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Outcome Analysis Comparing Muscle and Fasciocutaneous Free Flaps for Heel Reconstruction: Meta-Analysis and Case Series

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Abstract

Background Choosing the components of free flap (fasciocutaneous or muscle) is one of the crucial but controversial decisions in heel reconstruction. This meta-analysis aims to provide an up-to-date comparison of fasciocutaneous flaps (FCFs) and muscle flaps (MFs) for heel reconstruction and to ascertain if one flap has an advantage over the other.

Methods Following the Preferred Reporting Item for Systematic Reviews and Meta-Analyses guidelines, a systematic literature review was performed identifying studies on heel reconstruction with FCF and MF. Primary outcomes were survival, time of ambulation, sensation, ulceration, gait, need for specialized footwear, revision procedures, and shear. Meta-analyses and Trial Sequential Analysis (TSA) were performed to estimate the pooled risk ratios (RRs) and standardized mean difference (SMD) with fixed effects and random effects models, respectively.

Results Of 757 publications identified, 20 were reviewed including 255 patients with 263 free flaps. The meta-analysis showed no statistically significant difference between MF and FCF in terms of survival (RR, 1; 95% confidence interval [CI], 0.83, 1.21), gait abnormality (RR, 0.55; 95% CI, 0.19, 1.59), ulcerations (RR, 0.65; 95% CI, 0.27, 1.54), footwear modification (RR, 0.52; 95% CI, 0.26, 1.09), and revision procedures (RR, 1.67; 95% CI, 0.84, 3.32). FCF had superior perception of deep pressure (RR, 1.99; 95% CI, 1.32, 3.00), light touch, and pain (RR, 5.17; 95% CI, 2.02, 13.22) compared with MF. Time to full weight-bearing (SMD, –3.03; 95% CI, –4.25, –1.80) was longer for MF compared with FCF. TSA showed inconclusive results for comparison of the survival of flaps, gait assessment, and rates of ulceration.

Conclusion Patients reconstructed with FCF had superior sensory recovery and early weight bearing on their reconstructed heels, hence faster return to daily activities compared with MFs. In terms of other outcomes such as footwear modification and revision procedure, both flaps had no statistically significant difference. The results were inconclusive regarding the survival of flaps, gait assessment, and rates of ulceration. Future studies are required to investigate the role of shear on the stability of the reconstructed heels.

Keywords
- weight-bearing heel
- reconstruction
- fasciocutaneous
- musculocutaneous

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Introduction

Soft tissue defects of the heel pose a challenging problem in reconstruction, due to lack of local tissues for transfer and weight-bearing requirement of this region.[1] The thick, glabrous skin of the heel, is anchored to the deeper plantar aponeurosis by plenty of fibrous septa traversing the subcutaneous tissue which divides the subcutaneous fat into small loculi.[2] These loculi act as a shock absorbing system preventing shear and withstanding prolonged weight bearing.

Although local flaps can be used for small defects, extensive defects require microsurgical reconstruction.[1] Two types of transfers predominantly done are split-skin grafted muscle and fasciocutaneous flaps (FCFs).[3] Muscle flaps (MFs) have better adherence to wound bed, skin-grafted muscle integrates to form a pad which resists shearing and can provide three-dimensional coverage for extensive defects.[4] The disadvantage is the absence of sensation which makes it prone to ulceration. FCF are thin, pliable, and can be neurotized providing neurosensory flaps, but are more prone to shear.[5]

Owing to the lack of high-level evidence in the previous meta-analysis conducted in 2015,[6] whether one flap is better than the other remains unclear. There is also lack of evidence regarding sensory recovery, time to mobilize, and gait abnormalities between the two flaps in the previous reported studies. Thus, the purpose of this study was to perform a systematic review and meta-analysis to ascertain if there was an advantage of one flap over the other. Furthermore, this study seeks to better understand whether sensory recovery improved the durability of the flaps, and the role of neurosensory flaps. Lastly, this study reviews the outcomes of time to full weight-bearing and gait abnormalities reported on reconstructed heels.

We present our illustrative case series of patients reconstructed with MF for heel defects. This is followed by systematic review and meta-analyses of available literature on reconstruction of heel defects with free MF and FCF.

