JOURNAL OF PLASTIC SURGERY AND HAND SURGERY
2021, VOL. 55, NO. 4, 242–248
https://doi.org/10.1080/2000656X.2020.1858843

ARTICLE

Outcome of distal lower leg reconstruction with the propeller perforator flap in diabetic patients

Kyubeom Kim[a], Junhyung Kim[a], Woonhyeok Jeong[a], Taehee Jo[a], Sang Woo Park[b]* and Jaehoon Choi[a]*

[a]Department of Plastic and Reconstructive Surgery, Keimyung University School of Medicine, Daegu, Republic of Korea; [b]Department of Plastic and Reconstructive Surgery, Samsung Changwon Hospital, Sungkyunkwan University School of Medicine, Changwon, Republic of Korea

ABSTRACT

In diabetic foot patients, wound coverage options are quite limited due to vascular abnormalities. However, even though significant atherosclerotic changes are found in major vessels of the lower leg in diabetic foot patients, perforating vessels, which are used as the vascular pedicle of propeller perforator flaps, are often spared from atherosclerosis. Therefore, the propeller perforator flap could be an alternative option for diabetic foot patients. The purpose of this study was to compare the outcome of the propeller perforator flap between diabetic and nondiabetic patients in reconstruction of the distal lower leg. We retrospectively included all patients who underwent reconstruction of the distal lower leg with a propeller flap between 2014 and 2018. Thirty-five propeller perforator flaps in 20 diabetic patients and 15 nondiabetic patients were included. Of the 35 patients, 21 showed complete healing, and 14 showed flap complications. The rate of complications in diabetic patients was approximately 85.7%. Sex ($p = .002$), diabetes ($p = .007$), chronic renal failure ($p < .001$), and diabetic neuropathy ($p = .011$) were associated with flap complications. Crude regression analysis showed that the female sex ($p = .002$), diabetes ($p = .01$), and diabetic neuropathy ($p = .012$) were significant risk factors for the occurrence of any complications, but the significance of diabetes and diabetic neuropathy was not maintained in the adjusted models. Therefore, the propeller perforator flap might not be effective for reconstructing diabetic foot ulcers.

ARTICLE HISTORY
Received 23 August 2020
Revised 25 November 2020
Accepted 29 November 2020

KEYWORDS
propeller perforator flap; distal lower leg reconstruction; diabetic foot; medial calcification

Introduction

In diabetic foot patients with medium or large wounds, wound coverage options are quite limited due to delayed wound healing, poor vascularity, uncontrolled infection or comorbidities. Recently, many studies have reported favorable results of microvascular free flaps in the reconstruction of diabetic foot ulcers [1,2]. However, the complication rates of free flaps remain high in diabetic patients [3,4]. In addition, the relatively prolonged operative duration required for free-flap reconstruction could systemically exacerbate the general health of diabetic patients with comorbidities, such as cardiovascular disease or chronic renal failure (CRF).

The propeller perforator flap is a local island fasciocutaneous flap made of two paddles of unequal length, separated by the nourishing perforating vessel forming the pivot point [5]. The propeller perforator flap has several advantages like the lack of a need for microvascular anastomosis, which can shorten the operation and yield minimum donor site morbidity compared to free flaps [6]. Hong noted that although significant atherosclerotic changes are found in the major vessels of the lower leg in diabetic foot patients, perforating vessels, which are used as the vascular pedicle of propeller perforator flaps, are often spared from atherosclerosis [7]. Recently, Ioannis *et al.* [8] and Jiga *et al.* [9] reported favorable results of propeller flaps in diabetic foot patients. Therefore, the propeller perforator flap could be an alternative option for diabetic foot patients. However, diabetic vasculopathy is commonly associated with microvascular injury as well as macrovascular injury, like atherosclerosis [10]. The complication rate in diabetic patients treated with perforator flaps can be affected by other factors, like impaired microcirculation. Ioannis *et al.* [8] and Jiga *et al.* [9] reported favorable results with the use of propeller flaps in diabetic foot patients, but these reports were small case series, and the authors did not compare the outcome with that in nondiabetic patients. Therefore, the purpose of this study was to compare the outcome of the propeller perforator flap between diabetic and nondiabetic patients and analyze factors affecting the outcome of the propeller perforator flap in reconstruction of the distal lower leg.

