orthopaedics: evolving concepts in the treatment of patients who have sustained orthopaedic trauma. Instr Course Lect 2005;54:447–462
16 Hildebrand F, Giannoudis P, Kretteck C, Pape HC. Damage control: extremities. Injury 2004;35(07):678–689
17 Steiert AE, Gohritz A, Schreiber TC, Krettek C, Vogt PM. Delayed flap coverage of open extremity fractures after previous vacuum-assisted closure (VAC) therapy - worse or worth? J Plast Reconstr Aesthet Surg 2009;62(05):675–683
18 Utvåg SE, Iversen KB, Grundnes O, Reikerås O. Poor muscle coverage delays fracture healing in rats. Acta Orthop Scand 2002;73(04):471–474
19 Anderson GI, Richards RR, Paitich B, McKee M, Schemitsch EH. Soft-tissue blood flow after segmental osteotomy of the canine tibia. Ann Plast Surg 1991;27(01):49–55
20 Richards RR, McKee MD, Paitich CB, Anderson GI, Bertoia JT. A comparison of the effects of skin coverage and muscle flap coverage on the early strength of union at the site of osteotomy after devascularization of a segment of canine tibia. J Bone Joint Surg Am 1991;73(09):1323–1330
21 Calderon W, Chang N, Mathes SJ. Comparison of the effect of bacterial inoculation in musculocutaneous and fasciocutaneous flaps. Plast Reconstr Surg 1986;77(05):785–794
22 Gosain A, Chang N, Mathes S, Hunt TK, Vasconez L. A study of the relationship between blood flow and bacterial inoculation in musculocutaneous and fasciocutaneous flaps. Plast Reconstr Surg 1990;86(06):1152–1162, discussion 1163
23 Harry LE, Sandison A, Paleolog EM, Hansen U, Pearse MF, Nanchahal J. Comparison of the healing of open tibial fractures covered with either muscle or fasciocutaneous tissue in a murine model. J Orthop Res 2008;26(09):1238–1244
24 Harry LE, Sandison A, Pearse MF, Paleolog EM, Nanchahal J. Comparison of the vascularity of fasciocutaneous tissue and muscle for coverage of open tibial fractures. Plast Reconstr Surg 2009;124(04):1211–1219
25 Evans CH, Liu FJ, Glatt V, et al. Use of genetically modified muscle and fat grafts to repair defects in bone and cartilage. Eur Cell Mater 2009;18:96–111
26 Vogt PM, Boorboor P, Vaske B, Topsakal E, Schneider M, Muehlberger T. Significant angiogenic potential is present in the microenvironment of muscle flaps in humans. J Reconstr Microsurg 2005;21(08):517–523
27 Schindeler A, Liu R, Little DG. The contribution of different cell lineages to bone repair: exploring a role for muscle stem cells. Differentiation 2009;77(01):12–18
28 Sabino J, Franklin B, Patel K, Bonawitz S, Valerio IL. Revisiting the scapular flap: applications in extremity coverage for our U.S. combat casualties. Plast Reconstr Surg 2013;132(04): 577e–585e

29 Yazar S, Lin CH, Wei FC. One-stage reconstruction of composite bone and soft-tissue defects in traumatic lower extremities. Plast Reconstr Surg 2004;114(06):1457–1466

30 Fox CM, Beem HM, Wiper J, Rozen WM, Wagels M, Leong JC. Muscle versus fasciocutaneous free flaps in heel reconstruction: systematic review and meta-analysis. J Reconstr Microsurg 2015; 31(01):59–66

31 Salgado CJ, Mardini S, Jamali AA, Ortiz J, Gonzales R, Chen HC. Muscle versus nonmuscle flaps in the reconstruction of chronic osteomyelitis defects. Plast Reconstr Surg 2006;118(06):1401–1411

32 Paro J, Chiou G, Sen SK. Comparing muscle and fasciocutaneous free flaps in lower extremity reconstruction - does it matter? Ann Plast Surg 2016;76(03, Suppl 3):S213–S215

33 Duffy FJ Jr, Brodsky JW, Royer CT. Preliminary experience with perforator flaps in reconstruction of soft-tissue defects of the foot and ankle. Foot Ankle Int 2005;26(03):191–197

34 Demirtas Y, Kelahmetoglu O, Cifci M, Tayfur V, Demir A, Guneren E. Comparison of free anterolateral thigh flaps and free muscle-musculocutaneous flaps in soft tissue reconstruction of lower extremity. Microsurgery 2010;30(01):24–31

35 Lin CH, Mardini S, Wei FC, Lin YT, Chen CT. Free flap reconstruction of foot and ankle defects in pediatric patients: long-term outcome in 91 cases. Plast Reconstr Surg 2006;117(07): 2478–2487

36 Kimura N, Satoh K. Consideration of a thin flap as an entity and clinical applications of the thin anterolateral thigh flap. Plast Reconstr Surg 1996;97(05):985–992

37 Song YG, Chen GZ, Song YL. The free thigh flap: a new free flap concept based on the septocutaneous artery. Br J Plast Surg 1984; 37(02):149–159

38 Park JE, Rodriguez ED, Bluebond-Langer R, et al. The anterolateral thigh flap is highly effective for reconstruction of complex lower extremity trauma. J Trauma 2007;62(01):162–165

39 Lee MJ, Yun IS, Rah DK, Lee WJ. Lower extremity reconstruction using vastus lateralis myocutaneous flap versus anterolateral thigh fasciocutaneous flap. Arch Plast Surg 2012;39(04): 367–375

40 Cherubino M, Turri-Zanoni M, Battaglia P, et al. Chimeric anterolateral thigh free flap for reconstruction of complex cranio-orbito-facial defects after skull base cancers resection. J Craniomaxillofac Surg 2017;45(01):87–92

41 Wei FC, Jain V, Celik N, Chen HC, Chuang DC, Lin CH. Have we found an ideal soft-tissue flap? An experience with 672 anterolateral thigh flaps. Plast Reconstr Surg 2002;109(07):2219–2226, discussion 2227–2230

42 Reddy V, Stevenson TR. MOC-PS(SM) CME article: lower extremity reconstruction. Plast Reconstr Surg 2008;121(4, Suppl):1–7

43 Evans K, Clemens M, Salgado C, Moran S, Mardini S. Fasciocutaneous versus muscle flap in soft tissue reconstruction. In: Pu LLQ, Levine JP, Wei F-C, eds. Reconstructive Surgery of the Lower Extremity, Part II. Chap. 22. St. Louis, USA: QMP; 2013:345–368

44 Innocenti M, Cardin-Langlois E, Menichini G, Baldrighi C. Gastrocnaemius-propeller extended miocutanous flap: a new chimaeric flap for soft tissue reconstruction of the knee. J Plast Reconstr Aesthet Surg 2014;67(02):244–251

45 Ensat F, Hladik M, Larcher L, Mattiassich G, Wechselberger G. The distally based peroneus brevis muscle flap-clinical series and review of the literature. Microsurgery 2014;34(03):203–208

46 Ceran C, Demirseren ME, Aksam E, Cicek C, Demiralp CO. Lateral malleolar region defects with exposed implants: proximally based peroneus brevis muscle flap. J Wound Care 2015;24(08): 372–377

47 Koshima I, Fukuda H, Utunomiya R, Soeda S. The anterolateral thigh flap; variations in its vascular pedicle. Br J Plast Surg 1989; 42(03):260–262

48 Agostini V, Dini M, Mori A, Franchi A, Agostini T. Adipofascial anterolateral thigh free flap for tongue repair. Br J Plast Surg 2003; 56(06):614–618

49 Parrett BM, Bou-Merhi JS, Buntic RF, Safa B, Buncke GM, Brooks D. Refining outcomes in dorsal hand coverage: consideration of aesthetics and donor-site morbidity. Plast Reconstr Surg 2010; 126(05):1630–1638

50 Cherubino M, Berli J, Turri-Zanoni M, et al. Sandwich fascial anterolateral thigh flap in head and neck reconstruction: evolution or revolution? Plast Reconstr Surg Glob Open 2017;5(01): e1197

51 Bhadkamkar MA, Wolfswinkel EM, Hatef DA, et al. The ultra-thin, fascia-only anterolateral thigh flap. J Reconstr Microsurg 2014;30 (09):599–606

52 Fox P, Endress R, Sen S, Chang J. Fascia-only anterolateral thigh flap for extremity reconstruction. Ann Plast Surg 2014;72(01, Suppl 1): S9–S13

Retrospective Analysis in Lower Limb Reconstruction: Propeller Perforator Flaps versus Free Flaps

Marta Cajozzo, MD[1] Francesca Toia, MD, PhD[1] Alessandro Innocenti, MD[2]
Massimiliano Tripoli, MD, PhD[1] Giovanni Zabbia, MD, PhD[1] Salvatore D'Arpa, MD, PhD[1,3]
Adriana Cordova, MD[1]

[1] Division of Plastic and Reconstructive Surgery, Department of Surgical, Oncological and Oral Sciences, University of Palermo, Palermo, Italy
[2] Division of Plastic and Reconstructive Microsurgery, Careggi University Hospital, Florence, Italy
[3] Department of Plastic and Reconstructive Surgery, Gent University Hospital, Gent, Belgium

Address for correspondence Francesca Toia, MD, PhD, Division of Plastic and Reconstructive Surgery, Department of Surgical, Oncological and Oral Sciences, University of Palermo, via Delvespro, 129-90127, Palermo, Italy (e-mail: francescatoia@gmail.com).

J Reconstr Microsurg 2017;33:S34–S39.

Abstract

Background Technical advancements and increasing experience in the management of soft tissue defects in lower extremities have led to the evolution of decisional reconstructive algorithms. Both propeller perforator flaps (PPFs) and free flaps (FFs) proved to be useful methods of reconstruction for lower extremities defects, offering alternative reconstructive tools. We present a case series of PPFs and FFs for reconstruction of lower limbs defects, analyzing and comparing treatment and outcomes.

Methods Through a retrospective analysis, we report our experience in performing PPFs or FFs for reconstruction of soft tissue defects of the lower extremities, in patients admitted between 2010 and 2015 at the Department of Plastic and Reconstructive Surgery, University of Palermo. In these patients, we evaluated location and causes of defects, types of flaps used, recipient vessels, complications, time to healing, and aesthetic outcome.

Results A primary healing rate was obtained in 13 patients for PPF and 16 cases for FF. Revision surgery for partial skin necrosis was required in eight cases (PPF: four and FF: four). Recovery time and hospitalization period were eventually shorter in patients with FFs, due to lower rate of complications and revision surgery.

Conclusion In the past years, our indications for reconstruction with PPFs in the lower limb have become more restricted, while we favor reconstruction with FFs. Recommendations are provided to orient surgical treatment in small, medium, and large lower limb defects.

Keywords
- lower limb reconstruction
- propeller perforator flap
- free flap

Defects of the lower limbs still represent a significant challenge in reconstructive surgery, since local reconstructive options are limited, especially for complex defects with exposed tendons and/or bones.

Free flaps (FFs) have been widely used for lower limb reconstruction.[1–4] Increased knowledge of vascular anatomy[5,6] allowed for refinements in reconstructive strategy and flap harvesting techniques. Recently, propeller perforator flaps (PPFs) have gained popularity as a reconstructive tool[7–9] for lower limb defects of average size; compared with FFs, PPFs are considered simpler and less invasive, although effective.

received
June 20, 2017
accepted after revision
July 11, 2017

DOI https://doi.org/10.1055/s-0037-1606268.
ISSN 0743-684X.

Data from available literature are still controversial and do not provide unanimous guidelines for a lower limb reconstruction algorithm. Limited scientific evidence exists comparing reconstruction of the lower limb with FFs and PPFs.

In our department, following an initial enthusiasm for PPFs in reconstruction of the lower limbs, we have progressively switched back to a preferential use of FFs, based on complication risks and aesthetic sequelas of PPFs (►**Fig. 1**).

In this study, we evaluate our use of PPFs and FFs for reconstruction of lower limbs defects, analyzing and comparing treatment strategy and outcomes.

Patients and Methods

A retrospective analysis was performed, and patients operated between 2010 and 2015 for reconstruction of lower limb defects with a PPF or FF at the Department of Plastic and Reconstructive Surgery, University of Palermo were included.

