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Original Article

Efficacy of combining a medial superior malleolar perforator flap from the posterior tibial artery with a vacuum-assisted closure dressing for skin and soft tissue defects of the Achilles tendon area

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Abstract: Objective: This randomized clinical trial aimed to investigate the clinical efficacy of combining a medial superior malleolar perforator flap from the posterior tibial artery (PTAPF) with a vacuum-assisted closure (VAC) dressing for skin and soft tissue defects in the Achilles tendon area. Methods: Twenty-eight patients were randomly divided into two equally sized groups: the control group received treatment with a medial superior malleolar perforator flap, while the experimental group was treated with a perforator flap from the posterior tibial artery in combination with a VAC dressing. Perioperative data, including average operative time, intraoperative blood loss, intraoperative complications, time to ambulation, and hospital stay after surgery, were recorded. Clinical outcomes were assessed based on the time to first weight-bearing walking, time to full weight-bearing activity, Visual Analog Scale (VAS) score, American Orthopaedic Foot and Ankle Society hindfoot and ankle score, and the range of motion for ankle plantar flexion. Results: The patients were monitored for 3-12 months (average, 8.5), and it was observed that the flaps remained stable without enlargement, and their texture and color were similar to the surrounding tissue. Significantly enhanced postoperative indices were noted in the experimental group compared to the control group ($P<0.05$). Conclusion: The medial superior malleolar perforator flap from the posterior tibial artery, especially when combined with a VAC dressing, proves to be an effective method for repairing medium-sized skin defects in the Achilles tendon area. This approach offers several benefits, including a reliable blood supply, simplicity of the procedure, decreased damage to the donor site, improved aesthetic outcomes, and fewer postoperative complications.

Keywords: Posterior tibial artery, Achilles tendon, perforating branch, skin flap

Introduction

The Achilles tendon area is characterized by its thin skin and soft tissue, making it particularly vulnerable to infections and poor wound healing, posing challenges during Achilles tendon repair, and often leading to skin and soft tissue defects. Currently, there is no universally accepted method for repairing soft tissue defects in the Achilles tendon region. Existing approaches, such as autologous repair, allogeneic transplantation, and stem cell transplantation, have limitations in both clinical practice and research. To achieve the best possible repair outcomes, it is crucial to perform a meticulous, individualized evaluation of each patient's specific injury type and condition.

Regarding therapeutic approaches, sural neurovascular flap transplantation [1, 2] is a simple and reliable procedure; however, this method results in an enlarged flap and a bulky pedicle, frequently necessitating secondary plastic surgery. Intraoperative resection of the sural nerve can cause sensory disturbances of the lateral leg. In addition, complications, such as obstruction of venous return, edema of the flap, and congestion, tend to occur, potentially culminating in venous crises. The propeller flap [3, 4] technique for the lower leg uses either the pero-

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neal artery or posterior tibial artery perforator pedicle as the pivot point, with a flat pedicle and a large paddle covering the wound. A smaller portion of the flap is used to cover part of the donor site, ensuring color and texture similarity between the skin at the donor and recipient sites. However, a crucial step in this procedure is the exposure of the perforator vessels; otherwise, failure to do so may result in torsion and compression of the vascular pedicle, leading to venous return disorders [5, 6]. Furthermore, the vascular pedicle can only retain one perforator. Once the perforator is injured, there is a significant risk of flap necrosis and consequent surgical failure. Free flaps, such as the perforator flap from the descending branch of the lateral circumflex femoral artery [7] and the perforator flap from the medial sural artery [8], offer the advantages of a dependable blood supply and direct closure of the donor site; however, these approaches come with drawbacks, including the complexity of flap harvesting, the necessity for vascular anastomosis, and long surgery duration. The mainstream view is that autologous repair is currently the first choice for skin lesions in the Achilles tendon region owing to its simplicity, rapid recovery, absence of immune rejection response, and low financial cost. Specifically, retrograde sural flaps have been reported to be effective in repairing Achilles tendon defects in patients with diabetes and vascular insufficiency. However, the applicability of this method is primarily constrained by the defect's location and size [9]. The distal sural fasciocutaneous flap, which is supplied by perforated vessels along the sural nerve in the posterior part of the leg, is often used to treat soft tissue defects in the Achilles tendon region. The advantages of the aforementioned flap include easy dissection, rich soft tissue, dependable blood supply, and preservation of major arteries in the lower limbs [10, 11]. The proximal sural flap has been proven to be effective in repairing Achilles tendon and heel defects. Nonetheless, a significant limitation of this technique is the potential risk of sural nerve damage, which may compromise the vascular integrity of the flap [12]. Additionally, vacuum-assisted closure (VAC) has been shown to be effective for non-ruptured soft tissue defects in the Achilles tendon across various clinical studies due to reduced tissue edema and decreased bacterial load in the short term, thereby accelerating wound healing [13, 14]. Hence, VAC was also employed for the treatment in the experiment group.

