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REVIEW

A Systematic Review of Outcomes and Flap Selection Following Lower Extremity Free Tissue Transfer Versus Vascularized Perforator Pedicle Flap Transfer in Lower Limb Reconstruction

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The evolution of microsurgery and orthoplastics has expanded our ability as surgeons to manage complex lower extremity soft tissue defects. This evolution relies on the understanding of reconstructive surgical principles for problem solving and analyzing outcomes. The purpose of this review is to determine flap selection with a focus on reliability based on the outcomes of lower extremity free tissue transfer versus vascularized perforator pedicle flap transfer in lower limb reconstruction. A systematic literature search was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines using the databases PubMed/MEDLINE. Data were compiled by reviewing the number of patients, age, comorbidities, complications, size and location of defect. Outcomes were analyzed by indicated soft tissue defect size, location and cause, as well as subsequent flap size, type, survival, durability and their functional results. Overall, 72 topic related studies from 2014–2017 were reviewed. Sixteen of the 72 met the final inclusion criteria. Patient study sizes from the included articles ranged from 7–428 cases. The current qualitative systematic review of flap transfer in the lower extremity has contributed a summary of reported outcomes in literature thus far. After analyzing existing evidence, our study found no significant differences between reconstructive options with a paucity of evidence to clearly recommend the ideal flap transfer for microsurgical reconstruction of lower extremity soft tissue defects.

Keywords: vascularized perforator pedicle flap; free tissue transfer; lower limb reconstruction; outcomes; flap selection

Introduction

Microsurgical reconstruction for management of complex soft tissue defects of the lower extremity presents as a challenge for surgeons considering that the goal of reconstruction for these defects is essentially to provide a successful flap transfer that is not only functionally reliable but also an aesthetically acceptable result [5, 14, 18]. The ability of reconstructive surgeons to manage complex soft tissue defects of the lower limb has advanced over the years with a better understanding of the complex vasculature within the lower extremity and advanced microsurgical techniques [4, 16]. With numerous options existing for surgical reconstruction by way of flap transfer for the management of complex soft tissue defects of the lower extremity such as reconstruction using free flaps or vascularized perforator pedicle flaps, there is a need for greater data regarding flap selection based on flap outcomes to better improve patient care. It is also necessary to take into consideration several factors when selecting the most suitable flap transfer for each individual patient with regards to the location and size of the soft tissue defect, defect etiology, presence of existing comorbidities and the vascular condition at the recipient site [12, 14, 18, 19].

A growing body of literature has been published in recent years to identify the ideal flap for lower limb reconstruction. Despite the growing evidence in literature supporting advantages for use of free and vascularized pedicle perforator flaps as reconstructive options, identifying a clear

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recommendation has been quite controversial. Our review focuses on recent literature published from 2014–2017 to try to better identify the ideal flap based on the most updated and recent evidence over the past three years.

The purpose of this study is to report clinical experience of microsurgical techniques in the management of lower extremity defects by way of free tissue transfer versus vascularized pedicle perforator flap transfer as reconstructive options with a focus on outcomes and flap selection. This review aims to determine whether or not we can identify a clear recommendation for an advantage of using one flap over another by analyzing existing evidence for outcomes of flap transfer in lower extremity reconstruction.

Methods

Study Selection

A systematic review was conducted using the databases PubMed/MEDLINE. In the search for adequate reference articles, we searched the following phrases: foot flaps, free flap, perforator pedicle flap, lower extremity reconstruction, soft tissue defect, flap outcome and microsurgery flap. Studies that were considered to meet our eligibility criteria included articles published from the years 2014–2017 that studied patients who underwent lower limb reconstruction with a flap transfer for treatment of a soft tissue defect. Within our search, if foreign language articles were located, every effort was made to obtain the articles in English or to translate the article.

Eligibility Criteria

Inclusion criteria were articles with an adequate study design reporting on patient's that underwent lower limb reconstruction with free tissue transfer or vascularized perforator pedicle flap transfer. The studies included were original research articles, case-reports, meta-analyses, reviews and systematic reviews. The articles included had the following relevant information regarding the patient and the procedure: age, type of reconstruction, total number of reconstructions, total number of patients, post-operative outcomes, comorbidities and complications. Exclusion criteria were established to exclude studies that focused on methods other than microsurgical reconstruction of the lower extremity. Duplicate studies were excluded, as were single case reports, editorials, and discussions.

Data Extraction

Two reviewers performed the data extraction. After initial article titles were searched, articles were reviewed, duplicates were deleted and all included articles in our study or articles that could not be clearly included underwent full text review (**Figure 1**). The data collected from the articles included in our study were as follows: number of patients, age, comorbidities, etiology of defect, complications, size and location of defect and type of flap. **Table 3** provides a descriptive summary of information included in this study regarding the patient's demographic data and etiology of the defect.

Results

A total of 567 abstracts and/or titles were identified in this review with 502 rejected due to data that did not fulfill the inclusion/exclusion criteria to relate to this study. Seventy-two articles were included in our review and of these, 55 articles failed to again meet the review criteria. Thus, a total of 16 articles were included in this qualitative systematic review reporting on 313 free tissue transfers (**Table 1**) and 742 vascularized perforator pedicle flap transfers (**Table 2**) providing an overview of flap selection and outcomes in lower extremity reconstruction.

