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Reconstruction of moderate-sized soft tissue defects in foot and ankle in children: Free deep inferior epigastric artery perforator flap versus circumflex scapular artery perforator flap

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KEYWORDS
Deep inferior epigastric artery perforator flap;
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Summary *Background:* This retrospective study was conducted to compare the outcomes between the free deep inferior epigastric artery perforator (DIEP) flap and the circumflex scapular artery perforator (CSAP) flap in reconstruction of moderate-sized soft tissue defects in the foot and ankle of pediatric patients.
Patients and methods: From January 2004 to December 2016, 42 patients, ranging from 2 to 13 years old, underwent foot and ankle reconstruction, with a free DIEP flap in 21 cases and a free CSAP flap in the other 21cases.
Results: All the flaps survived. No marked differences were observed in the demographics, flap size, recipient vessels, and overall early or late complication rate ($p > 0.05$). The CSAP group had a shorter operation time (134.3 ± 25 min vs. 202.4 ± 24.3 min, $p < 0.05$) and flap harvest time (29.7 ± 8.1 min vs. 52.2 ± 9.8 min, $p < 0.05$) than the DIEP group had. In long-term follow-up, the CSAP group showed a lower fat hyperplasia rate (14% vs. 52%, $p < 0.05$) and better cosmetic outcomes than the DIEP group did ($p < 0.05$). The functional outcomes had no marked differences ($p > 0.05$).
Conclusions: The DIEP flap and the CSAP flap are both good options for foot and ankle reconstruction of moderate-sized defects in pediatric patients. The CSAP flap has a shorter operation

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time and flap harvest time, a lower fat hyperplasia rate, and better long-term cosmetic outcomes than the DIEP flap does.

Introduction

Soft tissue defects in the foot and ankle of pediatric patients often pose a difficult issue for reconstructive surgeons due to the relatively low regional tissue mobility and lack of vascularity. The small vessel caliber and the limited body surface area in pediatric patients add additional difficulties to the surgery.[1-4] Published studies reported many options for the reconstruction of the foot and ankle and showed satisfactory results, including regional pedicled flaps and free flaps.[5-15] Each solution has proper indications and limitations.

Nowadays, the deep inferior epigastric artery perforator (DIEP) flap has gained great popularity and has become a primary choice for post-mastectomy breast reconstruction since first described by Koshima et al. in 1989.[20] Recently, it has been used in reconstruction of other parts of the body and shown nice effects,[21-30] such as in pedicled DIEP flaps in abdominal and chest wall reconstruction, and free DIEP flaps have been used in limb and head-and-neck wounds. Our group similarly obtained satisfactory results in repairing the soft tissue defects of pediatric extremities, using DIEP flap.[33]

Circumflex scapular artery perforator (CSAP) flap was first reported by Dabernig et al.[37] relatively late in 2007. It derived from a scapular and para-scapular flap with a common blood supply by the circumflex scapular artery (CSA). The difference is that the CSAP flap is thinner, consisting of only skin and subcutaneous fat tissues. Since then, the CSAP flap has also been proved useful in soft tissue reconstruction.[37-39]

The aim of this study was to compare the outcomes between the DIEP flap and the CSAP flap in reconstruction for moderate-sized soft tissue defects in the foot and ankle of pediatric patients.

Patients and methods

Between January 2004 and December 2016, 42 pediatric patients, ranging in age from 2 to 14 years, received a free DIEP or CSAP flap for the reconstruction of moderate-sized foot and ankle defects of which half were reconstructed by a DIEP flap and the other half by a CSAP flap. The demographic data, intraoperative data, early complications, and long-term follow-up results were collected. Written informed consent was obtained from the guardians of the patients. The study was approved by the Ethics Committee of Xiangya Hospital. All the operations were finished by the same surgeon with his team.

Inclusion criteria included (1) patients younger than 14 years of age; (2) patients suffering from soft tissue defects in foot or ankle, with a defect size less than 120 cm^2; (3) patients with no underlying diseases or severe comorbidities; and (4) the guardians of the patients agreed to receive one-stage reconstructive surgery with a free DIEP or CSAP flap.

