ORIGINAL ARTICLE

UDC: 617.58-089.844
https://doi.org/10.2298/VSP170628139J

Neurocutaneous flaps for soft tissue reconstruction of the knee, lower leg, ankle and foot: clinical experience with 32 patients

Neurokutani režnjevi za rekonstrukciju defekata mekih tkiva kolena, potkolenice, skočnog zgloba i stopala: kliničko iskustvo sa 32 pacijenta

Mladen Jovanović*†, Zlata Janjić*†, Aleksandar Komarčević*‡, Vesna Mijatović-Jovanović*§, Marija Marinković*†, Miroslav Tomić†

University of Novi Sad, *Faculty of Medicine, Novi Sad, Serbia; Clinical Center of Vojvodina, †Clinic for Plastic and Reconstructive Surgery, Novi Sad, Serbia; ‡Institute for Child and Youth Health Care of Vojvodina, Novi Sad, Serbia; §Institute of Public Health of Vojvodina, Novi Sad, Serbia

Abstract

Background/Aim. Neurocutaneous flaps (NF) are the type of fasciocutaneous flaps whose clinical application has increasingly grown over the years. They have become an indispensable step in the reconstructive ladder for the small and medium soft tissue defects of the lower leg and foot. The aim of this study was to analyse the results of the treatment of patients with lower extremity soft tissue defects caused by trauma, infection, tumour removal or unstable scar formation, which were reconstructed with a variety of NF. **Methods.** This retrospective study includes 32 consecutive patients with soft tissue defects of the lower limb, treated in the Clinical Centre of Vojvodina from January 2004 to April 2017. All the operations were performed in regional anaesthesia with pneumatic tourniquet. Design of the flap and length of the pedicle were determined by the size and position of the recipient site after necessary debridement. The flap was harvested, rotated and positioned in the defect region. The patients and flap data were summarized upon their collection. **Results.** The average age of the patients, mostly males (81.2%), was 46.7 years. Distally based sural flaps were used in a majority of patients (56.2%), followed by the distally based saphenous (21.9%), lateral sural (12.5%) and proximally based sural flaps (9.4%). Defects were most often localized on the distal third of the lower leg and on the ankle (53.1%). The most common indication for surgery were trauma (46.9%) and chronic infection (31.2%). A satisfactory coverage of the defect was achieved in all 32 patients with no flap loss. A partial necrosis of the flap due to prolonged venous congestion was noted in 3 (9.4%) patients, which were healed by second intention or with delayed skin grafting. Five (15.6%) patients developed a localised infection. The infection signs withdrew spontaneously in 2 cases and after a surgical revision in 3 cases, where osteitis of the tibia had persisted. One of them required the Ilizarov orthopaedic procedure after bone resection. **Conclusion.** NF proved to be a paramount alternative to free-flap reconstruction of the lower limb. Intensive clinical application can be explained by the fact that it is a less technically demanding and time consuming surgical procedure with no major source vessel sacrifice. The reliability and safety of their utilisation are confirmed by our clinical data.

Key words:
ankle, joint; foot; lower extremity; reconstructive surgical procedures; surgical flaps; treatment outcome.

Apstrakt

Uvod/Cilj. Neurokutani ostrvasti režnjevi su vrsta fasciokutanih režnjeva čija je klinička primena u stalnom porastu poslednjih godina. Oni zauzimaju značajno mesto u rekonstruktivnoj lestvici za pokrivanje malih i srednjih defekata mekih tkiva potkolenice i stopala. Cilj ovog rada bio je da se analiziraju rezultati lečenja pacijenata sa defektima mekih tkiva donjih ekstremiteta usled traume, infekcije, uklanjanja tumora ili nestabilnog ožiljka koji su rekonstruisani različitim vrstama neurokutanih režnjeva. **Metode.** U ovu retrospektivnu studiju bila su uključena 32 pacijenta sa mekotkivnim defektima donjih ekstremiteta, koji su lečeni u Kliničkom Centru Vojvodine od januara 2004. do aprila 2017. Sve operacije su izvedene u regionalnoj anesteziji pod Esmarhovom poveskom. Dizajn režnjeva i dužina peteljki bili su determinisani veličinom i pozicijom recipijentne regije nakon neophodnog debridmana. Režnjevi su podizani,

