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Increasing Versatility of Reverse-Flow Sural Flap in Distal Leg and Foot Reconstruction

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ABSTRACT

The challenge of distal leg and foot reconstruction have been a matter of increasing interest to the reconstructive surgeons and stimulated the continued search, innovation and modification of various reconstructive modalities in a trial to reach an algorithm to achieve the ideal reconstructive goals for such defects. Various flaps have been described to solve this problem, each has its own indications, limitations, advantages and disadvantages with relatively few procedures showing effectiveness and low morbidity. The concept of the neuroskin island flap was first proposed by Masquelet et al., in 1992. They described a flap utilizing the median superficial sural artery (which runs along the sural nerve) as its vascular axis with a distal base nourished through the distal peroneal perforators. Hasegawa refined his technique and first published the reverse sural flap in 1994. The use of this flap received quick recognition with more clinical results reported in next years. They concluded that the territory of this flap can be expansive, but how far? Still a matter of debate. And to date there is no answer for this question. It is now clear that the anatomical findings can not be absolutely reproduced in real life. The clinical works based on these anatomical studies showed a significant increase in flap dimensions if compared to the conventional flap with non significant increase in flap morbidity, however they failed to predict a maximum limit for flap dimensions without compromising safety. There is still a question to be answered regarding what to do if larger flap is required or even if flaps of conventional sizes show signs of vascular insufficiency. This study tried to highlight the problem with extended flaps and how to anticipate and deal with their vascular problems.

INTRODUCTION

The challenge of distal leg and foot reconstruction have been a matter of increasing interest to the reconstructive surgeons and stimulated the continued search, innovation and modification of various reconstructive modalities in a trial to reach an algorithm to achieve the ideal reconstructive goals for such defects. Various flaps have been described to solve this problem, each has its own indications, limitations, advantages and disadvantages with relatively few procedures showing effectiveness and low morbidity **[1-5]**.

Inferiorly based muscle flaps for those regions are of restricted use, as they are not as safe and reliable there as when executed in the median and superior thirds of the leg. The donor site morbidity and bulkiness may add to the disadvantages of these flaps **[6,7]**.

The medial planter flap is considered extremely reliable in reconstruction of the weight bearing area of the heel, however, in most instances, the resultant trauma influenced the instep area or severed the vascular axis limiting the flap use in such conditions **[8]**.

The cross-leg flaps are still more limited because of their positional constrains and limitations. They require a long internment period and the adoption of uncomfortable postoperative positions and may further give rise to articular restrictions because of long immobilization **[9]**.

Reversed island flaps such as peroneal, anterior tibial and posterior tibial artery flaps are among the reconstructive options for such defects, however, the need to sacrifice a major artery in the leg is a serious disadvantage **[10,11,12]**.

Despite being of laborious execution, microsurgical free tissue transfer should always be considered. However, they may not suit certain categories of patients **[13]**.

Fasciocutaneous flaps of the proximal pedicle have little application in the distal third of the leg. The medial and lateral malleolar flaps may be used, but it presents limitations relative to its dimensions. Fascial and Fasciocutaneous flaps of the distal pedicle have been intensively researched and constitute another important alternative **[2,14,15,16]**.

In 1992, Masquelet and colleagues developed the concept of the neuroskin flaps. They described a fasciocutaneous flap with a distal base utilizing the median superficial sural artery (which runs along the sural nerve) as its vascular axis, what is now called the reverse sural artery flap **[17]**.

In the upper part of the leg, the sural nerve (and its accompanying artery, namely the median superficial sural artery) is buried between the two heads of gastrocnemius muscle. Masquelet and colleagues stated that the reverse sural artery flap is safe only if it is taken from the lower leg along the suprafascial course of the median superficial sural artery. Subsequent authors also noted that flap tip necrosis occurred in the area of the flap that extended proximal to the exiting point of the sural nerve from between the two heads of gastrocnemius muscle and concluded that the flap should not extend beyond this point **[17-20]**.

In a trial to extend the flap territory, hence its potentials to cover more distal defects, further anatomical studies were conducted to study the role of the subfascial segment of the sural nerve as well as the short saphenous vein and their accompanying arteries, in contribution to the arterial supply and the venous drainage of the extended revered sural flap. They stressed upon preserving the mesenteric-like connection between the sural nerve (and its accompanying artery) and the fascial element of the flap, they also clarified the role of short saphenous vein and its accompanying artery and delicate veins, in vascular augmentation of this flap. They concluded that the territory of this flap can be expansive, but how far? Still a matter of debate. And to date there is no answer for this question. It is now clear that the anatomical findings can not be absolutely reproduced in real life **[21-25]**.

The clinical works based on these anatomical studies showed a significant increase in flap dimensions if compared to the conventional flap with non significant increase in flap morbidity, however they failed to predict a maximum limit for flap dimensions without compromising safety. There is still a question to be answered regarding what to do if larger flap is required or even if flaps of conventional sizes show signs of vascular insufficiency **[23-26]**.

This study tried to highlight the problem with extended flaps and how to anticipate and deal with their vascular problems.

Applied anatomy:

The reverse-flow sural flap is supplied by 2 independent sources, namely, the artery accompanying the sural nerve (the median superficial sural artery) and the 2 arteries accompanying the lesser saphenous vein (originating from the median superficial sural artery).

In their anatomical description, Masquelet and colleagues demonstrated that the artery accompanying the sural nerve supplies only the skin of the lower two thirds of the posterior calf through multiple delicate neuro-cutaneous perforators that corresponds to the supra-fascial course of the sural nerve **[17]**.

Batchelor and McGuinness, 1996, noted that gastrocnemius musculocutaneous perforators frequently accompanied the sural nerve and its accompanying artery. Furthermore, these musculocutaneous perforators were noted to give off vascular branches to both the sural nerve and the fascia. This means that the midline gastrocnemius perforators, median superficial sural artery and its neuro-cutaneous perforators are all intercommunicating in the proximal part of the leg between the two heads of the gastrocnemius muscle. If the delicate mesentery-like connection, containing small perforator vessels, is preserved between the sural nerve, in its sub-fascial course and the deep fascia, This can ensure an irrigation source to the skin of the upper part of the posterior calf **[21]**.

Further anatomical study of Nakajima and colleagues stressed upon the importance of the arteries accompanying the lesser saphenous vein in contribution to the blood supply of the skin over the upper part of the calf as well. These arteries give off veno-cutaneous perforators to the skin along the entire length of the vein no matter the course of the vein in relation to the deep fascia **[23]**.