Patients and methods

Patients

We retrospectively included all patients who underwent reconstruction of the distal lower leg with the propeller flap at our institution between 2014 and 2018. The study was conducted after obtaining approval from the Institutional Review Board of Keimyung University (2019-06-046). Thirty-five patients had small to medium defects that were up to 50 cm^2 in size, with tendon or bone exposure [11]. The flap surgery was performed by one surgeon (JC) regardless of an abnormal ankle-brachial index (ABI) or an arterial abnormality on computed tomography (CT) angiography. Medical charts were reviewed for demographic characteristics, preoperative factors, such as obesity (body mass index $\geq$30), smoking status, and comorbidities, source of the perforator vessel, arc of flap rotation, and complications. The patients were divided

CONTACT Jaehoon Choi psjchoi@dsmc.or.kr Department of Plastic and Reconstructive Surgery, Keimyung University School of Medicine, 1035 Dalgubeol-daero, Dalseo-gu, Daegu, 42601, Republic of Korea
*Jaehoon Choi and Sang Woo Park contributed equally to this paper as corresponding authors.

into two groups as follows at 1 month postoperatively according to the operative outcome: a complete healing group, consisting of patients showing perfect healing without further treatment; and a complication group, consisting of patients requiring additional treatments or procedures, such as a skin graft, a local flap, reconstruction with new flap, or amputation. We classified complications into two groups; major and minor complications. Major complications were defined as partial or total flap necrosis that needed surgical intervention postoperatively. Complications cured with conservative treatment without surgical intervention postoperatively were considered minor complications.

Operative technique

Peroneal artery perforator-based propeller flaps were preferred for defects of the lateral malleolus and heel, while posterior tibial artery perforator-based propeller flaps were utilized for defects of the medial malleolus, foot dorsum and pretibia. Anterior tibial artery perforator-based propeller flaps were used for defects of the pretibia and foot dorsum.

After general or spinal anesthesia was induced, a thigh tourniquet was applied to the leg without exsanguination to allow easier identification of the perforators during exploration. After surgical debridement of any necrotic or infected tissue, the flap was designed with respect to the defect. Under loupe magnification, an exploratory incision was made in one of the anterior margins of the flap design to confirm the targeted perforator. Perforator vessel patency was checked with a handheld Doppler flowmeter preoperatively and intraoperatively, and after we raised all boundaries of the flap, we checked for the presence of fresh bleeding on all flap margins before flap rotation for at least 10 min. If the perforator vessel was reliable, all boundaries of the flap were raised with subfascial or suprafascial dissection. The septum surrounding the perforator was gently dissected to prevent kinking of the vessel when the flap was rotated. We chose a direction of rotation that did not cause vessel kinking. Once flap perfusion was verified after flap rotation, inset of the flap into the original defect was performed. If the donor site defect could not be closed primarily, a split-thickness skin graft was used preferentially to cover the defect.

Statistical analysis

Measurement data are expressed as median (range). Fisher's exact test and the Mann–Whitney U test were used to compare the factors between the nondiabetic and diabetic groups as well as between the complete healing and complication groups. A logistic regression model was used to determine the risk factors for flap complications. All the statistical analyses were performed using Stata 14.0 (Stata Co., College Station, TX, USA). p Values $<$ .05 were considered statistically significant.

Results

In all, 35 patients were included: 24 men and 11 women, with a mean age of 61 years (range = 30–79 years). Reconstruction was performed under general anesthesia in 29 patients and under spinal anesthesia in 6 patients. Of the patients, 20 had diabetes, 18 had hypertension, 11 had CRF, and 11 had diabetic neuropathy. The defects were in the lateral malleolus ($n = 15$), heel ($n = 10$), anterior tibia ($n = 6$), medial malleolus ($n = 2$), and foot dorsum ($n = 2$). The average defect size was 31 cm^2 (range = 4–250 cm^2). The causes of the defects were diabetic foot ulcer ($n = 20$), posttraumatic ($n = 4$), bursitis ($n = 2$), burn injury ($n = 2$), cellulitis ($n = 2$), oncological resection ($n = 2$), venous ulceration ($n = 1$), chronic ulceration ($n = 1$) and postoperative complication of orthopedic surgery ($n = 1$) (Table 1).