Initial thorough debridement was conducted before the patients were sent to our institution for subsequent reconstruction. All 39 traumatic patients had undertaken negative pressure wound therapy.

Routine ultrasonography of lower limb vessels was applied to ensure that no anatomical variations of major vessels or underlying vascular disease existed and to check the continuity of the main arterial trunk of the involved ankle and foot.

The perforators were detected and marked with a handheld Doppler preoperatively. The design was based on the defect template for drawing of the skin paddle during the operation.

In the DIEP group (Figure 1; ***Supplement materials Figure.1***), we detected and marked the perforators with the help of a handheld Doppler preoperatively. The design of the flap was based on the size and features of the defects during the operation. The flap was then raised from lateral to medial until all available perforators had been identified. Dissection of the pedicle was patiently conducted retrograde toward the proximal deep inferior epigastric artery through the anterior rectus fascia and rectus abdominis until proper pedicle length and diameter were available or reached the bifurcation of the external iliac vessels. During the dissection, the muscular vessel branches were coagulated or clipped to avoid bleeding. Frequently, we ligatured the rest of the perforators if the flap proved to be perfused thoroughly by the main perforator. In addition, the motor nerve of the rectus abdominis was preserved as perfectly as possible. The flap was then transferred to the recipient area with the microvascular reconstruction between the deep inferior epigastric vessels and recipient vessels, including the anterior tibial artery system (anterior tibial artery, dorsalis pedis artery, and their accompanying veins) and the posterior tibial artery system (posterior tibial artery, medial supramalleolar perforator of the posterior tibial artery, and their accompanying veins).

With a lateral decubitus position in the CSAP group (Figure 2; ***Supplement materials Figure.2***), we detected the CSA in the triangular space and the perforators of the transverse or descending branch of the CSA. The flap paddle was designed either in a transverse direction or a vertical direction. We then raised the flap from the medial to the lateral side overlying the deep fascia. After identifying the perforators, dissection of the pedicle was traced proximally to the origin of the CSA through the triangular space until the proper pedicle length and diameter were available or the bifurcation of the subscapular artery was found. The anastomosis was between the circumflex scapular vessels and recipient vessels, including the anterior tibial vessels and posterior tibial vessels.