Patient Characteristics

The age of patients in our review ranged from 1–91 years of age. Comorbidities were reported in nine out of the 16 articles included, with the most common comorbidity

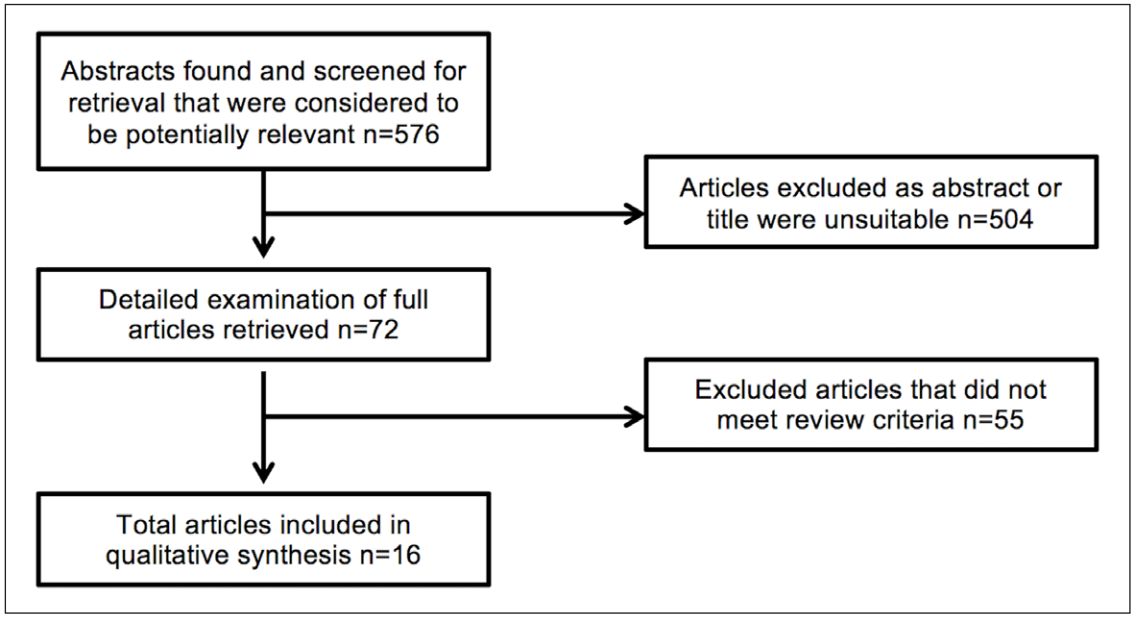

Figure 1: Flowchart describing the literature review.

Table 1: Summary of free tissue flaps reviewed.

Author (year)	Free tissue transfer	Number (N = 313)
Dawei et al (2015)	Bilobed medial sural artery perforator (BMSAP)	7
Guangfeng et al (2016); Jandali et al (2016)	Medial sural artery perforator (MSAP)	13
Guangfeng et al (2016)	MSAP composite tissue flap carrying medial head of gastrocnemius muscle (MSAPCTG)	3
Kadam (2016)	Radial artery forearm (RAF)	4
Kadam (2016); Li et al (2016); Sato, Yana & Ichioka (2017)	Anterolateral thigh (ALT)	72
Kadam (2016)	Gracilis muscle (GM)	4
Kim et al (2015); Luen & Sulaiman (2017); Sato, Yana & Ichioka (2017)	Latissimus Dorsi (LD)	190
Li et al (2016)	Anteromedial thigh perforator (AMTP)	1
Li et al (2016)	Free groin (FG)	4
Li et al (2016)	Free medial plantar (FMPT)	3
Luen & Sulaiman (2017)	Serratus anterior (SA)	2
Sato, Yana & Ichioka (2017)	Rectus Abdominis (RA)	10

being diabetes mellitus. The soft tissue defects included in our study most commonly arose from trauma. The etiology of lower extremity soft tissue defects was reported in all studies except one [10]. (**Table 3**)

Reconstructive Options

The most frequently used free tissue flap included in this series was the latissimus dorsi flap (LD) while the most frequently used flap for vascularized perforator pedicle flap transfer was the peroneal artery perforator flap (PAP). Majority of the studies included in this review reported on defects of the distal lower extremity. **Table 4** describes a detailed summary of flap selection, defect location, defect size, with subsequent flap size and complications.

Latissimus Dorsi Flap

Reconstruction for soft tissue defects using the free LD flap was reviewed in 190 patients (**Table 1**). We reviewed the LD flap in three separate studies; as a universal option in all reconstructive areas in comparison to the ALT flap, for functional outcomes after heel pad reconstruction, and in free flap reconstruction for diabetic foot limb salvage [10, 13, 17]. Defects (**Table 4**) were reported at the lower extremity (n = 181), heel pad (n = 7) and foot (n = 8). Complications associated with reconstruction using the LD flap are identified in **Table 4** with majority of complications resulting in flap loss due to arterial or venous thrombosis.

A ten year study was done to evaluate use of the LD flap as an ideal free flap for soft tissue reconstruction in all reconstructive fields as opposed to using the ALT flap as a universal donor site was reviewed in a total of 334 cases with defects of the lower extremity present in 181 patients [10]. Out of the 181 patients who underwent reconstruction with the LD flap for lower extremity defects, 25 patients reported complications (**Table 4**). The LD flap has been concluded to have the potential to be used in most reconstructive areas just as widely as, or in preference to the ALT flap based on the following advantages found in this study: ability of the LD flap to harvest positions without position change, the versatility of LD flap components such as permitting use of the 2-flap technique due to the vast amount of vessel branches present and the ability of the LD muscle to fill extensive defects [10].

A review of seven cases was performed to evaluate the functional outcomes after heel pad reconstruction using the free LD flap (n = 1), free serratus anterior flap (n = 1), free senate medial plantar flap (n = 1), pedicle sensate medial plantar flap (n = 3) and the distally based reverse sural flap (n = 1) [13]. Etiology of the defects included trauma (n = 3), diabetic ulcer (n = 2), melanoma (n = 1), and recurrent ulcer after reconstruction with the reverse sural flap (n = 1). Functional outcomes and sensation were evaluated using the subjective components of the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot clinical ratings scale and Semmes-Weinstein monofilaments, respectively. Complete flap survival was reported in all seven cases. The sensate medial plantar artery flap reported the highest mean AOFAS score with a score of 57.3 (maximum score of 60) and a return of deep sensation at six months with protective sensation at 1 year. Following the PSMP flap was the DBRS flap and following after that were the musculocutaneous flaps. Based on these results, this review concluded the PSMP flap as the preferred flap for small-to-moderate sized heel defects based its early return of deep sensation [13].