The source arteries of the perforator flap were the peroneal, posterior tibial, and anterior tibial arteries in 22, 10 and 3 cases, respectively. The arc of rotation of all flaps was 150–180°. Twenty-one patients showed complete healing, and 14 showed flap complications. Among all patients with complications, 8 had major complications and 6 had minor complications. Of the patients with partial necrosis, 9 patients had venous congestion, and 2 patients had wound dehiscence; in 6 patients, the defects were healed by secondary intention, while in 5 patients, the defects were treated with vacuum-assisted closure (VAC), followed by a skin graft. Of the patients with total necrosis, 2 patients had venous congestion, and 1 patient had arterial insufficiency; in 1 patient, the defect was treated with VAC, followed by a skin graft, while in the 2 other patients, no additional surgery was performed considering the patients' poor general condition. Donor sites were treated with primary closure in 24 cases and with a skin graft in 11 cases (Figures 1–5).

Sex, diabetes, CRF, and diabetic neuropathy were associated with flap complications. However, age, defect size, smoking, hypertension, and obesity were not associated with flap complications. Crude logistic regression analysis showed that the female sex ($p = .002$), diabetes ($p = .01$), and diabetic neuropathy ($p = .012$) were significant risk factors for the occurrence of any complications, but the significance of diabetes ($p = .209$) and diabetic neuropathy ($p = .358$) was not maintained in the adjusted models. Although all patients with CRF had flap complications, statistical significance was not obtained because analysis of one hundred percent failure is impossible in the logistic regression model. If more patients with CRF were included, this factor would be the most significant (Tables 2–4).

Discussion

In our study, the complication rate in the diabetic patients was approximately 60%. This rate was higher than that in other reports on the reconstruction of diabetic foot ulcers with the propeller perforator flap. Ioannis *et al.* and Jiga *et al.* noted complication rates of 17% and 33%, respectively [8,9]. However, their results were limited in that they were derived from small case series (6 cases). In a study by Ioannis *et al.*, the arc of rotation of the propeller perforator flap was smaller (45°–180°) than that in our study (150°–180°). The arc of rotation could affect the outcome of the propeller perforator flap because a larger arc of rotation is associated with a higher complication rate [12]. Georgescu *et al.* reported the outcome of the propeller perforator flap in 25 cases of diabetic foot ulcers [13]. They noted that complete healing was not achieved in 19 cases (76%) 1 month postoperatively.

In our study, diabetes was significantly associated with flap complications. In general, it is considered that the unpredictable reduction and loss of blood flow in diabetic vessels causes flap complications. After checking the reliability of the perforator vessel intraoperatively with a handheld Doppler flowmeter and checking for the presence of fresh bleeding on the flap margins, we thoroughly dissected all fascial strands and soft tissues around the perforator to prevent kinking of the perforator vessel upon flap rotation. Despite skeletonizing the vessel completely and confirming the viability of the flap before rotation, most flap complications occurred after flap rotation in diabetic patients. This may be because of the intrinsic structural change in the vessel wall

Table 1. Patient summary.