Case Series

Eight patients from 2017 to 2021 had undergone heel reconstruction with free MF. Patient age ranged from 32 to 50 years and indication for reconstruction was trauma due to road traffic accidents. Defects ranged in size from 80 to 510 cm^2. The most commonly used muscle was latissimus dorsi ($n = 7$) followed by gracilis ($n = 1$). During the surgery thorough wound debridement including resection of bony spurs was performed (►**Fig. 1**). All the anastomoses were done end-to-side to the posterior tibial artery and end-to-end to its vena comitantes. Muscle reinnervation was not attempted. During inset, the MF was tucked for 1 cm under the overlying skin to reduce the incidence of hyperkeratosis/hypertrophy at the skin-muscle junction. All the flaps survived requiring no anastomotic revisions during the immediate postoperative period. The patients were maintained on external fixators with elevating columns. After 4 weeks the elevating columns were removed and patients were started on gradual weight bearing and full weight bearing was achieved by 6 to 7 weeks. Custom-made supportive shoes were used in all patients. Direct observation of gait showed that, each patient developed an individual compensatory gait pattern. All patients had protective sensation and were aware of deep pressure sensation. Four out of eight patients (50%) developed superficial ulcers and were managed conservatively (►**Fig. 2**). Flap revisions and debulking were not required in these patients during follow-up.

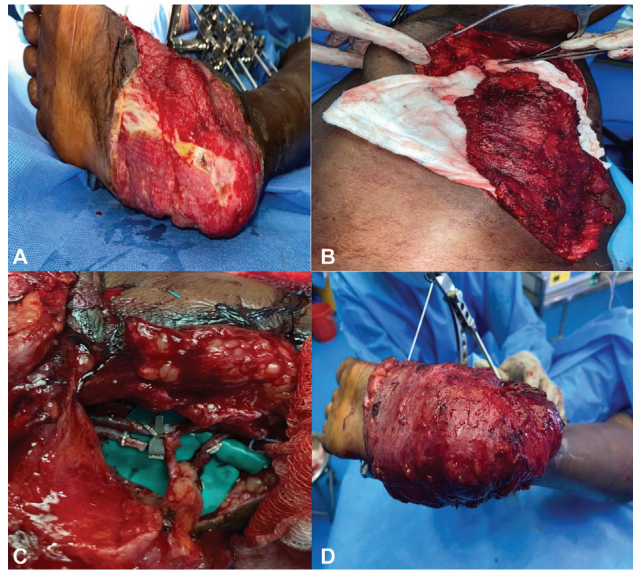

Fig. 1 (**A**) Heel defect with exposed calcaneum and plantar fascia. (**B**) Latissimus dorsi muscle flap with the pedicle. (**C**) Artery anastomosed end-to-side with posterior tibial artery, vein anastomosed end-to-end with venae comitantes. (**D**) Flap after inset.

Materials and Methods

Protocol and Registration

This systematic review and meta-analysis were conducted with a predefined protocol registered in PROSPERO (CRD42021250952). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines were followed.[7]

Fig. 2 Superficial ulceration in the lateral aspect of a free latissimus dorsi muscle flap.

Search Strategy and Data Extraction

A systematic literature search was performed in MEDLINE/PubMed, IndMED, ScienceDirect, and Cochrane Library using the following keywords “Muscle flap,” “free flap,” “fasciocutaneous flap,” “heel reconstruction,” “foot,” “trauma,” and “weight bearing.” These search terms were adapted with different bibliographic databases in combination with database-specific filters, for example, MEDLINE/PubMed search was performed with PubMed Advanced Search Builder using search terms entered with Boolean operator AND, OR, and AND NOT. Database search and extraction was done from April 23, 2021 to May 1, 2021. Title and abstract screening were done for all studies published till April 2021 by two reviewers. The inclusion criteria were: studies reporting outcome analysis for heel reconstruction with free MF or FCF and a minimum follow-up of 6 months. Case reports were included if sample size is ≥ 4. Letters to the editor, conference abstracts, book chapters, and expert reviews were all excluded. Studies reporting compound flaps were excluded. After removal of duplicates, full texts were obtained and screened. Full-text articles meeting our criteria were included. Reference list of included articles were screened for additional relevant studies. Conflicts were resolved by consensus. Independent data extraction and recording were done by two independent investigators. The following data were extracted from the included studies: name of the first author, year of the study, study design, sample size, etiology of the defect, mean age, gender, duration of follow-up, type of flap used, acute revision rates, survival of the flaps, innervation, wound healing complications, time of weight bearing, sensation, ulceration rates, gait analysis, shear, footwear modification, and need for revision procedures.