Table 2: Summary of vascularized perforator pedicle flaps reviewed.

Author (year)	Vascularized perforator pedicle flap transfer	Number (N = 742)
Ahn et al (2015); Bekara et al (2016); Li et al (2016)	Peroneal artery perforator (PAP)	137
Assi, Fawaz & Samaha (2016); Li et al (2016)	Sural neurocutaneous (SNC)	52
Bekara et al (2016); Li et al (2016)	Posterior tibial artery perforator (PTAP)	257
Bekara et al (2016)	Medial sural artery perforator (MSAP)	27
Bekara et al (2016)	Anterior tibial artery perforator (ATAP)	11
Bekara et al (2016)	Lateral retromalleolar artery perforator (LRMAP)	6
Bekara et al (2016)	Gluteal artery perforator (GAP)	5
Bekara et al (2016)	Lateral circumflex femoral artery perforator (LCFAP)	7
Bekara et al (2016)	Lateral sural artery perforator (LSAP)	4
Bekara et al (2016)	Superficial femoral artery perforator (SFAP)	4
Bekara et al (2016)	Deep femoral artery perforator (DFAP)	1
Bekara et al (2016)	Superior gluteal artery perforator (SGAP)	1
Bekara et al (2016)	Lateral superior genicular artery perforator (LSGAP)	2
Bekara et al (2016); Li et al (2016)	Dorsalis pedis (DP)	4
Collazo, Rathbone & Barnes (2017)	Reverse peroneus brevis (RBP)	7
Collazo, Rathbone & Barnes (2017)	Soleus	10
Li et al (2017)	Modified reversed superficial peroneal artery (MRSPAF)	12
Li et al (2016)	Antemalleolar (ATM)	1
Li et al (2016)	First dorsal metatarsal artery (FDMA)	3
Li et al (2016)	Gastrocnemius myocutaneous (GMC)	1
Li et al (2016)	Lateral supramalleolar (LSM)	4
Li et al (2016)	Medial pedis (MP)	1
Li et al (2016); Luen & Sulaiman (2017); Mahmoud (2017)	Medial plantar (MPT)	25
Li et al (2016)	Medial supramalleolar (MSM)	6
Luen & Sulaiman (2017)	Serratus anterior (SA)	1
Luen & Sulaiman (2017); Mahmoud (2017)	Distally based sural artery (DBRS)	16
Persaud et al (2017)	Sural (fasciocutaneous)	110
Sugg et al (2015)	Reverse superficial sural artery (RSSSA)	27

Anterolateral Thigh Flap

The free ALT flap was reviewed in 72 patients who underwent reconstruction with defects (**Table 4**) at the heel, foot and ankle region. We reviewed the ALT flap in three separate studies: for the effectiveness of free flaps in plantar ulcers of the insensate foot, for analysis of perioperative flap survival in reconstruction of the foot and ankle, and to evaluate the relationship between free flap success and postoperative ambulation in diabetic foot limb salvage [9, 12, 17].

Twenty-five patients underwent reconstruction with 26 free flaps for plantar ulcers of the insensate foot using the ALT (n = 18), RAF (n = 4) and GM (n = 4). Etiology (**Table 3**) of the soft tissue defects included diabetic neuropathy (n = 13), leprosy (n = 3), spinal/peripheral nerve injury (n = 7), spina bifida (n = 1) and peripheral neuropathy (n = 1) [9]. Associated systemic comorbidities were reported in fifteen patients (**Table 3**), with six having had previous flap transfer attempts. The mean duration of ulcer was 5.8 years; located over predominantly weight-bearing areas. The mean ulcer size measured 59.45 cm^2. All flaps survived except for a partial loss in one and ulcer recurrence occurred in three cases (**Table 4**). The average time to resume ambulation was six weeks. In this study, the ALT flap was regarded as the first choice for reconstruction of plantar ulcers due to having a dual advantage of

Table 3: Summary of demographic data and etiology of defect.

Author (year)	Patients	Age (range)	Comorbidities	Etiology
Ahn et al (2015)	12	18–76	HTN, DM, ESRD, CAOD, PAOD	Trauma, Pressure ulcers, Achilles tendinitis
Assi, Fawaz & Samaha (2016)	14	56–81	DM	Open tibia fracture (Gustillo IIIb), Chronic osteitis, Chronic heel ulcer
Bekara et al (2016)	428	1–89	DM, Arteriopathy, Smoker, HTN	Acute: Posttraumatic, Oncologic resection, Postoperative complications, Burns, Donor-site closure, Chronic: Chronic ulcer, Osteomyelitis, Pressure sore, Unstable scarring, Radionecrosis
Collazo, Rathbone & Barnes (2017)	17	34–66	DM, Smoker	Chronic osteomyelitis
Dawei et al (2015)	7	21–43	NR	Crush, Blunt puncture, Fire arm
Guangfeng et al (2016)	16	16–58	NR	Burn, Traffic accident, Crush
Jandali et al (2016)	22	31–73	Smoker	Posttraumatic, Ischemic-PAD with or without diabetic foot syndrome, Posttraumatic defects with preexistent PAD
Kadam (2016)	25	17–70	DM, HTN, CRF	DN, PN, SB, Leprosy, Spinal/peripheral nerve injury
Kim et al (2015)	322	8–88	NR	NR
Li et al (2017)	12	6–78	NR	Hot liquid scald, Electrical, Trauma
Li et al (2016)	144	3–74	HTN, DM, Osteomyelitis	Trauma, Skin ulcers & inflammation, Post-tumor resection, Scar contracture, Diabetic foot
Luen & Sulaiman (2017)	7	11–70	CHD, HTN, DM	Trauma, Diabetic ulcer, Melanoma, Recurrent ulcer
Mahmoud (2017)	30	18–60	NR	Trauma, Neuropathic ulcer, Tumor resection
Persaud et al (2017)	110	24–81	NR	Osteomyelitis
Sato, Yana & Ichioka (2017)	23	37–80	IHD, ESRD on dialysis, PAD, PVB, PET	Diabetic ulcer
Sugg et al (2015)	27	19–91 (EG), 12–72 (LG)	Smoking, DM, PAD, CVI	Trauma, Pressure sore, Osteomyelitis, Burn