Thirty-seven patients with traumatic, postoncologic, or chronic defects (osteomyelitis, diabetic ulcers, radiodermatitis, unstable scars) were included. Data on patient characteristics, etiology, and location of the defect and flap characteristics (size, vascular pedicle, movement rotation, and recipient vessels) were extrapolated.

Seventeen cases of reconstruction by PPF and 20 by FF were analyzed and compared in terms of survival, complication rate, need for secondary surgery, donor-site morbidity, and healing time. A subjective evaluation of the aesthetic outcome was also performed by two independent plastic surgeons. Statistical analysis of the complications rate and the healing time of the two groups were performed using the Fisher's exact test.

Results

Propeller Perforator Flap

Our clinical series of patients was composed of 17 patients (M/F: 12/5), with a mean age of 74 years (range: 64–82 years) (►**Table 1**).

In eight cases, the defect was located in the distal third of the leg; in six cases, in the middle third; in two cases, in the popliteal fossa; and in one single case, in the knee. The

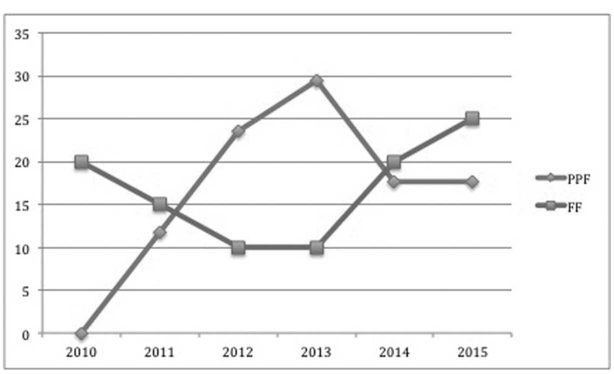


Fig. 1 Changes in annual incidence rates of PPF and FF. FF, free flap; PPF, propeller perforator flap.

Table 1 Patient demographics (PPF vs. FF)

	PPF	FF
Characteristics		
No. of patients	17	20
Mean age, y (range)	74 (64–82)	61 (41–77)
Diabetes mellitus no. (%)	7 (41)	5 (25)
Defect site no. (%)		
Knee	1 (6%)	–
Popliteal fossa	2 (12%)	3 (15%)
Middle third leg	6 (35%)	3 (15%)
Distal third leg	8 (47%)	8 (40%)
Forefoot	–	2 (10%)
Midfoot	–	2 (10%)
Hindfoot	–	1 (5%)
Defect size no. (%)		
Small defects (<4 cm)	13 (76%)	2 (10%)
Medium defects (>4 cm)	4 (23%)	8 (40%)
Large defects (>8 cm)	–	10 (50%)
Etiology no. (%)		
Trauma	9 (53%)	11 (55%)
Tumor excision	6 (35%)	6 (30%)
Infection	1 (6%)	–
Diabetic ulcer	1 (6%)	1 (5%)
Irradiation	–	1 (5%)
Unstable scarring	–	1 (5%)
Exposure of bone or tendon no. (%)	4 (23%)	7 (35%)
Flap source artery no. (%)		
PTA	8 (47%)	–
PA	7 (41%)	–
ATA	2 (12%)	–
Flap arc of rotation no. (%)		
180 deg	15 (88%)	–
90 deg	2 (12%)	–
Free flap no. (%)		
ALT flap	–	8 (40%)
VL flap	–	4 (20%)
Latissimus dorsi flap	–	3 (15%)
DIEP flap	–	3 (15%)
Fibular flap	–	1 (5%)
Gracilis flap	–	1 (5%)
TAP flap	–	1 (5%)
Radial flaps	–	1 (5%)
Time to heal, d (range)	38 (20–80)	20 (15–30)
Donor-site closure no. (%)		
STSG	17 (100%)	1 (5%)
Primary closure	–	19 (95%)

Abbreviations: ALT, anterolateral thigh; ATA, anterior tibialis artery; DIEP, deep inferior epigastric perforator; FF, free flap; PA, peroneal artery; PPF, propeller perforator flap; PTA, posterior tibialis artery; STSG, split-thickness skin graft; TAP, thoracodorsal artery perforator; VL, vastus lateralis.

etiology of the defect was posttraumatic in nine cases, postoncological resection in six cases, osteomyelitis in one case, and a chronic diabetic defect in one case.

All flaps were based on a single perforator. The perforator originated from the posterior tibialis artery in eight cases, from the peroneal artery in seven cases, and from the anterior tibialis artery in two cases. Dimensions of the flaps ranged from 8 × 3 to 26 × 5 cm.

The flap rotated 90 degrees in 2 cases and 180 degrees in 15 cases. During the flap inset, as a preventive measure, we routinely record, through film or photograph, the flap rotation movement so that in case of salvage reintervention, the flap could be easily derotated.

The results of this retrospective analysis show an overall primary healing success rate of 71% cases (five cases from posterior tibialis artery [PTA]-PPF, seven from peroneal artery-PPF, and one case from anterior tibialis artery [ATA]-PPF). We observed four cases of vascular insufficiency (23%, one ATA-PPF and three PTA-PPF). Partial necrosis occurred in four cases (23%) and required revision surgery (surgical debridement and skin graft or V-Y secondary flap); one case (6%) of transient venous congestion solved with conservative treatment and secondary healing.

Mean healing time was 38 days (range: 20–80 days). The main reasons for delayed healing were the need for revision surgery and an incomplete donor-site closure. Donor-site complications occurred in two cases (12%), due to failure of the skin graft, which was related, in one case, to the presence of infection. Split-thickness skin graft (STSG) reconstruction was also the main factor related to the poor aesthetic outcomes. The cosmetic result was evaluated as poor in 59%, acceptable in 29%, and good in 12% of cases.

Free Flap

Our clinical series of patients was composed of 20 patients (M/F: 18/2), with a mean age of 61 years (range: 41–77 years) (►**Table 2**).

In six cases, the defect was located in the distal third of the leg; in three cases, in the middle third; in three cases, in the popliteal fossa; in two cases, in the foot arch, in the forefoot, and at the level of lateral malleolus; and in one single case, in the heel.

Table 2 Patient complications (PPF vs. FF)

	PPF	FF
Flap loss no. (%)		
Partial	4 (23%)	4 (20%)
Complete	–	–
Infection no. (%)	1 (6%)[a]	–
STSG loss no. (%)	2 (12%)[a]	–
Donor-site complication no. (%)	2 (12%)[a]	1 (5%)
Overall complication rate no. (%)	6 (35%)	5 (25%)

Abbreviations: FF, free flap; PPF, propeller perforator flap; STSG, split-thickness skin graft.
[a]A total of two patients showed donor-site complications, namely, two STSG partial loss, one of which due to an infection.

The etiology of the defect was posttraumatic in 11 cases, postoncological resection in 6 cases, and in 1 case related to radiodermatitis, unstable scarring, and diabetic chronic ulceration.

The flap for microsurgical reconstruction was chosen based on size and location of the defect and presence of bone defects or osteomyelitis. We performed eight anterolateral thigh flap, four vastus lateralis muscle-sparing flap,[4] three deep inferior epigastric perforator flap, three latissimus dorsi muscle Flap, one fibula osteocutaneous flap, one radial forearm flap, one gracilis muscle flap, and one thoracodorsal artery perforator flap for coverage of defects with dimensions averaged from 5 × 10 to 10 × 30 cm. In five cases, bone exposure was present. Recipient vessels included the PTA in 15 cases, the popliteal artery in 3 cases, and the anterior tibial artery in 2 cases.

Flap donor sites were directly closed with sutures in majority of cases (95%) and covered through STSG in one case. There were no complications at donor sites requiring surgical treatment. Results achieved through FF reconstructions showed to have less complications and need for revision surgery, a shorter healing time and better global aesthetic results.

Primary healing without complications was achieved in 16 cases (80%). Partial necrosis with need of secondary surgery occurred in four cases (20%): three cases were related to venous congestion and one case to arterial insufficiency, with need of re-exploration. Surgical revision included STSG and application of dermal substitute before grafting. Mean healing time was 20 days (range: 15–30 days).

For the aesthetic evaluation, the FF group received generally higher scores from the two independent assessors, compared with the series of PPF. The assessment was good in 45%, acceptable in 35%, and poor in 20%.

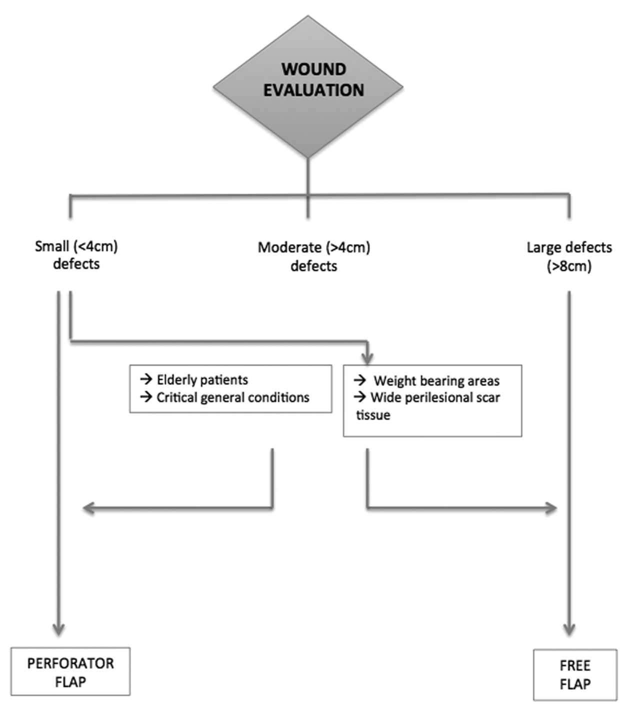


Fig. 2 Our algorithm for lower limb defects reconstruction.

Fisher's exact test did not show any statistically significant difference between the two groups, with regard to overall or single complication rates and healing time.

Discussion

The lower limb presents few anatomical peculiarities that make it a region difficult to approach. Particularly, the weight-bearing area of the foot and the distal third of leg show lack of suitable skin substrate, with frequent posttraumatic exposure of important structures such as bones and tendons. With regard to the latter aspect, a long-term stability of soft tissue coverage becomes of primary importance and this is the reason because we do adopt the concept of "reconstructive elevator,"[10] favoring the use of more complex reconstruction, such as local or FF, rather than simpler option.

Over the years, several algorithms have been proposed and applied for management of lower limbs defects. Based on our clinical experience and literature evidence, we propose some suggestions for surgical approach to these defects (►**Fig. 2**). The main aims are to obtain a short healing time, to minimize mayor complications, such as infections and osteomyelitis, and to restore regional anatomy and function, replacing "like-with-like" tissue, with minimal donor-site morbidity.[11–13] The use of PPF follows these main principles, with the preservation of nerves and muscles[14,15] and a short operating time. However, despite their recent more frequent use, there is still high concern for partial or total flap necrosis,[16] with the related risk of creating an even bigger defect. This is one of the reasons why standard or supermicrosurgical FFs are still considered by most a first choice option for complex reconstruction and coverage of wide cutaneous defects in lower limbs.[1,17]

Fig. 3 **(a)** Squamous cell carcinoma of the popliteal fossa, in a 69-year-old man. **(b)** A 26 × 7 cm propeller perforator flap based on posterior tibialis artery perforator is planned to cover the postoncological excision defect (4 × 5 cm). **(c)** The flap is isolated on the pedicle. **(d)** Immediate postoperative result, after a 180-degree rotation. STSG is used to partially cover the donor site. **(e)** One-year postoperative view, with a resulting poor aesthetic outcome at the donor site. STSG, split-thickness skin graft.

According to the proposed recommendations, for small defects, when local tissues are in good condition, our first choice are PPFs, while FFs are reserved for cases with extensive perilesional scarring. For medium-sized defects, FFs are our preferred option, but patients' systemic conditions and presence of local limiting conditions are taken into account to orient treatment toward PPFs or FFs (►**Figs. 3** and **4**). For wide defects, FFs are always our first reconstructive option.