The important finding regarding the anatomic relationships between the lesser saphenous vein and the sural nerve is that each run independently in different layers in the upper half of the leg, but coursed together in the same layer in the lower half of the leg. The accompanying arteries of both are contained in the flap, with a free communication in the fascial planes between both systems, however, the majority of the blood supply to the skin is provided by the accompanying arteries of the lesser saphenous vein in the upper half of the flap, but a contribution by the accompanying arteries of the sural nerve may exist, to a lesser extent in some cases. In the lower half of the flap, the blood supply to the skin is shared equally between both accompanying arteries proper to the lesser saphenous vein and the sural nerve **[23]**.

Few anatomical studies demonstrated clearly the fine framework of connection between the superficial sural artery and the septocutaneous peroneal perforators. Most workers found a constant vascular anastomosis with the lowest septocutaneous peroneal perforators at about 3-7 cm above the lateral malleolus. This constant vascular anastomosis forms an arterial network around the course of the whole length of the sural nerve distally. The septocutaneous peroneal perforator can capture the vascular territory of the superficial sural artery, therefore, supplying a reverse-flow sural flap **[17, 25]**.

The study of the relationship between the size of the most significant distal peroneal perforator and dimensions of the skin island, though considered logical, was not aroused. Also, it is uncertain how large a flap can be raised safely, because there are few studies on maximum flap dimensions. The dimensions of the flaps used vary according to the surgeons' own experiences and not based on a previous anatomical report **[27]**.

Whether a reverse arterial flow could be established or not following proximal separation of the sural pedicle is a matter of question. Torii et al., concluded from their anatomical study that the reverse flow would occur in any artery of large size. This situation is not considered the role in the reverse- sural flap and the way of termination of the sural artery may point out to the potentiality of flow reversal. Masqulet et al., found, from their anatomical study, that the sural artery descends to the ankle in 65% of cases, while in the other 35% it is reduced to an interlacing vascular network in the distal 1/3 of the leg **[17,29]**.

There is some argument about the reverse-flow venous drainage of this flap. A recent publication indicated that there is fine long veins alongside the lesser saphenous vein and sural nerve that were considered the concomitant veins of their accompanying arteries. They anastomose with the lesser saphenous vein in some places and play a role in bypassing the valves in the lesser saphenous vein, hence, the reverse of the venous flow in the flap **[22]**.

PATIENTS AND METHODS

The reverse flow sural flap was used in 27 patients with complex lower limb defects in the period from August 2001 to December 2003. Twenty one patient were males and 6 were females with their ages ranged between 9-62 years (average age 32 years). The flaps were used to reconstruct complex distal leg, ankle and foot defects. The aetiology of the defects is shown in table (1) with trauma being the leading cause (81.5% of cases). In traumatic defects, delayed reconstruction, following repeated debridment, was planned after an average period of 11 days (range 5-26 days) in 17 patients and was performed on emergency basis as immediate reconstruction in 5 patients. The choice between delayed or immediate coverage depended on the local condition of the wound, exposure of vital structures and the general condition of the patient. Cases with trauma involving the posterior calf were excluded.

A routine color-flow duplex scan was performed in all elective cases to ensure the patency of the peroneal artery and map their perforators, to delineate the course and patency of the lesser saphenous vein as well as the superficial sural artery. I always tried to match these findings with those which could be gained by a handy Doppler and I found out that both were compatible with almost the same accuracy offering a versatile and easy way of immediate preoperative study in emergency cases.

In a trial to predict the adequacy of flap perfusion preoperatively, a more comprehensive ultrasound study of the correlation between the distal significant peroneal perforator DSPP (Distal Significant Peroneal Perforator) and the 3 D dimensions of the flap, was performed in the last 17 patients by measuring the diameter and blood flow volume in the DSPP in conjunction with measurement of the thickness of subcutaneous fat in the donor area of the flap. The DSPP was defined based on a preliminary pilot study on control group of 50 volunteers with healthy lower limb vessels in whom the distal peroneal perforators were mapped with measurement of the diameter and blood flow volume in the largest one that directed posteriorly.

Eleven flaps were used as adipofascial flaps and 16 were fasciocutaneous (case study, Tables 2-3). The size of the flap ranged from 5x4cm to 18x11cm with an average dimensions of 9.3x6cm. Flap dimensions in adipofascial flap is the effective part of the flap that will fit over the defect. The choice between using an adipofascial or a fasciocutaneous flap depended mainly on the reconstructive requirement of the defect. Donor site consideration regarding skin condition and thickness of subcutaneous fat was also considered.

Operative step-wise evaluation of flap circulation with subsequent management was effected following release of tourniquet. Flap delay was needed in one case where inadequate flap circulation was noted just following tourniquet release. Flap supercharge was needed in one case, flap superdrainge was needed in 2 cases, one of them was performed immediately after flap inset and the other was performed 36 hours postoperatively when venous congestion was noted and venous Doppler signal was found to be markedly diminished. Flap delay was needed in another case with arterial insufficiency where arterial anastomosis was not feasible. Two weeks should be elapsed to re-rotate the delayed flap.

Based on the above mentioned concepts of the preoperative prediction of adequate flap perfusion and the possible need for vascular augmentation this work passed into 2 phases: the first phase before adopting these concepts (10 cases, Table 2) and the second one with adoption of these concepts (17 cases, Table 3).

The donor site of adipofascial flap was closed primarily while that of fasciocutaneous flap was grafted in all patients.

Postoperative positioning was designed in order to avoid compression on the flap, its pedicle and the hinge point.

Routine postoperative prophylactic anticoagulant therapy in the form of low-molecular weight heparin was administered during the period of immobilization (5 days).

Postoperative flap monitoring both visual and by checking arterial and venous signals using Doppler probe was assessed every 2 hours for the first 48 hours and then every 6 hours for the next 3 days with preparation for possible secondary intervention in the form of supercharge and/or superdrainage in case of vascular insufficiency.

Postoperative follow up for flap survival, early and late wound complications of both the flap and the donor site and their aesthetic outcome. The average follow up period was 10 months.