Abbreviations: NR, not reported; HTN, hypertension; DM, diabetes mellitus; ESRD, end-stage renal disease; CAOD, coronary artery occlusive disease; PAOD, peripheral artery occlusive disease; PAD, peripheral artery disease; CRF, chronic renal failure; DN, diabetic neuropathy; PN, peripheral neuropathy; SB, spina bifida; IHD, ischemic heart disease; PVB, prior vascular bypass; PET, prior endovascular therapy; EG, early group; LG, late group; CVI, chronic venous insufficiency.

both a fasciocutaneous and muscle flap providing a stable walking surface while the RAF is preferred for defects at the metatarsal heads and forefoot and GM flaps for defects where obliteration of the dead space is necessary such as in cases of osteomyelitis [9].

In a study of 144 patients, 14 different flaps (**Table 4**) were reviewed to determine the correlation between non-technical risk factors and the perioperative flap survival rate in regards to evaluating the choice of free or pedicled flaps for reconstruction of the foot and ankle [12]. The perioperative period was defined as within 2 weeks after flap transfer. Risk factors identified included: cigarette smoking, hypertension, osteomyelitis, preoperative wound bed inflammation, trauma activation, anatomical region, type of flap, and postoperative wound infection. A total of 57 free flaps and 87 pedicled flaps were reviewed. The most frequently used free flap in this study was the ALT flap (n = 49) while the most frequently used pedicled flap was the SNC flap (n = 38). Free flap necrosis rate was 5.26% (3 of 57 cases) while the necrosis rate of the pedicled flaps was 20.69% (18 of 87 cases). Partial necrosis was reported in twelve cases; pedicled flaps (n = 11), free flaps (n = 1), and complete necrosis was reported in nine; pedicled flaps (n = 7), free flaps (n = 2). Preoperative wound bed inflammation was reported in 25 pedicled flaps and 17 free flaps. Eighteen pedicled flaps and nine free flaps reported postoperative wound infection. The overall flap survival rate of pedicled and free flaps was 85.42% (123 of 144 cases). Independent risk factors influencing flap survival rate were both flap type and postoperative wound infection [12]. Postoperative wound infection was also a risk factor for the pedicled flap but not for the free flap [12]. This review determined that free flaps are a safer and more reliable option for the reconstruction of complex or wide soft tissue defects of the foot or ankle and that the ALT flap is particularly a good choice for these defects at the forefoot because a thin flap is required in this area [12].

Twenty-three cases of diabetic foot ulcers underwent reconstruction using the RA (n = 10), LD (n = 8)

Table 4: Summary of outcomes for lower extremity flap transfers included in this series.

Author (year)	Flap selection	Defect location	Defect size (cm^2)	Flap size (cm^2)	Complications
Ahn et al (2015)	PAP	AT, HP	3 × 4–14 × 10	5 × 4–20 × 8	Minor wound dehiscence (n = 2)
Assi, Fawaz & Samaha (2016)	SNC	RF, MA, LA	NR	NR	Total flap necrosis (n = 1), Skin edge necrosis (n = 3), Hypoesthesia of lateral aspect of foot (n = 10)
Bekara et al (2016)	PPP (PTAP, PAP, MSAP, ATAP, LRAP)	Thigh, Knee, Leg, Heel, Ankle, Foot	NR	NR	Partial necrosis (n = 44), Complete necrosis (n = 15), Epidermal necrosis (n = 15), Transient venous congestion (n = 13), Infected (n = 11), Hematoma (n = 6), Wound dehiscence (n = 4)
Collazo, Rathbone & Barnes (2017)	RPB, Soleus	Distal 1/3 leg, HF	19.6 cm^2	NR	Superficial infection (n = 3), Hematoma (n = 2), Amputation above knee (n = 1)
Dawei et al (2015)	BMSAP	PT, DF	4 × 3–9 × 7	5 × 4–10 × 8	Distal flap necrosis (n = 1), Wound infection (n = 1),
Guangfeng et al (2016)	MSAP, MSAPCTG	ADF	4 × 3–10 × 7	5 × 4–11 × 8	0
Jandali et al (2016)	MSAP	MF, Hallux, Ankle-HF	4 × 4–18 × 7	6 × 4–21 × 9	Venous congestion (n = 1), Marginal flap necrosis (n = 1)
Kadam (2016)	RAF, ALT, GM	Heel, MF, Head of metatarsals 1–5	59.7 (24–112)	NR	Partial flap lass (n = 1), Ulcer recurrence (n = 3)
Kim et al (2015)	LD, ALT	LE	NR	NR	Flap failure (n = 4); arterial thrombosis (n = 1), venous thrombosis (n = 3), Partial loss (n = 9), Donor-site complications (n = 11), Temporary brachial palsy (n = 1)
Li et al (2017)	MRSPAF	Foot, Ankle	NR	4.0 × 6.0–18.0 × 10.0	Partial necrosis (n = 1)
Li et al (2016)	Pedicled: ATM, DP, FDMA, GMC, LSM, MP, MPT, MSM, PAP, PTAP, SNC Free: ALTP, AMTP, FG, FMPT	FT, MF, HF, AR	NR	4 × 3–35 × 20	Preoperative wound bed inflammation (n = 42), Complete necrosis (n = 9), Partial necrosis (n = 12), Postoperative wound infection (n = 27)
Luen & Sulaiman (2017)	LD, SA, PSMP, DBRS	HP	59 (12–270)	NR	0
Mahmoud (2017)	DBRS, MPT	Heel, AT, MM, LM	9–35 (MPAF), 36–120 (RSAF)	NR	MPAF: Marginal necrosis (n = 1), Infection (n = 1), Paresthesia in medial 3 toes (n = 2) RSAF: Total flap necrosis (n = 1), Marginal flap necrosis (n = 2)
Persaud et al (2017)	Sural	DLE	NR	NR	Combined complication/failure (n = 22)