Methods

General information

From January 2018 to December 2021, 28 patients (16 males and 12 females) were enrolled in our study. The study protocol was approved by the Institutional Review Board of Yongkang Orthopedic Hospital. All participating individuals signed the informed consent. All experiments involving human samples were conducted following the *Declaration of Helsinki*. The age of participants spanned from 20 to 56 years, with an average age of 36.6 years. The disease duration ranged from 10 to 40 days, with an average of 23.6 days. The causes of injury were wound nonunion after Achilles tendon repair in 10 cases and trauma-induced soft tissue defects in the Achilles tendon area in 18 cases. The size of the defects varied, measuring between 1.5 cm × 3.0 cm to 3.5 cm × 6.5 cm. Bacterial cultures of wound secretions and drug susceptibility tests were carried out for all patients.

Randomization, grouping and blinding

At the time of treatment, patients were randomized and blinded to their assigned group. The randomization, grouping, and study content remained confidential, known only to the study principal investigators. All patients, physicians, and nurses were blinded to group assignments. Both the control and the experimental groups comprised 8 males and 6 females. The control group was treated with posterior tibial artery perforator flaps, whereas the experimental group was treated with additional VAC dressings. The specific process was shown in **Figure 1**.

Surgical methods

Flap design: Before surgery, a Doppler ultrasound blood flow detector was used to project along the surface of the posterior tibial artery in the lower leg, from near the edge of the wound to the proximal end, ranging from the tip of the medial malleolus up to a distance of 4.0-9.0 cm. The locations of the perforating vessels emerging from the posterior tibial artery were marked to guide the surgical procedure.