No.	Location of wound	Size (cm^2)	Perforator source vessel	Diabetes	Complications
1	Lateral malleolus	2 × 2	PA	Y	None
2	Foot dorsum	2 × 2	ATA	Y	None
3	Lateral malleolus	2 × 2	PA	Y	None
4	Anterior tibia	10 × 25	ATA	N	None
5	Heel	5 × 13	PTA	N	None
6	Lateral malleolus	2 × 13	PA	N	None
7	Anterior tibia	10 × 7	PTA	N	None
8	Heel	5 × 8	PA	Y	Partial flap necrosis
9	Heel	5 × 8	PTA	Y	Wound dehiscence
10	Heel	3 × 3	PTA	Y	Partial flap necrosis
11	Foot dorsum	6 × 6	ATA	N	None
12	Lateral malleolus	4 × 4	PA	N	None
13	Medial malleolus	5 × 5	PTA	Y	None
14	Lateral malleolus	7 × 7	PA	Y	None
15	Anterior tibia	6 × 4	PA	N	None
16	Lateral malleolus	3 × 3	PTA	Y	Partial flap necrosis
17	Lateral malleolus	3 × 3	PA	Y	None
18	Lateral malleolus	6 × 5.5	PA	Y	None
19	Anterior tibia	10 × 5	PA	Y	Total flap necrosis
20	Heel	3 × 3	PA	Y	None
21	Lateral malleolus	5 × 5	PA	N	None
22	Heel	3 × 3	PA	Y	Partial flap necrosis
23	Medial malleolus	12 × 8	PTA	N	None
24	Heel	4 × 5	PA	Y	Total flap necrosis
25	Heel	5 × 3	PA	N	Partial flap necrosis
26	Lateral malleolus	3 × 3	PA	N	None
27	Anterior tibia	5 × 3	PTA	N	None
28	Lateral malleolus	4 × 4	PA	N	Partial flap necrosis
29	Lateral malleolus	2 × 6.5	PA	Y	Partial flap necrosis
30	Lateral malleolus	2 × 3	PA	N	None
31	Lateral malleolus	5 × 6	PA	Y	Partial flap necrosis
32	Heel	3 × 3	PTA	Y	Wound dehiscence
33	Lateral malleolus	11 × 2	PA	Y	Total flap necrosis
34	Anterior tibia	3 × 2	PTA	Y	Partial flap necrosis
35	Heel	2 × 2	PA	N	None

PA: peroneal artery; PTA: posterior tibial artery; ATA: anterior tibial artery; Y: yes; N: no.

Figure 1. (Left) A 72-year-old man with a 6x5 cm chronic ulceration on the lateral malleolus underwent treatment with a peroneal artery perforator-based propeller flap. (Right) Four weeks postoperatively.

Figure 2. (Left) A 74-year-old man with a chronic wound with plate exposure on the lateral malleolus underwent treatment with a peroneal artery perforator-based propeller flap. (Right) Four weeks postoperatively.

caused by diabetes. Diabetes is well known to affect vessel walls and lead to vascular calcification. There are two types of vascular calcification: medial and intimal vascular calcification. Calcification of the intima is a feature of atheroma (atherosclerotic calcification) associated with luminal narrowing and tends to be more proximal. Intimal calcium deposition in the context of atherosclerosis is mostly observed in the coronary arteries and large vessels [14]. On the other hand, medial calcification is characterized by the deposition of hydroxyapatite, mainly localized in peripheral vessels, with deposition along the elastic lamina and extracellular matrix [15]. Medial calcification, which is known as Monckeberg medial sclerosis, frequently occurs in the lower extremity vessels of diabetic patients and is associated with vascular stiffening [16,17]. In the lower extremity vessels of diabetic patients, medial vascular calcification occurs earlier than intimal calcification [18]. Therefore, vessels in the lower extremities of diabetic patients can have severe vascular stiffening even if the vessel blood flow is intact. The vessel's intrinsic stiffness could yield a high possibility of vessel kinking upon propeller perforator flap rotation despite the surgeon's delicate dissection. In some cases, we could visually check the medial calcification of the perforator vessel. In normal perforator vessels, vein engorgement is observed after tourniquet inflation. However, in the case of a perforator vessel with severe medial calcification, the vessel appears as a single white and rigid cord-like structure without demarcation between the artery and vein (Figure 6). Therefore, intrinsic changes in the perforator vessel may have contributed to the high complication rate of the propeller perforator flap in diabetic patients. Diabetic vasculopathy is commonly associated with microvascular injury as well as macrovascular injury. Microcirculation changes in diabetic patients can be another cause of propeller perforator flap complications. Diabetes is known to lead to microvascular changes that can hamper flap microperfusion [19]. Diabetic neuropathy, which was associated with flap complications in our study, is also closely related to the impaired microcirculation [20]. Therefore, impaired microcirculation may be one of the causes of propeller perforator flap complications.