Correspondence to: Mladen Jovanović, University of Novi Sad, Faculty of Medicine, Department of Surgery; Hajduk Veljkova 3, 21 000 Novi Sad, Serbia. E-mail: mladen.jovanovic@mf.uns.ac.rs

rotirani i pozicionirani na mesto defekta. Podaci o režnjevima i pacijentima su neposredno beleženi i sumirani. **Rezultati.** Pacijenti su bili pretežno muškog pola (81,2%), prosečne starosti 46,7 godina. Distalno bazirani suralni režanj je korišćen kod većine pacijenata (56,2%), zatim distalno bazirani safenski (21,9%), lateralni suralni (12,5%) i proksimalno bazirani suralni režanj (9,4%). Lokalizacija defekta je kod većine pacijenata bila na distalnoj trećini potkolenice i skočnom zglobu (53,1%). Najčešće indikacije za operaciju su bile povreda (46,9%) i hronična infekcija (31,2%). Zadovoljavajuće pokrivanje defekta postignuto je kod sva 32 pacijenta, bez ijednog izgubljenog režnja. Delimična nekroza režnja usled produžene venske kongestije je zabeležena kod 3 (9,4%) pacijenta, a zarasla odloženo ili nakon postavljanja slobodnog kožnog transplantata. Lokalna infekcija je zabeležena kod pet (15,6%) pacijenata. Znaci infekcije su se spontano povukli kod dva pacijenta, a posle hirurške revizije kod tri, kao posledica rezidualnog osteitisa tibije. Jedan od njih je nakon resekcije kosti podvrgnut ortopedskoj proceduri po Ilizarovu. **Zaključak.** Neurokutani režnjevi su značajna alternativa slobodnim režnjevima za rekonstrukciju defekata na donjim ekstremitetima. Učestalost kliničke primene se može objasniti činjenicom da ova hirurška procedura nije tehnički i vremenski zahtevna, te da se pri tome ne kompromituje magistralnu arterijsku cirkulaciju. Naša klinička studija potvrđuje pouzdanost i sigurnost korišćenja ovih režnjeva.

Ključne reči:
skočni zglob; stopalo; potkolenica; hirurgija, rekonstruktivna, procedure; režnjevi, hirurški; lečenje, ishod.

Introduction

Reconstruction of soft tissue defects of the lower leg and foot is still a challenge for surgeons. Exposed tendons, bones or joints as a result of trauma, infection or tumour removal require an adequate soft tissue coverage. There are various reconstruction options that can be used such as local, pedicle and free flaps. Since they were introduced into clinical practice, neurocutaneous flap (NF) have become an excellent choice for solving distal lower leg, ankle and foot defects. Previously, these defects could only have been reconstructed with much more demanding and less reliable surgical procedures.

Neurocutaneous island flaps are the type of fasciocutaneous flaps whose clinical application has increasingly grown over the years. They became an indispensable step in the reconstructive ladder for the small and medium soft tissue defects of the lower extremity.

Pontén [1] first described fasciocutaneous flaps in 1981. The anatomical vascular basis of the axillary fasciocutaneous pedicled flap was demonstrated by Cormack and Lamberty [2] in 1984. Vascularization of NF is enabled by longitudinal chain-linked adipofascial plexus as well as the neurovascular axis around the sensitive nerves of the lower leg. In essence, the vessels accompanying the sensitive superficial nerves will allow skin flaps to survive. Nutrition of the distally based adipofascial pedicle flaps is ensured through a retrograde flow from the septocutaneous and musculocutaneous perforators of posterior tibial artery, anterior tibial artery and peroneal artery which were first described by Masquelet et al. [3] in 1992 and Hasegawa et al. [4] in 1994. Dominant vascularization of proximally based flaps is achieved due to direct cutaneous arteries that accompany sensitive nerves on their way through the lower leg. These arteries course subfascially in its proximal third and suprafascially in the distal two thirds of the calf [5].

The aim of this study was to summarize and analyse the treatment results of patients with lower extremity soft tissue defects caused by trauma, infection, tumour removal or unstable scar formation which were reconstructed with NF.

Methods

Data for this retrospective study were collected from the Clinic for Plastic and Reconstructive Surgery and the Clinic for Orthopaedic Surgery and Traumatology, Clinical Centre of Vojvodina from January 2004 to April 2017. This study, approved by the Ethics Board of the same institution, included 32 consecutive patients in whom we used the proximally and distally based sural, lateral sural and distally based saphenous flaps. All the obtained data were statistically processed upon their collection.

The Doppler ultrasound examinations were performed in all patients to evaluate vascularization and to identify the map of perforators. The operation started under regional anaesthesia with a patient in the prone position. Exsanguination was achieved with pneumatic tourniquet to enable better identification and dissection of the vital structures. Design of the flap and length of the pedicle were determined by the size and position of the recipient site after necessary debridement. Adipofascial pedicles were from 3 to 5 cm wide, surrounding the neurovascular bundle equally from each side to ensure the vascularization of the fasciocutaneous island. The raised flaps were rotated from 90^{o} to 180^{o} and placed over the defect through the subcutaneous tunnel in the majority of patients. The donor area was covered either with a split thickness skin graft or with a direct closure if the defect was less than 5–6 cm wide.