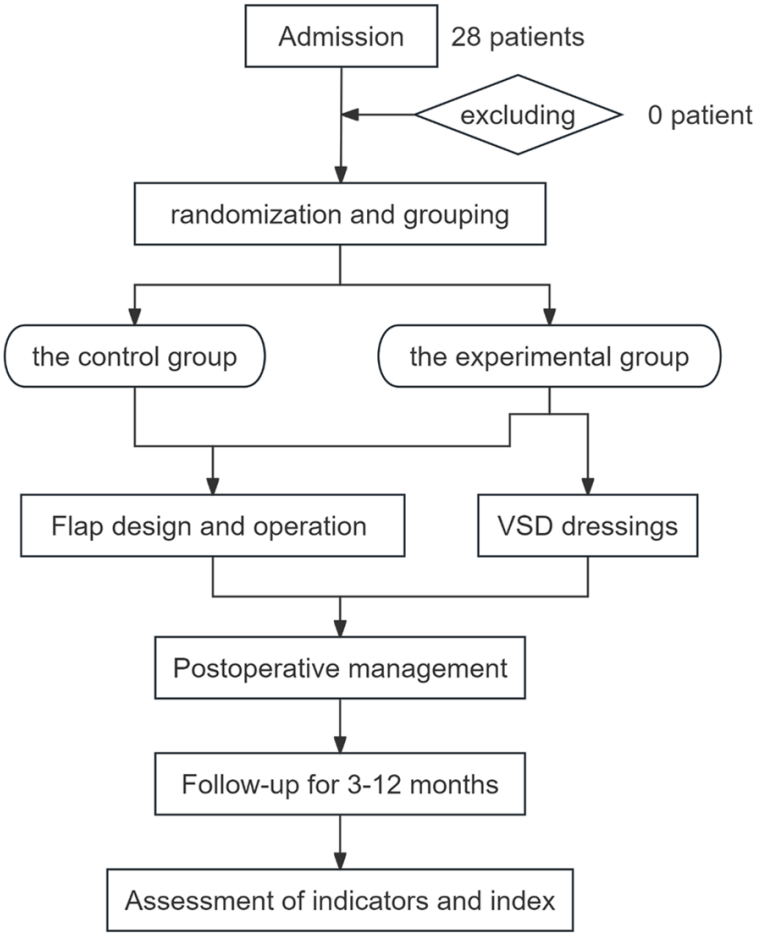

Figure 1. Flow charts of the randomized clinical trials.

Flap cut and wound cover: The patient lay in a supine position, with the affected limb elevated for 1-2 min to facilitate venous drainage. Hemostasis was achieved using a balloon tourniquet, followed by a thorough debridement of the area. As shown in **Figure 2**, an incision was made at the posterior edge of the flap, the superficial layer of the deep fascia was separated backward, and the perforator of the posterior tibial artery was identified based on the previously marked points. After the deep fascia was incised to meticulously release the perforator vessels, an additional incision was then executed along the anterior edge of the flap, and the perforator vessels were freed along the direction of the main trunk of the posterior tibial artery. The flap was advanced in a distal, antegrade fashion to cover the skin defect in the Achilles tendon. Finally, the flap and the donor site were sutured, and a drainage tube was placed at a lower level to facilitate fluid evacuation and promote healing.

VAC: The detailed operation methods were reported in a previous literature [15].

Postoperative management: After surgery, the patient's head was raised and cushioned with a soft pillow, with the affected area immobilized using plaster for one week. The dressing was changed every other day, complemented by supportive care, such as anti-infection, spasmolysis, and blood volume supplementation. Two weeks later, patients undertook passive ankle functional exercises. Three to four weeks after the surgery, the plaster cast was replaced to ensure the maintenance of a neutral position for passive movement. Six weeks later, the patients gradually began to do partial weight-bearing training. Twelve weeks later, patients successfully transitioned to full-weight-bearing walking.

Potential complications management: Piperacillin sodium and tazobactam sodium injections were administered to prevent nosocomial infection, and anisodamine was administered to relieve local spasms. The electrolyte balance and blood volume of patients were monitored, and appropriate supportive care was provided.

Evaluation indices

Perioperative data, including average operation duration, average intraoperative blood loss, intraoperative complications, time to ambulation, and length of hospital stay after surgery, were recorded.

Clinical outcomes were evaluated using several key parameters: the time to initiate first weight-bearing walking, the onset of full weight-bearing activity, the visual analog scale (VAS) score, the American Orthopedic Foot and Ankle Society (AOFAS) hindfoot and ankle score, and