Statistical Analysis

A kappa statistic was calculated for interreviewer agreement for study inclusion.[8] We analyzed each outcome separately and each analysis included only studies reporting those outcomes. Risk ratios (RRs) and their corresponding 95% confidence intervals (CIs) for comparable outcomes were measured using a fixed effect model with Mantel–Haenszel analysis method. Some outcomes were measured with standardized mean difference using a random effects model with an inverse-variance approach. Heterogeneity among studies was quantified with chi-square test and I^2 statistic.[9] $I^2 > 75\%$ represented considerable heterogeneity.[10] Subgroup analysis was performed for outcomes with considerable heterogeneity. Trial Sequential Analysis (TSA) with monitoring boundaries was performed to overcome the low methodological quality, outcome measure bias, publication bias, and small study bias. Sequential monitoring boundaries were applied to meta-analysis to improve the statistical significance of results.[11] Funnel plots were used for assessing the small study effects and reporting bias.[12] Meta-analysis was conducted with Review Manager (RevMan) [Computer program], Version 5.4, The Cochrane Collaboration, 2020.[13] TSA was performed with TSA [Computer program], Version 0.9.5.10 Beta, The Copenhagen Trial Unit, Centre for Clinical Intervention Research, The Capital Region, Copenhagen University Hospital – Rigs Hospitalet, 2021.[14]

Assessment of Methodological Quality

Methodological quality assessment was performed by two independent reviewers using the Methodological Index for Non-Randomized Studies (MINORS) scale.[15] MINORS scale contains 12 items, the first 8 for noncomparative studies and additional 4 items for comparative studies. The global ideal score is 16 for noncomparative studies and 24 for comparative studies.

Results

Study and Patient Characteristics

Of the 757 records identified, 20 articles published from 1983 to 2020 were included (►**Fig. 3**). Studies included 14 prospective and 6 retrospective cohorts. Ten articles[16–25] reported on FCF reconstruction, three[26–28] included MF, and seven[1,29–34] compared both flaps (►**Table 1**). The 20 included studies encompassed 255 patients with a mean follow-up of 2.79 ± 1.52 years. Patient age ranged from 2.5 to 80 years. The majority of heel reconstructions were performed for trauma-related indications ($n = 163$ [63.9%]), the remaining were done for malignancies (11%), diabetic foot ulcers (5%), and others (18%).

Surgical Characteristics

The meta-analysis included 263 flaps with 134 (50.9%) MF and 129 (49.1%) FCF. MF included latissimus dorsi ($n = 74$ [55%]), rectus abdominis (29%), gracilis (13%), medial gastrocnemius (1.4%), and biceps femoris (0.74%). Among the

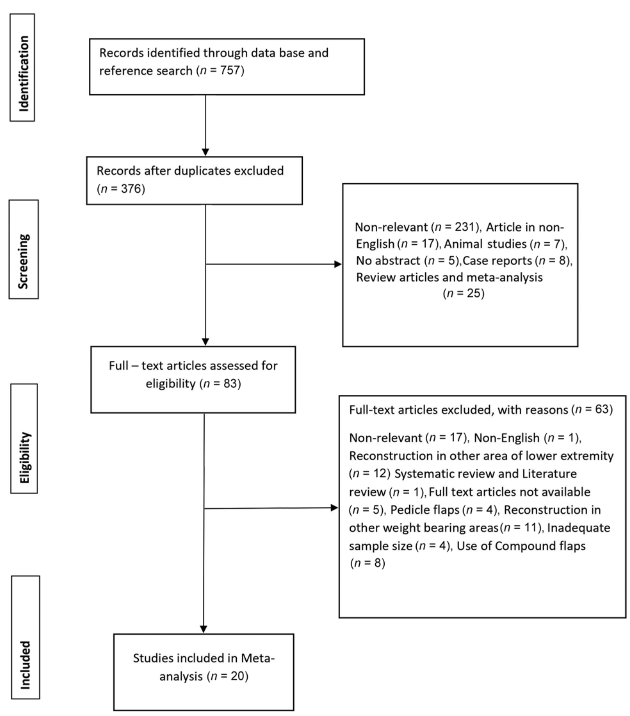

Fig. 3 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart.