Anatomical considerations and surgical approach

Anatomical considerations and surgical technique for the flaps used in this clinical study are given below.

Lateral sural flap

Neurovascular basis of the lateral sural flap consists of the lateral sural nerve, the lateral cutaneous sural artery and two concomitant veins. The lateral sural artery is usually a direct branch of the popliteal artery, originating from the level of the lateral condyle of the tibia. From the popliteal fossa,

the artery courses subfascially alongside the lateral sural nerve, which is a branch of the peroneal nerve, and after 4–6 cm pierces the deep fascia. In its further course, it travels along the surface of the lateral head of the gastrocnemius muscle, forming a subfascial and suprafascial vascular chain along with the extrinsic vascular plexus of the lateral sural nerve. Terminal branches of the lateral sural artery anastomose with musculocutaneous and septocutaneus perforators of the peroneal artery in the middle and distal third of the lower leg [6].

This flap is an excellent solution for covering the soft tissue defects around the knee and proximal part of the lower leg [5]. The flap is elevated along the posterolateral side of upper two-thirds of the lower leg in the subfascial plane. The maximum size ranges from the tibial plateau to the lower margin of the gastrocnemius belly. The lateral sural artery and nerve should be in the mid axis of the flap. A surgical dissection begins from the distal edge of the flap and continues upwards. The pivot point of the fasciosubcutaneous pedicle is usually in the popliteal fossa [7].

Proximally and distally based sural flaps

The neurovascular basis of these flaps consists of the sural nerve and superficial sural artery with two concomitant veins for proximally based and the small saphenous vein for distally based pedicle. In most cases, the superficial (median) sural artery branches directly off from the popliteal artery or from the lateral sural artery. From the popliteal fossa, together with the sural nerve it passes between the two heads of the gastrocnemius muscle, pierces the fascia in the middle third of the lower leg, ending its course along the lateral side of the Achilles tendon and anastomosing with branches of the peroneal artery. The medial sural nerve originates from the tibial nerve and unites with a communicant branch of the lateral sural nerve in the suprafascial plane, forming a common sural nerve in the middle third of the lower leg [4]. The neurovascular axes of both flaps are the same. The proximally based flap circulation mainly depends on the median superficial sural artery together with the extrinsic vascular plexus of the sural nerve. The distally based flap circulation is achieved due to a retrograde flow from septocutaneus perforators of the peroneal artery which anastomoses with the superficial vascular network of the sural artery around the nerve [5].

Proximally based sural flap is a good alternative for the reconstruction of soft tissue defects around the knee and proximal half of the lower leg [8]. The flap is elevated along the posterior side of the upper two-thirds of the calf, from distal to proximal. The subfascial plane of dissection starts with ligation of the median sural artery, the sural nerve and lesser saphenous vein, all of which should be in the middle of the flap axis. The pivot point of the pedicle is usually on the midline of the popliteal skin crease [5].

The distally based sural flap has a widespread clinical use for reconstruction of defects in the distal part of lower leg, ankle and foot [4, 9]. The neurovascular axis extends across the middle of the calf and descends obliquely towards the posterior side of the lateral malleolus. The subfascial dissection begins on the boundary between the proximal and middle third of the calf downwards, with identification and ligation of the median sural artery, sural nerve and lesser saphenous vein. The pivot point of the adipofascial pedicle should be at least five centimetres above the lateral malleolus to preserve anastomosis with an important septocutaneous perforator of the peroneal artery [10].

Distally based saphenous flap

The neurovascular basis of the flap consists of the saphenous nerve, saphenous artery and great saphenous vein. The saphenous nerve is the largest cutaneous branch of the femoral nerve. It runs together with the great saphenous vein, downwards from the medial aspect of the knee to the medial aspect of the foot. The saphenous artery is a constant branch of the descending genicular artery which comes down the lower leg along and in front of the saphenous nerve. In the middle third of the lower leg it forms a vascular network around the nerve and dominantly anastomoses with intermuscular septal branches of the posterior tibial artery. The most distal cluster of perforator vessels around the medial malleolus provides a nutrient basis for the distally based pedicle [6, 11].

The flap is a good solution for soft tissue defect reconstructions around the ankle and heel. The axial line of the flap extends from the anterior margin of the medial malleolus to the medial epicondyle of the femur. Elevation begins at the proximal part of the fasciocutaneous island and includes the saphenous nerve and artery as well as the great saphenous vein. The dissection of the adipofascial pedicle continues into the subfascial plane up to the point of rotation which is usually 5–6 cm above the medial malleolus. The pivot point is determined by the location of the most distal anastomosis with perforator of the posterior tibial artery [12].