Figure 3. (Left) A 48-year-old woman with a 2x2 cm wound with Achilles tendon exposure underwent treatment with a peroneal artery perforator-based propeller flap. (Right) One week postoperatively.

Figure 4. (Left) A 60-year-old man with a 3x3 cm chronic wound on the lateral malleolus due to infective bursitis underwent treatment with a peroneal artery perforator-based propeller flap. (Right) Four weeks postoperatively.

Diabetic neuropathy and nephropathy were significantly associated with flap complications in our study. These factors occur in the progression of diabetes. Therefore, they are strongly associated with the possibility of vessel stiffness and impaired microcirculation. Additionally, many studies have proven that diabetic neuropathy and nephropathy are related to medial arterial calcification [15,21–23]. Edmonds *et al.* [21] and Young *et al.* [22] found medial arterial calcification in a greater percentage of diabetic patients with neuropathy than diabetic patients without neuropathy. McCullough *et al.* [23] and Mackey *et al.* [15] noted that medial arterial calcification is very common in CRF patients. Therefore, diabetic neuropathy and nephropathy are predictive definite factors of vessel stiffness in diabetic foot patients compared to patients who do not have these complications.

Paik *et al.* [12] suggested that the complication rate was higher in flaps with an arc of rotation between 150° and 180° than flaps with an arc of rotation less than 150°. On the other hand, others suggested that torsion had no effect on vascular patency. Bekara *et al.* [24] evaluated the risk factors of perforator-pedicled propeller flap failure in lower extremity defects. They noted no significant difference in flap complications between a rotation of less than 120° and greater than 120°. Amoroso *et al.* [25] reported that in a study of superficial inferior epigastric artery flaps in a rat model, twisting the pedicle by 90, 180, and 270° had no effect on

Figure 5. (Left) A 51-year-old man with an 8x6 cm wound with tendon exposure on the ankle underwent treatment with a posterior tibial artery perforator-based propeller flap. (Left center) Intraoperatively. (Right center) Two days postoperatively; venous congestion. (Right) Two weeks postoperatively; partial necrosis.

Table 2. Differences in the preoperative factors between the complete healing and complication (minor and major) groups.

	Complete Healing Group ($n = 21$)	Complication Group: Minor Complications ($n = 6$)	Complication Group: Major Complications ($n = 8$)	p
Age	60 (40–91)	62 (42–75)	61 (30–77)	.637
Sex				
Male	19 (90.48)	3 (50.00)	2 (25.00)	.002*
Female	2 (9.52)	3 (50.00)	6 (75.00)	
Defect size	24 (1–250)	38 (3–40)	35 (9–50)	.735
Smoking	9 (42.86)	3 (50.00)	3 (37.50)	>.999
Hypertension	8 (38.10)	4 (66.67)	6 (75.00)	.086
Diabetes	8 (38.10)	5 (83.33)	7 (87.50)	.007*
CRF	0 (0.00)	4 (66.67)	7 (87.50)	<.001*
DM neuropathy	3 (14.29)	2 (33.33)	6 (75.00)	.011*
Obesity	4 (19.05)	1 (16.67)	5 (62.50)	.151

*$p < .05$.

Table 3. Differences in the factors between the nondiabetic and diabetic groups.

	Nondiabetic Group ($n = 15$)	Diabetic Group ($n = 20$)	p
Age	63 (46–91)	59 (30–77)	.594
Sex			.069
Male	13 (86.67)	11 (55.00)	
Female	2 (13.33)	9 (45.00)	
Defect size	46 (3–250)	20 (1–50)	.159
Smoking	6 (40.00)	9 (45.00)	>.999
Hypertension	6 (40.00)	12 (60.00)	.315
CRF	0 (0.00)	11 (55.00)	.001*
DM neuropathy	0 (0.00)	11 (55.00)	.001*
Obesity	3 (20.00)	7 (35.00)	.458
Flap complication	2 (13.33)	12 (60.00)	.007*

*$p < .05$.