Recently, practical recommendations were proposed by Bekara et al[18] for the use of this technique, identifying age older than 60 years, diabetes, and arteriopathy as significant risk factors for complications. Though, it is still controversial whether preexisting patient comorbidities may influence the surgical outcome and represent real risk factors for complication,[12,19] as reported by Paik and Pyon.[20]

Selection of the more adequate technique also depends on local factors, such as the possibility to achieve donor-site

Fig. 4 **(a)** A nonhealing posttraumatic ulcer (4 × 7 cm) of the medial malleolus, in a 65-year-old man. **(b)** A 16 × 7 cm anterolateral free flap is planned for reconstruction. **(c)** Immediate postoperative result. **(d, e)** One-year postoperative view. The donor site is closed primarily, allowing for the best result possible.

closure, presence of scars, perilesional tissue conditions, presence of edema, inflammation, thickness of subcutaneous tissue, and quality of recipients vessels and not least the surgical expertise.

Our retrospective analysis did not show a superiority of PPF over FF in terms of healing time, complications rate, and aesthetic outcomes.

Patients selected for microsurgical procedures had a lower average age, underwent a longer operating time, but a shorter hospitalization period, due to lower incidence of complications and second surgery. FFs patients achieved a primary healing rate up to 80%, with a 20% of complications requiring second surgery. On the contrary, in PPFs patients, we reported a slightly lower primary healing success rate (71%), with slightly higher rate of complications (29%), although these differences were not statistically significant. A considerable difference was reported in the mean recovery time, which required half the time to heal in FFs (20 days) when compared with PPFs cases (38 days), but this difference did not reach statistical significance. Not less important is the need to achieve an acceptable aesthetic outcome: a primary closure of the secondary defect, if achieved without tension, should be the optimal solution with best aesthetic result. Often though, when performing PPF, to avoid excessive tension, which compromises the local blood perfusion, STSGs are used to partially or sometimes wholly cover the donor site.[20]

During the past years, we have become more aware of the potential and risks related to the use of PPFs and after an initial decrease of microsurgical procedures, we have switched back to a preferential use of FFs as first reconstructive option for coverage of defects of the lower limb.

A limit of our study is the small sample size; although a statistical comparison of complication rates and healing time was performed, the results need to be confirmed on a larger series to achieve a higher statistical power. Current literature does not present either conclusive evidence comparing outcomes of the two reconstructive options and/or demonstrating the superiority of one of these techniques. Randomized controlled trials comparing the two techniques are desirable to better assess advantages, disadvantages, and indications for the use of PPFs and FFs in lower limb reconstruction.

Conclusion

According to the recommendations we propose, PPFs remain a valid option for lower limb reconstruction, but we do not consider it as first choice option and we recommend their use for selected patients. In our clinical practice, its use is indicated in small defects at the level of the lower leg and foot,[21] or in medium-sized defects for elderly patients or patients who cannot undergo a microsurgical procedure, preferably when good local tissues are present.

We still encourage the conventional use of microsurgery for lower limb reconstruction to provide a more reliable coverage and a better aesthetic results in weight-bearing areas and complex wounds for either small, moderate, or large defects.

Conflict of Interest
None.

References

1 Kang MJ, Chung CH, Chang YJ, Kim KH. Reconstruction of the lower extremity using free flaps. Arch Plast Surg 2013;40(05):575–583
2 Bekara F, Herlin C, Somda S, de Runz A, Grolleau JL, Chaput B. Free versus perforator-pedicled propeller flaps in lower extremity reconstruction: what is the safest coverage? A meta-analysis. Microsurgery 2016
3 Soltanian H, Garcia RM, Hollenbeck ST. Current concepts in lower extremity reconstruction. Plast Reconstr Surg 2015;136(06): 815e–829e
4 Toia F, D'Arpa S, Brenner E, Melloni C, Moschella F, Cordova A. Segmental anatomy of the vastus lateralis: guidelines for muscle-sparing flap harvest. Plast Reconstr Surg 2015;135(01):185e–198e
5 Taylor GI, Palmer JH. The vascular territories (angiosomes) of the body: experimental study and clinical applications. Br J Plast Surg 1987;40(02):113–141
6 Saint-Cyr M, Wong C, Schaverien M, Mojallal A, Rohrich RJ. The perforasome theory: vascular anatomy and clinical implications. Plast Reconstr Surg 2009;124(05):1529–1544
7 D'Arpa S, Cordova A, Pignatti M, Moschella F. Freestyle pedicled perforator flaps: safety, prevention of complications, and management based on 85 consecutive cases. Plast Reconstr Surg 2011; 128(04):892–906
8 Pignatti M, Ogawa R, Hallock GG, et al. The "Tokyo" consensus on propeller flaps. Plast Reconstr Surg 2011;127(02):716–722
9 Teo TC. The propeller flap concept. Clin Plast Surg 2010;37(04): 615–626, vi
10 Gottlieb LJ, Krieger LM. From the reconstructive ladder to the reconstructive elevator. Plast Reconstr Surg 1994;93(07):1503–1504
11 Jakubietz RG, Jakubietz MG, Gruenert JG, Kloss DF. The 180-degree perforator-based propeller flap for soft tissue coverage of the distal, lower extremity: a new method to achieve reliable coverage of the distal lower extremity with a local, fasciocutaneous perforator flap. Ann Plast Surg 2007;59(06):667–671
12 Innocenti M, Menichini G, Baldrighi C, Delcroix L, Vignini L, Tos P. Are there risk factors for complications of perforator-based propeller flaps for lower-extremity reconstruction? Clin Orthop Relat Res 2014;472(07):2276–2286
13 Tos P, Innocenti M, Artiaco S, et al. Perforator-based propeller flaps treating loss of substance in the lower limb. J Orthop Traumatol 2011;12(02):93–99
14 Geddes CR, Morris SF, Neligan PC. Perforator flaps: evolution, classification, and applications. Ann Plast Surg 2003;50(01):90–99
15 Pignatti M, Pasqualini M, Governa M, Bruti M, Rigotti G. Propeller flaps for leg reconstruction. J Plast Reconstr Aesthet Surg 2008;61 (07):777–783
16 Nelson JA, Fischer JP, Brazio PS, Kovach SJ, Rosson GD, Rad AN. A review of propeller flaps for distal lower extremity soft tissue reconstruction: is flap loss too high? Microsurgery 2013;33(07):578–586
17 Seo SW, Kim KN, Yoon CS. Extended scope of the use of the peroneal perforator flap in lower limb reconstruction. J Reconstr Microsurg 2015;31(09):654–659
18 Bekara F, Herlin C, Mojallal A, et al. A systematic review and meta-analysis of perforator-pedicled propeller flaps in lower extremity defects: identification of risk factors for complications. Plast Reconstr Surg 2016;137(01):314–331
19 Gir P, Cheng A, Oni G, Mojallal A, Saint-Cyr M. Pedicled-perforator (propeller) flaps in lower extremity defects: a systematic review. J Reconstr Microsurg 2012;28(09):595–601
20 Paik JM, Pyon J-K. Risk factor analysis of freestyle propeller flaps. J Reconstr Microsurg 2017;33(01):26–31
21 Masia J, Moscatiello F, Pons G, Fernandez M, Lopez S, Serret P. Our experience in lower limb reconstruction with perforator flaps. Ann Plast Surg 2007;58(05):507–512

Achilles Region Soft-Tissue Defects: A Reconstructive Algorithm Based on a Series of 46 Cases

Marco Innocenti, MD[1] Alessandro Innocenti, MD[1] Serena Ghezzi, MD[1] Luca Delcroix, MD[1]

[1] Department of Plastic and Reconstructive Microsurgery, Careggi University Hospital, Florence, Italy

J Reconstr Microsurg 2017;33:S40–S47.

Address for correspondence Alessandro Innocenti, MD, Department of Plastic and Reconstructive Microsurgery, Careggi University Hospital, Viale Giacomo Matteotti 42, 50132 Firenze, Italia (e-mail: innocentialessandro@alice.it).

Abstract

Background Several options have been described for soft-tissue reconstruction in Achilles tendon region (ATR). The best procedure should be customized according to any single case taking into account the number of structures involved, the quality of the neighboring skin, and patient's general condition. The aim of this article is to describe a simplified reconstructive algorithm based on personal experience and reviewing literature.

Methods Forty-four patients, who underwent ATR soft-tissue reconstruction between 1998 and 2016, have been retrospectively reviewed. Etiologies of the defect include the following: 18 posttraumatic, 10 postoncologic, 14 dehiscence/infection, and 2 chronic ulcers. Follow-up ranges between 12 and 96 months. Free flaps have been used in 30 cases (including two secondary surgeries due to propeller flap failure) and propeller flaps have been used in 16 cases.

Results Thirty-six flaps survived uneventfully (78.3%). Total flap necrosis occurred in three cases (6.5%), namely, two propeller flaps and one free flap. Partial necrosis of the flap was observed in seven cases (15, 2%): three in the free flap group and four in the propeller group. The functional recovery was very good in all the patients without involvement of the tendon and also all the patients who underwent a simultaneous reconstruction of the tendon with different techniques recovered a full weight bearing and a satisfactory range of motion.

Conclusion Propeller flaps are a valuable option for skin reconstruction in case of defects of small and medium size not involving the tendon. In case of larger defects and when a simultaneous ATR reconstruction is required, a free flap seems to be a better option.

Keywords
- Achilles tendon reconstruction
- soft tissue
- algorithm

Achilles region contains several important anatomical entities. Among them, the Achilles tendon, the posterior tibial vessels, and the tibialis nerve have particular relevance in terms of function. At the same time, the Achilles region is often involved in trauma, infections, and tumors. Furthermore, it is a very visible area with a high cosmetic impact, particularly in females. Meticulous orthoplastic reconstruction is therefore the recommended approach in dealing with defects located in that area to provide the best functional and cosmetic results.[1] The number of tissues involved, the size of the defect, the etiology of the defect, and the overall condition of the affected extremity should guide the surgeon to choose the best and customized treatment for each patient. Upgrading in reconstructive microsurgery provided a wide

received
May 24, 2017
accepted after revision
August 2, 2017

DOI https://doi.org/10.1055/s-0037-1606554.
ISSN 0743-684X.

range of options which have been advocated by many authors; however, no specific algorithm based on a single-institution experience is available in the international literature. Although we feel that the experience of the surgeon maintains a primary role in decision making, we would like to share our retrospective evaluation of our outcomes according to a simplified algorithm which has been refined over the years.

Patients and Methods

Between 1998 and 2016, forty-four patients underwent vascularized soft-tissue reconstruction of the Achilles region. Only patients who required a vascularized tissue were included in this study, and those patients who were treated with advanced medication and/or skin graft were excluded. There were 29 males and 15 females ranging in age between 9 and 92 years (average: 50 males, 5 females). The etiologies of the defect were as follows: posttraumatic in 18 cases (40, 9%), postoncologic in 10 cases (22, 7%), dehiscence/infection in 14 cases (31, 8%) and chronic ulcers in 2 cases (4, 5%). The skin was involved in all cases (100%) and additional full-thickness tendon defect was recorded in 16 cases (36, 3%). In 30 cases (65, 2%), a free flap was used for reconstruction and a propeller flap in the remaining 16 cases (34, 78%). The length of tendon defect ranged between 4.5 cm and 15 cm. The skin defect ranged in size between 7 and 22 cm in length and 3 and 20 cm in width. All the patients underwent reconstruction either with a propeller flap or a free flap. In 30 patients, when only the skin had to be reconstructed, 10 anterolateral thigh (ALT) flaps, 3 latissimus dorsi flaps, 1 dorsalis pedis, and 16 propeller flaps were performed. In 16 cases (including two failed propeller flaps), a simultaneous reconstruction of skin and tendon was needed. A radial forearm flap with flexor carpi radialis was used in ten cases, an ALT flap with fascia lata in three cases, and a latissimus dorsi and tendon reconstruction with artificial tendon and fascia lata in three cases.