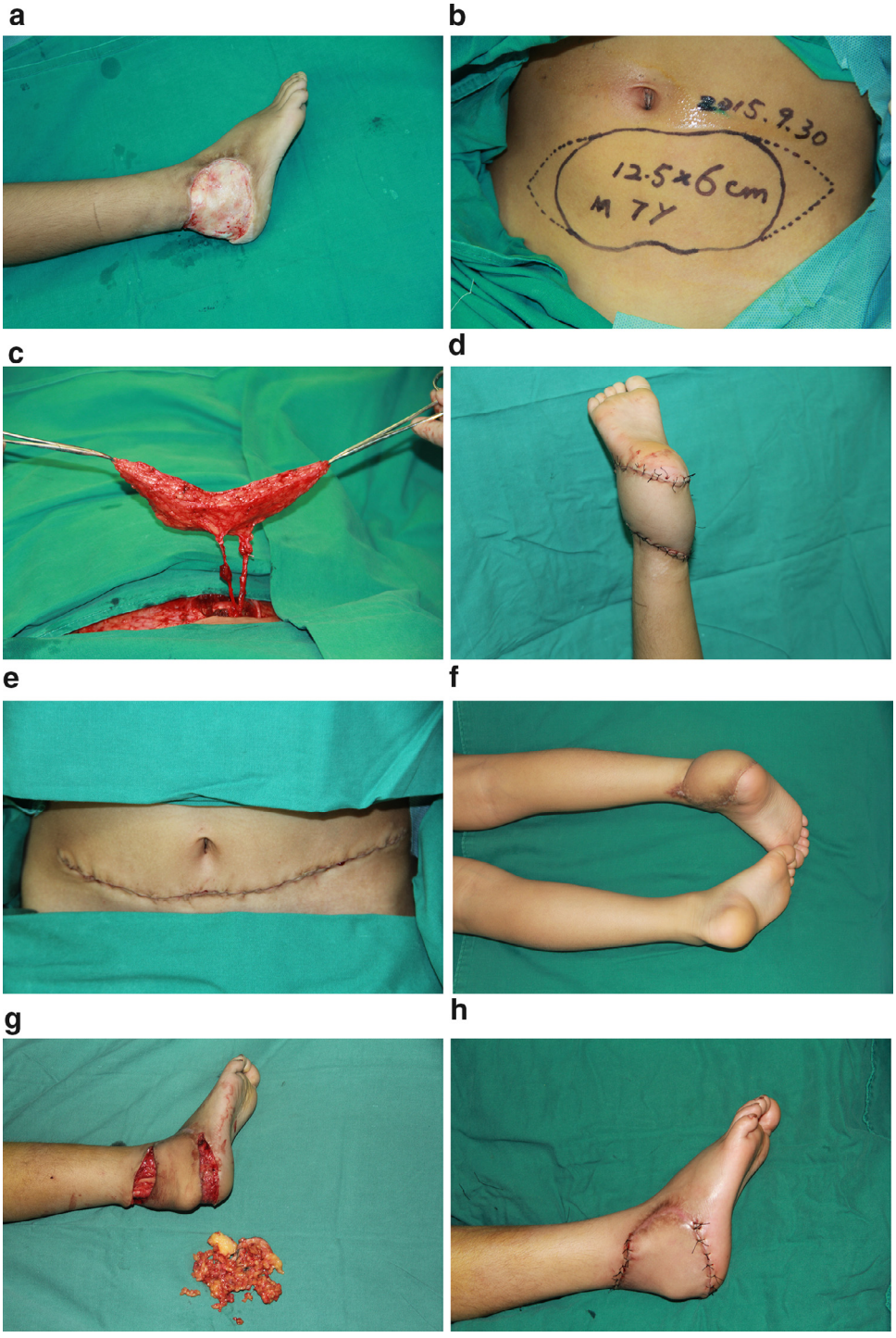

Figure 1 A 7-year-old boy. (A) Soft tissue defects on the right ankle. (B) Design of a DEIP flap. (C) Harvest of the flap. (D) Inset of the flap. (E) Primary closure of the donor site. (F) Postoperative view of the reconstructed site at the 3-month follow-up. (G) Defatting procedure and removal of fat tissues three months after the reconstruction operation. (H) Postoperative view of the recipient site after thinning procedure.

All the flaps were harvested without a first-stage thinning procedure. The vascular reconstruction was end-to-end anastomosis. The donor site was primarily closed without exception.

Follow-up was performed at three, six, and nine months after the surgery and yearly after that. We recorded complications and evaluated the cosmetic and functional results. Cosmetic results of the recipient sites were evaluated subjectively by the guardians of the patients and objectively by a blinded third-party observer based on a level points between 0 (not satisfied) and 10 (very satisfied). Specifically speaking, 0–2 points were considered poor, 3–5 were