Table 1 Summary of study characteristics

Study	No. of patients	Fasciocutaneous flap	Muscle flap	Innervation of the flap	Reexploration in acute period	Time to ambulation	Gait abnormality
Harris et al, 1994	13	–	LD-13	No	2 vein revisions	1 month	No abnormality
Heymans et al, 2005	6	Temporal flap-6	–	No	1 vein revision	NR	FCF-1
Kuran et al, 2000	5	RF-3	RA-2	RF-3	NR	NR	NR
Langstein et al, 2002	9	RF-2 ALT-1	Gr-3, LD-1, RA-1, BF-1	No	2 vascular revisions	2.5 months	NR
Noever et al, 1986	4	RF-4	–	RF-4	Nil	NR	FCF-4
Oztürk et al, 2005	72	–	LD-42, RA-30	No	7 vascular revisions	2.5 months	NR
Potparić and Rajacić, 1997	15	RF-5, Scapular-1	LD-6, RA-1, MG-2	RF-5, LD-2, MG-1	NR	NR	MF-7, FCF-2
Rautio et al, 1989	6	Scapular-6	–	No	1 artery revision	NR	NR
Roggero et al, 1993	6	RF-2, Lateral chest-1	LD-3	All	NR	NR	NR
Santanelli et al, 2002	16	RF-16	–	RF-9	Nil	NR	FCF-1
Weinzweig and Davies, 1998	8	RF-8	–	No	1 vein revision	NR	FCF-2
Yücel et al, 2000	19	RF-7, ALT-14	LD-2, Gr-8, RA-1	RF-7	NR	3 months	FCF-1, MF-1
Duncan et al, 1985	5	Dorsalis pedis-5	–	All	Nil	NR	No abnormality
Elgohary et al, 2018	25	RF-11, ALT-14	–	All	NR	NR	NR
El-Shazly et al, 2008	6	RF-3	RA-3	No	NR	1 month	NR
Grauberger et al, 2020	12	ALT-1	Gr-4, LD-6, RA-1	No	NR	NR	NR
Han et al, 2020	16	Medial plantar-11	–	No	Nil	NR	FCF-8
Qing et al, 2018	4	ALT-4	–	All	Nil	NR	NR
Varghese et al, 2016	4	–	LD-1, Gr-3	No	Nil	1.5 months	No abnormality
Wood et al, 1983	4	Groin-4	–	Groin-1	Nil	NR	NR

Abbreviations: ALT, anterolateral thigh; BF, biceps femoris; FCF, fasciocutaneous flap; Gr, gracilis; LD, latissimus dorsi; MF, muscle flap; MG, medial gastrocnemius; NR, not reported; RA, rectus abdominis; RF, radial forearm.

FCF, the most commonly done was radial forearm flap ($n = 61$ [47%]), followed by anterolateral thigh flap (26%), medial plantar flap (8.5%), scapular flap (5.4%), temporal flap (4.6%), dorsalis pedis flap (3.8%), groin flap (3.1%), and lateral chest flap (0.77%). Among the 10 articles[17,19,21,22,24,25,29,31–33] describing neurosensory flaps, FCFs (80%) were commonly reinnervated compared with MF (20%). Radial forearm flap innervation was done with lateral cutaneous nerve of the forearm as donor nerve to available recipient nerves. Lateral cutaneous nerve of thigh was used to neurotize the anterolateral thigh flap, superficial peroneal nerve for the dorsalis pedis flap,[21] and intercostal nerves for the lateral chest flap.[32] In MF reinnervation was done either by coaptation of recipient nerve to motor nerve of the muscle or an onlay nerve graft between the muscle and skin graft.[31,32]

Thirteen studies[16–21,23–28,30] report revision procedures in the immediate postoperative period. Anastomotic revisions were higher in MF (10.5%) compared with FCF (6.3%). Regarding the survival of flaps the meta-analysis showed an estimated RR of 1 (95% CI, 0.83, 1.21, $p = 0.99$) indicating no significant difference between FCF and MF (►**Supplementary Fig. S1**, online only). However, TSA results were inconclusive. Heterogeneity among the studies was not important ($I^2 = 0$, $p = 1.00$).