Results

The mean follow up period was 12 months (range: 6–18 months). Satisfactory coverage of the defect was achieved in all 32 patients with no flap loss. The average age of the patients, mostly males (81.2%), was 46.7 years. The largest size of the fasciocutaneous island was 17 x 10 cm, and the smallest one was 5 x 3.5 cm. The average time duration for elevation and flap placement was 1 h and 25 min. The patients usually stayed in the hospital for 5.5 days after the surgery.

The clinical summary of patient and flap data is shown in Table 1. The distally based sural flap was most frequently used (56%). Defects were most often localised on the distal third of the lower leg and ankle (53%). The most common indications for surgery were trauma (47%) and chronic infection (31%).

Venous congestion occurred in 4 distally based flaps (2 sural and 2 saphenous), which resulted in partial necrosis in 3 cases. In two of them, which had marginal necrosis, spontaneous wound healing was achieved upon conservative treatment. In the third one, a complete surface necrosis was developed. However, the residual adipofascial flap tissue was well vascularised, allowing a delayed free skin grafting to be performed.

Table 1

Clinical summary of patient and flap data

Characteristics	Values
Number of flaps	32
Age (years), mean (range)	46.7 (20–78)
Sex ratio, (male/female)	4.3
Male, n (%)	26 (81.2)
Female, n (%)	6 (19.8)
Localization, n (%)	
knee	4 (12.5)
proximal third of lower leg	2 (6.2)
medial third of lower leg	2 (6.2)
distal third of lower leg	12 (37.5)
ankle	5 (15.6)
heel	4 (12.5)
foot	3 (9.4)
Etiology, n (%)	
trauma	15 (46.9)
chronic infection	10 (31.2)
tumour	4 (12.5)
unstable scar	3 (9.4)
Type of flaps, n (%)	
distal sural	18 (56.2)
distal saphenous	7 (21.9)
lateral sural	4 (12.5)
proximal sural	3 (9.4)
Time of reconstruction, n (%)	
delayed	24 (75)
immediate	8 (25)
Size of the flap (cm^2), mean (range)	35 cm^2 (9–170)
Tunnelling of the pedicle, n (%)	28 (87.5)
Skin blade harvesting, n (%)	11 (34.4)
Donor site, n (%)	
split thickness skin grafts	25 (78.1)
primary closure	7 (21.9)
Complications, n (%)	
infection	5 (15.6)
distal venous congestion	4 (12.5)
partial necrosis	3 (9.4)
partial dehiscence	2 (6.2)
Follow-up (months), mean (range)	12 (6–18)
Long/wide ratio, mean (range)	5.1 (4–8)

A postoperative flap infection occurred in 5 patients, mostly in cases with a former chronic infection of the soft tissue or osteitis of tibia (4 out of 5). The infection signs withdrew spontaneously in 2 patients, in 2 after a surgical revision and with fistulisation in one patient. The last one required the Ilizarov orthopaedic procedure after bone resection.

Only one quarter of the patients underwent an immediate surgical reconstruction. The reason for the large number of delayed treatments can be explained by the fact that complicated cases with unsolved lower limb conditions were referred to our Clinic from other, regional hospitals.

There was no significant donor site morbidity. All flaps provided a stable defect coverage with a satisfactory colour, texture and contour. A few patients complained of numbness or reduced sensitivity in the skin area which was innervated by a particular sacrificed nerve but it did not influence their daily activities. A vast majority of patients was satisfied with the functional and aesthetic outcome.

Characteristics of four cases are presented below.

Case 1

A 22-year-old male patient was admitted to our Clinic with soft tissue necrosis of the knee and an exposed patella. Three weeks earlier, he was polytraumatized in a severe traffic accident with injuries of the head, chest, liver, spleen and open fracture of the patella (grade 3B). Therefore, among other urgent surgical procedures, a partial patellectomy and reinsertion of the ligament were performed. After stabilisation of the patient's general condition and demarcation of the necrotic tissue, a radical debridement was done with elevation of the lateral sural flap (size 9 x 5.5 cm). The wound healing was completed without any complications. The donor site was primarily closed. Eight months later, he had a normal gait with an excellent function of the knee joint (Figure 1).

Case 2

A 37-year-old male patient referred to our Clinic four weeks after a corn picker injury and traumatic amputation of the lower leg. Reconstruction of the defect was achieved by the distally based direct saphenous flap from the opposite limb as a "cross leg" procedure. The external fixation for both legs was carried out for three weeks. The flap completely survived after separation. The function of the knee joint was fully preserved. Three months later, the patient was able to walk with a lower leg prosthesis (Figure 2).

Fig. 1 – a) Necrosis of soft tissue of the knee and exposed patella; b) Wound after radical surgical debridement; c) Reconstruction with lateral sural flap (7 days post-op).