In case of tendon reconstruction using radial flap plus flexor carpi radialis (FCR), a gait analysis was performed to assess the functional outcome. A resistive pressure platform BTS P-Walk (BTS Engineering, Italy) embedded in the ground flush with the floor surface and collecting at 50 Hz was used to collect basic time–distance gait parameters during barefoot walking at a self-selected speed.[2,3] We used baropodometric acquisition of "mid-gait" protocol described by Meyers-Rice et al[4] in 1994, walking pace with a comfort. The resolution of this system is 1 sensor/cm^2, and the sensor area of the platform measures 1,920 mm $\times$ 480 mm, with a total of 9,216 sensors, and a pressure range of 30 to 400 kPa. Five trials were collected for both the left and right foot, a sufficient number of trials for the attainment of reliable within-session data as proposed by Hughes et al.[5]

All patients were given time to familiarize themselves with the process of walking over the platform. Patients were asked to not look at the platform as they walked but instead to walk "normally" and not to be concerned with the platform. If a patient obviously aimed at the platform and altered the gait pattern to ensure full contact, the trial was not included for further analysis.

We assessed at the first basic time–distance gait parameters: the stance phase, the time to heel off, and steps length. The time to heel off was normalized as a proportion of the stance phase to exclude increases in the ankle dorsiflexion range of motion (ROM) caused by speed. Step length of the gait cycle was normalized to the ipsilateral limb. All measurements were obtained following the method used by Titianova et al.[6] Each measurement is given as the average difference percentage between the injured side and the contralateral limb.

In seven out of the ten patients who underwent simultaneous reconstruction of the Achilles tendon using the radial forearm flap plus FCR tendon, magnetic resonance imaging (MRI) was taken at a follow-up longer than 1 year to study the quality of tendon reconstruction at medium term. Three patients were excluded because they had a follow-up shorter than 1 year.

To avoid bias, all the patients with bilateral involvement of Achilles region, or who underwent previous surgery at any joint of the lower limbs, were excluded. The follow-up ranges between 12 and 96 months. During the first year after surgery, all the patients have been followed by clinical examination and ultrasound investigation. In selected cases, among those patients who underwent simultaneous reconstruction of the Achilles tendon, MRI was taken and gait analysis was performed.

Reconstructive Algorithm

After an integration between the data available in the current literature and our personal clinical experience, we suggest the following algorithm to orientate in the soft-tissue reconstruction of the Achilles region taking into account the type of defect and the tissues involved (►**Fig. 1**).

Exposure of Subcutaneous Tissue up to Parthenon

After meticulous debridement and removal of nonviable and infected tissue, it is advisable to wait for a few days for a well-vascularized granulation tissue which is mandatory for taking of the skin graft.[1,7,8] During a period ranging between 7 and 15 days, several options are available to improve the granulation tissue which may also be used in association. Hyperbaric oxygen therapy showed improvement in the healing process reducing postoperative complications especially in patients with comorbidity such as diabetes.[9] Negative pressure dressing may help the healing process, providing a better cleaning of the wounds and promoting the proliferation of granulating tissue.[10,11] Advanced medications such as hyaluronic acid may promote secondary intention healing, even if long time is often required.[12] Skin graft is a reasonable option in many cases; however, the skin overlying the Achilles tendon is exposed to significant mechanical stress and the skin graft may not be enough.[13] An improvement in the quality of the grafted skin may be achieved using a dermal matrix for 10 days before grafting.

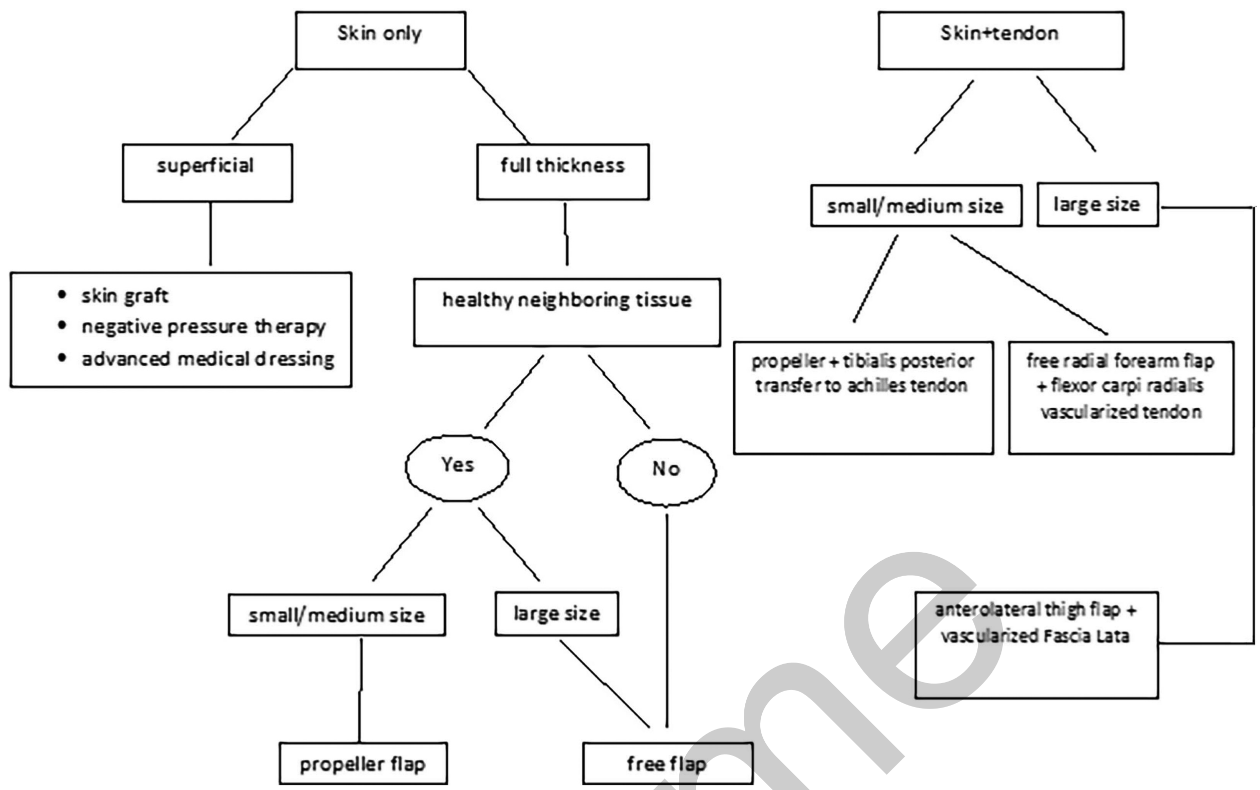


Fig. 1 Reconstructive algorithm of soft-tissue defects MRI of the Achilles region at 12 months of follow-up showing the two segments of flexor carpi radialis tendon reached in size of the original Achilles tendon.

This improves the thickness of the subcutaneous tissue and the resistance to shearing stresses.[14]

Exposure of the Achilles Tendon and/or Partial Necrosis of the Tendon

When the Achilles tendon is widely exposed and in case of partial necrosis, vascularized tissue needs to be used to cover the defect. The defect of the tendon, following debridement, is usually superficial and requires a simple suture of the parthenon, sometimes reinforced with the plantaris gracilis tendon (►**Fig. 2**). Nevertheless, a vascularized skin flap is mandatory and may be either a propeller flap or a free flap. In our opinion, the quality of the neighboring tissues and the dimension of the defect are the most important variables to

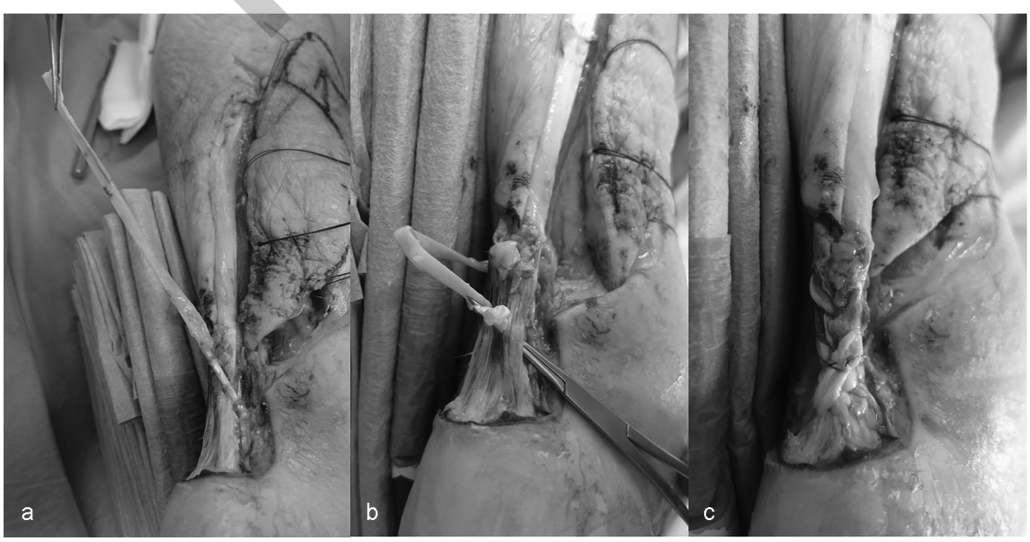


Fig. 2 In case of partial necrosis of Achilles tendon, conventional reconstruction with plantaris gracilis tendon may be easily performed. The plantaris tendon is severed at the junction with the muscle (**a**) and passed several times in the residual portion of Achilles tendon (**b**, **c**).

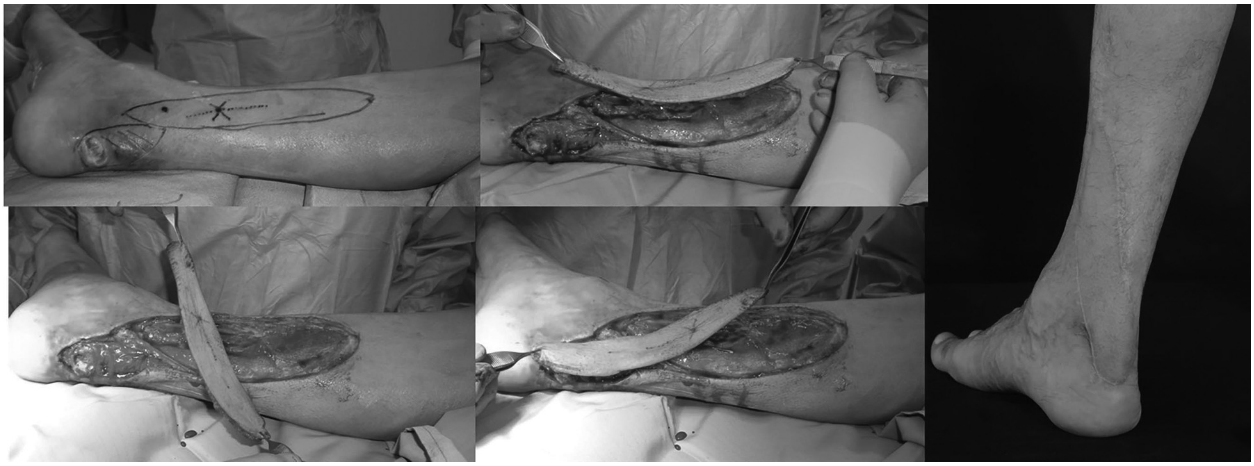


Fig. 3 Wound dehiscence after acute tendon rupture repair. The exposed tendon required only a superficial debridement, being otherwise healthy. A propeller flap 6 $\times$ 15 cm in size was raised on a perforator of the posterior tibial artery. The donor site was closed primarily and the flap survived uneventfully.

be considered in planning the reconstruction. We suggest a propeller flap, based either on the posterior tibial artery perforators (first choice) or on the peroneal artery perforators, in case of small/medium size defects in a leg otherwise healthy.[15] The calf is a good source of skin and for the earlier-mentioned dimension, the donor site may be closed directly in most of the cases (►**Fig. 3**). In case of larger defects and in case of inadequate neighboring skin, either edematous or poorly vascularized, a free flap may be a wiser choice. ALT flap is definitely a workhorse in the reconstruction of Achilles region for several reasons: large dimension, long and reliable pedicle, adjustable thickness, minimal donor-site morbidity, and possibility of spinal block anesthesia.[16] Posterior tibial artery, either end-to-end or end-to-side, is usually the preferred recipient vessel.