Complications in Wound Healing

Eleven articles[1,16,17,21,22,24,26,27,30,33,34] reported on complications in wound healing in terms of infection, hematoma, partial thickness loss, and graft loss in 5.2% of MF and 5.4% of FCF (►**Table 2**). However, because of limited data regarding complications, a meta-analysis comparing MF and FCF was not possible.

Time to Full Weight Bearing

Time to weight bear on the reconstructed heels varied from 4 weeks to 3 months.[1,26–28,30,33] Standardized mean difference with inverse-variance approach was –3.03 (95% CI, –4.25, –1.80, $p < 0.00001$) suggesting that time to bear weight and subsequent return to daily activities were earlier with FCF compared with MF (►**Supplementary Fig. S2**, online only). The p-value was 0.19 indicating moderate ($I^2 = 41\%$) interstudy heterogeneity. Though only two studies compared the time to full weight bearing, TSA Z curve crossed the conventional test boundaries with both studies reinforcing the results of meta-analysis.

Gait Abnormality

Information on gait assessment was available in 101 flaps in 10 studies[16,17,19–21,23,26,27,31,33] but comparison was reported only in two studies.[31,33] Assessment was done either by observing the gait or using patients' description. The gait pattern analyzed by two studies[29,33] with dynamic pedogram indicated reduced contact area of the reconstructed foot relative to the healthy foot. However, during walking, the reconstructed area was weight bearing and the pressure recorded was not less than the normal foot. The calculated RR was 0.55 (95% CI, 0.19, 1.59, $p = 0.27$) suggesting no significant difference in gait abnormalities between FCF and MF. TSA results were inconclusive for this outcome (►**Supplementary Fig. S3**, online only). Interstudy heterogeneity was not important ($I^2 = 0\%$, $p = 0.27$).

Sensation

Sensory assessment was reported in five studies.[1,29,31–33] Meta-analysis (RR of 1.99 [95% CI, 1.32, 3.00, $p = 0.001$]) and TSA Z curve indicated that heels reconstructed with FCF developed superior protective sensation compared with MF (►**Supplementary Fig. S4**, online only). There was substantial heterogeneity among the studies ($I^2 = 90\%$, $p < 0.00001$) due to inclusion of different study populations. Subgroup analysis could not be performed due to nonavailability of data regarding the individual participant types. There was superior perception of light touch and pain by patients who underwent FCF reconstruction (RR, 5.17, 95% CI, 2.02, 13.22, $p = 0.00006$). TSA Z curve confirmed the findings (►**Supplementary Fig. S5**, online only). Interstudy heterogeneity was moderate ($I^2 = 34\%$, $p = 0.22$).

Ulceration

Six studies[1,29–33] assessed the incidence of ulceration on reconstructed heels. Though, a fixed effects meta-analysis model yielded no significant difference in the rates of ulceration (RR, 0.65, 95% CI, 0.27, 1.54, $p = 0.33$) between FCF and MF, TSA graph was inconclusive (►**Supplementary Fig. S6**, online only). Interstudy heterogeneity was not important ($I^2 = 0\%$, $p = 0.42$).

Footwear Modification

Four studies[1,29,31,33] reported on footwear modification. Comparing the need for footwear modification on reconstructed heels (►**Supplementary Fig. S7**, online only), no significant difference was observed between the two flaps in the meta-analysis (RR of 0.52 [95% CI, 0.26, 1.09, $p = 0.09$]) and TSA. There was substantial interstudy heterogeneity ($I^2 = 73\%$, $p = 0.01$).

Revision Procedures

Debulking (68.7%) was the commonly reported procedure among the five studies[1,29–31,33] reporting revisions following reconstruction. The estimated RR of 1.67 (95% CI, 0.84, 3.32, $p = 0.38$) and TSA Z curve indicated no significant difference in the rates of revision procedures between MF and FCF (►**Supplementary Fig. S8**, online only). The p-value of chi-squared test was 0.38 ($I^2 = 2\%$) suggesting interstudy heterogeneity was not important.