Author (year)	Flap selection	Defect location	Defect size (cm^2)	Flap size (cm^2)	Complications
Sato, Yana & Ichioka (2017)	RA, LD, ALT	FT, PF, DF	NR	NR	CHF with fatal consequences within 14 days postoperatively (n = 2), Total flap loss (n = 5), Venous thrombosis (n = 2), arterial thrombosis (n = 2), Infection in anastomosis (n = 1), Wound dehiscence (n = 1), Partial flap loss (n = 3), Ulcer recurrence (n = 6), Major amputation (n = 1)
Sugg et al (2015)	RSSA	Calcaneus, PH, LM, MM, Anterior leg, DF	4.5–150 (EG), 9–140 (LG)	NR	EG: Venous congestion (n = 5), Infection (n = 1), Hematoma (n = 1), Dehiscence (n = 2), Partial necrosis (n = 4), Complete necrosis (n = 2), LG: Infection (n = 4), Hematoma (n = 1), Dehiscence (n = 1), Partial necrosis (n = 1), Complete necrosis (n = 1), Partial loss of skin graft (n = 3)

Abbreviations: PAP, peroneal artery perforator; AT, Achilles tendon; HP, heel pad; SNC, sural neurocutaneous; RF, rear foot; MA, medial ankle; LA, lateral ankle; PPP, perforator pedicled propeller; PTAP, posterior tibial artery perforator; PAP, peroneal artery perforator; MSAP, medial sural artery perforator; ATAP, anterior tibial artery perforator; LRAP, lateral retromalleolar artery perforator; RPB, reverse peroneus brevis; HF, hindfoot; BMSAP, free bilobed medial sural artery perforator; PT, plantar foot; DF, dorsal foot; ADF, anterior dorsal foot; MSAPCTG, medial sural artery perforator composite tissue flap carrying medial head of gastrocnemius muscle flap; MF, midfoot; RAF, radial artery forearm; ALT, anterolateral thigh; LE, lower extremity; GM, gracilis muscle; LD, latissimus dorsi; MRSPA, modified reversed superficial peroneal artery; ATM, antemalleolar; DP, dorsalis pedis; FDMA, first dorsal metatarsal artery; GMC, gastrocnemius myocutaneous; LSM, lateral supramalleolar; MP, medial pedis, MPT, medial plantar; MSM, medial supramalleolar; ALTP, free anterolateral thigh perforator; AMTP, Free anteromedial thigh perforator; FG, free groin; FMPT, free medial plantar; FT, forefoot; AR, ankle region; SA, free serratus anterior; PSMP, pedicle sensate medial plantar; DBRS, distally based reverse sural; HP, heel pad; DBSA, distally based sural artery; MM, medial malleolus; LM, lateral malleolus; CAF, cutaneous adipose fascial; SPP, septal peroneal perforator; RS, reverse sural; PB, peroneus brevis; DLE, distal lower extremity; RA, rectus abdominis; RSSA, reverse superficial sural artery; PH, posterior heel.

and ALT flap (n = 5) [17]. Patients had defects at the forefoot (n = 12), plantar foot (n = 10) and dorsal foot (n = 1). Sixteen patients reported flap success and of those patients, 12 achieved independent ambulation. Free flap reconstruction was found to possibly increase independent ambulation in the diabetic ulcer population (p = 0.047) with 12/16 patients (75%) achieving independent ambulation. However, on the basis of this review it still remains unclear whether free flap reconstruction increases the chances for independent ambulation [17].

Peroneal Artery Perforator Pedicle Flap

Reconstruction using the PAP was reviewed in 137 patients (**Table 1**) in three separate studies; reconstruction of ankle and heel defects (Ahn et al 2015), identification of risk factors for complications using perforator pedicled propeller flaps in lower extremity defects (Bekara et al 2016), and for analysis of perioperative flap survival in reconstruction of the foot and ankle (Li et al 2016). The defects (**Table 4**) were located at the Achilles tendon, heel pad, thigh, knee, leg, foot, and ankle region [1, 3, 12].

Reconstruction of ankle and heel defects with the PAP was reviewed in twelve patients with defects at the Achilles tendon and heel pad [1]. Nine patients had defects of the Achilles tendon, which were treated using eight propeller flaps and one peninsular flap. Three patients had defects of the heel pad, which were treated using the propeller flap. Etiology (**Table 3**) of the soft tissue defects included trauma (n = 4), pressure ulcers (n = 6), tendinous xanthoma (n = 1) and Achilles tendinitis (n = 1). The following comorbidities were reported: hypertension (n = 5), diabetes mellitus (n = 3), coronary artery occlusive disease (n = 1), end-stage renal disease (n = 1), and peripheral artery occlusive disease (n = 1). Flap size ranged from 5 × 4 to 20 × 8 cm^2 and size of the defect ranged from 3 × 4 to 14 × 10 cm^2 (**Table 4**). In this study, all 12 patients were reported to have complete healing with the only complication being minor wound dehiscence (n = 2). Thus, the PAP flap was regarded to be a useful and reliable option for reconstruction of soft tissue defects of the ankle and heel with the advantage of a reliable blood supply from involvement of a large fasciocutaneous flap, which does not require the need for microvascular anastomosis [1].