Massive Defect of Skin and Achilles Tendon

In case of small defects, it may be still possible to use propeller flaps. In that case, the Achilles tendon should be reconstructed with a tendon transfer, such as the tibialis posterior transfer, and simultaneously covered with a propeller flap.[17–19] In our opinion, however, a composite free flap is a safer option. Both radial forearm flap with FCR tendon and ALT flap with fascia lata are effective options when dealing with simultaneous reconstruction of skin and tendon.[7] The quality and the length of the incorporated FCR tendon is the major advantage of the radial flap. The drawbacks are the small dimension of the cutaneous paddle, a visible scar at the donor site, and the sacrifice of radial artery. ALT flap may reach considerable size and has a very low morbidity at the donor site. However, the reconstruction of the Achilles tendon with a tubular fascia lata flap cannot be as good as that achieved by a true tendon-like FCR.[20] Therefore, we suggest ALT flap in case of large skin defects and radial forearm flap in case of smaller skin defects and when a more reliable reconstruction of the tendon is needed.

Results

Thirty-six flaps survived uneventfully (78.3%). Complications were observed both in free flaps group and propeller flaps group. Total necrosis of the flap occurred in two propeller flaps and in one free flap (6.5%). A free flap was successfully performed after the failure of the two propeller flaps, while an amputation was required after the full-thickness necrosis of the free flap. Partial necrosis of the flap was observed in seven cases (15, 2%): three in the free flap group and four in the propeller group. All of them underwent secondary treatment which includes debridement and skin graft in one case, advanced medical dressing (alginate and Silver impregnated dressing) in five cases, and negative pressure therapy in one case.

Those patients who underwent Achilles tendon reconstruction by means of radial forearm flap plus FCR tendon

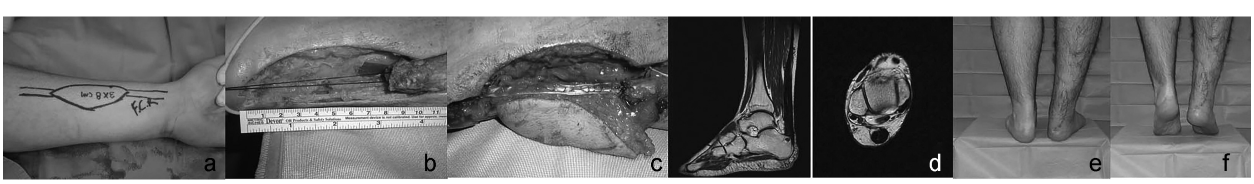


Fig. 4 Long-standing wound dehiscence with subsequent full-thickness necrosis of the Achilles tendon with a residual defect of 8 cm (**a**). A radial forearm flap including vascularized flexor carpi radialis tendon was harvested (**b**) and transferred to the recipient area (**c**). MRI taken 1 year postoperatively showed excellent reconstruction of the tendon in terms of dimension and density as demonstrated inT2-weighted sagittal and axial view (**d**). The functional recovery was full (**e**, **f**).

Fig. 5 The most frequent complication in propeller flap is a superficial necrosis of the distal tip of the flap, more often due to venous congestion. In this case, an excessive thinning (**a**, **b**, **c**) of the distal portion of the flap was probably responsible for a superficial necrosis (**d**) which healed with the help of vacuum-assisted closure (VAC) therapy (**e**).

with at least 1 year of follow-up were studied with MRI. In all cases, the reconstructed tendon showed density and size very similar to the contralateral side demonstrating a very satisfactory reconstruction (►**Fig. 4a**–**f**). In all cases, the gait analysis showed a nearly total recovery of the function of the ankle joint and the foot.[7] The average difference percentage between the injured side and contralateral limb in passive ankle dorsiflexion was 5.41 (range: 3.14–6.72) with the knee extended and 6.32 (range: 5.88–6.92) with the knee flexed. These differences were equivalent to less than 4 degrees of ROM. The recovery of a nearly normal ROM helped to achieve a more symmetrical stance phase, time to heel off, and step length of the gait. The average difference percentage between limbs at a minimum FU of 12 months after surgery was only 3.87 (range: 2.1–5.01) in stance phase, 3.92 (range: 2.74–5.11) in time to heel off, and 5.27 (range: 4.57–6.05) in step length.

Discussion

In approaching the reconstruction of this anatomical district, the first goal should be to restore or preserve the function of the Achilles tendon. Then a stable and resistant skin coverage should be provided to respond properly to the mechanical stress typical of this area.[21] Many different reconstructive options have been described in the past and some of them still maintain some role in selected cases.[22–30] However, in our opinion, muscle flaps and myocutaneous flaps should be considered only in case of total ankle fusion, particularly in case of infection and need to obliterate a dead space. They are definitely not the best choice to cover Achilles tendon because of bulky and prone to adhesion with the underlying tendon. Also conventional local fasciocutaneous flaps such as the sural flap have narrow indications in the era of propeller flaps and should be chosen only as salvage procedure.

On the other hand, propeller flaps proved to be a very useful addition to the reconstructive toolbox and gained increasing diffusion in recent years.[17,31,32] The propeller concept increased the number of potential donor sites particularly in those anatomical districts, such as the Achilles region, where conventional pedicled flaps are not feasible because they do not have enough arch of rotation. Propeller flaps allow for reconstruction "like with like" and present a very low morbidity at the donor site; in addition, they are relatively fast procedures and can be done in peripheral anesthesia. As a drawback, although total necrosis of the flap is unusual, they suffer a high percentage of minor complications such as venous congestion, epidermolysis, and superficial necrosis (►**Fig. 5a**–**e**). In a previous review of our clinical series of propeller flaps in lower limb reconstruction analyzing risk factors and related complications, we found that the arch of rotation and the dimension of the flap did not have a statistically relevant impact on complications and we concluded that a nonadequate dissection of the perforator may be one of the reasons for complications.[15] Of paramount importance is also the quality of the soft tissue of the affected extremity and we discourage the use of propeller flaps in case of edematous and poorly vascularized skin. In the first circumstance, the dissection may be difficult due to the imbibition of the subcutaneous tissue and primary closure of the donor site is almost always impossible without excessive tension. In the second, even in the presence of a healthy and sizable perforator, the skin paddle may result poorly vascularized, increasing significantly the failure rate (►**Fig. 6a**–**f**).

Free flaps have been advocated to be the first choice in case of reconstruction of soft-tissue defects located in the

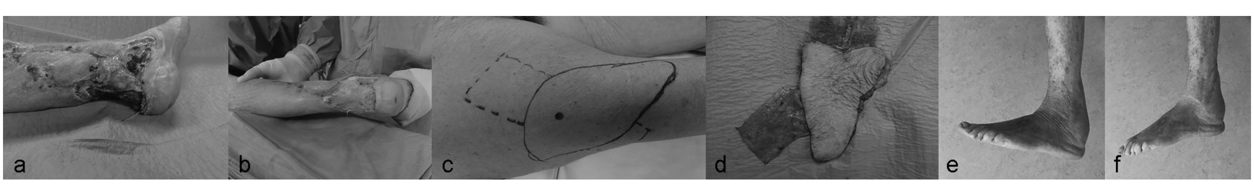


Fig. 6 Failure of previous propeller flap in a 82-year-old patient. Despite the healthy looking of the chosen perforator raising from the posterior tibial artery, the skin resulted to be extremely thin and fragile. In a few days, an extensive skin necrosis involving also the neighboring skin developed (**a**). After thoughtful debridement (**b**), a large ALT flap including the fascia lata was harvested from the contralateral thigh for skin and tendon reconstruction (**c**, **d**). Acceptable function was recovered 4 months after surgery (**e**, **f**).

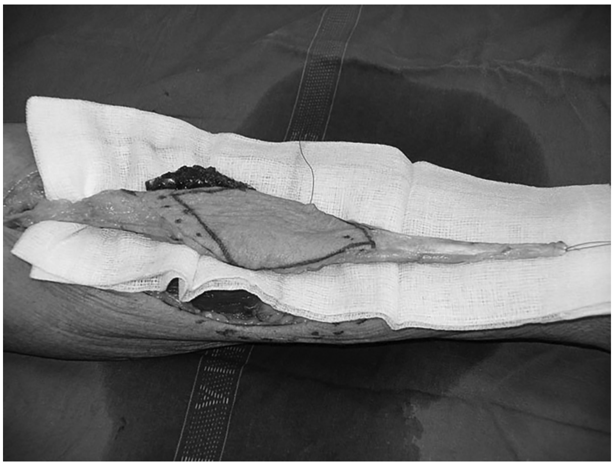


Fig. 7 The flexor carpi radialis tendon incorporated in a radial forearm flap provides up to 12 cm vascularized tendon graft.

distal anatomical districts of the leg. There is no doubt that a distant free tissue transfer is the best option in case of large defects, infections, and bad quality of the skin around the defect. A strong indication to free flaps is the need of simultaneous reconstruction of skin and Achilles tendon. Actually, few procedures have been described for composite reconstruction using regional flaps. And most of the reports are case reports or short series. Wei et al[31] reported satisfactory results using a composite perforator flap based on the ipsilateral posterior tibial artery in three cases. Similar results were reported by Zheng et al[33] using a peroneus brevis transfer and sural flap in 10 cases. Cavadas and Landin in 2003[34] described the posterior tibial perforator-saphenous subcutaneous flap for one-stage reconstruction of skin and tendon. Although this procedure is relatively simple and straightforward, the author limits the indication to small defects and discloses some complications mainly related to the taking of the skin graft. In our opinion, all the procedures based on the simultaneous harvest of skin and tendon from the ipsilateral extremity should be preferred only in selected cases of small defects, in patients with moderate functional requests.

In our experience, actually, local flaps have few indications in massive defects of the Achilles tendon, while radial forearm flap with FCR tendon (►**Fig. 7**) and ALT flap with fascia lata resulted to be effective and reliable surgical options to reconstruct multiple tissue defects in one stage. Our preference is for the radial forearm flap plus vascularized FCR which, in our hands, allowed to achieve 100% of good and excellent results in a population of 10 patients. The quality of the tendon, which is well supplied by the radial artery,[21] is the major advantage of this option and the possibility to achieve a very stable connection with the calcaneus bone significantly improves the effectiveness of this procedure (►**Fig. 8**).

When the skin defect is large, an ALT flap plus fascia lata may be a better option.[16,21,25,35] Although there are no limits in the dimension of the flap, it may be bulky and therefore we suggest to defat the flap to the desired thickness and separate the fascia from the skin to suture it in a tubular fashion to reconstruct the Achilles tendon and simultaneously guarantee an acceptable gliding plane between the skin and the tendon. Although this procedure is well established and suggested by many authors as the first choice, in our opinion tendon reconstruction by fascia lata cannot be as good as that provided by a true tendon. There are some concerns about the quality of the blood supply to the fascia lata after splitting from the overlying skin, and, particularly, in case of distal bone insertion the reconstruction cannot be as stable as that achieved by rerouting a sizable tendon in a bony tunnel.

Conclusion

The optimal surgical procedure should be planned according to the type and size of the defect and the general conditions of the patients. Meticulous debridement of the lesion is a prerequisite for any successful reconstruction,

Fig. 8 In case of distal reconstruction of the Achilles tendon, a tunnel is drilled in the calcaneus bone (**a**) and the FCR tendon is driven inside the tunnel (**b**) providing a very reliable distal insertion. Total recovery of function 1 year postoperatively (**c**).

independently from its complexity. Vascularized tissue transfer is the gold standard in case of tendon exposure and, even more, in case of full-thickness necrosis of the tendon. Propeller flaps are a fast and effective procedure but present a high percentage of minor complications and are not indicated in case of large defects and poor quality of the skin of the calf. Moreover, in case of tendon defect, there is the need for conventional tendon reconstruction (tendon transfer, allograft, prosthesis) which is not always feasible due to potential contamination of the recipient site. Free flaps, either simple or composite, are definitely more versatile and they should be the first choice in case of large defects and when the Achilles tendon should be simultaneously repaired.

Disclosure

The authors have no financial interest to declare in relation to the content of this article.

Conflict of Interest

None.