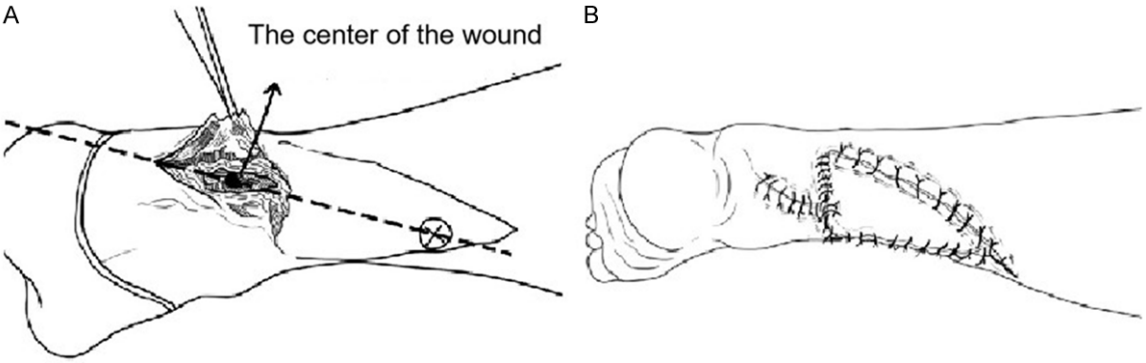

Figure 2. Schematic diagram of flap design and suture.

Table 1. Perioperative data

	Average surgery duration	Average intraoperative blood loss	Complications
Control group	26.6±8.4	18.6±6.4	None
Experimental group	43.4±7.9	31.7±7.3	None
t	5.482	5.065	
P	0.001	0.001	

Table 2. Postoperative recovery time

	Average walking time	Average length of hospital stay
Control group	5.3±0.8	8.8±1.4
Experimental group	4.2±1.1	7.4±1.3
t	3.195	2.706
P	0.004	0.012

the range of motion (ROM) for ankle plantar flexion. Then, the outcomes were recorded at 1 and 3 month(s) post-surgery.

Statistical analysis

SPSS software (version 17.0) was used for statistical analysis. The data are presented as mean ± standard deviation (SD). The independent sample *t*-test was used for the comparison of measurement data. Furthermore, Bonferroni post hoc test was applied to further compare the VAS, AOFAS, and ROM scores. Statistical significance was set at $\alpha = 0.05$.

Results

Perioperative data

The flap size varied from 2.0 cm × 4.0 cm to 8.0 cm × 10.0 cm. The distance from the flap to the distal end was 4.0 cm, with an average of 3.3 cm. All the flaps withstood wear and resisted infection.

The average operative time was 26.6 and 43.4 min for the control group and experimental group, respectively. The average intraoperative blood loss was 18.6 and 31.7 mL, respectively. Both the average operative time and average intraoperative blood loss were significantly reduced in the control group compared to the experimental group (shown in **Table 1**, $P<0.05$). No patients experienced noticeable complications during the surgery.

Postoperative recovery time

The average time until initiation of walking post-surgery was 5.3 and 4.2 days for the control and experimental groups, respectively. The average length of hospital stay was 8.8 and 7.4 days, respectively. Both the walking time and hospital stay were significantly shorter in the experimental group compared to those in the control group (shown in **Table 2**, $P<0.05$).

Basic parameters of postoperative follow-up

Patients were monitored for 3-12 months, with an average time of 6.5 months. The flaps showed neither swelling nor ulcers. The texture and color were similar to the surrounding tissue. Postoperatively, all patients demonstrated

Table 3. Postoperative recovery time results

	Average first weight-bearing walking time	Average full weight-bearing walking time
Control group	47.4±5.4	52.1±5.3
Experimental group	41.8±3.7	44.3±4.6
t	3.206	4.166
P	0.004	0.001

Table 4. VAS scores post-surgery

		1 month post-surgery	3 months post-surgery
Control group		5.3±0.8	2.8±0.3
Experimental group		4.7±0.4	1.4±0.3
Independent sample *t*-test	*t*	2.530	12.365
	P	0.02	<0.001
Post hoc Bonferroni test	F	195.653	
	P	<0.001	

Table 5. AOFAS scores post-surgery

		1 month post-surgery	3 months post-surgery
Control group		72.8±3.4	83.3±3.6
Experimental group		77.4±4.9	89.6±4.1
Independent sample *t*-test	*t*	-2.902	-4.342
	P	0.007	<0.001
Post hoc Bonferroni test	F	45.357	
	P	<0.001	