Table 4. Results of logistic regression analysis of flap complication data.

	Crude		Adjusted	
	OR (95% CI)	p	OR (95% CI)	p
Sex				
Male	Reference	–	Reference	–
Female	17.10 (2.77–105.70)	.002*	12.53 (1.70–92.26)	.013*
Age	0.98 (0.93–1.03)	.431		
Defect size	0.98 (0.95–1.01)	.304		
Smoking	1.00 (0.25–3.92)	>.999		
Hypertension	4.06 (0.95–17.42)	.059		
Diabetes	9.75 (1.72–55.37)	.01*	4.27 (0.44–41.15)	.209
CRF	–	–		
DM neuropathy	8.00 (1.59–40.30)	.012*	2.76 (0.32–24.08)	.358
Obesity	3.19 (0.70–14.56)	.135		

* $p < .05$.

flap survival. However, 360° pedicle torsion resulted in flap edema, congestion, and necrosis. Wang *et al.* [26] reported that the 360° arc of pedicle torsion had no detrimental effect on dynamic perforasome perfusion or survival in a study of intercostal artery perforator flaps in a rat model. Bektas *et al.* [27] found that 360° of torsion did not affect perforator flap viability in a study of bilateral posterior thigh perforator-based flaps in a rat model. However, the abovementioned studies used propeller flaps with intact vessel walls. Therefore, in vessels with medial vascular calcification, an arc of rotation less than 150° might be considered for favorable flap survival.

Taeger *et al.* [28] noted that pedicled perforator flaps can be raised with width:length ratios up to 1:5. In a study by Mehrotra *et al.* [29], the largest ratio of flap width to length for a peninsular perforator flap could approach 1:4.5. In our study, the ratio of flap width to length did not exceed 1:4. However, in several patients with diabetes, venous congestion occurred in the distal portion of the flap, which resulted in partial flap loss. Saint-Cyr *et al.* [30] noted that hyperperfusion of a single perforator can capture multiple adjacent perforator vascular territories through direct and indirect linking vessels. Diabetes is known to lead to microvascular changes that can hamper flap microperfusion. Therefore, impaired microcirculation may occurred in the distal and less-vascularized portion of the flap through the dysfunction of the linking vessels caused by microvascular injury in diabetic patients [19,31]. Recently, many researchers have evaluated the microperfusion of the perforator flap using indocyanine green fluorescence angiography [32–34]. Further studies will need to investigate the appropriate ratio of flap width to length for perforator flaps in diabetic patients using indocyanine green fluorescence angiography.

There are several limitations to our study. First, this study was not a randomized control study and could have selection bias. Second, it was a retrospectively designed study. Third, our study was a relatively small-scale study for comparing two groups and performing a risk factor analysis. Despite these disadvantages, a single experienced surgeon performed all of the abovementioned procedures in a single center, and to the best of our knowledge, this is the largest study to compare the outcome of the propeller perforator flap between diabetic and nondiabetic patients.

Conclusions

We found that diabetic patients had a significantly higher flap complication rate than nondiabetic patients. This may be because of medial vascular calcification and impaired microcirculation