References

1 Langer V. Management of major limb injuries. Sci World J 2014; 2014:640430
2 Hayafune N, Hayafune Y, Jacob HAC. Pressure and force distribution characteristics under the normal foot during the push-off phase in gait. The Foot 1999;9:88–92
3 Murphy DF, Beynnon BD, Michelson JD, Vacek PM. Efficacy of plantar loading parameters during gait in terms of reliability, variability, effect of gender and relationship between contact area and plantar pressure. Foot Ankle Int 2005;26(02):171–179
4 Meyers-Rice B, Sugars L, McPoil T, Cornwall MW. Comparison of three methods for obtaining plantar pressures in nonpathologic subjects. J Am Podiatr Med Assoc 1994;84(10):499–504
5 Hughes J, Pratt L, Linge K, Clark P, Klenerman L. Reliability of pressure measurements: the EM ED F system. Clin Biomech (Bristol, Avon) 1991;6(01):14–18
6 Titianova EB, Mateev PS, Tarkka IM. Footprint analysis of gait using a pressure sensor system. J Electromyogr Kinesiol 2004; 14(02):275–281
7 Innocenti M, Tani M, Carulli C, Ghezzi S, Raspanti A, Menichini G. Radial forearm flap plus flexor carpi radialis tendon in Achilles tendon reconstruction: surgical technique, functional results, and gait analysis. Microsurgery 2015;35(08):608–614
8 Hallock GG. Evidence based medicine: lower extremity acute trauma. Plast Reconstr Surg 2013;132:1733–1741
9 Gehmert S, Geis S, Lamby P, et al. Evaluation of hyperbaric oxygen therapy for free flaps using planar optical oxygen sensors. Preliminary results. Clin Hemorheol Microcirc 2011;48(01):75–79
10 Repta R, Ford R, Hoberman L, Rechner B. The use of negative-pressure therapy and skin grafting in the treatment of soft-tissue defects over the Achilles tendon. Ann Plast Surg 2005;55(04): 367–370
11 Stannard JP, Volgas DA, McGwin G III, Steward RL, Obremskey W, Moore T. Incisional negative pressure wound therapy after high risk lower extremity fractures. J Orthop Trauma 2012;26:3742
12 Vaienti L, Marchesi A, Palitta G, Gazzola R, Parodi PC, Leone F. Limb trauma: the use of an advanced wound care device in the treatment of full-thickness wounds. Strateg Trauma Limb Reconstr 2013;8(02):111–115
13 Attinger CE, Ducic I, Hess CL, Basil A, Abruzzese M, Cooper P. Outcome of skin graft versus flap surgery in the salvage of the exposed Achilles tendon in diabetics versus nondiabetics. Plast Reconstr Surg 2006;117(07):2460–2467
14 Marchesi A, Brioschi M, Parodi PC, Marchesi M, Brambilla R, Vaienti L. Allogeneic epidermal substitutes in the treatment of chronic diabetic leg and foot ulcers. Plast Aesthet Res 2014;1:74–80
15 Innocenti M, Menichini G, Baldrighi C, Delcroix L, Vignini L, Tos P. Are there risk factors for complications of perforator-based propeller flaps for lower-extremity reconstruction? Clin Orthop Relat Res 2014;472(07):2276–2286
16 Lee JW, Yu JC, Shieh SJ, Liu C, Pai JJ. Reconstruction of the Achilles tendon and overlying soft tissue using antero-lateral thigh free flap. Br J Plast Surg 2000;53(07):574–577
17 Jiga LP, Barac S, Taranu G, et al. The versatility of propeller flaps for lower limb reconstruction in patients with peripheral arterial obstructive disease: initial experience. Ann Plast Surg 2010; 64(02):193–197
18 Ignatiadis IA, Georgakopoulos GD, Tsiampa VA, Polyzois VD, Arapoglou DK, Papalois AE. Distal posterior tibial artery perforator flaps for the management of calcaneal and Achilles tendon injuries in diabetic and non-diabetic patients. Diabet Foot Ankle 2011;2:2
19 Vaienti L, Calori GM, Leone F, Brioschi M, Parodi PC, Marchesi A. Posterior tibial artery perforator flaps for coverage of Achilles region defects. Injury 2014;45(Suppl 6):S133–S137
20 Raspanti A, Delcroix L, Ghezzi S, Innocenti M. Study of the tendinous vascularization for the compound radial forearm flap plus flexor carpi radialis tendon. Surg Radiol Anat 2016;38(04): 409–414
21 Houtmeyers P, Opsomer D, Van Landuyt K, Monstrey S. Reconstruction of the Achilles tendon and overlying soft tissue by free composite anterolateral thigh flap with vascularized fascia lata. J Reconstr Microsurg 2012;28(03):205–209
22 Smit JM, Darcy CM, Audolfsson T, Hartman EH, Acosta R. Multilayer reconstructions for defects overlying the Achilles tendon with the lateral-arm flap: long-term follow-up of 16 cases. Microsurgery 2012;32(06):438–444
23 Kim CH, Tark MS, Choi CY, Kang SG, Kim YB. A single-stage reconstruction of a complex Achilles wound with modified free composite lateral arm flap. J Reconstr Microsurg 2008;24(02): 127–130
24 Huemer GM, Larcher L, Schoeller T, Bauer T. The free gracilis muscle flap in Achilles tendon coverage and reconstruction. Plast Reconstr Surg 2012;129(04):910–919
25 Kuo YR, Kuo MH, Chou WC, Liu YT, Lutz BS, Jeng SF. One-stage reconstruction of soft tissue and Achilles tendon defects using a composite free anterolateral thigh flap with vascularized fascia lata: clinical experience and functional assessment. Ann Plast Surg 2003;50(02):149–155
26 Michel G, Ho Quoc C, Assaf N, Delay E, Sinna R. Dynamic reconstruction of Achilles tendon by free composite perforator flap with functional assessment [in French]. Ann Chir Plast Esthet 2015;60(01):78–83
27 Dabernig J, Shilov B, Schumacher O, Lenz C, Dabernig W, Schaff J. Functional reconstruction of Achilles tendon defects combined with overlaying skin defects using a free tensor fasciae latae flap. J Plast Reconstr Aesthet Surg 2006;59(02):142–147
28 DeFazio MV, Han KD, Evans KK. Functional reconstruction of a combined tendocutaneous defect of the Achilles using a segmental rectus femoris myofascial construct: a viable alternative. Arch Plast Surg 2014;41(03):285–289
29 Stamate T, Budurcă AR, Tamaş C, Lazăr AN. A free microsurgical transfer of a radial (Chinese) flap in reconstructing the lower limb [in Romanian]. Rev Med Chir Soc Med Nat Iasi 1998;102(3-4): 161–166
30 Coşkunol E, Ozdemir O, Ozalp T. Free radial forearm flap transfer for the reconstruction of the Achilles tendon and soft tissue defect: a case report [in Turkish]. Ulus Travma Acil Cerrahi Derg 2005;11(03):258–262

31 Wei ZR, Sun GF, Wang DL, Tang XJ. Reconstruction of the Achilles tendon and overlying skin defect: 3 case reports. Ann Plast Surg 2014;73(03):325–329
32 D'Arpa S, Toia F, Pirrello R, Moschella F, Cordova A. Propeller flaps: a review of indications, technique, and results. BioMed Res Int 2014;20(14):7
33 Zheng L, Zhang XS, Dong ZG, Liu LH, Wei JW. One-staged reconstruction of Achilles tendon and overlying skin defects with suppuration: using peroneus brevis tendon transfer and reversed sural neurofasciocutaneous flap. Arch Orthop Trauma Surg 2011; 131(09):1267–1272
34 Cavadas PC, Landin L. Reconstruction of chronic Achilles tendon defects with posterior tibial perforator flap and soleus tendon graft: clinical series. Plast Reconstr Surg 2006;117(01):266–271
35 Marchesi A, Parodi PC, Brioschi M, et al. Soft-tissue defects of the Achilles tendon region: Management and reconstructive ladder. Review of the literature. Injury 2016;47(Suppl 4): S147–S153

The Propeller Concept Applied to Free Flaps and the Proposal of a "Clock Flap" Nomenclature

Andrea Antonini, MD[1] Carlo Rossello, MD[2] Carlo Salomone, MD[1] Giuliana Carrega, MD[1] Lamberto Felli[3] Giorgio Burastero, MD[1]

[1] MIOS, Infectious Diseases and Septic Orthopaedics, S. Maria di Misericordia Hospital, Albenga, ASL2 Savonese, Savona, Italia
[2] Hand Surgery Unit, ASL2 Savonese, Savona, Italy
[3] Orthopaedic Clinic, IRCCS, S. Martino Hospital, Genova, Italia

Address for correspondence Andrea Antonini, MD, MIOS, Infectious Diseases and Septic Orthopaedics, S. Maria di Misericordia Hospital, Ospedale SMdM, via martiri della Foce, 40, 17131, Albenga, Savona, Italia (e-mail: aantoninimd@gmail.com).

J Reconstr Microsurg 2017;33:S48–S52.

Abstract

Background It is a common experience for reconstructive surgeons to feel the necessity for large flaps and minimal donor-site morbidity at the same time. In the reported cases where we felt this call intraoperatively, we have met our need by applying the "propeller concept" to fasciocutaneous or composite flaps, separating and rotating its different tissue components.

Methods We present a series of five cases in which we separated and rotated diversely fascial and cutaneous components of free perforator flaps to enhance the extension of the flap or to tailor it better on the tissue gap for optimal functional and aesthetic results. We also propose a simple nomenclature system for rotation angles' definition, summarized as the "clock flap" classification, where the different components of the flap represent the arms of a clock which has the main vessel axis on the 12–6 line.

Results All reconstructive procedures succeeded with only minor complications. No partial failure due to vessel rotations was noticed.

Conclusion Applying "propeller style" rotations to different components of free flaps seems to be a safe procedure which may help maximize flap performance in terms of coverage of the recipient site, while minimizing scars and impairment of the donor site. Also, the proposed nomenclature gives the opportunity to record and compare surgical procedures for statistical analysis.

Keywords
- free flap
- propeller
- clock flap

The ideal free flap for soft tissue reconstructions should be reliable, potentially large in size, extremely adaptable to defect shape, and its harvest should cause as little donor-site morbidity as possible, both under a functional and aesthetic point of view.

Fasciocutaneous perforator flaps used as free tissue transfers are often smaller in size and much less moldable if compared with muscle flaps, especially if the aim is to achieve primary closure of the donor site. At the same time, the literature[1–7] and surgical experience on propeller flaps shows how these local flaps may be elevated both on a subfascial and suprafascial planes, with no significant difference on survival rates.

We therefore applied the "propeller concept" to our free flaps by splitting skin from deep tissues and rotating the tissues on the perforator axis, to meet the defect shape, size, and the need for movement in articular areas.

Materials and Methods

We report a series of five cases performed in our department from 2011 to 2014. In these procedures, the area to be covered turned to be larger and/or different in shape in respect to the fasciocutaneous paddles that had been harvested.

The patients were four males and one female, age range from 36 to 46 years. We therefore intraoperatively decided to

received
May 23, 2017
accepted after revision
July 11, 2017

DOI https://doi.org/10.1055/s-0037-1606269.
ISSN 0743-684X.

improve the flaps' congruity with the defects by applying the "propeller concept" to the flaps once they were revascularized in the recipient site.

In each case, different portions or components of the flap had to be diversely rotated on the vascular axes to obtain effective soft tissue reconstructions. Four flaps were fasciocutaneous anterolateral thigh (ALT) flaps, and one was an osteocutaneous fibula flap. They were all employed for delayed lower limb reconstructions after trauma and secondary infection.

We also propose a simple nomenclature for this technique which can be summarized as the "clock flap" procedure, where the vascular pedicle axis, or its tangent—if the pedicled is laid along a curved line, defines the 12–6 clock orientation, the deep tissue position is expressed as the hours' arm value, while the superficial tissue axis will define the minutes in the clock's time (see ►**Fig. 1**). The deep tissue may be bone muscle or fascia, while the superficial part will mainly be the skin paddle, but the classification can be applied to different kinds of composite flaps.