Table 6. ROM scores post-surgery

		1 month post-surgery	3 months post-surgery
Control group		33.6±3.7	44.5±3.6
Experimental group		38.4±3.1	49.6±3.2
Independent sample *t*-test	*t*	-3.630	-3.931
	P	0.001	0.001
Post hoc Bonferroni test	F	59.706	
	P	<0.001	

satisfactory ankle flexion, extension, and walking. According to the criteria of the American Orthopedic Association Foot and Ankle Surgery Branch [16], 24 cases were classified as excellent and 4 cases as good.

Postoperative recovery time

The average duration until the initiation of first weight-bearing walking was 47.4 and 41.8 days for the control group and experimental group, respectively. The average time to achieve full-weight-bearing walking was 52.1 and 44.3 days, respectively. Notably, the time required for walking in the experimental group was significantly reduced compared to that in the control group (shown in **Table 3**, $P<0.05$). Assessment based on the first weight-bearing walking showed that patients in the experimental group recovered better after surgery.

VAS scores

The average VAS score was 5.3 and 4.7 for the control and experimental groups, respectively, at 1 month after surgery, and 2.8 and 1.4, respectively, at 3 months after surgery. The score for the experimental group was significantly lower than that for the control group (shown in **Table 4**, $P<0.05$). This indicates that patients in the experimental group experienced less postoperative pain and a decreased negative impact on their daily lives.

AOFAS scores

The average AOFAS score was 72.8 for the control group and 77.4 for the experimental group 1 month post-surgery. At 3 months post-surgery, the experimental group showed a score of 89.6, which was significantly higher than 83.3 in the control group (shown in **Table 5**, $P<0.05$), indicating a better recovery in the experimental group.

ROM scores for ankle plantar flexion

The average ROM scores of the control group were 33.6 and 44.5 points at 1 month and 3 months post-surgery, respectively. The average ROM scores of the experimental group were 38.4 and 49.6 at 1 month and 3 months after surgery, respectively. The scores were significantly higher in the experimental group than those in the control group (shown in **Table 6**, $P<0.05$), suggesting an improved recovery in the experimental group.

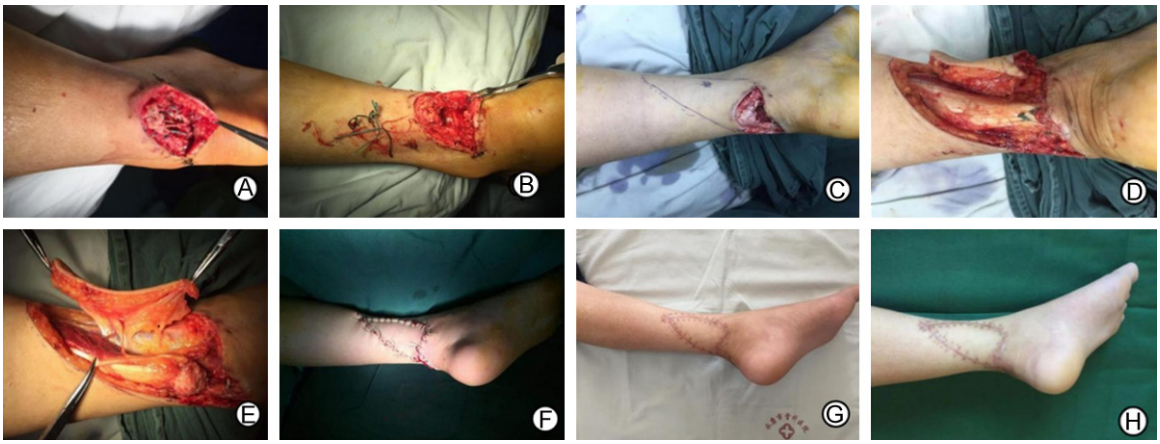

Figure 3. Recovery diagram of case study 1.