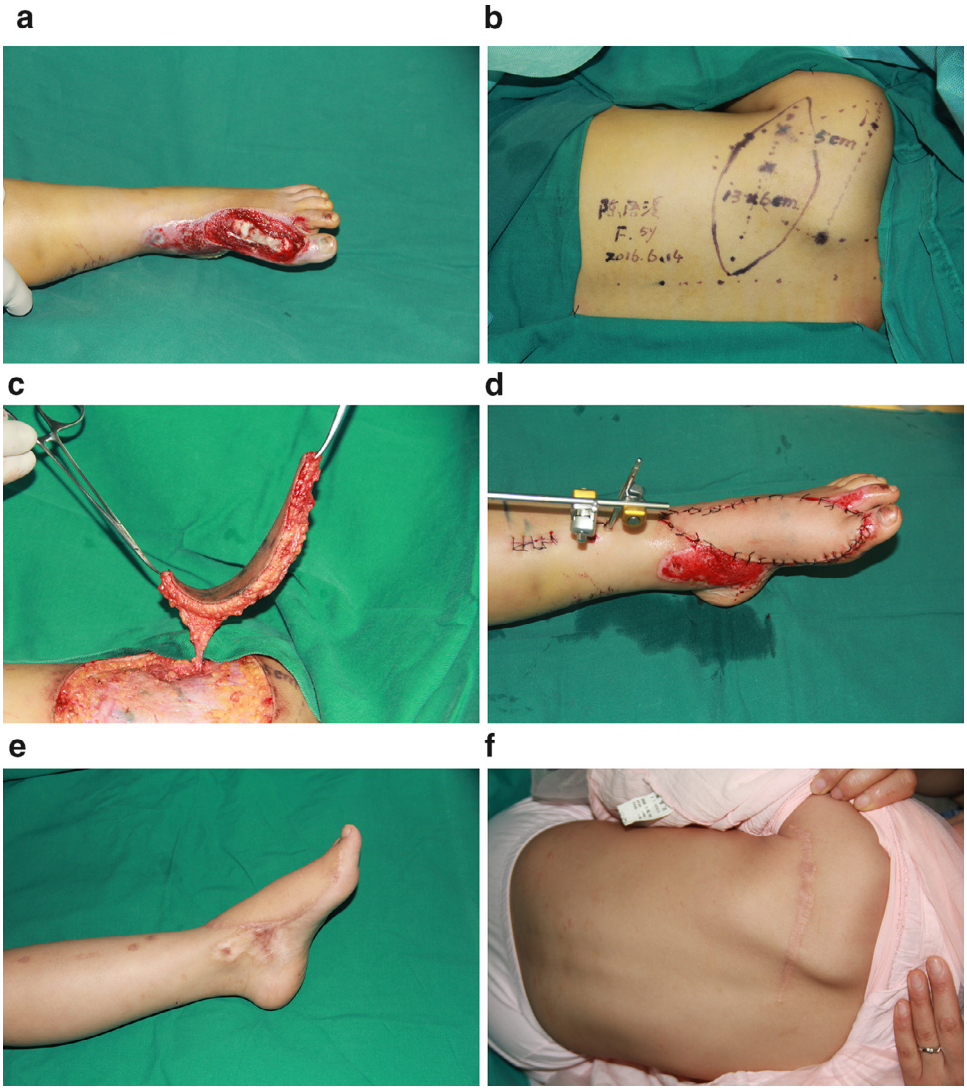

Figure 2 A 5-year-old girl. (A) Soft tissue defects on the left dorsal foot. (B) Design of a CSAP flap. (C) Harvest of the flap. (D) Inset of the flap. (E) Postoperative view of the reconstructed site at the 10-month follow-up. (F) Postoperative view of the donor site at the 10-month follow-up.

moderate, 6–8 were good, and 9–10 were excellent. Similarly, functional results were assessed by questionnaires on disease-specific items (pain, activity, and walk function) based on a scale of 0 (poor) to 100 scores (excellent).[40]

Quantitative data were expressed as means ± standards (standard deviation) and compared using the Student's *t*-test. Qualitative data were expressed as numbers or percentages and compared using the $\chi 2$ test and Fisher's exact test. Statistical analysis was performed by SPSS 20.0 software (SPSS Inc., USA). $P < 0.05$ was considered statistically significant.

Results

Forty-two patients ranging in age from 27 months to 13 years, with variable defects of 6 × 4 cm to 16 × 6 cm, were included in the present study. Defects sizes were 5–16 cm in length and 3–7 cm in width.