Fig. 2 – a) Amputation stump with granulated tissue and exposed tibia; b) Distally based saphenous flap from the opposite leg as "cross leg" procedure; c) Appearance of the flap 15 days after separation.

Fig. 3 – a) Defect of soft tissue and calcaneus with avulsion of the Achilles tendon attachment; b) reinsertion of the tendon and reconstruction of the defect with large distally based sural flap; c) appearance of the flap 4 weeks post-op.

Fig. 4 – a) Necrosis of soft tissue with osteomyelitis of the tibia and exposed tibialis anterior tendon; b) radical surgical debridement with sequestrectomy of the tibia; c) Reconstruction of the defect with distally based sural flap (4 days post-op).

Case 3

A 48-year-old male patient was admitted to our Clinic from a regional hospital one month after a severe lawn-mower injury of the heel and ankle with defects of soft tissue and calcaneus, and avulsion of the Achilles tendon insertion. A radical debridement was performed with the tendon reinsertion and defect reconstruction with the distally based sural flap (size: 17 x 10 cm). A minor dehiscence on the distal part of the flap healed spontaneously five weeks later. Four months after the surgery, the patient had a satisfactory function of the ankle joint and a normal gait with an orthopaedic insert (Figure 3).

Case 4

A 35-year-old male patient referred to our Clinic three weeks after an injury in fight. He sustained an open fracture of the distal part of the tibia. Osteomyelitis and dehiscence of the wound occurred after initial internal osteosynthesis. After the tibia sequestrectomy, the plate was removed and external fixation was placed. Reconstruction of the defect was achieved by the distally based sural flap (size: 8.5 x 8.5 cm). On the seventh postoperative day, an infection developed under the flap. This was followed by debridement of the bone with a focus of the residual infection. After the operation, the infection retreated with a full consolidation of the flap (Figure 4).

Discussion

NF have wide clinical applications, particularly those distally based as they are used for the reconstruction of defects on distal parts of the lower leg, ankle and foot [13]. The reliability and safety of their use are confirmed by our clinical data. Despite the specified complications, there was not a single flap loss. A recent meta-analysis study which have in-

cluded 907 patients, reported a distally based sural flap loss rate of 3.2%. The overall complication and flap failure rate were lower when compared to free flap surgery [14].

The rate of complications is affected by many systemic and local factors. Risk factors may be: patient's age (older than 60 years), smoking, obesity and peripheral vascular disease [14, 15]. Chronic venous insufficiency leads to complications ninefold frequently. For these groups of patients some authors advocate a delayed surgical treatment [16, 17]. It can be a two or three stage procedure that includes elevation of the distal portion of the flap or pedicle, one or two weeks before the final inset of the flap. According to them, this technique provides a better safety for flap survival.

Unlike in the proximally based, a temporary venous congestion is common in the distally based flaps due to the retrograde flow of the venous blood and one-way valvular system. This problem is more pronounced in the distally based saphenous flaps due to more intense blood flow [12]. Small concomitant bypass veins surrounding the small and great saphenous veins enable drainage of the flaps. In our series, when the flap suffered moderate or severe congestion during the operation (22% of cases), it was relieved by ligation of the magistral superficial vein at the proximal base of the pedicle. This procedure is recommended by several authors. Loonen et al. [17] and Wong and Tan [18] suggested anastomosis of the lesser saphenous vein to the surrounding vein at the recipient site. Supercharging the free end of the vein should provide the "flow-through" venous flow and enhance the venous blood return [19]. Salvage of NF with venous congestion can also be achieved using the intravenous cannula inserted into the proximal stump of the cutaneous vein for intermittent bleeding [20]. Despite the proposed solutions, the venous congestion remains a major problem in the elevation of distally based flaps. All partial and superficial necroses of flaps in our series were a consequence of this complication.

Local infection following the neurocutaneous flap surgery is a relatively rare complication. A recent pool-analysis study reported a distally based flap infection rate of 2.5% [14]. In our series, the surgical site infection developed significantly more often (15.6%), which can be explained by a large number of patients with chronic wounds, osteomyelitis or bone non-union. In cases with an underlying osteomyelitis, recurrence of infection occurs in 5% to 20% of flaps. For these patients additional surgical treatment with selected antibiotic therapy is necessary in order to achieve a satisfactory outcome [21].

The length-width ratio of the pedicle as well as the size of the flap may affect flap perfusion. Sound planning of the flap implies that the ratio does not exceed 5 : 1. The accepted opinion is that the localization of the top edge at the lower 7/9 of the calf is safe and reliable for distally based flaps [15, 22]. In our data, the average ratio was 5.1 : 1, which is in accordance with recommendations by other authors. A larger adipofascial pedicle (up to 7 cm) may improve the survival rate, but practical usage is limited due to difficulties with rotation and tunnelisation as well as with bulky appearance [23]. Our pedicles did not exceed a width of over 5 cm.