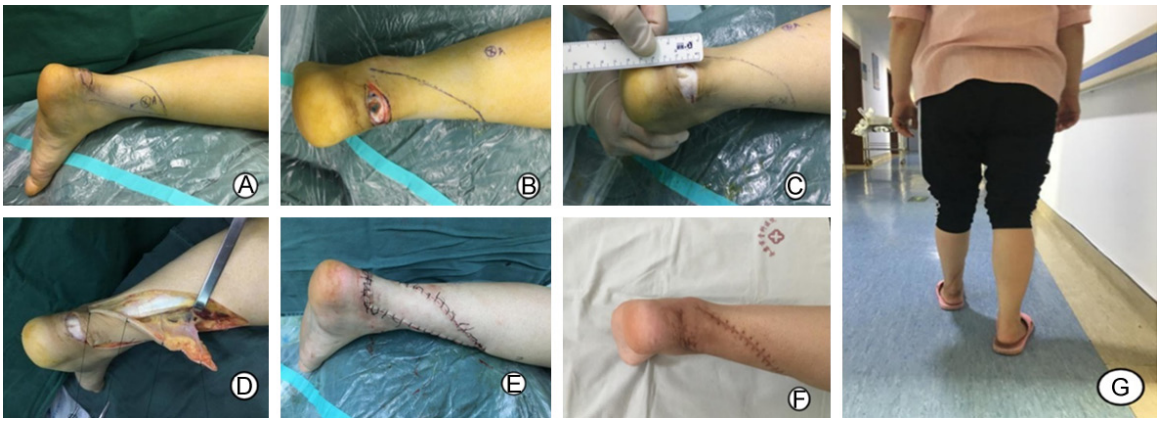

Figure 4. Recovery diagram of case study 2.

Case study

Case 1: A female patient suffered from pain and limited movement of the left foot for 2 h following an injury caused by iron sheet cuts. An emergency repair of the left Achilles tendon was carried out. However, 1 month post-surgery, there was a recurrence of wound exudation, redness, and swelling, persisting for 15 days (**Figure 3A**). Preoperative bacterial cultures indicated no obvious bacterial growth. The suture was removed during the first stage of debridement (**Figure 3B**), and the Achilles tendon was debrided and repaired (**Figure 3E**). The skin defect in the Achilles tendon area measured approximately 3.2 cm × 6.5 cm (**Figure 3C**). Consequently, a triangular flap of approximately 6.5 cm × 15.2 cm was designed based on the medial superior malleolus perforator artery in the left medial leg (**Figure 3C**). The flap was excised as shown in **Figure 3D**, then posteriorly advanced along the V-Y distal end (**Figure 3F**), and the proximal end was sutured directly (**Figure 3G**). At the 6th month post-surgery, the appearance and texture of the flaps were healthy, without any signs of enlargement, as shown in **Figure 3H**. The AOFAS ankle-hindfoot function score was excellent, indicating a successful outcome.

Case 2: A female patient reported pain and bleeding for 1 h in her left foot due to a glass cut. Following the emergency repair of the Achilles tendon, the patient experienced a recurrence of wound exudation, redness, and swelling two months post-surgery, persisting for 12 days. Preoperative bacterial cultures tested positive for staphylococcus aureus, so antibiotics were administered, and a thorough debridement was carried out (**Figure 4B**). The suture of the Achilles tendon was conducted as depicted in **Figure 4C**. The skin defect in the

Achilles tendon area was approximately 2.0 cm × 5.5 cm (**Figure 4C**), and a 6.0 cm × 14.5 cm triangular flap was designed (**Figure 4C**) centered on the medial superior malleolus perforator artery in the left medial leg (**Figure 4A**). The flap was dissected to expose the perforator vessels (**Figure 4D**), followed by advancing the distal end using the V-Y technique, while the proximal end was sutured directly (**Figure 4E**). Follow-ups at 3 months (**Figure 4F**) and 6 months after surgery (**Figure 4G**) showed that the appearance and texture of the flaps were healthy and not enlarged. The AOFAS ankle-hindfoot function score was excellent.