Operative technique and technical tips:

Regional anesthesia was used in 19 patients while general anesthesia was applied in the remainders. Marking sites of the distal peroneal perforators and the course of the short saphenous vein were confirmed by handy Doppler. With the patient in prone position, flap markings was performed by first measuring the defect dimensions and orientation, defining the pivot point just proximal to the DSPP, then the flap was marked accordingly on the posterior calf skin. In case of adipofascial flaps, the proximal and distal limits of the flap was marked. In case of fasciocutaneous flaps, the skin island is drawn with accurate dimensions and orientation in relation to the defect and pivot point. In the last 3 fasciocutaneous flaps, a modification was used in the shape of skin island in the form of a triangular tail with its tip pointing to the pivot point (Fig. 1). The length of this triangular extension vary according to the expected area of tightness around the defect either induced by a normal anatomical configuration or abnormal edema and induration as a direct effect of trauma.

Under tourniquet control, flap dissection was started. If an adipo-fascial flap was harvested, the skin over the flap was undermined leaving at least one fat globule over the fascia to protect the fascial plexus. The skin was incised around the skin island in case of fasciocutaneous flap with further undermining of the surrounding skin to include a fascial cuff larger than the skin island. Attention was now paid to identification, isolation and dissection of the pedicle proximally which was achieved by extending the skin incision proximally for 2-3 cm. the pedicle should be dissected proximally for an adequate length to allow for possible vascular anastomosis. The deep fascia was then incised medially and laterally and deeper dissection started from medial to lateral over the medial head of gastrocnemius and from lateral to medial over the lateral head of gastrocnemius to reach the furrow between the two heads where the pedicle could be traced there, protected and kept attached to the flap with a fine mesentery-like structure (Figs. 2,3). Dissection was continued distally to reach the point of transition where the sural nerve and short saphenous vein join each other and change their plane from subfascial to suprafascial plane, then dissection was continued distally to reach just above the pivot point without the need to skeletonize the DSPP. An adipofascial pedicle of adequate width, about 2-3 cm, should be preserved (Fig. 4).

A step-wise evaluation of flap circulation with subsequent management of vascular insufficiency was adopted in the second phase group of patients in the following order (Fig. 5): The adequacy of flap perfusion both through visual assessment of the flap capillary circulation and evaluation of the axial vessels using a sterile Doppler probe was confirmed following release of tourniquet. This was effected in 3 steps, the first step following the establishment of normal ante grade flow that reflects the adequacy of the neuro-cutaneous and veno-cutaneous perforators to support different elements of the flap. The second step was evaluation while the flap is still attached proximally by its proximal pedicle then, proximal clamping to detect the establishment of the reverse arterial and venous flow through the median superficial sural artery and short saphenous vein (the arterial and venous signals can be elicited precisely in the subfascial course of the vessels because the sural artery and saphenous vein are lying separately in this segment). If adequate flap circulation was assured then, the axial vessels were separated proximally, the flap was rotated over the defect and the third evaluation was done to assess flap circulation as effected by the axial rotation of the pedicle. Vascular insufficiency was better dealt with by performing vascular anastomosis to a recipient vessel that lay nearby the defect provided that a tension-free anastomosis without the need for a vein graft could be achieved, otherwise, flap delay was considered the only possible way for vascular augmentation. Flap supercharge was effected through an end-to end anastomosis between the median superficial sural artery and the medial planter artery in the foot. Flap superdrainge was effected through anastomosing the short saphenous vein to the medial planter vein in one case and a mobilized dorsal foot vein in the other case. Both anastomoses were performed in an end-to- end fashion.

The flap was ready to be inset, in the initial experience, I used to lay open the tunnel between the pedicle and the defect and cover the resultant defect with a split skin graft. The V-shape extension of the skin island, just described, avoided using a graft.

Closure with suction drainage and grafting the donor area of fasciocutaneous flaps was performed, while immediate grafting of the fascial surface of adipofascial flaps was done.

RESULTS

Case presentation (Figs. 7-10), patient summary (Tables 2-3).

The results achieved through duplex scan were helpful in flap planning. Patency of the peroneal axis as well as a normal triphasic flow was a prerequisite to the choice of this flap. Contrary to this, a biphasic or interrupted flow through both anterior tibial and/or posterior tibial arteries was not considered a contraindication of the procedure. Interruption of flow through the short saphenous vein should herald the need for vascular augmentation.

Based on the preliminary pilot study, the DSPP is defined as being the distal peroneal perforator that runs posteriorly and lies within 3-7 cm from the lateral malleolus. Its diameter should be larger than 0.9 mm, with a blood flow volume higher than 2 ml/min.

In the second group of our patients, the distal significant peroneal perforator (DSPP) was located at a distance ranged from 3.3 to 5.8 above the lateral malleolus, it measured 0.9 to 1.6 mm in diameter, with a blood flow volume averaged 2-4 ml/min (Fig. 6). The thickness of subcutaneous fat in the donor area of the flap measured 3 mm to 1.6 cm. a small diameter or a decreased blood flow volume in the DSPP in the presence of thick subcutaneous fat was considered either a contraindication for the use of the flap or heralded the necessity for vascular augmentation.

Vascular augmentation was needed in 5 out of 17 flaps of the second group of patients (29.4%). Two were in the form of flap delay, 2 in the form of flap superdrainage and 1 in the form of flap supercharge.

Partial flap necrosis occurred in 4 flaps (14.8%), 3 of them were adiposofascial and one was fasciocutaneous. There were 2 cases of total flap loss (7.4%) one of them was adiposofascial and one was fasciocutaneous. All cases with flap loss necessitated surgical debridment. The resultant secondary defect healed conservatively with repeated dressing in 2 cases. Secondary intervention was needed in 4 cases in the form of split skin graft (2 cases), re-advancement of the flap (one case) and a free microsurgical transfer (one case). All cases, except 2, of flap loss whether partial or complete were in the early experience (first phase). In the second phase group of patients, I had only 2 cases of partial flap loss in adiposofascial flaps. Postoperative infection occurred in 7 patients (25.9%), 4 in the recipient area and 3 in the donor area. All of them were controlled with antibiotic therapy in a varied period of time. Partial loss of the graft over a viable adipofascial flap occurred in 2 cases (18% of adipofascial flaps). Partial loss of the graft over the donor area of fasciocutaneous flaps occurred in 3 cases (18.8% of fasciocutaneous flaps), 2 of them owed to infection in the donor area. All of them healed completely with repeated dressing, and proper antibiotic therapy in cases with infection, without the need for secondary surgical intervention. Flap edema was noted in 8 cases (29.6%) with total resolution in all of them following the application of pressure garments at the proper time when sound healing and adequate flap circulation were assured (average 2 months). Unsightly scarring of either the flap or the donor area was reported in 6 patients (22.2%), 5 of them were females.