Shear

Three articles[16–18] described the mobility of tissues across tangential shear forces on the reconstructed heels. Heymans et al reported that temporal FCFs were able to resist shear owing to their architectural similarity to the heel. Shear was measured by Noever et al by hooking a 100-g weight to the center of the flap and measuring the yield in vertical position. The range of shifting was from 1 to 1.7 cm. Rautio et al postulated that shear resistance was not associated with the stability of the reconstruction. Laxity of the scapular flaps did not correlate with the size and thickness of the flap.

Table 2 Outcomes of included studies

Study	Ulceration	Sensation	Footwear modification	Revision procedures
Harris et al, 1994	MF-5	Protective sensation present in all	MF-1	MF-1 debulking, 1 hypertrophic nodule excision and skin graft 3 excisions of the MF and replacement with lateral arm flaps
Heymans et al, 2005	FCF-1	Protective sensation present in all	FCF-1	FCF-1 debulking
Kuran et al, 2000	MF-2	MF- no sensation, FCF (innervated)- Semmes-Weinstein monofilament (SMW)- positive, Light touch, pin prick present	MF-2	MF-1 debulking
Langstein et al, 2002	MF-1	NR	NR	FCF-1 debulking
Noever et al, 1986	No ulcer	Touch, pain, temperature in all flaps (innervated)	FCF-2	No revision procedures
Oztürk et al, 2005	MF-20	Protective sensation present in all	MF-42	MF-11 debulking, 9 bony prominence excision, fistulae correction-18
Potparić and Rajacić, 1997	MF-3, FCF-2	Protective sensation in all, touch present in FCF-5, MF-3 (innervated)	MF-8	MF-3 ulcer excisions, 2 osteomyelitis requiring bone excision, FCF-3 ulcer, 1 flap replaced with MF due to repeated ulcerations, 2 osteomyelitis requiring bone excision
Rautio et al, 1989	FCF-4	NR	FCF-3	NR
Roggero et al, 1993	MF-2	No sensation in MF-2, protective sensation in FCF-1	NR	NR
Santanelli et al, 2002	FCF-5	Positive SWM test, touch, pain, temperature in all flaps Two-point discrimination in 9 flaps (innervated)	FCF-1	No revision procedures
Weinzweig and Davies, 1998	FCF-2	Protective sensation present in all	FCF-2	FCF-1 debulking
Yücel et al, 2000	FCF-2, MF-1	Protective sensation decreased in all MF, FCF- protective sensation present Positive SWM test present in FCF-7 (innervated)	FCF-2	FCF-2 debulking
Duncan et al., 1985	No ulcer	Protective sensation present in all	FCF-5	No revision procedures
Elgohary et al, 2018	FCF-3	Protective sensation, two-point discrimination – 20 (innervated), absent sensation-5	FCF-3	FCF-4 debulking
El-Shazly et al, 2008	No ulcer	Protective sensation in all groups	FCF-3, MF-3	No revision procedures
Grauberger et al, 2020	NR	NR	NR	NR
Han et al, 2020	No ulcer	Touch, pain, temperature in all flaps	FCF-1	No revision procedures
Qing et al, 2018	NR	SMW test positive in all cases, touch, two-point discrimination in all	NR	NR
Varghese et al, 2016	MF-1	NR	No footwear modification	MF-2 debulking, 1 excision of painful callosity
Wood et al, 1983	FCF-2	NR	NR	FCF-1 excision of hyperkeratotic lesion

Abbreviations: FCF, fasciocutaneous flap; MF, muscle flap; NR, not reported; SMW, Semmes-Weinstein monofilament.

Funnel plot showed symmetry suggesting the absence of publication bias and small study effects (►**Supplementary Fig. S9**, online only).

Methodological Quality

The mean MINORS score was 11/16 (range: 10–12) and 15/24 (range: 14–16) for comparative and noncomparative studies, respectively, suggesting the studies were of low methodological quality (**Supplementary Material 1** and **2**, online only). Concordance between the reviewers' assessment was excellent with intraclass correlation 0.80 (95% CI).