Perforator Pedicled Propeller Flaps (PPP)

Identification of risk factors associated with PPP flap failure was reviewed in 428 patients with defects of the lower extremity between the ages of 1–89 years old [3]. Flaps used in this study included the PTAP, PAP, MSAP, ATAP, and the LRAP. Etiology (**Table 3**) of the defect was divided into acute and chronic. The most common cause of soft tissue defects in the acute group was posttraumatic, while the most common cause of defects in the chronic group was chronic ulcer. Most of the defects (**Table 4)** in this study involved the distal third of the lower leg. The factors analyzed included age >60 years (n = 24), diabetic (n = 11), arteriopathy (n = 4), smoking (n = 9), acute cause (n = 11), posttraumatic (n = 18), bone fracture (4), lower third of the leg (n = 24), fascia inclusion (n = 2), pedicle rotation >120 degrees (n = 10) and surface area >100 cm^2 (n = 14). Complications were reported in 108 cases (**Table 4**) and of the 428 cases reviewed, complete flap survival was reported in 361. This study identified three significant risk factors for PPP flap failure in reconstruction of the lower extremity; age >60 years (p = 0.03), diabetes (p = 0.02), and arteriopathy (p = 0.01) [3].

Reverse Peroneus Brevis and Soleus Muscle Flaps

Vascularized perforator pedicle flap transfer using the reverse peroneus brevis (n = 7) and soleus (n = 10) muscle flaps as an integrated means of reconstruction was studied in 17 patients rendered as candidates for amputation with full thickness wounds of the distal lower limb [4]. A combinatorial approach to avoid amputation in these patients was performed with muscle flap reconstruction, concentrated bone marrow aspirate, platelet-rich plasma, INTEGRA wound matrix, vacuum-assisted closure and split-thickness skin grafts. All 17 patients treated had ulcers of the distal 1/3 leg or hindfoot to the level of bone and tendon. The following comorbidities were present (**Table 3**): chronic osteomyelitis (n = 17), diabetes mellitus (n = 11), and a history of smoking (n = 9). All patients in the study were treated with intravenous antibiotics for six weeks and at the time of surgery four of the patients had active superficial infections and osteomyelitis; treated with systemic antibiotics up until six weeks after the procedure. This study reported that wounds were successfully covered using the RPB and soleus flaps with complications reported in six patients (**Table 4**) thus, concluding this combinatorial approach to avoid amputation an effective method of lower limb reconstruction [4].

Modified Reversed Superficial Peroneal Artery Flap

The MRSPAF was used to treat twelve patients with foot and ankle defects following severe burns or trauma, in which the superficial peroneal nerve was preserved during reconstruction [11]. The MRSPAF is characterized as a perforator flap that uses the superficial peroneal artery as its pedicle [11]. Etiology (**Table 3**) of the wounds included trauma (n = 6), electrical injury (n = 5) and hot liquid scald (n = 1). Involvement of the superficial peroneal artery provided nourishment for this reverse-flow flap through its anastomosis with the terminal peroneal artery perforator. All flaps survived with satisfactory outcomes both functionally and aesthetically. Complications (**Table 4**) were reported in one patient who experienced partial necrosis with a decreased temperature of the lower limb skin and flap darkening. Stenosis of the popliteal artery was revealed by computed tomography angiography (CTA) and the flap was successfully salvaged a week later after placement of a stent and wound dressing changes. No complications were noted regarding hypoesthesia of the lower legs and patients were completely satisfied with the flap. The MRSPAF was thus concluded to be a useful option with a reliable blood supply for reconstruction of the foot and ankle especially when the axis of the superficial peroneal nerve remains intact after severe burns or trauma [11].

Free Medial Sural Artery Flap

Free tissue transfer with the MSAP flap was reviewed in three separate studies for reconstruction of the lower limb; repairing penetrating wounds of the foot, repairing anterior dorsal foot wounds, and in soft tissue reconstruction of small-to-moderate sized defects of the foot and ankle [6, 7, 8].

The effectiveness of the free bilobed medial sural artery perforator (BMSAP) flap in repairing penetrating wounds of the foot was studied in seven patients [6]. Cause of injury (**Table 3**) for these patients included crush (n = 4), blunt puncture (n = 2) and firearm (n = 1). The location of the wound was on the left foot in four cases and right foot in three cases. Five of the cases were a longitudinal penetrating injury and two cases were a transverse penetrating injury. The free BMSAP flap was used to repair penetrating wounds on both sides and reconstruct sensation. Post-operative complications included distal flap necrosis (n = 1) and wound infection (n = 1). Primary healing occurred in five cases and all skin grafts survived. The AOFAS score was reported to be 8697 (mean, 93.6) and the British Medical Research Council (BMRC) sensory function assessment system scored one case as S_2, four cases as S_3, and two cases as S_{3+}. This study concluded that the free BMSAP flap is a suitable option for repairing penetrating wounds of the foot due to the advantages of being able to repair two wounds at the same time as well as reconstructing sensation of the skin [6].

Sixteen patients with skin and soft tissue defects of anterior dorsal foot wounds underwent reconstruction using the free MSAP flap [7]. The MSAP flap was used to repair wounds in 13 cases and the MSAP composite tissue flap carrying the medial head of gastrocnemius muscle flap was used in three cases. The cause of defects (**Table 3**) in these patients were burn (n = 5), traffic accident (n = 8), and crush injury (n = 3). All cases had exposure of tendon and patients with combined injury defects had defects of the lateral collateral ligament (n = 3) and bone exposure (n = 12). All flaps survived and no complications were reported. This review rendered the free MSAP as one of the better options to repair wounds of the anterior dorsal foot due to advantages of a reliable blood supply, a relatively constant perforator anatomy and ability of carrying the gastrocnemius muscle flap for compound tissue defects [7].