Trophic ulceration of the flap skin occurred in 2 out of 7 fasciocutaneous flaps utilized to cover pressure area of the heel (28.6%) (Table 4).

Fig. (1): Flap design with a V- shape extension of the skin island.

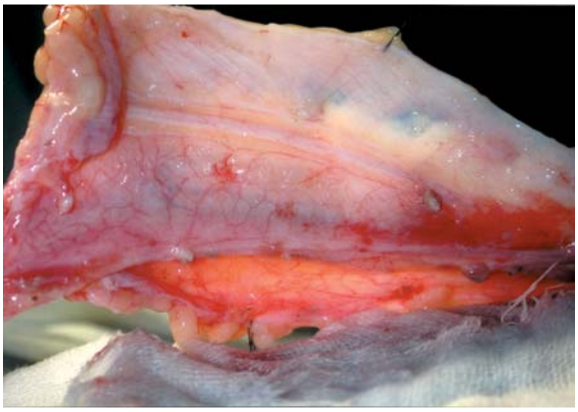

Fig. (2): The dissected flap off the septum with unity preservation between the flap and the pedicle by a fine mesentery-like structure.

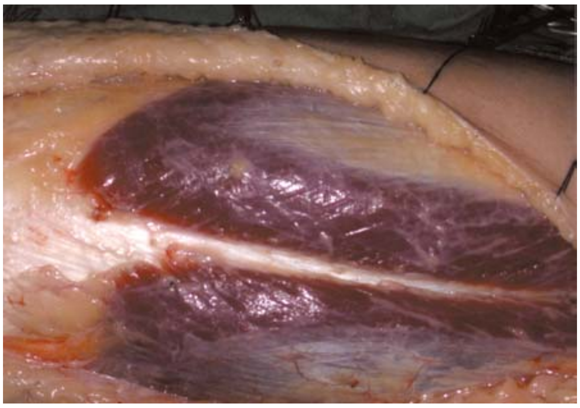

Fig. (3): The furrow between the 2 heads of gastrocnemius after completion of flap dissection.

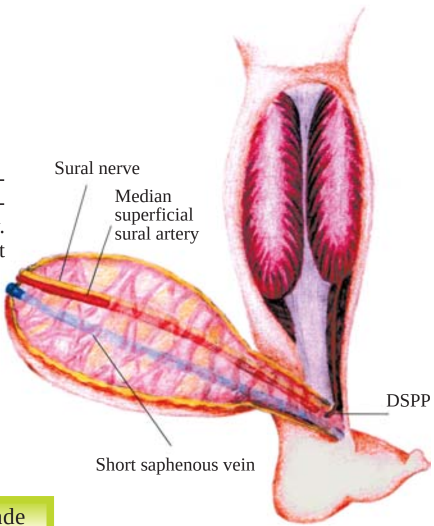

Fig. (4): Diagrammatic illustration of the reverse-sural flap anatomy. (DSPP): Distal Significant Peroneal Perforator.

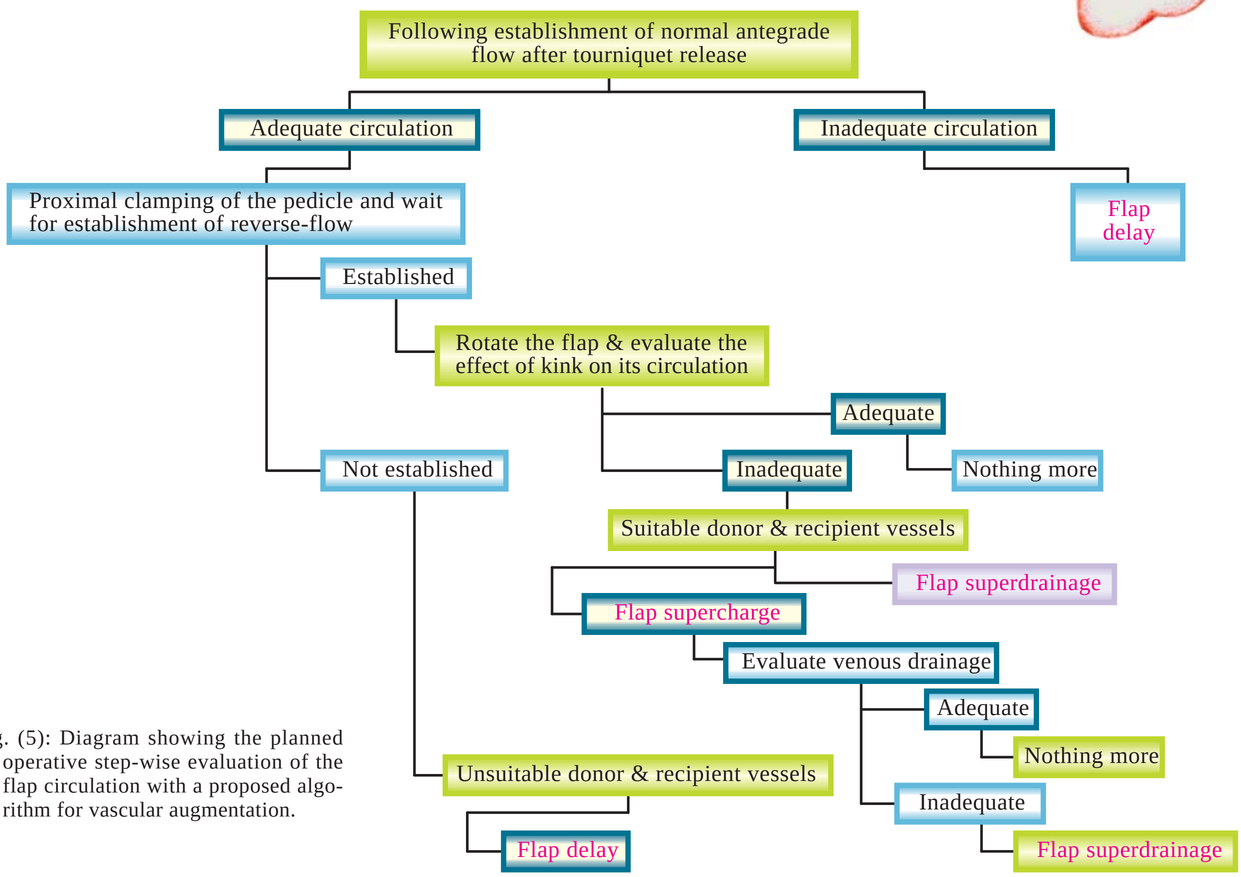

Fig. (5): Diagram showing the planned operative step-wise evaluation of the flap circulation with a proposed algorithm for vascular augmentation.