Discussion

This meta-analysis showed no statistically significant difference between the two flaps in terms of survival, gait abnormalities, rates of ulceration, need for specialized footwears, and requirement of subsequent revision procedures. Patients reconstructed with FCF had superior perception of deep pressure, light touch, and pain compared with MF. Moreover, time to full weight-bearing walking following reconstruction was longer in MF compared with FCF. TSA confirmed the findings of meta-analysis for all the outcomes except for survival of flaps, gait assessment, and rates of ulceration. In these outcomes, TSA was inconclusive suggesting that further information is required before any firm conclusion can be reached.

Higher rates of vascular revisions were observed in MF in the immediate postoperative period. One study[28] in our analysis which described MF ($n = 72$, 53%) for severe land mine injuries reported the highest number of vascular revisions (9.7%). Land mine injuries generally result in composite tissue defects with extensive soft tissue damage which might account for the higher rates of vascular emergencies in MF. Common causes for delay in wound healing among MF were loss of skin grafts requiring regrafting[26,34] and infection leading to partial loss of the muscle,[33] whereas hematoma,[33] infection,[17] and partial thickness loss[21,22] led to delay in FCF.

Patients who underwent heel reconstruction with MF took longer to begin full weight bearing compared with FCF. Among the two studies included for analyzing the time to ambulate, Kuran et al[29] compared sensate and nonsensate flaps for reconstruction of the heel. Neurosensory radial forearm flaps were used in one group and the comparative group included noninnervated MFs. The defects in the sensate group were slightly smaller than those in the nonsensate group. In Langstein et al[30] the mean defect size was 63.4 cm^2 for MF and 38 cm^2 for FCF. Larger defects with longer healing times might contribute to the delay in weight-bearing in heels reconstructed with MF.

Assessment of gait[31,33] was based on single surgeon's subjective observation as the patient walked bare foot and with his footwear. Potparić and Rajacić devised a scale of "normal," "acceptable," and "poor" considering ambulatory distance, stair climbing, ability to run, recreational activity, and use of ancillary support. Our analysis was unable to distinguish the role of reconstruction on gait suggesting more data are required before a firm conclusion can be reached. This view was supported by previous investigators who reported that gait was more dependent on the functional and anatomical status of the foot rather than the soft tissue replacement.[35,36] Perttunen et al[37] proposed that patients with free flap reconstruction of the sole, reduced loading on their flaps by altering their weight-bearing patterns. Gait patterns were modified by patients to shorten the time spent over the reconstructed foot.

Although it would seem that heel reconstruction would require a sensate flap to avoid recurrent breakdowns, literature is unclear on this point. Though neurosensory FCF provide better sensory perception, the final results were not superior to MF, as indicated by many authors.[29,31,33,38] On the contrary, Roggero et al[32] with a small cohort, favored neurosensory FCF stating that patients with nonsensate flaps had higher incidence of cutaneous breakdown compared with sensate flaps. Some authors reinnervated MFs by coaptation of motor to sensory nerve or onlay nerve grafting.[31,39] Although improved sensation was achieved in these flaps, the overall results were not better than noninnervated MF. Our review and meta-analysis concurred with previous reports[20,31,38,40] that some form of protective sensation is sufficient to provide durable flaps, and FCF irrespective of their innervation status had superior protective sensation compared with MF. On the other hand, innervated FCF may be relevant in selected cases like incomplete spinal cord injury, where transfer of some residual innervation outside the heel, if possible, can restore deep pressure sensation and provide durable flaps.

Several studies[40–42] highlighted the fact that ulceration is not correlated with the type of reconstruction, flap sensibility, and the cause of the primary defect. Our results were inconclusive in this regard suggesting more data are required for further analysis. Ulcerations, however, are mechanical in origin and arise from either exogenous or endogenous causes. Flaps that are thick and conform poorly to the underlying osseous architecture are prone to exogenous ulcers. Hence, there is a need for flap tailoring before inset. Ulcers from endogenous origin arise in conjunction with weight-bearing points and pressure areas overlying osseous deformities. These high pressure sites are the most common reason for recurrent ulcerations which can be prevented by paying attention to the skeletal architecture during reconstruction.[40] It is important not only to resect the bony spurs and perform appropriate orthopaedic procedures but also to provide supportive footwear for better gait and prevention of recurrent breakdowns.

