A systematic review and meta-analysis of perforator flaps in plantar defects: Risk analysis of complications

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Abstract
The purpose of this study was to identify the risk factors for complications of perforator flaps in plantar reconstruction. A systematic review was performed by searching the PubMed, Cochrane Library, MEDLINE, and EMBASE databases from their inception date up to October 2020. Only studies on reconstructing plantar defects with perforator flaps were included, and specific data were required for each patient in the included studies. A total of 14 studies involving 111 flaps were identified and included in the meta-analysis. Our meta-analysis identified two risk factors for postoperative complications: flap size over 50 cm² (risk ratio [RR] = 3.12; \( P = .02 \)), diabetes mellitus foot (RR = 3.26; \( P = .03 \)). No significant differences were found regarding heel defects (\( P = .34 \)), single perforator (\( P = .57 \)), age older than 60 years (\( P = .19 \)), chronic aetiology (\( P = .13 \)), trauma (\( P = .33 \)), tumour resection (\( P = .60 \)), ulcer (\( P = .84 \)), and burn (\( P = .76 \)). Although more high-quality studies with adequate sample sizes are needed, this meta-analysis indicated that flap size over 50 cm² and diabetes mellitus foot were significant risk factors for postoperative complications of perforator flaps in plantar reconstruction.

KEYWORDS
complication, meta-analysis, perforator flap, plantar defect, risk factor

1 | INTRODUCTION

Reconstruction of plantar defects has always been a difficult problem. The plantar aspect of the foot, as a weight-bearing part of the human body, has tough skin, thick cuticle, and strong resistance to pressure and wear.\(^1\,\,^2\) Forefoot and hindfoot are weight-bearing areas with thicker skin and fat pads to support the body's weight.\(^3\) Non-weight-bearing areas include toe and midfoot, which have relatively thin skin that helps maintain balance.\(^1\) One of the main factors in plantar reconstruction is the provision of skin with texture, thickness, and sensitivity similar to plantar skin.\(^4\) Because Koshima and Soeda first reported a perforator flap, the technique of perforator flaps has been widely used for the reconstruction of soft tissue defects.\(^5\) A perforator flap is an axial flap consisting of skin and subcutaneous tissue based on one or more deep arterial perforators.\(^6\) The technique of perforator flaps can obtain thin and flexible flaps with good blood perfusion while retaining the innervation, blood supply, and functionality of the donor site muscles.\(^7\) Thus, the incidence of complications in the donor site can be reduced.\(^8\) In recent years, with the development of perforator flaps, different types and concepts have emerged.\(^9\,\,^{13}\)
Perforator flaps can repair plantar defects while minimising the risk of complications in the donor site, but the reliability of perforator flaps has not been well verified. As far as we know, there is currently no meta-analysis performing a risk analysis of complications of perforator flaps in plantar reconstruction, and our study can fill this knowledge gap. In this study, a meta-analysis was performed to identify the risk factors for complications of perforator flaps in plantar reconstruction.

2 | MATERIALS AND METHODS

2.1 | Search strategy

A systematic review was performed by searching the PubMed, Cochrane Library, MEDLINE, and EMBASE databases from their inception date up to October 2020 for all literature on reconstructing plantar defects with perforator flaps. The following keywords were used in the search: “Perforator Flap,” “Flap, Perforator,” “Flaps, Perforator,” “Perforator Flaps,” “Plantar,” “Forefoot,” “Midfoot,” “Hindfoot,” “Heel,” and “defect.” References cited in the study were also reviewed in search of other suitable literature.

2.2 | Selection criteria

All original studies using perforator flaps to repair plantar defects were included. The location of the defect was limited to the forefoot sole, midfoot sole, and hindfoot sole. Specific data were needed for each patient in the study. Only articles published in English were included. Case reports, letters, purely technical descriptions, comments, guidelines, and reviews were excluded. Data from the same author's studies were reviewed, and duplicates data were deleted.