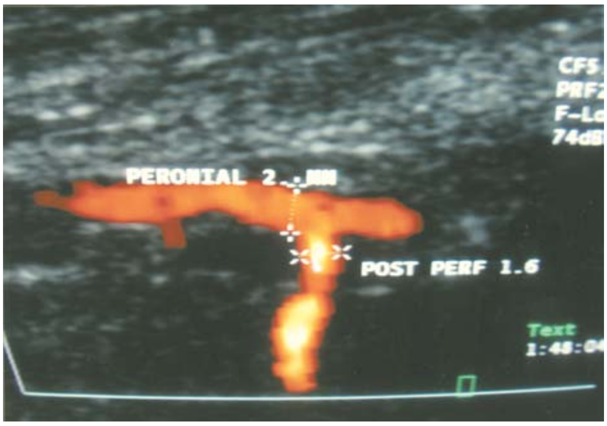

Fig. (6): Preoperative color flow duplex scan showing a DSPP of 1.6 mm in diameter.

Fig. (7-A): Preoperative view of exposed repaired tendoachillis.

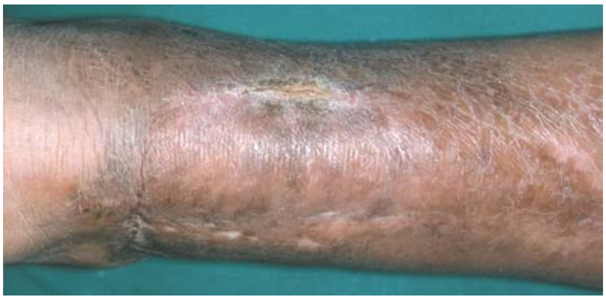

Fig. (7-B): Late postoperative view showing stable coverage of tendoachillis with a reverse-sural adipofascial flap.

Fig. (8-A): Preoperative view of a post-traumatic complex medial ankle defect.

Fig. (8-B): Postoperative view showing coverage with a reverse-sural fasciocutaneous flap.

Fig. (9-A)

Fig. (9-B)

Fig. (9)
(A): Preoperative view of a heel ulcer following diabetic foot infection.
(B): Late postoperative view showing stable coverage of the heel with a reverse-sural fasciocutaneous flap.

Fig. (10-A): Preoperative view of traumatic degloving of the heel.

Fig. (10-B): Late postoperative view showing stable coverage of the heel with a reverse-sural fasciocutaneous flap.

Table (1): Etiology of the defects.

Etiology of the defect	No. of patients (%)
Trauma	22 (81.5)
Diabetic infection	2 (7.5)
Pressure ulcer	1 (3.6)
Ischemia	1 (3.6)
Unstable scar	1 (3.6)

Table (2): Patient summary (initial phase).

Case	Ag (yrs), sex	Etiology of defect	Site of defect	Type of flap	Size of the flap (cm. length x width)	Flap morbidity	Donor site morbidity
1	19F	Traffic accident	Distal 1/3 leg	Adipofascial	8x5	Partial Necrosis & Unsightly scar	–
2	34M	Traffic accident	Dorsum of The foot	Adipofascial	6.5x4	Partial graft loss	–
3	11M	Traffic accident	Distal 1/3 leg	Adipofascial	8x4	Flap oedema	–
4	56M	Diabetic infection	Heel	Fasciocutaneous	10x7.5	Partial Necrosis	–
5	37M	Pressure ulcer	Heel	Fasciocutaneous	9x6	–	Infection & Partial graft Loss
6	16F	Traffic accident	Distal 1/3 leg	Adipofascial	5.5x4	Total Necrosis	–
7	22M	Traffic accident	Ankle	Adipofascial	5x4	Infection	–
8	26F	Traffic accident	Distal 1/3 leg	Fasciocutaneous	9x6	Flap oedema & Unsightly scar	Unsightly scar
9	13M	Fall from a height	Medial malleolus	Fasciocutaneous	6x3.5	Total necrosis	–
10	42M	Traffic accident	Back of the Heel	Adipofascial	7x5	–	–

Table (3): Patient summary (second phase).

Case	Ag (yrs) & sex	Etiology of defect	Site of defect	Type of flap	Size of the flap (cm. length x width)	Thickness of fasciocuta neous flap (cm)	Site of DSPP* (cm above lateral malleolus	Diameter of DSPP (mm)	Bl.FV in DSPP** ml/min	Need for vascular augmentation	Flap morbidity	Donor site morbidity
1	58M	Ischemia	Heel	Fasciocutan eous	14x8	0.7	4.2	1.4	3	–	Flap oedema	–
2	17F	Traffic accident	Dorsum of The foot	Adipofascial	13x8		3.7	1.1	3	–	Partial necrosis & Unsightly scar	–
3	9M	Unstable scar	Ankle	Fasciocutan eous	6x4	0.6	3.4	1.5	4	–	Infection	–
4	53M	Traffic accident	Ankle	Adipofascial	8x5.5		5.1	0.9	2	–	Trophic ulcer	–
5	26M	Traffic accident	Heel	Fasciocutan eous	12x7	1.6	4.8	1.1	3	Superdrainge	Flap oedema	–
6	38M	Traffic accident	Distal 1/3 leg	Fasciocutan eous	9x4.5	0.5	3.9	1.2	3	–		Infection & Partial graft loss & unsightly scar
7	23M	Fall from a heigh	Distal 1/3 leg	Fasciocutan-eous	7.5x5.5	0.8	4.6	1.3	3	–	Flap oedema	
8	30M	Traffic accident	Heel	Fasciocutan-eous	18x11	0.7	3.3	1.4	4	Flap delay	Infection	Partial graft Loss
9	39M	Traffic accident	Distal 1/3 leg	Adipofascial	10x7		5.4	1.2	3	Superdrainge	–	–
10	19F	Traffic accident	Ankle	Adipofascial	11x9		3.7	0.9	2	–	Partial necrosis & unsightly scar	–
11	48M	Traffic accident	Distal 1/3 leg	Fasciocutan-eous	8.5x6	0.4	4.5	1.1	2			–
12	24M	Traffic accident	Heel	Fasciocutan-eous	12x8	0.7	5.8	1.6	4	Supercharge	Flap oedema	–
13	35M	Traffic accident	Dorsum of The foot	Adipofascial	11x7.5		4.3	1.5	4	–	Partial graft loss & Flap oedema	Infection
14	62M	Traffic accident	Ankle	Fasciocutan-eous	6x4.5	0.6	4.9	1.3	3	–	–	–
15	12M	Traffic accident	Distal 1/3 leg	Fasciocutan-eous	7x4	0.3	4.7	1.2	2	–	–	–
16	60F	Diabetic infection	Heel	Fasciocutan-eous	16x10	1.1	3.5	1.3	4	Flap delay	Infection & trophic ulcer	
17	37M	Traffic accident	Distal 1/3 leg	Fasciocutan-eous	9x5	0.9	5.2	0.9	3		Flap oedema	