The size of the flap is also a limiting factor that may significantly affect the number of complications and overall survival. It is recommended that the width of the fasciocutaneous island does not exceed 8 cm [14, 22]. Larger flaps after successful acception could induce prolonged swelling. In the three largest flaps of our series oedema was noted to persist for one to two months.

Liu et al. [24] and Dhamangaonkar et al. [25] showed that a skin blade (1.5–2 cm wide) over the pedicle, from the skin island to the pivot point of rotation, could enhance perfusion of the flap by subdermal vascular network. As a result, the length-width ratio could be increased, which would allow distally based flaps to cover defects of the forefoot. The disadvantage of this procedure is the aesthetic appearance and scarification, which is visible when the pedicle passes on the anterior side of the lower leg and foot. In our clinical practice we used skin extension over the distal part of the pedicle only for large flaps with the arc of rotation exceeding 150°. This procedure surely reduces kinking and protects the pedicle.

Subcutaneous tunnelling of the adipofascial pedicle is a procedure that was most commonly used in our series (88% of cases). We did not use it only in situations where it could jeopardize the perfusion of the flap. The skin condition under the tunnel, thickness and size of the pedicle and flap as well as the rotation arch, should be considered before making a decision on the flap placement method. Many authors believe that subcutaneous tunnelling is a safe procedure unless there is a presence of comorbidities [14, 26, 27]. Additional skin extension of the distal part of the pedicle, which we performed in some cases, can reduce the pressure on the neurovascular bundle. Yildirim et al. [28] and Nuri et al. [29] recommended a back-cut incision up to the defect for long and thick fasciocutaneous pedicles with a high arc of rotation. On the other hand, transverse incisions in the leg could have negative influences on venous and lymphatic drainage. We believe that a wide subcutaneous undermining of the tunnel reduces the risk of complications in a majority of cases and contributes to favourable cosmetic outcomes.

Proximally based flaps possessed normal sensation in the majority of cases. The loss of sensation in distally based flaps could be a problem especially for covering defects on weight bearing areas. Some authors suggested reinnervation for faster sensory nerve recovery 30, 31. Although earlier restoration of sensation after the nerve coaptation was observed, the overall protective sensation after 12 months was similar as compared with the groups of patients without initial reinnervation. Thus, this procedure, which extends the operating time and requires microsurgical skill, is not necessary.

The intrinsic and extrinsic vascular network based on nervous axes is very important for flap perfusion. In order to preserve function, a group of authors spared the sural nerve during the dissection, leaving the perineural vascular network of the flap [32]. Although the results showed that there were no significant consequences on the vitality of the flap, we believe, among many other authors, that this procedure is inadequate and additionally jeopardizes flap circulation [15, 19, 23]. Furthermore, the sensory deficiency caused by the sacrifice of the saphenous or sural nerve has never been emphasized by our patients.

On the base of the vascular communication between the subfascial sural neurovascular axis and musculocutaneous

perforators of the medial and lateral head of the gastrocnemius muscle, musculoneurocutaneous distally based sural flaps were introduced into the clinical practice [33, 34]. At first, the muscle cuff around the intergastrocnemius sural nerve was used in an attempt to improve the vascularisation of the most distal flap portion. However, an increased donor site morbidity does not justify this method except in situations with chronic osteomyelitis or bone defect, when insetting the muscle can solve the problem. Better perfusion of the flap could be achieved by placing the dissection plane just above the epimysium which allows the preservation of the sural neurovascular mesentery structure of the skin flap [15, 22].

The methods of reconstruction of the lower leg and foot with fasciocutaneous locoregional flaps have been constantly improving and evolving over the recent years. Perforator style flaps and their modification such as propeller flaps, are essentially distally based flaps whose perfusion is ensured by a single perforator with sufficient calibre from the peroneal or tibial posterior artery [35–38]. Pedicle circulation is based on the same principles as in NF through the vascular chain surrounding the saphenous or sural nerve. The keystone and V-Y design perforator island flaps have to be also taken into consideration for the reconstruction of the lower limb [39]. All of these flaps have their advantages and limitations which must be taken into account when making decisions about their application.

Conclusion

NF proved to be a paramount alternative to free-flap reconstruction of the lower limb. Their use has been steadily increasing for the last 20 years. They are an excellent choice for solving small and medium soft tissue defects on the lower leg and foot. Utilisation of newly modified techniques to increase the perfusion of distally based flaps can extend the coverage of larger and more distal defects. The reliability and safety of their application are also confirmed through our clinical data. Intensive clinical application can be explained by the fact that it is a less technically demanding and time consuming surgical procedure. Preservation of major source vessels, low donor site morbidity with violation of only the involved limb as well as similarity of surrounding tissue should also be considered as advantages of these flaps. Proper patient selection is very important. Characteristics of the defect and overall patient condition are crucial for the choice of the most appropriate reconstructive surgical procedure.