There were 15 males and six females in the DIEP group, with an average age of 7.1 ± 1.6 years, and 10 males and 11 females in the CSAP group, with an average age of 6.7 ± 2.8 years. The body mass indexes (BMIs) were 16.2 ± 1.1 and 16.5 ± 1.1, and the body surface areas (BSAs) were 0.9 ± 0.1 m^2 and 0.9 ± 0.2 m^2 in the DIEP and CSAP groups, respectively. The defects were caused by trauma in 39 cases (93%) and by other causes in three cases (7%), including one case of scar hyperplasia, one case of chronic ulcer in the CSAP group, and one case of internal fixation exposure in the DIEP group. Defect sites are shown in Table 1. The defect size was calculated to be 69.4 ± 18.7 cm^2 in DIEP group and 58.9 ± 22.3 cm^2 in CSAP group. There were no serious comorbidities in any of the cases. The two groups showed no significant differences in age, gender, BMI, BSA, etiology, defect site, or defect size (Table 1).

In the DIEP group, flap sizes were 8–17 cm in length and 5–8 cm in width; in the CSAP group, they were 6–17 cm in length and 4–7 cm in width. The flap dimensions were

Table 1 Demographic data.

Variable	DIEP group ($N=21$)	CSAP group ($N=21$)	p Value[#]
Age (year)	7.1 ± 1.6	6.7 ± 2.8	0.637
Gender			0.116
Male	15	10	
Female	6	11	
BMI	16.2 ± 1.1	16.5 ± 1.1	0.387
BSA (m^2)	0.9 ± 0.1	0.9 ± 0.2	0.664
Etiology			1.000
Traumatic	20	19	
Others[*]	1	2	
Defect site			0.825
Dorsal foot	5	6	
Ankle	12	10	
Dorsal foot and ankle	4	5	
Defect size (cm^2)	69.4 ± 18.7	58.9 ± 22.3	0.105

DIEP, deep inferior epigastric artery perforator; CSAP, circumflex scapular artery perforator.
BMI, body mass index; BSA, body surface area.
[*] Scar hyperplasia, chronic ulcer, internal fixation exposure.
[#] Two-sided Fisher's exact test.

Table 2 Intraoperative data.

Variable	DIEP group ($N=21$)	CSAP group ($N=21$)	p Value
Flap size (cm^2)	74.8 ± 18.7	64.5 ± 23.5	0.121
Recipient vessels			0.533
Anterior tibial system	11	13	
Posterior tibial system	10	8	
Operation time (min)	202.4 ± 24.3	134.3 ± 25	0.0001
Flap harvest time (min)	52.2 ± 9.8	29.7 ± 8.1	0.0001

calculated to be 74.8 ± 18.7 cm^2 and 64.5 ± 23.5 cm^2, respectively, in the DIEP and CSAP groups ($p > 0.05$) (Table 2).

Intraoperatively, the pedicles of 11 DIEP flaps were anastomosed to the anterior tibial artery system (seven cases of anterior tibial vessels, four cases of dorsalis pedis vessels), and the other 10 DIEP flaps were to the posterior tibial system (nine cases of posterior tibial vessels and one case of the medial supramalleolar perforator of the posterior tibial vessels). The recipient vessels in the CSAP group consisted of 13 cases involving the anterior tibial artery system (six cases of anterior tibial vessels and seven cases of dorsalis pedis vessels) and 10 cases involving the posterior tibial vessels (Table 2).

The operation time was 202.4 ± 24.3 min, including a flap harvest time of 52.2 ± 9.8 min in the DIEP group, and that was significantly longer than for the CSAP group, with 134.3 ± 25 min to finish the operation and 29.7 ± 8.1 min to elevate the flap (Table 2).

All flaps survived in both groups. Partial necrosis occurred in both the DIEP group ($n=1$) and the CSAP group ($n=1$), and they were successfully salvaged by the subsequent dressing. In addition, one CSAP flap suffered artery insufficiency and was revised by surgical re-exploration. A delayed donor site healing occurred in the CSAP group. The two groups did not show marked differences in early complications ($p > 0.05$) (Table 3).

Table 3 Early complications.

Variable	DIEP group ($N=21$)	CSAP group ($N=21$)	p Value[#]
Early complications	1	3	0.303
Flap-related complications			0.500
Total flap necrosis	0	0	
Partial flap necrosis	1	1	
Artery insufficiency	0	1	
Venous congestion	0	0	
Donor site morbidity			0.500
Delayed wound healing	0	1	

Table 4 Long-term follow-up results.