*DSPP: Distal significant peroneal perforator. ** Bl.FV in DSPP: Blood flow volume in DSPP.

Table (4): Complications of sural flaps.

Complication	Initial phase % out of 10 patients	Late phase % out of 17 patients	Total % out of 27 patients
Flap loss			
Partial	2 (20%)	2 (11.8%)	4 (14.8%)
Complete	2 (20%)	–	2 (7.4%)
Infection			
Flap	1 (10%)	3 (17.7%)	4 (14.8%)
Donor area	1 (10%)	2 (11.8%)	3 (11.1%)
Graft loss (donor area)			
Partial	1 (10%)	2 (11.8%)	3 (11.1%)
Complete	–	–	–
Graft loss (adipofascial flap)			
Partial	1 (10%)	1 (5.9%)	2 (7.4%)
Complete	–	–	–
Flap oedema	2 (20%)	6 (35.3%)	8 (29.6%)
Unsightly scar			
Flap	2 (20%)	2 (11.8%)	4 (14.8%)
Donor area	1 (10%)	1 (5.9%)	2 (7.4%)
Trophic ulcer	1 (10%)	1 (5.9%)	2 (7.4%)

DISCUSSION

Reconstruction of soft tissue defects around the ankle remains a demanding procedure in plastic surgery. The development of advanced technique in microsurgery and various designs of pedicled flaps have solved many problems that were presumed to be impossible to overcome in the past. However, the anatomical arrangement of the leg structures made most of the described regional flaps in-amenable to be applied in such situation, therefore, the option for ankle reconstruction is more prone to the usage of microsurgical free flaps **[5,7,13]**.

There are still some clinical situations in which the patients are not suitable for microsurgical procedures. The solution for limb reconstruction in these cases becomes compounded and stimulated the continued search for other reconstructive modalities **[3,4]**.

The concept of the neuroskin island flaps was first proposed by Masquelet et al. **[17]**. The vascular axis around the superficial sensory nerves ensures vascularization of the nerve and the cutaneous branches of the accompanying arteries of the superficial nerve are anastomosed with the septocutaneous arteries from the deep vessels. They described a flap utilizing the median superficial sural artery (which runs along the sural nerve) as its vascular axis with a distal base nourished through the distal peroneal perforators. Hasegawa refined this technique and first published the reverse sural flap **[19]**. The use of this flap received quick recognition with more clinical results reported in the next 4 years **[20,27]**.

The original clinical experiences, based on Masquelet anatomical report, stressed on the importance of limiting the flap extent only to that part of the leg that coincide with the suprafascial course of the sural nerve. This limitation of the flap territory restricted the applicability of this flap to larger and more distal defects **[17]**.

Some authors tried to extend the flap proximally on random pattern basis and they described their flaps as being unpredictable with high percent of loss of the distal portion of the flap **[14,30,31]**.

Further anatomical studies tried to find an answer concerning the role of the sub-fascial course of the sural nerve, short saphenous vein and their accompanying vessels, in irrigation of the skin of the upper part of the leg, they concluded that the inclusion of the neurovascular bundle with preservation of the mesenteric-like connection between it and the flap would ensure adequate irrigation of a more proximal territory of the flap that surely increased the flap dimensions, however, they were uncertain as to how large a flap could be elevated successfully [23,26,27].

Based on previous anatomical reports, the potentiality for reversal of arterial and venous flow in sural flaps is not absolute, also, other haemodynamic factors could play an influencing role in flap vascularity following establishment of flap circulation.

It is obvious that, to date, there is no answer about the flap extent, dimensions and reliability and although extensive anatomical studies tried to answer these questions, yet, these findings could not be exactly reproduced in real life contributing to a relatively high percent of partial flap necrosis in some series [20,25]. In my initial experience, the same conclusion was reached that led to a proposal to improve flap versatility, no matter its location, dimensions and the diameter of the distal peroneal perforator in correlation to size and destination of the skin island.

Adequate flap circulation in all phases of flap harvest assures safety of the procedure. Certain technical refinements should be considered in a trial to increase flap versatility. The definition of the DSPP based on a preliminary pilot study with its consequent impact on the preoperative duplex study, the correlation between the size and blood flow volume in the DSPP with the volume of the flap, the inclusion of the subfascial portion of the sural nerve, short saphenous vein and their accompanying vessels in continuity with the flap, assessment of the establishment of reverse arterial and venous flow to the flap and assessment of the flap circulation following flap inset to evaluate the effect of kink on the pedicle with consideration of vascular augmentation of the flap, when indicated, are all factors that should be considered in order to improve flap survival.

The important data achieved from a preoperative duplex scan was helpful in patient selection, flap planning and prediction of the possible need for vascular augmentation. The diameter of and blood flow volume in the distal significant peroneal perforator (DSPP) should point out to the potential territory of the flap. A small diameter of the DSPP, or a low blood flow volume in it, should not be considered a contraindication for using a large flap, but it arouses the possibility of adopting a vascular augmentation maneuver.

The thickness of the subcutaneous fat in the donor area of the flap is an important contributing factor in determing the flap territory, so, what should be considered more important is the flap volume rather than its surface area. It was noticed that the small peroneal perforator that could support a flap with a large surface area could not support a flap with a large volume. It should be emphasized that inadequate flap circulation, following the establishment of normal ante grade flow, after tourniquet release, could be attributed to a large flap volume that necessitated flap delay as the sole way for vascular augmentation in such condition.