2.3 | Relevant study selection

Two reviewers independently reviewed all possible studies to screen out all eligible studies. First, the two reviewers (F. Y. F. and Z. P. Y.) directly removed unqualified articles that were not related to plantar reconstruction with perforator flaps by reading all the titles and abstracts of the articles. All qualified articles related to plantar reconstruction with perforator flaps were downloaded, and they sought the help of the original author for manuscripts that could not be downloaded. They identified all the studies that were included based on the selection criteria. If the two reviewers had different opinions, the issue was resolved by a more experienced reviewer (X. C. C.).

2.4 | Data extraction

Data from the eligible studies were extracted independently by the two reviewers (F. Y. F. and Z. P. Y.). If the two reviewers had different opinions, the issue was resolved by a more experienced reviewer (X. C. C.). The extracted data included the following basic information: number of patients, age, aetiology, location of the defect, type of the flap, preoperative preparation, flap size, dissection plane, number of perforators, donor site, follow-up time, and complications.

2.5 | Quality assessment

Because all the included studies were retrospective studies, the Newcastle-Ottawa Scale (NOS) was used to assess the risk of bias of each study. The primary indicators of NOS included selection, comparability, and outcome, with a total score of 9. A study with a quality score of ≤5 was considered to be low quality, suggesting a high risk of bias; a study with a quality score of >5 was considered to be high quality, suggesting a low risk of bias.

2.6 | Data analysis

We used the Revman 5.3 software to perform statistical analysis of the results. The risk ratio (RR) with the Mantel-Haenszel calculation method was selected and used to compare dichotomous variables, and the corresponding 95% confidence intervals (CIs) were calculated.
calculated. The chi-square test was used to estimate heterogeneity. We used a fixed-effect model when the result showed that the $I^2$ was less than 50%\textsuperscript{16}; otherwise, a random-effect model was used. Funnel plots were performed to assess publication bias. $P < .05$ was considered statistically significant.

3 | RESULTS

A total of 258 studies were initially searched from four databases. Then, 132 studies were excluded because they were duplicates, and 126 studies remained. After screening the titles and abstracts, 90 studies that were not related to plantar reconstruction with perforator flaps were deleted. After downloading and reading the full text of the remaining 36 studies, 22 studies were further removed. Figure 1 shows the selection process for eligible studies. Finally, 14 studies\textsuperscript{4,17-29} involving 111 flaps were identified and included in the meta-analysis (Table 1). The basic characteristics of patients and flaps are shown in Table 2. The quality scores of the included studies are presented in Table 1. One study\textsuperscript{19} was considered to be low quality, and the others\textsuperscript{4,17,18,20-29} were considered to be high quality.

### 3.1 | Overview of practices

#### 3.1.1 | Age

The mean age of the patients was 49.3 ± 19.1 years (range, 6-84 years). In 36.0% of cases (n = 40), the patients were over 60 years old (Table 2).

#### 3.1.2 | Aetiology

Causes of plantar defects were divided into acute and chronic causes (Table 2). Acute causes were those that can cause plantar defects in a short period of time, and chronic causes were those that require a period of development to cause plantar defects. Acute causes (n = 77, 70.6%) included trauma, tumour resection, vascular malformation resection, and burn; chronic causes (n = 32, 29.4%) included ulcer and diabetes mellitus foot. The proportion of all specific causes is shown in Figure 2. Tumour resection (37.6%) was the most common cause of plantar defects, followed by trauma (27.5%).

#### 3.1.3 | Location of the defect

In this meta-analysis, we observed that most plantar defects were at the hindfoot (n = 59, 75.6%), followed by the forefoot (n = 15, 19.2%) and the midfoot (n = 4, 5.1%) (Table 2).

#### 3.1.4 | Preoperative preparation

In our study, we observed that most cases (n = 89, 85.6%) used only Doppler ultrasound preoperatively to look for perforators. Surgeons used only CT angiography before operating in 4.8% of cases (n = 5). Besides, Doppler ultrasound and CT angiography were used in 9.6% of cases (n = 10) (Table 2).