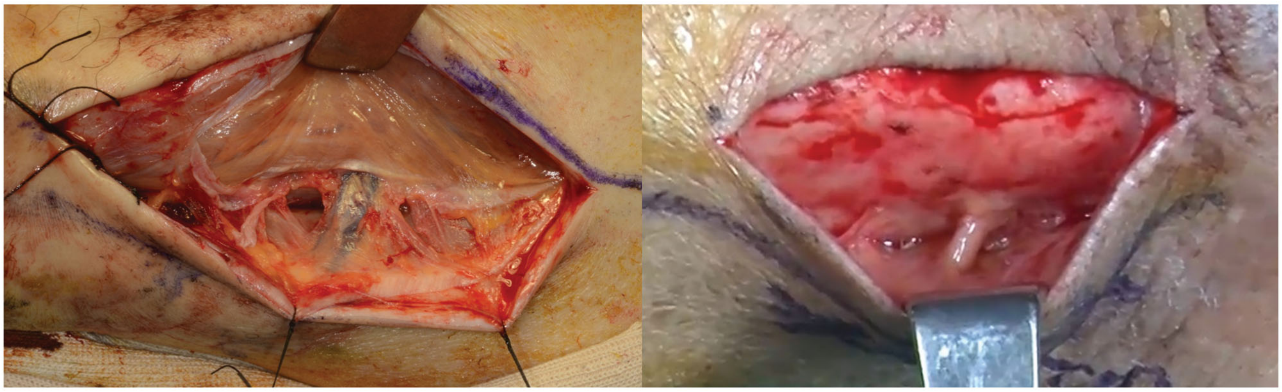

Figure 6. (Left) In normal vessels, vein engorgement is observed after tourniquet inflation. (Right) In cases of vessels with severe medial calcification, the vessel appears as a single white and rigid cord-like structure without demarcation between the artery and vein.

caused by diabetes. Therefore, the propeller perforator flap might not be effective for reconstructing diabetic foot ulcers.

Disclosure statement

No potential conflict of interest was reported by the authors.

Ethical approval

The study was conducted after obtaining approval from the Institutional Review Board of Keimyung University.

Funding

This work was supported by the National Research Foundation of Korea (NRF-2017R1D1A1B03029068 and NRF-2020R 1F 1A 1048406).