The appreciated role of handy Doppler in this study was unmistakable. Although it could not fulfill the above mentioned requirements for providing flap safety if compared to duplex scan results, yet the patient selection based on handy Doppler evaluation in emergency situation was considered of a paramount importance. Also it played the major role in the intraoperative evaluation of flap circulation that helped to create an algorithm for vascular augmentation. Finally, accurate postoperative flap monitoring was achieved using a handy Doppler.

The location and dimensions of the flap is determined according to the site and size of the defect regardless the diameter of the distal peroneal perforator as previously stated. A uniform relationship between the diameter of the distal peroneal perforator and the volume of the flap could not be settled. Although a direct proportion is found in most cases, yet there were some exceptions that call for the need for vascular augmentation when the volume of the flap exceeds the limit of the vascular territory of a small peroneal perforator.

Every effort should be made to preserve the unity of the flap with its neurovascular bundle in its subfascial course. Some authors believe that they have to preserve a cuff of gastrocnemius muscle on either sides of the mesenteric attachment between the flap and its neurovascular bundle. This modification was tried in one adipofascial flap, that survived well, while the muscle cuff did not, which could be attributed to a non-constant vascular pattern of this muscle cuff. It was found that this modification is not useful if careful dissection is made down to the raphe in between the 2 heads of gastrocnemius muscle that ensure the unity preservation between the flap and its neurovascular bundle (Figs. 2,3).

Two important points now would play a critical role in flap survival, namely, the question about the establishment of reverse arterial and venous flow through the axial vessels and the effect of kink on the pedicle following flap inset. Although the subjective evaluation of flap circulation always have a major role intraoperatively as well as in the early postoperative period, yet, a more objective evaluation would have a better impact on the overall flap survival with early detection and management of vascular problems. Evaluation of the axial arterial and venous flow in both steps using a sterile probe of handy Doppler will assure a more precise evaluation of flap circulation and define selection criteria for flaps demanding vascular augmentation. Based on the anatomical fact that both sural artery and short saphenous vein lie separately in their subfascial course, this would facilitate eliciting a clear Doppler signal from both artery and vein in that segment intraopatively. Marking these points on a corresponding points on the surface of the flap facilitate postoperative flap monitoring with Doppler probe.

The strategy of improving flap survival through vascular augmentation based on precise operative evaluation of flap circulation was introduced following an initial experience with 10 cases with unsatisfactory results (first phase). In the following 17 cases (second phase), a step-wise evaluation of flap circulation helped to propose an algorithm for vascular augmentation that, in turn, remarkably improved the flap survival, hence, its versatility (Fig. 5).

Vascular augmentation was needed in the following situations:

1- The need for a flap with large volume that exceed the vascular territory of a small peroneal perforator.

2- Interruption of the short saphenous vein in its distal segment.

3- Non-establishment of a reverse-flow after clamping of both sural artery and short saphenous vein.

4- Arterial and/or venous insufficiency after flap inset, caused by twist of the pedicle, either immediately or in the early postoperative period.

Flap delay, arterial supercharge, venous superdrainage are the possible modes for vascular augmentation. If suitable flap and recipient vessels are available and could be brought aside comfortably and directly without the need for a vein graft, then supercharge and/or superdrainge is preferred, otherwise, flap delay is elected.

Vascular augmentation was needed in 5 out of 17 flaps of the second group of patients (29.4%) that achieved flap survival in all cases except 2 with partial flap necrosis (11.8%). There was a remarkable improvement in flap survival in comparison with the first group of patients (40% out of 10 cases). This remarkable improvement of flap survival when adopting the policy of vascular augmentation make this flap, when available, extremely reliable in reconstructing the most complicated defects around the ankle.

The choice between using fasciocutaneous or adipofascial flap depends mainly on the requirement of the defect. Defects over pressure areas are considered an absolute indication for using fasciocutaneous flap, otherwise defects could accept and tolerate either of them. A thick subcutaneous fat within the potential territory of the flap, although not considered a contraindication, is considered a limiting factor for choosing the fasciocutaneous variety. Most authors preferred to use fasciocutaneous flap as it gives a more stable and durable wound coverage, a requirement that should be fulfilled in reconstruction of defects in such areas. This advantage is remarkably appreciated in this series. Another advantages of fasciocutaneous flap are their reliability with better survival over adiposofascial flap, easier dissection with less operative time and more reliable postoperative monitoring. Also, it seemed that the fasciocutaneous flap could withstand the axial rotation much better than the effect of turn-over on the adiposofascial flap. Although fasciocutaneous flap is much more preferable, yet the minimal morbidity of the donor site in adipofascial flap, especially in female patients, should be weighed in face of the great advantages of the fasciocutaneous variant of this flap **[28]**.

The tight skin around the defect either caused by the inflammatory edema or fibrotic induration, as an influence of trauma, made tunneling of the flap hazardous which might have a bad impact on the vascularity of the flap. In my initial experience, the author used to lay open the skin bridge and apply a graft over the pedicle. Inadequate graft take might expose the flap pedicle to the risk of infection that could endanger the flap itself. The later modification of the skin island in the form of a V-shape extension towards the pivot point in dimensions that allow comfortable adaptation in the corresponding V-cut of the tough skin nearby the defect avoided the risk of applying a graft over the pedicle, besides it added no further morbidity to the donor site as it was almost exclusively closed primarily. Another potential advantage of this V-shape modification is that it acts to stabilize the critical vascular pattern of the pedicle during its axial rotation minimizing the post-insetting vascular problems (Fig. 1).

The overall incidence of complications other than flap loss, though apparently high, are not considered that serious which would prohibit or limit the use of this flap. The only serious complication is the lack of adequate protective sensation that could potentially induce a trophic ulcer. This problem was found in 2 patients whom were treated in a conservative way till the moment, however those patients eventually will need further surgical intervention. This complication could be prevented if flap neurosensitization is performed **[28]**.

In conclusion, this work passed into several phases of refinement of the flap to improve its survival and reduce complications. A thorough preoperative flap planning based on duplex study, the inclusion of the subfascial course of both median superficial sural artery and short saphenous vein with preservation of the mesenteric connection between this vascular axis and the fascial element of the flap, the proposition of an algorithm for vascular augmentation and the V-shape extension of the skin island, are all factors that acted to optimize the ultimate results of this flap. Although it seemed reasonable to study the correlation between the flap volume and the diameter of the DSPP, yet, no standard correlation could be settled within the scope of this work. The only drawback in the fasciocutaneous variant of this flap when used to cover a weight-bearing area is the exposure to repeated ulceration, however this complication could be avoided if flap neuro-sensitization is performed and adequate postoperative protection and instructions are strictly followed.