#### 3.1.5 | Type of flaps

There were two types of perforator flaps for repairing plantar defects: pedicled flaps (n = 70, 63.1%) and free flaps (n = 41, 36.9%) (Table 2). According to the source of perforators, the commonly used pedicled perforator flaps included medial plantar artery perforator (n = 31, 27.9%), peroneal artery perforator (n = 13, 11.7%), posterior tibial artery perforator (n = 12, 10.8%), and lateral plantar artery perforator (n = 3, 2.7%); besides,
| Study            | No. of cases | Mean age (y) | Type of flaps                      | Surgical technique | Mean size (cm²) | Dissection       | No. of perforators | Donor site | Mean follow-up (mo) | Complications                                                                 | Quality score |
|------------------|--------------|--------------|-----------------------------------|--------------------|----------------|------------------|--------------------|-------------|-------------------|--------------------------------------------------------------------------------|---------------|
| Zheng et al      | 7            | 19.6         | PAP; pedicled                     | Doppler            | 27.2           | ND               | ND                 | Direct suturing | ND                | No significant complications                                                  | 6             |
| Scaglioni et al  | 28           | 54.4         | MPAP; pedicled (n = 26), free (n = 2) | Doppler            | 21.9           | Suprafascial     | One (n = 26), three (n = 2) | A split-thickness skin graft | 9                | Total lost (n = 1)                                                                 | 7             |
| Woo et al        | 10           | 64.9         | TDAP; free                        | Doppler, CT angiography | 50.0 | ND               | ND                 | ND          | 11.4              | Partial flap loss (n = 1), venous congestion (n = 1)                              | 7             |
| Balan et al      | 2            | 46.5         | MSAP; free                        | Doppler            | 104            | Subfascial       | One (n = 26), three (n = 2) | A split-thickness skin graft | 24.2             | No significant complications                                                   | 7             |
| Cho et al        | 5            | 61.2         | LCAP; free                        | Doppler            | 12.9           | Suprafascial     | One                | A split-thickness skin graft | ND               | No significant complications                                                   | 7             |
| Kim et al        | 5            | 56.4         | TDAP; free                        | CT angiography     | 56.8           | ND               | ND                 | Primary closure | 15.2              | Partial necrosis (n = 1), venous congestion (n = 1)                              | 6             |
| Song et al       | 4            | 26.25        | MPAP, FPMAP; pedicled             | Doppler            | 19.1           | Subfascial       | One                | A split-thickness skin graft | 16               | Skin graft necrosis (n = 1)                                                     | 7             |
| Valentin et al   | 7            | 64.7         | PMAP, CDAP; pedicled              | ND                 | ND             | ND               | Directly closed (n = 2), a skin graft (n = 5) | ND          | 9.9               | Delayed healing (n = 1)                                                        | 7             |
| Akhtar et al     | 7            | 39.9         | PTAP; pedicled                    | Doppler            | 41.5           | Subfascial       | ND                 | A split-thickness skin graft | ND               | Complete flap loss (n = 1), epidermolysis (n = 1), mild venous congestion (n = 1) | 6             |
| Georgescu et al  | 3            | 47           | PAP; pedicled                     | Doppler            | ND             | ND               | ND                 | ND          | ND                | Partial superficial necrosis (n = 1)                                             | 6             |
| Kim et al        | 8            | 53.9         | MPAP (n = 5), LPAP (n = 3); pedicled | Doppler            | ND             | Suprafascial     | One (n = 7), two (n = 1) | ND          | 13                | Venous congestion (n = 1)                                                      | 6             |
| Kim et al        | 9            | 48.1         | MSAP; free                        | Doppler            | 72.1           | Subfascial       | One (n = 5), two (n = 4) | Primary closure (n = 6), a split-thickness skin graft (n = 3) | ND          | Partial flap loss (n = 1), venous insufficiency (n = 1)                        | 7             |
| Bhattacharya et al | 8         | 50.3         | PTAP (n = 5), PAP (n = 3); pedicled | Doppler            | 167.0          | Subfascial       | ND                 | A split-thickness skin graft | ND               | Marginal necrosis (n = 1)                                                       | 7             |
| Koshima et al    | 8            | 33.3         | ALTP (n = 7), AMTP (n = 1); free  | Doppler            | 161.6          | Suprafascial     | ND                 | ND          | ND                | No significant complications                                                   | 6             |