Discussion

Current approaches to the repair of Achilles tendon region soft tissue injuries

Numerous reports worldwide discuss various repair methods for soft tissue defects in the Achilles tendon region, including autologous repair, autologous tissue transplantation, allogeneic transplantation, and other auxiliary methods [17-19]. Herein, the clinical effects of a medial superior malleolar perforator flap of the posterior tibial artery plus VAC dressing for skin and soft tissue defects in the Achilles tendon area are reported. Autologous repair methods, such as local random flaps, axial flaps, fasciocutaneous flaps, and myocutaneous flaps, use self-tissue to enrich the defect areas. Autologous tissue transplantation typically involves the transfer of tendons or muscles. Tendons are commonly used for allogeneic transplantation. Other repair methods include open adhesion, tendon fixation, stromal cell transplantation, and the application of fillers. Each repair method is guided by its own set of principles and indications. It is imperative to tailor treatment strategies to meet the unique needs of each patient in clinical practice.

Currently, there is no universally accepted standard procedure for treating soft tissue defects in the Achilles tendon region, and all existing methods have limitations in clinical application. While autologous repair is a straightforward approach, its success hinges on both the quality of the flap and the effectiveness of autologous tissue transplantation with bio-repair capabilities. Additionally, ensuring the appropriate sizing of the flap to match the injured area is crucial, and allogeneic transplantation may be required for large defects. Nevertheless, there remains controversy regarding the immunogenicity of allogeneic transplantation. While stromal cell transplantation holds promise in theory, its clinical efficacy necessitates long-term monitoring. The restoration process using filler materials necessitates ongoing monitoring of long-term results. It is essential to selectively utilize and potentially combine different methods to implement a therapeutic approach tailored to the specific type of injury and the individual circumstances of each patient, thereby achieving optimal repair outcomes. In the mainstream view, autologous repair is the first choice for skin lesions in the Achilles tendon region.

Studies have indicated that local flaps, when compared to free flaps, present several advantages including shorter surgery durations and lower costs in the repair of soft tissue defects in the foot and ankle. Moreover, local flaps have been found to be equivalent to free flaps in terms of wound healing and postoperative function [20]. In our studies, a local medial superior malleolar perforator flap from the posterior tibial artery combined with a VAC dressing for skin and soft tissue defects in the Achilles tendon area was successfully utilized to promote wound healing. Resorting to a flap combined with VAS dressing in this clinical trial rendered superior positive outcomes than using local flap alone, in a statistically significant manner. Previous reports have suggested the potential of similar approaches. In 1988, Hull [21] reported 18 cases of perforator advancement flaps for repairing complex tissue defects in the lower leg. Later, Chinese scholar Zhou *et al*. [22] reported positive outcomes utilizing a V-Y flap with perforators for repairing small wounds in the Achilles tendon area and posterior heel area; however, they noted that venous reflux led to skin necrosis, in contrast to the flap utilized in our studies. Huang *et al*. [23] reported that the limited advancement distance of the double-perforator pedicle limited the coverage area. In recent years, there has been a growing utilization of propeller perforator flaps based on various perforator vessels, including the peroneal artery [24], posterior tibial artery [25], and peroneal abdominal artery [26], owing to an enhanced understanding of lower limb vascular anatomy. This approach leverages artery-based perfora-

tor flaps to effectively address soft tissue defects in the Achilles tendon area. Additionally, it represents a straightforward procedure that incurs minimal trauma and results in favorable outcomes in terms of both function and appearance. Recent studies have highlighted the effectiveness of combining VAC with the medial superior malleolar perforator flap of the posterior tibial artery as an effective method to repair skin and soft tissue defects in the foot and ankle [27]. In summary, both traditional methods and emerging technologies for repairing soft tissue defects in the Achilles tendon region are continuously evolving, offering optimized solutions for skin and soft tissue repair and thereby improving clinical outcomes.