Acknowledgements

We are indebted to Boris Jovanović for helping with English translation.

REFERENCES

1. *Pontén B.* The fasciocutaneous flap: Its use in soft tissue defects of the lower leg. Br J Plast Surg 1981; 34(2): 215–20.
2. *Cormack GC, Lamberty BG.* A classification of fascio-cutaneous flaps according to their patterns of vascularisation. Br J Plast Surg 1984; 37(1): 80–7.
3. *Masquelet AC, Romana MC, Wolf G.* Skin island flaps supplied by the vascular axis of the sensitive superficial nerves: anatomic study and clinical experience in the leg. Plast Reconstr Surg 1992; 89(6): 1115–21.
4. *Hasegawa M, Torii S, Katoh H, Esaki S.* The distally based superficial sural artery flap. Plast Reconstr Surg 1994; 93(5): 1012–20.
5. *Kojić S.* Significance of neurocutaneous flaps in reconstruction of foot and lower leg defects [dissertation]. Belgrade: University of Belgrade, Faculty of Medicine; 2005. (Serbian)
6. *Nakajima H, Imanishi N, Fukuzumi S, Minabe T, Aiso S, Fujino T.* Accompanying arteries of the cutaneous veins and cutaneous nerves in the extremities: Anatomical study and a concept of the venoadipofascial and/or neuroadipofascial pedicled fasciocutaneous flap. Plast Reconstr Surg 1998; 102(3): 779–91.
7. *Deng C, Wei ZZ, Wang B, Jin W, Zhang W, Tang X,* et al. The proximally based lateral superficial sural artery flap: a convenient and optimal technique for the reconstruction of soft-tissue defects around the knee. Int J Clin Exp Med 2016; 9(8): 15167–76.
8. *Pan H, Zheng Q, Yang S.* Utility of proximally based sural fasciocutaneous flap for knee and proximal lower leg defects. Wounds 2014; 26(5): 132–8.
9. *Ilyas Tahirkheli MU, Ellahi I, Dar MF, Sharif A.* Distal Based Sural Fascio-Cutaneous Flap: A Practical Limb Saviour for Wounds of War and Peace. J Coll Physicians Surg Pak 2016; 26(5): 399–402.
10. *Ciofu RN, Zamfirescu DG, Popescu SA, Lascar I.* Reverse sural flap for ankle and heel soft tissues reconstruction. J Med Life 2017; 10(1): 94–8.
11. *Cavadas PC.* Reversed saphenous neurocutaneous island flap: Clinical experience. Plast Reconstr Surg 1997; 99(7): 1940–6.
12. *Zhong W, Lu S, Chai Y.* Distally based saphenous neurocutaneous perforator flap: A versatile donor site for reconstruction of soft tissue defects of the medial malleolar region. J Foot Ankle Surg. 2016; 55: 391–6.
13. *Zhu Y, Wang Y, He X, Zhu M, Li F, Xu Y.* Foot and ankle reconstruction: An experience on the use of 14 different flaps in 226 cases. Microsurgery 2013; 33(8): 600–4.
14. *de Blacam C, Colakoglu S, Ogunleye AA, Nguyen JT, Ibrahim AM, Lin SJ,* et al. Risk factors associated with complications in lower-extremity reconstruction with the distally based sural flap: A systematic review and pooled analysis. J Plast Reconstr Aesthet Surg 2014; 67(5): 607–16.
15. *Herlin C, Sinna R, Hamoui M, Canovas F, Captier G, Chaput B.* Distal lower extremity coverage by distally based sural flaps: Methods to increase their vascular reliability. Ann Chirur Plastique Esthetique 2017; 62(1): 45–54.
16. *Erdmann D, Gottlieb N, Humphrey SJ, Le TC, Bruno W, Levin SL.* Sural flap delay procedure: A preliminary report. Ann Plast Surg 2005; 54(5): 562–5.
17. *Loonen MP, Kon M, Schuurman AH, Bleys RL.* Venous bypass drainage of the small saphenous vein in the neurovascular pedicle of the sural flap: Anatomical study and clinical implications. Plast Reconstruct Surg 2007; 120(7): 1898–905.
18. *Wong C, Tan B.* Maximizing the reliability and safety of the distally based sural artery flap. J Reconstr Microsurg 2008; 24(8): 589–94.
19. *Fujiwara M, Nagata T, Matsushita Y, Ishikawa K, Yusuke O, Fukamizu H.* Delayed distally based sural flap with temporary venous supercharging. Microsurgery 2013; 33(7): 534–8.
20. *Eker G, Akan I, Aydoğdu E, Aköz T.* Salvage of neurocutaneous flaps with venous congestion using intravenous cannula. Plast Reconstr Surg 2003; 112(4): 1191–2.