Abbreviations: ALTP, anterolateral thigh perforator; AMTP, anteromedial thigh perforator; CDAP, common digital artery perforator; CT, computed tomographic; FPMAP, first plantar metatarsal artery perforator; LCAP, lateral calcaneal artery perforator; LPAP, lateral plantar artery perforator; MPAP, medial plantar artery perforator; MSAP, medial sural artery perforator; ND, not determined; PAP, peroneal artery perforator; PMAP, plantar metatarsal artery perforator; PTAP, posterior tibial artery perforator; TDAP, thoracodorsal artery perforator.
plantar metatarsal artery perforator flaps and common digital artery perforator flaps were also reported. The most common free perforator flaps were thoracodorsal artery perforator (n = 15, 13.5%), followed by medial sural artery perforator (n = 11, 9.9%), anterolateral thigh perforator (n = 7, 6.3%), lateral calcaneal artery perforator (n = 5, 4.5%), and anteromedial thigh perforator (n = 1, 0.9%).

### 3.1.6 Flap size

The average size of the flaps was 59.2 ± 60.4 cm² (range, 6.25-360 cm²). In 36.8% of the flaps (n = 37), the size was greater than 50 cm² (Table 2).

### 3.1.7 Dissection plane

The dissection plane was suprafascial in 62.0% of cases (n = 49), and 38.0% of cases (n = 30) were dissected to the subfascial plane (Table 2).

### 3.1.8 Number of perforators

Single perforator was retained in 86.0% of perforator flaps (n = 43), two in 10.0% (n = 5), and three in 4.0% (n = 2) (Table 2).

### 3.1.9 Donor site

The defect of the donor site was covered by a skin graft in most cases (n = 62, 75.6%), and the donor site was closed by primary closure in 24.4% of cases (n = 20) (Table 2). When covering the donor site with a skin graft, most surgeons used a split-thickness skin graft.

### 3.1.10 Complications

Complications of perforator flaps are shown in Table 3. The following conditions were considered postoperative complications and included in our study: flap necrosis and related causes; wound dehiscence,
incomplete wound coverage, poor healing, and related causes; hematoma, infection, and related causes. Complications related to recipient and donor sites were included in the analysis. We found complications in 13.5% of cases (n = 15). In our study, the most common flap-related complication was partial necrosis (n = 5, 4.5%), followed by venous congestion (n = 4, 3.6%), complete necrosis (n = 2, 1.8%), epidermolysis (n = 1, 0.9%), venous insufficiency (n = 1, 0.9%), and delayed healing (n = 1, 0.9%). We observed that donor-site-related complication was skin graft necrosis (n = 1, 0.9%).

### 3.2 Meta-analysis of risk factors

#### 3.2.1 Flap size over 50 cm²

A total of four studies describing flap size were included in the pooled analysis. The analysis showed no heterogeneity (Chi² = 1.48, P = .69, I² = 0%); thus, a fixed-effect model was used. The pooled analysis showed a significantly increased risk of complications for flap size greater than 50 cm² compared with flap size less than 50 cm² (RR = 3.12, 95% CI = 1.18-8.23, P = .02) (Figure 3).

#### 3.2.2 Aetiology

A total of six studies were included to compare the risk of complications between chronic and acute aetiology. The analysis showed no heterogeneity (Chi² = 2.92, P = .71, I² = 0%); thus, a fixed-effect model was used. This analysis showed no significant difference in the risk of complications between chronic and acute aetiology (RR = 1.86, 95% CI = 0.84-4.13, P = .13) (Figure 4). Besides, we performed pooled analyses for complication risk of specific causes, including diabetes mellitus foot, trauma, tumour resection, ulcer, and burn (Table 4). The results showed a

| Complications                  | No. of cases (%) |
|--------------------------------|------------------|
| Partial necrosis              | 5 (4.5)          |
| Complete necrosis             | 2 (1.8)          |
| Venous congestion             | 4 (3.6)          |
| Epidermolysis                 | 1 (0.9)          |
| Venous insufficiency          | 1 (0.9)          |
| Delayed healing               | 1 (0.9)          |

*a = 111 cases.

FIGURE 3 Forest plot for complication risk analysis of flap size over 50 cm²

FIGURE 4 Forest plot for complication risk analysis of chronic aetiology
significantly increased risk of complications for diabetic foot compared with non-diabetic foot (RR = 3.26, 95% CI = 1.14-9.28, \( P = .03 \)) (Figure 5), while no significant differences were observed regarding other causes.