References

[1] Fitzgerald O'Connor EJ, Vesely M, Holt PJ, et al. A systematic review of free tissue transfer in the management of non-traumatic lower extremity wounds in patients with diabetes. Eur J Vasc Endovasc Surg. 2011;41(3):391–399.
[2] Oh TS, Lee HS, Hong JP. Diabetic foot reconstruction using free flaps increases 5-year-survival rate. J Plast Reconstr Aesthet Surg. 2013;66(2):243–250.
[3] Lee YK, Park KY, Koo YT, et al. Analysis of multiple risk factors affecting the result of free flap transfer for necrotizing soft tissue defects of the lower extremities in patients with type 2 diabetes mellitus. J Plast Reconstr Aesthet Surg. 2014;67(5):624–628.
[4] Sato T, Yana Y, Ichioka S. Free flap reconstruction for diabetic foot limb salvage. J Plast Surg Hand Surg. 2017;51(6):399–404.
[5] Pignatti M, Ogawa R, Hallock GG, et al. The "Tokyo" consensus on propeller flaps. Plast Reconstr Surg. 2011;127(2):716–722.
[6] Gir P, Cheng A, Oni G, et al. Pedicled-perforator (propeller) flaps in lower extremity defects: a systematic review. J Reconstr Microsurg. 2012;28(9):595–602.
[7] Hong JP. The use of supermicrosurgery in lower extremity reconstruction: the next step in evolution. Plast Reconstr Surg. 2009;123(1):230–235.
[8] Ioannis A. Distal posterior tibial artery perforator flaps for the management of calcaneal and Achilles tendon injuries in diabetic and non-diabetic patients. Diabetic Foot Ankle. 2011;2:7483.
[9] 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(2):193–197.
[10] Mota RI, Morgan SE, Bahnson EM. Diabetic vasculopathy: macro and microvascular injury. Curr Pathobiol Rep. 2020;8(1):1–14.
[11] Bajantri B, Bharathi RR, Sabapathy SR. Wound coverage considerations for defects of the lower third of the leg. Indian J Plast Surg. 2012;45(2):283–290.
[12] Paik JM, Pyon JK. Risk factor analysis of freestyle propeller flaps. J Reconstr Microsurg. 2017;33(1):26–31.
[13] Georgescu AV, Matei IR, Capota IM. The use of propeller perforator flaps for diabetic limb salvage: a retrospective review of 25 cases. Diabetic Foot Ankle. 2012;3(1):18978.
[14] Lanzer P, Boehm M, Sorribas V, et al. Medial vascular calcification revisited: review and perspectives. Eur Heart J. 2014;35(23):1515–1525.
[15] Mackey RH, Venkitachalam L, Sutton-Tyrrell K. Calcifications, arterial stiffness and atherosclerosis. Adv Cardiol. 2007;44:234–244.
[16] Avogaro A, Fadini GP. Mechanisms of ectopic calcification: implications for diabetic vasculopathy. Cardiovasc Diagn Ther. 2015;5(5):343–352.
[17] Giachelli CM. Vascular calcification mechanisms. J Am Soc Nephrol. 2004;15(12):2959–2964.
[18] Jeffcoate WJ, Rasmussen LM, Hofbauer LC, et al. Medial arterial calcification in diabetes and its relationship to neuropathy. Diabetologia. 2009;52(12):2478–2488.
[19] Eren S, Rübben A, Krein R, et al. Assessment of microcirculation of an axial skin flap using indocyanine green fluorescence angiography. Plast Reconstr Surg. 1995;96(7):1636–1649.
[20] Flynn M, Tooke J. Diabetic neuropathy and the microcirculation. Diabet Med. 1995;12(4):298–301.
[21] Edmonds ME, Morrison N, Laws JW, et al. Medial arterial calcification and diabetic neuropathy. Br Med J (Clin Res Ed)). 1982;284(6320):928–930.
[22] Young MJ, Adams JE, Anderson GF, et al. Medial arterial calcification in the feet of diabetic patients and matched non-diabetic control subjects. Diabetologia. 1993;36(7):615–621.
[23] McCullough PA, Agrawal V, Danielewicz E, et al. Accelerated atherosclerotic calcification and Monckeberg's sclerosis: a continuum of advanced vascular pathology in chronic kidney disease. Clin J Am Soc Nephrol. 2008;3(6):1585–1598.
[24] 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(1):314–331.
[25] Amoroso M, Özkan Ö, Başsorgun Cİ, et al. The effect of normovolemic and hypervolemic hemodilution on a perforator flap with twisted pedicle model: experimental study in rats. Plast Reconstr Surg. 2016;137(2):339e–346e.
[26] Wang L, Wu H, Lin C, et al. Effects of pedicle torsion on dynamic perforasome survival in a multiterritory perforator flap model: an experimental study. J Plast Reconstr Aesthet Surg. 2019;72(2):188–193.
[27] Bektas G, Ozkan O, Cinpolat A, et al. Comparing the effects of pedicle torsion on axial or perforator flaps; improving the perforator flap resistance to pedicle torsion with delay phenomenon. J Reconstr Microsurg. 2014;30(8):531–538.
[28] Taeger C, Horch R, Dragu A, et al. [Perforator flaps. A new era in reconstructive surgery]. Chirurg. 2012;83(2):163–171.
[29] Mehrotra S. Perforator-plus flaps: a new concept in traditional flap design. Plast Reconstr Surg. 2007;119(2):590–598.
[30] Saint-Cyr M, Wong C, Schaverien M, et al. The perforasome theory: vascular anatomy and clinical implications. Plast Reconstr Surg. 2009;124(5):1529–1544.
[31] Cajozzo M, Jiga LP, Jandali Z, et al. Complications and solutions in propeller flap surgery. Semin Plast Surg. 2020;34(3):210–220.
[32] Anker AM, Prantl L, Strauss C, et al. Clinical impact of DIEP flap perforator characteristics - a prospective indocyanine green fluorescence imaging study. J Plast Reconstr Aesthet Surg. 2020;73(8):1526–1533.

[33] Visconti G, Bianchi A, Hayashi A, et al. Thin and superthin perforator flap elevation based on preoperative planning with ultrahigh-frequency ultrasound. Arch Plast Surg. 2020; 47(4):365–370.

[34] Suzuki Y, Shimizu Y, Kasai S, et al. Indocyanine green fluorescence videoangiography for reliable variations of supraclavicular artery flaps. Arch Plast Surg. 2019;46(4): 318–323.