Variable	DIEP group ($N=21$)	CSAP group ($N=21$)	p Value [#]
Late complications	14	7	0.064
Flap fat hyperplasia	11	3	0.022
Donor site scar hyperplasia	3	4	1.000
Defatting procedure	7	1	0.049
Cosmetic evaluation			
Subjectively[a]			0.022[C]
Excellent	4	10	
Good	6	8	
Moderate	11	3	
Poor	0	0	
Objectively[b]			0.035[C]
Excellent	5	12	
Good	7	7	
Moderate	9	2	
Poor	0	0	
Functional evaluation			0.659[C]
Excellent	8	10	
Good	11	7	
Moderate	2	4	
Poor	0	0	

[a] Guardians of the patients.
[b] blinded third-party observer.
[C] excellent and good rate.

The follow-up ranged from 24 to 180 (mean 94) months. The overall late complication rate showed no statistical differences between the two groups (67% in the DIEP group vs. 33% in the CSAP group, $p > 0.05$). However, 11 cases (52%) of flap fat hyperplasia in the DIEP group were noted during the follow-up, among which seven cases underwent a defatting procedure, and these were significantly more than in the CSAP group with three bulky flaps (14%), of which one flap was defatted ($p < 0.05$). Donor site scar hyperplasia occurred in the DIEP group ($n=3$) and the CSAP group ($n=4$) (Table 4).

All cases gained satisfying results concerning the cosmetic appearance. No matter whether the guardians of the patients or the blinded third-party professional evaluated the flaps, significantly higher excellent and good rates were found in the CSAP group (86% and 91%) than those in the DIEP group (48% and 57%) ($p < 0.05$). Comparison of functional results between the two groups remained insignificant ($p > 0.05$) (Table 4).

Discussion

Reconstruction of soft tissue defects in the foot and ankle of pediatric patients has been a challenging issue for reconstructive surgeons because of the lack of spare tissue and relatively poor perfusion. In particular, the limited dimension of soft tissue and relatively small vessel diameter make the surgery more difficult in pediatric patients. A variety of local and free flaps were reported to be effective in the reconstruction around the foot and ankle. Regional flaps in the calf are commonly used, including a free medial sural artery perforator flap,[5,6] a reverse posterior tibial artery perforator flap,[7,8] a reverse peroneal artery perforator flap,[9,10] and a reverse sural flap.[11,12] These local flaps provide a thin and pliable flap, providing a fine cosmetic match with similar skin color and texture for the involved foot and ankle. A pedicled flap was known to be conducted easily and quickly without microvascular restoration.

However, the disadvantages of these regional flaps are obvious. First, many female patients note the long scar in the calf, even if it was a liner scar sutured subcutaneously. Second, considering the limited surface area and compact subcutaneous tissues in pediatric patients, we usually were not able to close the donor site primarily after harvesting a wide flap, and skin grafting was required, thus leaving an ugly and itchy second donor site behind. In addition, the compression and twist of the pedicle, which causes the potential risk of flap failure, made more surgeons prefer free flaps to cover the defects.

The lateral circumflex femoral artery perforator flap, also known as the anterolateral thigh (ALT) perforator flap, was one of the most widely used free flaps for foot and ankle reconstruction.[13-15] The advantages of the ALT flap include constant anatomy, long pedicle, potentially large areas of robust skin, and expedited dissection.[16,17] By taking the lateral femoral cutaneous nerve, the ALT flap can be used to reconstruct sensory function of the recipient site. However, in overweight patients, the ALT flap can be notably thick for covering the defects in the foot and ankle where a thinner flap is needed. Although several authors remarked that the excessive thickness could be reduced by one-stage or second-stage flap defatting techniques, these procedures were reported to have a potential risk of flap failure or partial necrosis.[18,19] In addition, the dense and thick skin and subcutaneous tissues on the thigh in children restricted the application of an ALT flap to cover the foot and ankle defects.