### 3.2.3 Heel defects

Four studies reporting both heel defects and non-heel defects were included in this analysis. The analysis showed no heterogeneity (Chi\(^2\) = 2.90, \( P = .41, I^2 = 0\% \)); thus, a fixed-effect model was used. There was no significant difference in the risk of complications between heel defects and non-heel defects (RR = 0.56, 95% CI = 0.17-1.87, \( P = .34 \)) (Figure 6).

### 3.2.4 Single perforator

Three studies were included to compare the risk of complications between single perforator and multiple perforators. This analysis showed no heterogeneity (Chi\(^2\) = 0.23, \( P = .89, I^2 = 0\% \)); thus, a fixed-effect model was used. No significant difference was found in the risk of complications between single perforator and multiple perforators (RR = 0.64, 95% CI = 0.14-2.99, \( P = .57 \)) (Figure 7).

### 3.2.5 Age older than 60 years

In this pooled analysis, we evaluated a total of eight studies. The analysis showed no heterogeneity (Chi\(^2\) = 4.76, \( P = .69, I^2 = 0\% \)); thus, a fixed-effect model was used. There was no
significant difference in the risk of complications between patients aged older than, and younger than 60 years (RR = 1.67, 95% CI = 0.78-3.60, P = .19) (Figure 8).

### 3.2.6 Assessment of publication bias

Figure 9 shows a funnel plot for flap size over 50 cm², and Figure 10 for the diabetic foot. These funnel plots are relatively symmetrical, suggesting a low possibility of any publication bias.

### 4 DISCUSSION

Koshima and Soeda⁵ first reported the use of an inferior epigastric artery skin flap without rectus abdominis muscle in 1989. Kroll and Rosenfield⁶ reported that the...
blood supply stability of perforator flaps was similar to that of musculocutaneous flaps, but the incidence of donor-site-related complications was reduced by retaining muscle tissue. Although many new types and concepts of perforator flaps have been described, perforator flaps are generally divided into pedicled perforator flaps and free perforator flaps. Pedicled perforator flaps avoid microsurgical techniques and save operating time.

The special anatomical structure of the plantar foot makes plantar defects seriously affect the normal life of the patients. It is a challenging problem for surgeons to repair plantar defects and restore normal functions. Many types of flaps are used to reconstruct plantar defects, but few can support the weight of the human body. So far, perforator flaps have been widely used in the repair of defects various in location and size, and have been successfully used to repair plantar defects. As far as we know, up until now, no meta-analysis has focused on the risk factors for complications of perforator flaps in plantar reconstruction.

The results of our study indicated that flap size over 50 cm² increased the risk of postoperative complications. The risk of complications of large perforator flaps may be related to insufficient blood perfusion, and maintaining good blood perfusion of the flaps is a challenge that many surgeons face. When a large perforator flap is needed, obtaining a good appearance and normal function of the donor site is also a problem. The donor site of a large pedicled perforator flap may look good for older patients with sagging skin but maybe ugly for younger patients with delicate skin. Therefore, free flaps from other parts of the body may be a better option for repairing extensive plantar defects. When flap size is over 50 cm², we recommend that surgeons fully consider all treatments and then choose the most appropriate one based on the patient’s condition and the surgeon’s experience and ability.

According to our study, diabetic foot increased the risk of postoperative complications compared with non-diabetic foot. Because of problems such as vascular disease, neuropathy, and immunopathy, diabetic patients are at greater risk of limb ischaemia, often with severe soft tissue defects. In diabetic patients, reduced tissue perfusion can be secondary to injury in the macrocirculation or microcirculation. Diabetic patients are susceptible to serious infections, making wound healing more difficult. Increasing blood perfusion and avoiding infection when reconstructing plantar defects in diabetic patients is a challenge that surgeons face. For intractable diabetic foot, surgeons need to consider all possible methods and choose the best method. Combination therapy can be used if necessary.

The heel bears the force of standing and walking, and the reconstruction of the heel is a challenging problem. In our study, most defects were at the heel, and heel defects did not increase the risk of postoperative complications compared with other plantar defects.