The deep tissue will be usually laid in the 6 hours' position to minimize pedicle rotations, but in some cases, it may be necessary to apply some degrees of twisting to the deepest perforator segment as well. This nomenclature allows a 15-degree maximum approximation by considering only full hours and 5-minute intervals in clock arm movements.

In two of the five cases, we only needed to cover an area that was slightly larger than the fasciocutaneous island, and therefore, separated the skin from the fascia up to the perforator until we were able to safely rotate the skin paddle and the fascia from the vascular axis, as already described for the combined latissimus dorsi and thoracodorsal artery perforator flap or "razor flap"[8] and for the "gastrocnemius-propeller extended flap."[9]

In these two straightforward cases, the "clock" flap rotations would be defined as follows:

- A 30 × 10 cm fasciocutaneous ALT flap for a 20-cm ipsilateral fibulaprotibia transfer for acute posttraumatic osteomyelitis rotated in a 4:30 clock style (►**Fig. 2**).

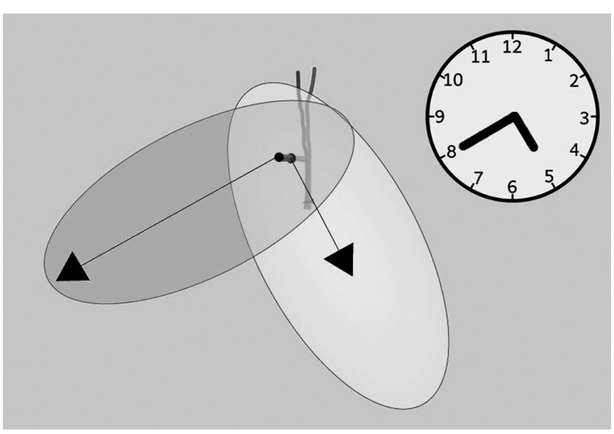


Fig. 1 Illustration of the clock flap concept, showing clock orientation on the main vessel axis, fascia rotation 30 degrees counterclockwise on the 5 hours' position and skin paddle rotation 60 degrees clockwise on the 40 minutes' position.

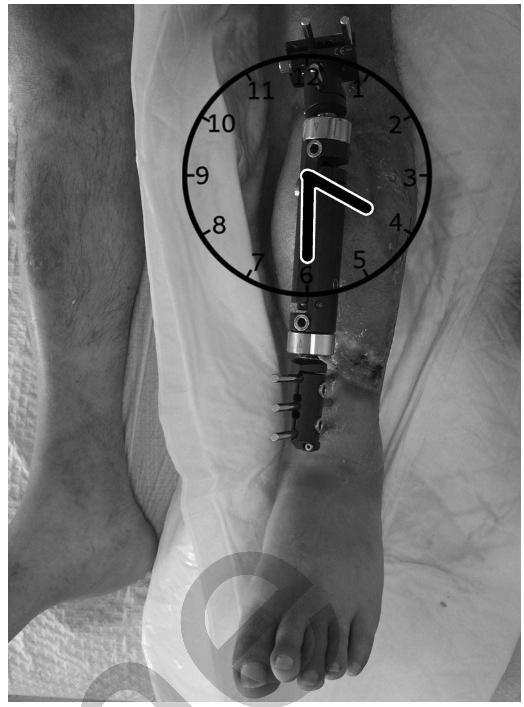


Fig. 2 A 5:40 fasciocutaneous clock flap: the clock axis along the vessel in the anterior compartment (see text), the hours' arm toward the grafted fascia on the 4 hours' position, and the minutes' arm along the vessels' axis, therefore pointing 4:30. Notice the distal tip superficial necrosis.

- A 22 × 8 cm fasciocutaneous ALT flap for the coverage of an exposed patella and patellar tendon rotated in a 6:20 clock style (►**Fig. 3**).

The reason for not keeping the vascular pedicle on the 6:00 axis in case 1 (as would seem the most logical option to minimize overall rotations) was that we preferred to lay the vessels deep inside the anterior compartment of the leg, where the anastomosis to the anterior tibial vessels was performed, to avoid vessel compression due to skin paddle and skin graft traction.

In both cases, the fascial component was covered with split-thickness skin grafts from the medial contralateral or ipsilateral thigh.

The other two ALT flaps were used for bilateral coverage of the ankle, and therefore, the fasciocutaneous paddle was split based on two different perforators, passing the distal one in the space between the Achilles' tendon and the distal tibia. In one of these cases, after a terminolateral anastomosis of the lateral circumflex femoral artery (LCFA) to the posterior tibial artery in its middle third, the proximal paddle had to cover the medial face of the tibia (and a 7-cm resection of an infected fracture); therefore, the distal island was rotated of 180 degrees along the axis of the LCFA descending branch to reach the lateral submalleolar region and then approximately 60 degrees counterclockwise on the perforator axis to fit with its triangular shape the loss of substance, which can be summarized in a 6:20 clock style rotation of the distal skin paddle. The fascia corresponding to the distal skin paddle was kept on the 6:00 axis because its distal tip was used to

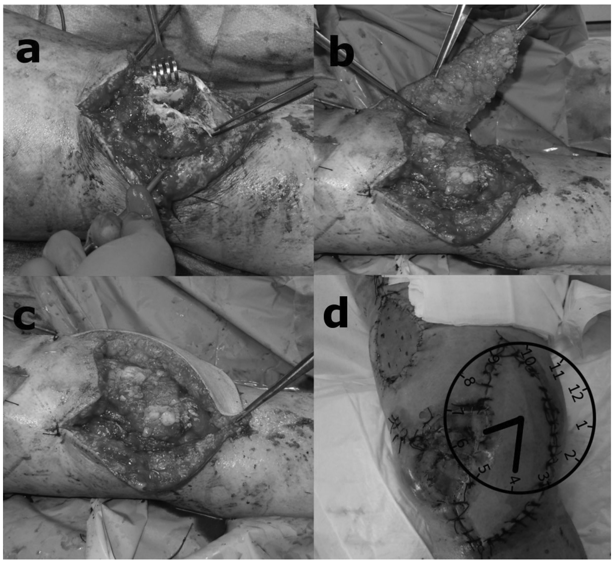


Fig. 3 **(a)** Knee wound after debridement and partial patellectomy for infected necrosis. **(b)** The ipsilateral ALT flap already revascularized on the medial genicular artery and its fascial and cutaneous components split on the superficial fascia layer up to the subcutaneous perforator. Fascia will need to cover the remaining patellar bone. **(c)** The skin paddle rotated on the perforator to cover the patellar tendon and allow knee flexion. **(d)** Donor site and flap fascia grafted with split-thickness skin grafts, and the application of the clock flap concept to the procedure. ALT, anterolateral thigh.

reinforce the calcaneal insertion of the Achilles' tendon; therefore, the cutaneous portion had to be rotated separately to fit the skin gap.

The other case was a separate coverage of both malleoli after an infected exposed bimalleolar fracture. In this case, after an end-to-end anastomosis to the anterior tibial artery, the skin was split into two different islands corresponding to two different perforators harvested, while the fascia was kept in continuity in between the two distinct perforators and tunneled in the space between the distal tibia and the Achilles' tendon. The distal skin island was then rotated 60 degrees counterclockwise on a suprafascial plane to best fit the defect on the medial malleolus. The distal skin paddle was therefore also rotated in a 6:20 clock style.

The last case was a composite reconstruction of a post-traumatic infected loss of substance of the first metatarsal and dorsomedial soft tissues of the left midfoot. We harvested an osteocutaneous fibula flap from the right leg with an 18 cm × 6 cm skin paddle based on two different septal perforators. After an end-to-end anastomosis with the anterior tibial artery above the extensor retinaculum (level of traumatic vessel interruption) the 2.8-cm fibula segment was used to reconstruct the first metatarsal diaphysis along the same vascular axis. The skin paddle was unsuitable for size and orientation for direct closure of the entire soft tissue loss. It was, therefore, split into two islands based on the two different perforators. The proximal island received a 180-degree propeller rotation along the perforator axis to fill the soft tissue gap of the foot dorsum, while the distal island only needed a 90-degree rotation to cover the medial aspect of the midfoot (►**Figs. 4** and **5**). It could be therefore summarized, being the bone the flap's deep portion, as a "6:55, 6:15 double paddle osteocutaneous fibula clock flap."

All splittings and rotations were performed after flap revascularization, positive patency tests, and evaluation of physiological perfusion of the entire skin paddle.

Results

All microvascular flaps survived. In one case (the split ALT flap for bimalleolar coverage), we had an early postoperative venous congestion with a thrombosis due to kinking of the main pedicle vein, just distal to the site of anastomosis, in the

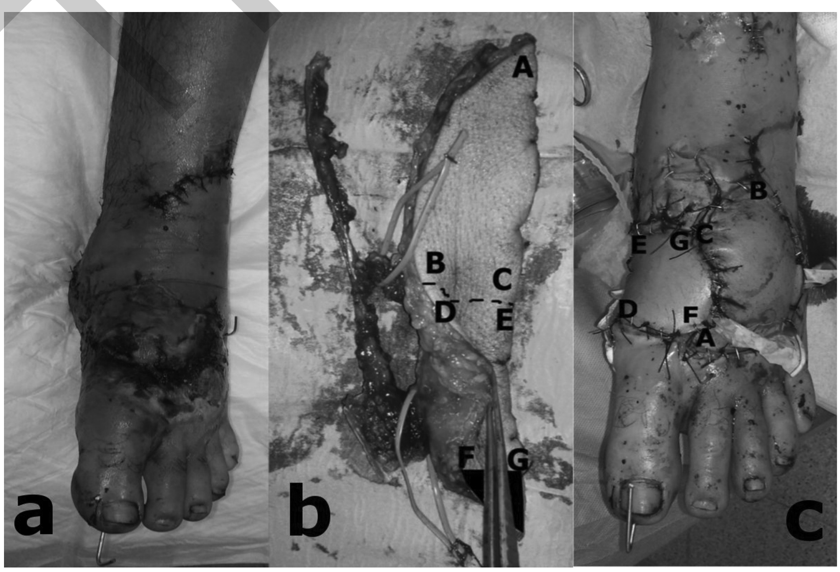


Fig. 4 **(a)** Soft tissue necrosis overlying a first metatarsal bone gap after motorcycle trauma. **(b)** A harvested osteocutaneous fibula flap, showing the way in which it will be split into two different paddles based on the two perforators and corners marked with letters for better comprehension (distal tip excised). **(c)** Flap after insetting. The two islands have been rotated to fill the soft tissue gap in the best possible way. A–G mark the corners of the two skin paddles.

Fig. 5 The final result of the case 1 year after the procedure. **(a)** Final donor site and reconstructed foot appearance with no secondary surgery. **(b)** X-rays showing the underlying effective bone reconstruction, preserving the metatarsal formula and foot morphology.

pedicle segment proximal to any rotation site, and therefore, not attributable to the vessel rotations. Anastomosis was revised and thrombus removed within 20 hours from the primary procedure with complete flap salvage.

In another case (the 4:30 ALT clock flap), we had a superficial necrosis of the distal tip (2.5 cm) of the 30-cm long skin paddle (►**Fig. 2**), without any exposure of deep structures, and complete secondary healing with no need for further surgical treatment. This minor complication might be due to the separation of the two components of the flaps, and we admit that maintaining the fasciocutaneous connections between the plexuses could have improved the skin survival, but we also know that 30 cm is about the maximum allowed length for an ALT flap harvested on a single proximal perforator.

All other flaps had uneventful postoperative healing. Three ALT flap donor sites out of four were closed primarily (►**Fig. 6**), the ipsilateral ALT for knee coverage donor site was grafted to avoid skin traction proximally to the anastomotic site which could affect venous hemodynamics, but eventually all grafted areas were excised concomitantly to a femoral nail removal 8 months after the primary procedure (►**Fig. 7a**). The fibula donor site was grafted (►**Fig. 5a**).

Skin grafts on fascial components had normal healing behavior (revascularization by neoangiogenesis visible after 6 days, 70–95% survival rates, and complete re-epithelialization of grafted area in 3–5 weeks).

Discussion

This technique gave us the possibility to enhance the area a harvested flap could cover or helping our skin paddles fit the defects without traction, excessive bulkiness or unaesthetic wrinkles due to incongruence between flap and recipient site margins, without jeopardizing flap vitality nor needing to add donor-site scarring.