REFERENCES

1- Maruyama Y., Iwahira Y. and Ebihara H.: V-Y advancement flaps in the reconstruction of skin defects of the posterior heel and ankle. Plast. Reconstr. Surg., 5: 759-64, 1985.

2- Hallock G.G.: Distal lower leg local random fasciocutaneous flaps. Plast. Reconstr. Surg., 2: 304-11, 1986.

3- Clark N. and Sherman R.: Soft tissue reconstruction of the foot and ankle. Orthop. Clin. North Am., 3: 489-503, 1993.

4- Attinger C. and Cooper P.: Soft tissue reconstruction for calcaneal fractures or osteomyelitis. Orthop. Clin. North Am., 1: 135-70, 2001.

5- Levin L.S.: Soft tissue coverage options for ankle Wounds. Foot Ankle Clin., 4: 853- 66, 2001.

6- Tobin G.R.: Hemisoleus and reversed hemisoleus flaps. Plast. Reconstr. Surg., 1: 87-96, 1985.

7- Chen H.C., Tang Y.B. and Noordhoff M.S.: Distally based gastrocnemius myocutaneous flap augmented with an arterial anastomosis – a combination of myocutaneous flap and microsurgery. J. Trauma, 1: 110-4, 1988.

8- Duman H., Er E., Isik S., Turegun M., Deveci M., Nisanci M. and Sengezer M.: Versatility of the medial planter flap: Our clinical experience. Plast. Reconstr. Surg., 3: 1007-12, 2002.

9- Mooney J.F. 3rd, De Franzo A. and Marks M.W.: Use of cross-extremity flaps stabilized with external fixation in severe pediatric foot and ankle trauma: an alternative to free tissue transfer. J. Pediatr. Orthop., 1: 26-30, 1988.

10- Wee J.T.: Reconstruction of the lower leg and foot with the reverse-pedicle anterior tibial flap: preliminary report of a new fasciocutaneous flap. Br. J. Plast. Surg., 3: 327-37, 1986.

11- Chuenkongkaew T., Chayakula N. and Srirojanakul S.: Reverse flow posterior tibial island flap: preliminary report of a new fasciocutaneous flap. Ann. Plast. Surg., 4: 306-10, 1990.

12- Shalaby H.A.: The distally based peroneal island flap. Br. J. Plast. Surg., 1: 23-6, 1995.

13- Heller L. and Levin L.S.: Lower extremity microsurgical reconstruction. Plast. Reconstr. Surg., 4: 1029-41, 2001.

14- De Almeda O.M., Monteiro A.A. Jr. , Neves R.I., De Lemos R.G., Braz J.C., Brechtbuhl E.R., Gemperli R. and Ferreira M.C.: Distally based fasciocutaneous flap of the calf for cutaneous coverage of the lower leg and dorsum of the foot. Ann. Plast. Surg., 4: 367-73, 2000.

15- Skoll P.J.: The distally based dermo-adipofascial flap. Plast. Reconstr. Surg., 2: 620-24, 2001.

16- Koshima I., Itoh S., Nanba Y., Tsutsui T. and Takahashi Y.: Medial and lateral malleolar perforator flaps for repair of defects around the ankle. Ann. Plast. Surg., 6: 579-83, 2003.

17- Masquelet A.C., Romana M.C. and 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., 89: 1115-21, 1992.

18- Rajacic N., Darweesh M., Jaykrishnan K., Gang RK. and Kojic S.: The distally based superficial sural flap for reconstruction of the lower leg and foot. Br. J. Plast. Surg., 49: 383, 1996.

19- Hasegawa M., Torii S., Katoh H. and Esaki S.: The distally based superficial sural artery flap. Plast. Reconstr. Surg., 93: 1012, 1994.

20- Jeng S.F. and Wei F.C.: Distally based sural island flap for foot and ankle reconstruction. Plast. Reconstr. Surg., 99: 744, 1997.

21- Batchelor J.S. and McGuinness A.: A reappraisal of axial, non-axial lower leg fascial flaps. An anatomic study in human cadavers. Plast. Reconstr. Surg., 97: 993, 1996.

22- Imanishi N., Nakajima H., Fukuzumi S. and Aiso S.: Venous drainage of the distally based lesser saphenous-sural veno-neuro-adipofascial pedicled fasciocutaneous flap: A radiographic perfusion study. Plast. Reconstr. Surg., 103: 494, 1999.

23- Nakajima H., Imanishi N., Fukuzumi S., Minabe T., Fukui Y., Miyasaka T., Kodama T., Aiso S. and Tujino T.: Accompanying arteries of the lesser saphenous vein and sural nerve: Anatomic study and its clinical application. Plast. Reconstr. Surg., 103: 104, 1999.

24- Le Fourn B., Caye N. and Pannier M.: Distally based sural fasciomuscular flap: anatomic study and application for filling leg or foot defects. Plast. Reconstr. Surg., 107: 67, 2001.

25- Yang D. and Morris S.: Plast. Reconstr. Surg. F. Reversed sural island flap supplied by the lower septocutaneous perforator of the peroneal artery. Ann. Plast. Surg., 49: 375, 2002.

26- Al-Qattan M.M.: A modified technique for harvesting the reverse sural artery flap from the upper part of the leg: inclusion of a gastrocnemius muscle cuff around the sural pedicle. Ann. Plast. Surg., 47: 269, 2001.

27- Ayyappan T. and Chadha A.: Super sural neurofasciocutaneous flaps in acute traumatic heel reconstructions. Plast. Reconstr. Surg., 109: 2307, 2002.

28- Price M.F., Capizzi P.J., Watterson P.A. and Lettieri S.L.: Reverse sural artery flap: Caveats for success. Ann. Plast. Surg., 48: 496, 2002.

29- Torii S., Namiki Y. and Mori R.: Reverse-flow island flap: clinical report and venous drainage. Plast. Reconstr. Surg., 79: 600, 1987.

30- Fraccalvieri M., Verna G. and Dolcet M.: The distally based superficial sural flap. Our experience in reconstructing the lower leg and foot. Ann. Plast. Surg., 45: 132, 2000.

31- Jeng S.F., Wei F.C. and Kuo Y.R.: Salvage of the distal foot using the distally based sural island flap. Ann. Plast. Surg., 43: 499, 1999.