In this study, we reported our experience of the reconstruction of moderate-sized soft tissue defects in the foot and ankle of pediatric patients by the free DIEP flap and CSAP flap. A major advantage of the two flaps is the easily concealable donor site in the abdomen or back region. In addition, our results showing that all the flaps survived revealed the reliability of the two flaps. However, there had been no literature comparing the outcomes of these two flaps.

The DIEP flap was first reported by Koshima in 1989,[20] who innovatively refined the traditional transverse rectus abdominis myocutaneous (TRAM) flap by dissecting the perforators originating from the deep inferior epigastric vessels without taking the muscle. By not sacrificing the rectus abdominis muscle, the decrease of abdominal wall competence, an important drawback of the TRAM flap, was reduced.

Nowadays, the DIEP flap has gained great popularity and has become a safe and reliable choice for post-mastectomy autologous breast reconstruction, mainly due to the satisfying esthetic results it brings.[21-23] Moreover, it has displayed a versatile option for the reconstruction of the head and neck and upper and lower extremities, including the foot and ankle, with multiple advantages.[24-30] The DIEP flap preserves the continuity of the rectus muscle and decreases the postoperative abdominal hernia or bulge. Anatomical studies reported that the perforator location is considerably constant because most perforators can be found within 5 cm of the umbilicus.[31,32] A not very long intramuscular dissection also made the surgery go smoothly. The proper caliber of the pedicle provides the DIEP flap with a reliable blood supply. The adequate pedicle length makes flap design and vessel anastomoses easier. By rational design, a moderate- to large-dimension DIEP flap can be raised with a primarily closed donor site.

In pediatric patients, the perforator caliber is believed to be thinner than that in adults, but in our experience, it can also provide enough perfusion to the flap. Furthermore, with less redundant tissue and undeveloped abdominal muscle, it would not be very difficult to dissect the perforators in children. In spite of proven versatility, we found the fat hypertrophy was the main liability for the DIEP flap. None of the patients in our series was obese or had excessive subcutaneous fat tissue in the belly. However, we noticed that most DIEP flaps gained various degrees of bulkiness as patients grew and gained weight, despite the initially postoperative smooth contour.[33]

In the present study, we did not encounter donor site morbidity such as abdominal bulge or hernia, but we were still concerned about this issue because the nature factor, that is, the thin abdominal wall in children, may cause an abdominal hernia or underlying risks when female patients become pregnant. Previously reported adult cases of DIEP flap in breast reconstruction noted this situation. Blondeel[22] reported a unilateral abdominal bulge of all 100 DIEP flaps. Gill et al.[21] described a 0.7% (5/758 patients) postoperative abdominal hernia or bulge rate. In an Asian report, Paik et al.[34] noted a higher abdominal bulge rate (8/217 patients) but with no hernia. Literature sources indicated that the incidence of total flap loss ranged from 0.5% to 3% and partial flap loss from 2% to 7%.[21-23,34,35] In our series, there was no total flap necrosis. The distal part of a DIEP flap (about 5% of the flap) exhibited necrosis and was salvaged by subsequent dressing. We ascribed it to the 16 cm long flap in a transverse design in our early experience. Afterward, we optimized the DIEP flap design, and then when we needed a long flap (usually longer than 12 cm), we designed

the skin paddle in an oblique orientation. This refinement makes the most use of the abdominal area to maximize the total length and avoids the poor perfusion of Zone IV.[36]

The CSAP flap was first reported by Dabernig et al.[37] relatively late in 2007. It derived from the traditional scapular and para-scapular flap with a common blood supply from the CSA but consists of only skin and subcutaneous fat tissue without the deep fascial layer. Thereafter, surgeons gradually accepted that the CSAP flap was a useful method to cover defects with a well-localized main perforator, long vascular pedicle, proper diameter vessels, and concealed donor site.[37–39] In addition, the skin of the dorsal scapular region is pliable, hairless, and thin, especially in children. Moreover, pedicle dissection is not difficult because the perforators run above the teres muscles and go through the triangular space, thus involving no intramuscular dissection, and that was why it took less time for us to harvest the flap and finish the surgery in the CSAP group than in the DIEP group. Moreover, based on the present study, the CSAP flap brought satisfactory long-term cosmetic outcomes.