Reconstruction using the free MSAP flap for small-to-moderate sized soft tissue defects was reviewed in 22 patients evaluating its versatility by comparing outcomes at the foot and ankle [8]. Etiologies (**Table 3**) of the soft tissue defects were posttraumatic (n = 5), ischemic-PAD with or without diabetic foot syndrome (n = 16), and posttraumatic defects with preexistent PAD (n = 1). Smoking was reported in two-thirds of the patients (**Table 3**). Patients were divided into three groups based on the anatomic region of reconstruction: ankle-hindfoot; heel, malleolus or Achilles tendon region (n = 6), midfoot; dorsal or medial foot after degloving injury or anterior midfoot after hallux or transmetatarsal amputation (n = 12), and hallux; dorsal metatarsophalangeal joint of the great toe (n = 4). Flap survival and return to ambulation was reported in all patients. Complications (**Table 4**) were reported in 2 cases: venous congestion (n = 1) and marginal flap necrosis (n = 1); both cases were successfully resolved. Patients were evaluated using the AOFAS ankle-hindfoot, midfoot and hallux scale for clinical-functional evaluation and the SF-36 health survey for subjective quality-of-life measurement (statistically significant = $p < 0.05$). In comparison to patients without reconstruction in the regions studied, AOFAS scores of the ankle-hindfoot or hallux were found to be significantly lower than those of the midfoot, which had an equal AOFAS score; ankle-hindfoot ($p = 0.021$), hallux ($p = 0.034$), midfoot ($p = 0.265$). Scores were reported to be statistically insignificant for the subjective quality-of-life measurement using the SF-36. This study concluded the free MSAP flap a reliable option in reconstruction of small-to-moderate sized defects of the foot and ankle due to its thin and pliable aesthetic appearance and its evident advantages in the midfoot ($p = 0.265$) with a reliable vascular pedicle [8].

Fasciocutaneous Sural Artery Perforator Pedicle Flap

The sural flap was reviewed in four separate studies as a method of lower limb reconstruction for management of foot and ankle soft tissue defects in the diabetic population, for treatment of wounds with underlying osteomyelitis, for complex lower extremity and foot reconstruction, and in comparison to the medial plantar flap in foot and ankle reconstruction [2, 15, 18, 14].

The reliability of the sural neurocutaneous flap was reviewed in 14 patients for management of foot and ankle soft tissue defects in the diabetic population [2]. All patients had type II diabetes and underwent reconstruction using an ipsilateral sural flap to treat defects of the rear foot (n = 11), lateral malleolar region (n = 1), and medial malleolar region (n = 2). The etiology (**Table 3**) of the soft tissue defects included a recent open tibia fracture with loss of skin (n = 3), chronic osteitis of the hindfoot (n = 4) and heel ulcers (n = 7). Complications (**Table 4**) included total flap necrosis (n = 1), skin edge necrosis (n = 3), and hypoesthesia of the lateral aspect of the foot (n = 10). Shoe fitting in twelve patients was described as normal while the remaining two patients described it as acceptable. Thus, this study concluded the sural flap to be a reliable option for treatment of foot and ankle soft tissue defects in the diabetic population due to a low frequency of serious complications (one case of total flap necrosis; 1/14) and patient satisfaction with shoe fitting, rendering it an ideal flap to treat skin losses and infected-noninfected ulcers with or without bone infection [2].

Treatment of lower extremity wounds using the sural flap was evaluated in 110 patients with underlying osteomyelitis to determine the success rate of this fasciocutaneous flap within this specific patient population [15]. The primary outcome measure in this study was the estimated pooled success rate for treatment of chronic osteomyelitis using the sural flap (92%), while the secondary outcome measure was to examine any associated flap outcomes by comparing flap size, flap shape (aspect-ratio) and patient age. The weighted mean age of patients was 51.3 years (**Table 3**). This study found that smaller flap sizes showed a significant correlation with flap

success, with the mean flap areas in this study ranging from 32.4 cm^2–115.4 cm^2 [15]. The reported average graft size in patients who did not experience any complications was 36.54 cm^2 and the average graft size in patients with complications/graft failure was 51.87 cm^2. Flap shape (aspect-ratio) was reported to not be of statistical significance (p value of <.05 considered statistically significant) [15]. Short-term complications (**Table 4**) were reported in 22 patients and total flap failure was reported in nine patients. The sural fasciocutaneous flap for the treatment of wounds with underlying osteomyelitis is was proven to be a reliable option due to its success rate of 92% [15].

The reverse superficial sural artery flap (RSSAF) for management of complex lower extremity and foot reconstruction was reviewed in 27 patients (early group n = 12, late group n = 15) describing early experience using the RSSAF with the subsequent operative changes made leading to better outcomes [18]. All 15 patients in the early group underwent reconstruction with an island flap while patients in the late group underwent reconstruction with an island flap (n = 1), fasciocutaneous flap (n = 8) or an adipofascial flap (n = 6). Postoperative complications (**Table 4**) in the early group occurred in nine patients with patients experiencing multiple complications and a high rate of venous congestion observed (n = 5); infection (n = 1), hematoma (n = 1), dehiscence (n = 2), partial necrosis (n = 4) and complete necrosis (n = 2). Ten patients in the late group experienced complications of infection (n = 4), hematoma (n = 1), dehiscence (n = 2), partial necrosis (n = 4), complete necrosis (n = 2), and partial loss of skin graft with the adipofascial flap (n = 3). No cases of venous congestion occurred in the late group due to the uniform change in operative technique, which included increasing the pedicle width to at least 4 cm to enhance venous drainage increasing survival of the RSSAF. Although a high rate of complications was observed in both groups the RSSAF was concluded to be a recommendable option for management of complex lower extremity and foot defects especially when a shorter operative time is desired or microsurgical resources are limited [18].