Although 70% of patients required footwear modification in our review, the meta-analysis showed no difference in this aspect between the two flaps. Custom-made footwear has been advocated to provide additional padding, reduce shear, and to shift weight to a more stable area. Use of silicon insoles to reduce peak vertical pressure forces and pressure-gait analysis to design footwear accordingly have been suggested by the previous authors.[38,43]

The meta-analysis comparing the rates of revision showed no statistically significant difference between the two flaps similar to results from previous investigators.[6] This review suggests that nature of the recipient bed and flap inset are major contributors to the need for later revisions, rather than factors inherent to the reconstruction itself. Adequate restoration of the skeletal components by means of bone grafts, selective osteotomies, and/or fusions should be undertaken before soft tissue reconstruction.[31] Flap contouring before inset can reduce the shear and subsequent revisions.

Although shear was addressed in two studies,[17,18] the impact of shear on ambulation was not reported. Authors described their methods of measuring shear by using weights and ultrasound. Rautio et al measured the resistance to shear of the scapular flap and postulated that resistance was not related to the soft tissue stability of the reconstruction. Further, thinning and tightening of the scapular flap did not reduce the flap laxity in their study.

Shear plays an important role in the development of postoperative ulcerations, hyperkeratosis, and hypertrophic scar formation[16] on the reconstructed heels. The thick skin of the plantar region and the underlying subcutaneous fat allow the dispersion of shearing forces that accompany walking. Once reconstructed with the transferred flaps, this dispersion component is lost resulting in sliding of the foot on the flap while the patient walks. Unlike the heel skin, the transferred free flaps are not strongly attached to the underlying calcaneum. Skin-grafted muscle can develop two independent mobile tissue planes—one at the muscle-skin graft interface and a second at the muscle-wound bed interface. However, with time MF attach more strongly to the underlying bone thereby obliterating the muscle-wound bed shear. To achieve a similar effect, theoretically, the fascia in FCF can be anchored to the underlying periosteum to reduce shear. But the subcutaneous tissue between the fascia and skin may contribute to shear leading to instability with ambulation. Though the architecture of the FCF resembles more the subcutaneous elastic architecture of the plantar skin, they are often too bulky and are difficult to attach to the underlying periosteum.[16] MFs are advantageous in this aspect since they "stick" well and their bulk reduces overtime with atrophy resulting in a stable construct which can withstand shear. The impact of shear remains less understood though it is described as a key justification in choosing MF over FCF. Further studies with adequate comparison groups are warranted to evaluate the role of shear in the soft tissue stability of the different free flaps used for reconstruction.

This meta-analysis is not without its limitations. Even though systematic literature search was performed, it is possible that not all relevant studies were captured, such as those not searchable on the included databases. This review does not exclude the temporal bias due to the recent trends of compound flaps used for heel reconstruction. Several studies could not be included in our analysis because they did not specify the weight-bearing area and described reconstruction of the entire sole. There was no consensus of the defect size with some included studies describing small defects exclusively, and several authors chose MF for extensive defects. Etiology of the defects were variable with some etiologies altering the osseous architecture like land mine injuries while others preserved the skeletal elements like cutaneous malignancies, leading to comparison of heterogeneous groups. Randomized control trials with adequate comparison groups should be conducted comparing both the flaps standardizing the defect size and etiology to further investigate the advantage of one flap over the other.

Conclusion

Patients reconstructed with FCF had superior sensory perception and early weight bearing on their reconstructed heels, hence faster return to daily activities compared with MF. In terms of other outcomes like footwear modifications and revision procedures both flaps had no statistically significant difference. Regarding survival of flaps, gait assessment, and rates of ulceration, the results were inconclusive suggesting that further information is required before any firm conclusion can be reached. Although FCF had superior sensory perception there was no improvement in durability compared with MF. Flap reinnervation by direct nerve coaptation is worthwhile in selected patients. Further biomechanical studies are required to investigate the role of shear on the stability of the reconstructed heels.

Authors' Contributions
A.C.: Conception and design, acquisition of data, drafting the article, and final approval of the version. S.K.J.: Conception and design, acquisition of data, drafting the article, and final approval of the version. R.B.A.: Conception and design, acquisition of data, drafting the article, and final approval of the version.

Conflict of Interest
None declared.

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