To our knowledge, we are the first to evaluate the complications and long-term follow-up outcomes of the free DIEP and CSAP flaps in the soft tissue reconstruction for moderate-sized defects in the foot and ankle of pediatric patients. Regarding the early complications, one DIEP flap suffered partial flap necrosis with no donor site morbidity. In the CSAP group, three patients suffered partial flap loss, artery insufficiency, and delayed wound healing, respectively. The results showed no marked differences. We considered several key points for avoiding perioperative complications. First, we elevated the flap with only necessary tissues to cover the superficial wound on the foot and ankle; the preservation of deep fascia would ease the primary closure of the donor site. Second, the delicate dissection of the pedicle and high-quality tension-free anastomosis of vessels is essential for flap survival. Third, the rational flap design is of vital importance. As mentioned, an oblique design for the DIEP flap can protect a long flap from poor perfusion of ZONE IV.

In the CSAP group, we designed 14 cases of transverse skin paddles and seven cases of vertical skin paddles. In our experience, we preferred to apply a transverse-designed skin island in the CSAP flap with the transverse branch of the CSA. In this way, the scar was parallel to the muscle fibers underlying the flap, thus lowering skin tension.

After a long-term follow-up, we found that the DIEP flap had a notably higher possibility to become bulky than the CSAP flap had (11/21 flaps vs. 3/21 flaps). The excessive volume of the flap hindered the patient from normally wearing shoes. In turn, patients more often underwent a second thinning procedure in the DIEP group than in the CSAP group to put shoes on properly and improve the contour of the foot or ankle. Although the adipocytes were transferred from belly to foot or ankle together with the flap, they still seemed to remember that they are the most capable fat keeper in the human body. Thus, the flap became bulky as the pediatric patient grew and gained weight. That was the main reason the CSAP group presented a markedly higher excellent and good rate than the DIEP group did, in the opinions of both the guardians of the patients and the blinded third-party observer in the present study.

Interestingly, all seven cases of scar hyperplasia in the two groups happened in the donor site. We suspected it was attributed to combined factors of personal cicatricial diathesis and incision closure with a certain tension. Our results showed insignificant differences in the functional outcomes between the two flaps after reconstruction. We considered that the functional outcomes of the foot and ankle were influenced mostly by the preexistent functional impairment. No abdominal bulges or hernias or other evidence suggested impairment of the rectus abdominis in the DIEP group, and shoulder joint dysfunction did not appear in the CSAP group either.

There were some limitations of the two flaps. The lack of specific sensory innervation makes the flap prone to developing wear, scalds, and non-sensory ulcers.[28,29,33] In rare cases, the skin and subcutaneous tissues of the back and scapular areas in children were compact and dense, in which case we had to choose another donor site such as the abdomen or thigh individually. Our study excluded the cases with first-stage defatting procedure; otherwise, we cannot tell whether it will affect the flap fat hyperplasia and the rate of second-stage defatting procedure, and the relationship between the first-stage and second-stage thinning still remains to be answered.

We recommend the use of the two flaps for covering the dorsal foot, malleolus, and the non-weight bearing areas of the planta. However, the two flaps are unsuitable for the reconstruction of weight-bearing areas, including the plantar anterior midfoot and heel where a more durable and thicker flap is needed, and for the defects with dead space where fillers such as fascia and muscles are necessary.

Conclusions

The DIEP flap and the CSAP flap are both good alternatives for foot and ankle reconstruction of moderate-sized defects in pediatric patients. The CSAP flap has a shorter operation time and flap harvest time, a lower fat hyperplasia rate, and better long-term cosmetic outcomes than the DIEP flap has. In light of these findings, we recommended the CSAP flap as a more appropriate option for reconstruction of moderated-sized soft tissue defects in the foot and ankle of pediatric patients.

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Level of evidence

III, Retrospective

Author contributions

Xinlei Sui and Zheming Cao contributed equally to this work.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.bjps.2019.05.026.

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