21. *Schmitt SK*. Osteomyelitis. Infect Dis Clin North Am 2017; 31(2): 325–38.
22. *Wei J, Dong Z, Ni J, Liu L, Luo S, Luo Z,* et al. Influence of flap factors on partial necrosis of reverse sural artery flap: A study of 179 consecutive flaps. J Trauma Acute Care Surg 2012; 72(3): 744–50.
23. *Tsai J, Liao HT, Wang PF, Chen CT, Lin CH*. Increasing the success of reverse sural flap from proximal part of posterior calf for traumatic foot and ankle reconstruction: Patient selection and surgical refinement. Microsurgery 2013; 33(5): 342–9.
24. *Liu L, Zou L, Li Z, Zhang Q, Cao X, Cai J*. The extended distally based sural neurocutaneous flap for foot and ankle reconstruction: a retrospective review of 10 years of experience. Ann Plast Surg 2014; 72(6): 689–94.
25. *Dhamangaonkar AC, Patankar HS*. Reverse sural fasciocutaneous flap with a cutaneous pedicle to cover distal lower limb soft tissue defects: Experience of 109 clinical cases. J Orthopaed Traumatol 2014; 15(3): 225–9.
26. *Uygur F, Evinç R, Noyan N, Duman H*. Should we hesitate to use subcutaneous tunneling for fear of damaging the sural flap pedicle. Ann Plast Surg 2009; 63(1): 89–93.
27. *Parrett BM, Pribaz JJ, Matros E, Przylecki W, Sampson CE, Orgill DP*. Risk Analysis for the Reverse Sural Fasciocutaneous Flap in Distal Leg Reconstruction. Plast Reconstr Surg 2009; 123(5): 1499–504.
28. *Yildirim S, Akan M, Aköz T*. Soft-tissue reconstruction of the foot with distally based neurocutaneous flaps in diabetic patients. Ann Plast Surg 2002; 48(3): 258–64.
29. *Nuri T, Ueda K, Maeda S, Otsuki Y*. Anatomical study of medial and lateral sural cutaneous nerve: Implications for innervated distally-based superficial sural artery flap. J Plast Surg Hand Surg 2012; 46(1): 8–12.
30. *Santanelli F, Tenna S, Pace A, Scuderi N*. Free flap reconstruction of the sole of the foot with or without sensory nerve coaptation. Plast Reconstr Surg 2002; 109(7): 2314–22.
31. *Orbay H, Ogawa R, Ono S, Aoki S, Hyakusoku H*. Distally based superficial sural artery flap excluding the sural nerve. Plast Reconstruct Surg 2011; 127: 1749–50.
32. *Chen S, Chen T, Wang H*. The distally based sural fascio musculocutaneous flap for foot reconstruction. J Plast Reconstr Aesthet Surg 2006; 59(8): 846–55.
33. *Fodor L, Horesh Z, Lerner A, Ramon Y, Peled IJ, Ullmann Y*. The Distally Based Sural Musculoneurocutaneous Flap for Treatment of Distal Tibial Osteomyelitis. Plast Reconstr Surg 2007; 119(7): 2127–36.
34. *Chen X, Xu Y, Chen J, Ma Z, Guan L, Xu J,* et al. Dominant perforator neurocutaneous flaps for one-staged reconstruction of defects caused by high energy at lower legs, ankles and feet. Zhonghua Zheng Xing Wai Ke Za Zhi 2013; 29(2): 81–7. (Chinese)
35. *Terzić Z, Djordjević B*. Clinical aspects of reconstruction of the lower third of the leg with fasciocutaneous flap based on peroneal artery perforators. Vojnosanit Pregl 2014; 71(1): 39–45.
36. *Toia F, Arpa SD, Pignatti M, Noel W, Cordova A*. Axial propeller flaps: A proposal for update of the "Tokyo consensus on propeller flaps". J Plast Reconstr Aesthet Surg 2017; 70(6): 857–60.
37. *Ozalp B, Aydınol M*. Perforator-based propeller flaps for leg reconstruction in pediatric patients. J Plast Reconstr Aesthet Surg 2016; 69(10): e205–11.
38. *Chaput B, Herlin C, Espié A, Meresse T, Grolleau JL, Garrido I*. The keystone flap alternative in posttraumatic lower-extremity reconstruction. J Plast Reconstr Aesthet Surg 2014; 67(1): 130–2.

Received on June 28, 2017.
Revised on September 19, 2017.
Accepted on September 21, 2017.
Online First Septeber, 2017.