A comparative study between the distally based reversed sural artery (DBRS) flap versus the proximally based island medial plantar artery flap (MPAF) was reviewed in a study of 30 patients comparing the outcomes of these flaps in reconstruction of soft tissue defects of the foot and ankle [14]. Patients were divided into two equal groups: reconstruction using the proximally based island medial plantar artery flap; MPAF group, and reconstructing using the distally based reversed sural artery flap; RSAF group. Etiology (**Table 3**) of the soft tissue defects included trauma (n = 25), neuropathic ulcers (n = 3) and excision of squamous cell carcinoma (n = 2). Patient defects were localized to the heel (n = 18), medial malleolus (n = 4), lateral malleolus (n = 2), and exposed Achilles tendon (n = 6). Outcomes within the two groups were assessed by flap survival, durability of coverage and functional outcome. Patients of the MPAF group had defect sizes ≤5 × 7 cm, an intact instep area of the sole of their foot and had a patent posterior tibial artery continuation into the medial plantar artery, while patients of the RSAF group had defects >5 × 7 cm, no injury present to the lateral aspect of the lower third of the leg (no possible interruption to vascularity of the flap) and had a patent peroneal artery. Notable differences between the two groups included a significantly smaller defect size in the MPAF group than in the RSAF group (22 ± 2.7 cm^2 versus 66.2 ± 7.7 cm^2; $p < .001$), longer operative time in the MPAF than in the RSAF group (100 ± 2.9 minutes versus 80.5 ± 3.1 minutes; $p < .001$), and weightbearing in the MPAF group was significantly earlier than in the RSAF group (5.8 ± 0.26 weeks versus 6.9 ± 0.19 weeks; $p = .003$) [14]. Flap survival was achieved in all patients of the MPAF group with one case of total flap necrosis occurring in the RSAF group. Complications (**Table 4**) in the MPAF group were found to be significantly less than the incidence of complications reported in the RSAF group (33% versus 80%; $p = .01$), with the findings of a significantly greater functional outcome in the MPAF group compared to the RSAF group ($p = .004$). With the MPAF having better functional outcomes and a lower frequency of postoperative complications it was thus concluded as a recommended option for reconstruction of moderate size defects of the foot and ankle region [14].

Discussion

In the present qualitative systematic review, we evaluated the clinical experience of microsurgical techniques in the management of lower extremity defects to determine flap selection with a focus on reliability based on the outcomes of free tissue transfer versus vascularized perforator pedicle flap transfer. Management of soft tissue defects of the lower extremity is very complex and requires advanced microsurgical knowledge to be able to adequately manage these patients. Flap transfer for reconstruction of soft tissue defects of the lower limb becomes even more challenging when comorbidities are present such as in patients with diabetes who exhibit vascular insufficiency and also depending on the location of the defect as in defects of weight-bearing regions [2, 3, 9]. Despite our advances in recent years regarding surgical technique and overall knowledge of microsurgical reconstruction, the ideal flap for complex soft tissue defects of the lower extremity still remains quite controversial and unidentified.

Reconstruction using vascularized perforator pedicle flap transfer for management of soft tissue defects located at the ankle and hindfoot poses many advantages such as a well described anatomy and vasculature [1, 3, 12]. The peroneal artery perforator based pedicle flap was found to be a reliable option in reconstruction of ankle and hindfoot soft tissue defects due to its advantages of not requiring a microvascular anastomosis, involvement of a reliable blood supply with preservation of the main vascular trunks, along with preservation of nerves, muscles and being able to reduce operating and hospitalization times [1, 3].

Free tissue transfer has been considered the mainstay of treatment for reconstruction of the traumatized lower limb over the past few decades due to local and regional flaps often having an unreliable blood supply

and insufficient local donor tissue [18]. The most widely used and most suited free flap for reconstruction of soft tissue defects of the lower extremity is said to be the free ALT flap [8, 9]. When undergoing reconstruction for diabetic foot ulcers the goal in treatment by way of free tissue transfer is to provide a flap with adequate bulk, shock absorption, and durability against the shearing forces of ambulation [9, 12]. Our study found an evident advantage for free tissue transfer in management of soft tissue defects present amongst the diabetic ulcer population. Specifically, free tissue transfer with the free ALT flap for patients with diabetic ulcer defects of the foot [9, 12, 17]. The free ALT flap has a dual advantage being able to provide good skin quality for the walking surface by presence of the Vastus Lateralis muscle being able to fill the deeper cavity [9]. Another possible advantage of free tissue transfer was found amongst patients with extensive soft tissue defects due to large diabetic ulcers, where free flap reconstruction was shown to possibly increase independent ambulation [17]. We did observe some possible complication drawbacks of undergoing reconstruction of the lower extremity using free tissue transfer which included donor site morbidity, lengthy operative times, bulky contour, recipient vessel trauma and the need for advanced surgical experience [18]. When comparing the overall advantages of free tissue transfer, the main advantage for this method of reconstruction is that the flap itself has good vascularity and is able to cover large oversized defects [1, 12]. A disadvantage of free tissue transfer when compared to reconstruction with vascularized peroneal perforator pedicle flap transfer is a higher degree of donor site morbidity is found with free flaps [1].

We recognize the many limitations present within our study. As a qualitative systematic review, our review is limited to existing results of published studies that summarize various surgical techniques performed by different surgeons that may be subject to numerous sources of bias. Second, data was missing for some of the studies regarding comorbidity, defect size with subsequent flap size, and etiology of the defect. Lastly, we did not focus on a certain population; the population reviewed exhibited a heterogeneous array of patients.

Conclusion

The current qualitative systematic review of free tissue transfer versus vascularized perforator pedicle flap transfer in lower extremity reconstruction has contributed a summary of reported outcomes in literature thus far. After analyzing existing evidence for outcomes on flap transfer, we cannot indicate that a clear recommendation exists for an advantage of reconstruction by way of free tissue transfer versus vascularized perforator pedicle flap transfer. Our review found no significant differences in flap selection based on reliability of flap outcomes. As such, an ideal flap transfer for microsurgical reconstruction of lower extremity soft tissue defects has not yet been made clear. We believe further research is needed comparing these two means of flap transfer and propose it would be beneficial to evaluate a specific patient population with a focus on including the effect of comorbidities.

Competing Interests

The authors have no competing interests to declare.

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