Of the two minor complications reported, only one (the superficial necrosis of the distal tip of the skin paddle) could be in relation to the surgical technique proposed, on the basis of a physiopathological reasoning. In our experience, though,

Fig. 6 The donor site of the largest ALT flap described in this article (30×10 cm), 3 months after primary closure. ALT, anterolateral thigh.

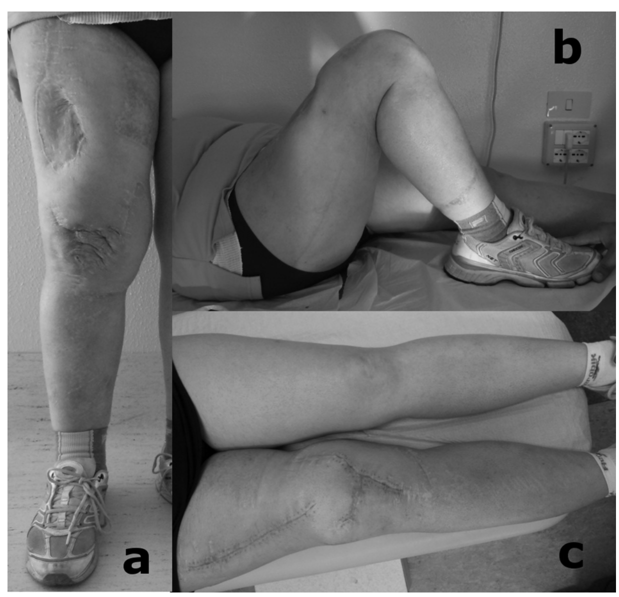


Fig. 7 The final result of case in ►**Fig. 3**. **(a)** Result 5 months postoperatively with skin grafts on donor site and on fascial component of the flap. **(b)** Good knee ROM thanks to flap enhancement applying the "clock flap" technique. **(c)** Final result after the excision of grafted areas 8 months after the flap procedure, while removing a femoral nail. ROM, range of motion.

superficial skin necrosis on the tip of a 30-cm long ALT flap with a single proximal perforator is a possible complication for the "traditional" fasciocutaneous flap as well.

This technique, hereby described as an intraoperative means to enhance a flap's covering potential, is in our opinion to be kept in mind for cases where final debridement leads to a tissue gap larger than expected, or when the skin paddle shape does not perfectly fit the loss of substance, as for the cases described in this article.

Of course, it may also be implemented as a preoperative decision, but in this case, it will have to be evaluated in comparison with other techniques.

Preexpansion of skin flaps, for example, may be a good solution to cover large defects or to be tailored to fit a peculiar shape, but it is not always compatible with reconstructive timing necessities, especially when dealing with trauma and infection as in our everyday practice. An alternative to the clock flap technique, of course, is the use of larger flaps, tailored, and customized to the defect, such as the deep inferior epigastric artery perforator flap,[10] which can provide a large amount of cutaneous tissue with a very acceptable scar.

The kiss flap technique[11] is, instead, the most direct competitor to the clock flap procedure, since it may be planned intraoperatively as well as before the procedure. Advantages of the clock flap technique are the dissection of one single pedicle (instead of multiple pedicles for the different "kissing" flaps) and the possibility to have one single donor site and linear scar. Disadvantages, instead, are the frequent need for skin grafting over fascial or muscle components (and the related graft donor-site morbidity), as well as the necessity of a more meticulous, careful and dangerous dissection of the pedicle inside the flap area which probably requires a more experienced and confident microsurgeon.

Our technique is yet one more option for surgeons coping with irregular or large soft tissue defects because it offers the opportunity to enhance the fasciocutaneous flap's reach for large areas reducing the need for larger flaps and allows to mold the skin and fascia paddles to the best possible shape, leading to a better functional and aesthetic result of both donor and recipient sites.

Our proposal for a new nomenclature aims to offer surgeons and scientists the possibility to evaluate success rates and compare complications on the basis of rotation angles of the free flaps' components. We believe the application of the clock arms' parallelism to flap paddle components may be a synthetic and easily understandable way to define the operative technique which may be useful to colleagues having to cope with early microvascular complications in such complex procedures, as well as to surgeons trying to classify their flaps for statistical analysis, as many authors are already doing with pedicled propeller flap case series, trying to formulate standard rules to minimize vascular complications.[7,12–16]

Conclusion

In our opinion, based on the small experience reported, perforator flaps may be considered structurally the same, no matter whether they are used as local flaps or they are transferred as free flaps. This means they can be split according to angiosomes of the donor site into different islands based on different perforators, and even separated into fascial and cutaneous components based on a single perforator, relying on the different plexuses (dermal/fascial) that perfuse the two different layers.

Of course, more cases and better experience are mandatory to validate the hereby proposed technique.

Conflict of Interest
None.

References

1 Teo TC. The propeller flap concept. Clin Plast Surg 2010;37(04):615–626, vi

2 Tos P, Innocenti M, Artiaco S, et al. Perforator-based propeller flaps treating loss of substance in the lower limb. J Orthop Traumatol 2011;12(02):93–99

3 Bravo FG, Schwarze HP. Free-style local perforator flaps: concept and classification system. J Plast Reconstr Aesthet Surg 2009;62(05):602–608, discussion 609

4 Cadenelli P, Bordoni D, Radaelli S, Marchesi A. Proximally based anterolateral-thigh (ALT) flap for knee reconstruction: an advancement propeller perforator flap. Aesthetic Plast Surg 2015;39(05):752–756

5 Artiaco S, Battiston B, Colzani G, et al. Perforator based propeller flaps in limb reconstructive surgery: clinical application and literature review. BioMed Res Int 2014;2014:690649

6 D'Arpa S, Toia F, Pirrello R, Moschella F, Cordova A. Propeller flaps: a review of indications, technique, and results. BioMed Res Int 2014;2014:986829

7 D'Arpa S, Cordova A, Pignatti M, Moschella F. Freestyle pedicled perforator flaps: safety, prevention of complications, and management based on 85 consecutive cases. Plast Reconstr Surg 2011;128(04):892–906

8 Cavadas PC, Teran-Saavedra PP. Combined latissimus dorsi-thoracodorsal artery perforator free flap: the "razor flap". J Reconstr Microsurg 2002;18(01):29–31

9 Innocenti M, Cardin-Langlois E, Menichini G, Baldrighi C. Gastrocnaemius-propeller extended miocutanous flap: a new chimaeric flap for soft tissue reconstruction of the knee. J Plast Reconstr Aesthet Surg 2014;67(02):244–251

10 Zhang YX, Hayakawa TJ, Levin LS, Hallock GG, Lazzeri D. The economy in autologous tissue transfer: part 1. The kiss flap technique. Plast Reconstr Surg 2016;137(03):1018–1030

11 Mahajan AL, Van Waes C, D'Arpa S, et al. Bipedicled DIEAP flaps for reconstruction of limb soft tissue defects in male patients. J Plast Reconstr Aesthet Surg 2016;69(07):920–927

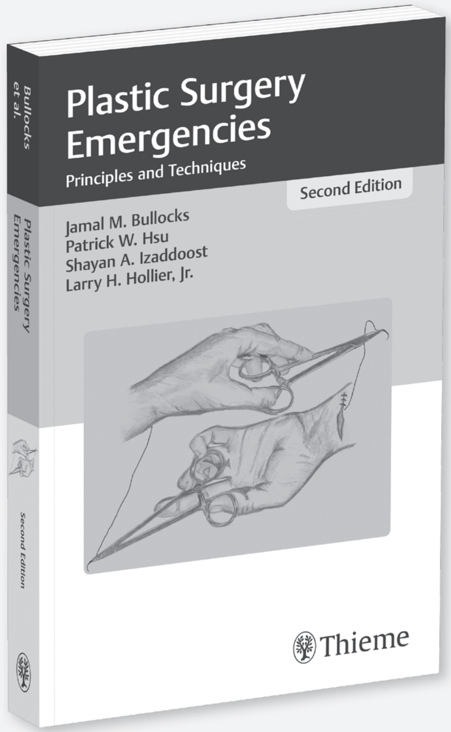
12 Paik JM, Pyon JK. Risk factor analysis of freestyle propeller flaps. J Reconstr Microsurg 2017;33(01):26–31

13 Innocenti M, Menichini G, Baldrighi C, Delcroix L, Vignini L, Tos P. Are there risk factors for complications of perforator-based propeller flaps for lower-extremity reconstruction? Clin Orthop Relat Res 2014;472(07):2276–2286

14 Gir P, Cheng A, Oni G, Mojallal A, Saint-Cyr M. Pedicled-perforator (propeller) flaps in lower extremity defects: a systematic review. J Reconstr Microsurg 2012;28(09):595–601

15 Townley WA, Royston EC, Karmiris N, Crick A, Dunn RL. Critical assessment of the anterolateral thigh flap donor site. J Plast Reconstr Aesthet Surg 2011;64(12):1621–1626

16 Bhadkamkar MA, Wolfswinkel EM, Hatef DA, et al. The ultra-thin, fascia-only anterolateral thigh flap. J Reconstr Microsurg 2014;30(09):599–606



Keep a level head under pressure—prepare for emergencies in advance

Plastic Surgery Emergencies

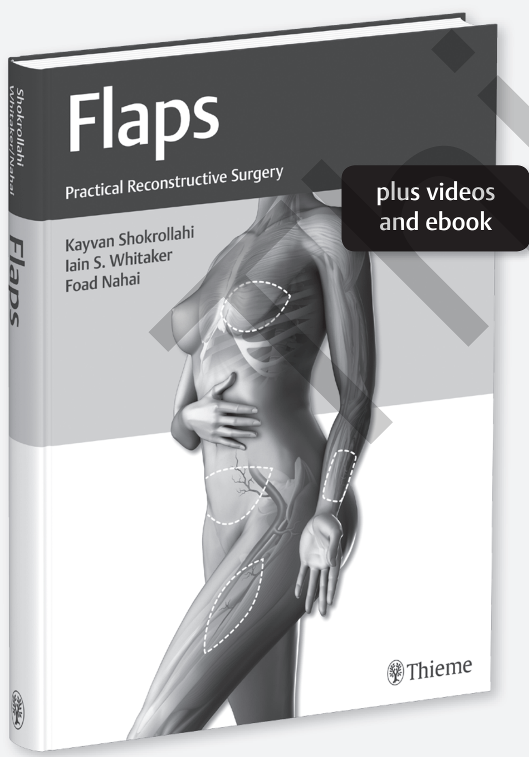
Principles and Techniques

Second Edition

Jamal M. Bullocks
Patrick W. Hsu
Shayan A. Izaddoost
Larry H. Hollier, Jr.

2017/304 pp./192 illus./softcover
ISBN 9781626231153
eISBN 9781626231160
Americas: $64.99
Europe, Asia, Africa & Australia: €59.99

This indispensable resource teaches clinicians, residents, and trainees to deal with emergencies in plastic surgery, from bite wounds to orbit fractures. Now in its second edition, the text is enhanced with additional chapters and illustrations in order to demystify simple problems and elucidate scenarios that require a higher level of care, so readers can gain the basic skills they need to be successful in practice.



Flap surgery, simplified: the quintessential manual on reconstructive flap use

Flaps

Practical Reconstructive Surgery

Kayvan Shokrollahi
Iain S. Whitaker
Foad Nahai

2017/704 pp./1480 illus./hardcover
ISBN 9781604067156
eISBN 9781604067163
Americas: $299.99
Europe, Asia, Africa & Australia: €279.99
Ebook: $209.99 / €194.99

Written by pioneering, world-renowned flap surgeons, this quintessential manual on reconstructive flap use has detailed, easy-to-follow instructions. This book focuses on the most advanced methods and simplifies them with high quality operative photos, illustrations, and videos, so readers can integrate techniques into surgical practice. This excellent practical reference for residents includes videos and a “Masterclass” section on pioneering techniques and plastic surgeons’ personal experiences.

Prices are subject to change without notice.

ORDER TODAY
thieme.com

@thiemepublishers @ThiemeNY @thieme-publishers @thieme.ny

Thieme