About 400 perforators are connecting the epidermis in the human body, and each perforator can be used to design a pedicled perforator flap. The more perforators a flap retains, the better the flap’s blood supply; however, too many perforators may limit the movement of the flap and pedicle rotation. According to the results of our study, a single perforator did not increase the risk of complications compared with multiple perforators. The data included in our study were limited and more high-quality studies are needed to validate our findings. Chang et al described that the size of perforator flaps, including a single perforator, should be limited to 8 cm by 20 cm. If a larger perforator flap is required, the flap may need to retain two or more perforators. Surgeons should determine the number of perforators that need to be retained based on the size of the perforator flap, distance of movement, and angle of pedicle rotation.

The results of the meta-analysis showed that patients aged older than 60 years did not increase the risk of complications. However, older patients are more likely to have diseases that affect prognosis, such as diabetes, nerve disease, vascular disease, and infection. Research by Sanak et al showed that age was not an independent variable that increased the risk of microvascular reconstruction, while the time of surgery, the American Society of Anaesthesiologists (ASA) risk score, and the location of reconstruction were related to the success rate of free tissue transfer. For older patients, surgeons should deal with the underlying disease before surgery and make reconstruction decisions based on the specific physical condition of the patients.

In our research, chronic causes included ulcer and diabetes mellitus foot; acute causes included trauma, tumour resection, vascular malformation resection, and burn. This analysis showed no significant difference in the risk of complications between chronic and acute causes. Our study also analysed the relationship between specific causes and complications. Trauma, ulcer, tumour resection, and burn did not increase the risk of postoperative complications, while diabetes mellitus foot had an increased risk of complications. It should be noted that different causes require different treatment methods. Treatment for plantar tumours should be chosen based on the size, location, and depth of the tumour. In the case of a malignant tumour, extended excision is necessary. For plantar defects caused by acute trauma, a thorough debridement should be performed and then treatment should be determined according to the specific situation. The common causes of ulcer are venous disease, arterial disease, and nerve disease. Because many factors
can cause ulcer, multidisciplinary knowledge is needed to assess patients, identify the aetiology, and choose the optimal treatment. In addition to the assessment, treatment, and repair of burn wounds, surgeons should also pay attention to anti-shock, improve breathing, prevent infection, and replenish nutrition.

In our study, the dissection plane was suprafascial in most cases. Because of the lack of relevant studies, this meta-analysis was unable to analyse the correlation between the dissection plane and complications. Brunetti et al suggested that dissection and separation of perforators at the subfascial plane would be preferred to obtain flaps of the limbs. Through the subfascial approach, perforators can be observed more clearly and flaps can be raised more quickly. Research by Chen et al showed that less sensory disturbance of donor site and higher patient satisfaction follow suprafascial anterolateral thigh flap.

Most donor site defects were repaired with skin grafts, followed by primary closures. When covering the donor site with a skin graft, most surgeons used a split-thickness skin graft. When the donor site defect is small, surgeons prefer primary closure. For older patients with sagging skin, large defects in the donor site may also be repaired by primary closure. For donor site defects that cannot be closed by primary closure, the use of skin grafts is a good choice. Most surgeons used split-thickness skin grafts because they are tough, soft, resistant to friction, and strong in vitality.

The present meta-analysis has the following limitations that must be taken into account: (a) Only studies published in English were included; thus, our study may have lost data on important studies published in other languages. (b) Surgical procedures in different studies were performed by doctors at different levels of operation, and there may be potential bias. (c) Because of the insufficient sample size in the included studies, there may be bias. (d) Because of limited studies included, data on skeletonisation of perforators, pedicle rotation, pedicle length were lacking. (e) All the included studies were retrospective studies, and a randomised controlled trial can validate and complement our findings.

5 CONCLUSION

This meta-analysis identified two risk factors—namely, flap size over 50 cm² and diabetes mellitus foot-for postoperative complications of perforator flaps in plantar reconstruction. Surgeons should consider the two risk factors before operating, and choose the best option for reconstruction based on the patient’s specific situation and the doctor’s experience. More high-quality studies with adequate sample sizes are needed to validate and complement our findings.

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CONFLICT OF INTEREST
The authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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