Anatomical basis of the medial supramalleolar perforator flap from the posterior tibial artery

According to Sun et al. [28], in the distal cutaneous branch vascular plexus, an average of 3.6 cutaneous branches are typically observed. Among these branches, at a distance of 6.37±1.22 cm from the tip of the medial malleolus, a large (≥1.0 mm) cutaneous branch originates from the posterior tibial artery [29]. The average diameter of the distal artery origin was 1.11±0.09 mm, and the average pedicle length was 6.53±1.51 mm. The design and creation of the flap can be customized according to the specific characteristics of the wound. The rotation point can be strategically chosen to ensure optimal vascular conditions within the selected vascular plexus. The design of the flap utilizes the vascular plexus as its axis, with the perforator vascular plexus forming a vascular chain along the long axis of the leg. The anatomical basis of this flap type lies in the lower perforator of the posterior tibial artery located in the medial malleolus. When the length of the vessels was limited, the pedicle could be extended to 3.4±0.6 cm by freeing the main trunk of the posterior tibial artery, ligating a few branches of the posterior tibial artery, and freeing the vessels that penetrate the superficial fascia.

Precautions during the procedures

The V-Y advancement flap with a medial superior malleolar perforator from the posterior tibial artery is relatively straightforward to execute, but specific considerations must be taken into account during surgery.

Before surgery, patients should be informed about the distribution of perforators in the posterior tibial artery. High-frequency color Doppler ultrasound can assist in locating perforators, providing visual information on their location, number, origin, course, and superficial exit point. Additionally, it allows for assessment of the vascular wall's smoothness, the presence of stenosis or plaque, and the patency of the body lumen. During the operation, it's essential to utilize the connection between the perforating point of the posterior tibial artery and the midpoint of the distal end of the wound as the axis. Additionally, the posterior side of the flap should be incised and flipped to the anterior side to identify the multiple perforators in the posterior part of the medial malleolus and assess the shape of the skin. The flap design should be adjusted to ensure that the angle of the proximal tip of the flap is greater than 30°. The bottom of the flap should extend 1.0 cm beyond the wound margins, while the anterior aspect of the flap should not surpass the anterior ridge of the tibia. Additionally, the distal portion of the flap should not extend beyond the midpoint of the lateral malleolar Achilles tendon. By properly preserving the skin and soft tissue on the fibular side, the blood supply and venous return of the flap can be significantly enhanced. In addition, multiple perforators may become apparent and can be preserved to ensure adequate blood supply to the flap, provided that the advancement distance of the flap allows for it. If a perforator is found to be insufficiently long, a more suitable perforator may be selected to optimize flap viability. In cases where a longer advancement distance is required for the flap, ligation of select branches of the posterior tibial artery can be performed, provided it is feasible with respect to the perforator vessels and the free posterior tibial artery trunk, and the skin vessels penetrating the superficial fascia can be dissociated to increase the length of the vascular pedicle and consequently extend the advancement distance of the flap [30, 31]. During the operation, it is necessary to carefully assess whether the perforator vessel has been damaged. A perforator that is close to the wound edge may be susceptible to trauma or erosion due to inflammation, potentially resulting in embolism. Shimin *et al*. [32] believed that for chronic wounds after trauma, perforators located at least 3.0 cm above the wound edge in healthy skin should be preferentially chosen. This approach aims to miti-

gate adverse effects on perforator vessels, such as inflammatory reactions and fibrous hyperplasia in the injured area. When positioning the flap for suturing, a 4-0 absorbable suture was used to suture the skin at the distal end in an oblique fashion to reduce both the tension of the proximal retraction after advancing the flap for suturing and the tension at the distal edge of the flap, thus safeguarding the blood supply of the flap.

In conclusion, the V-Y advancement flap based on the medial superior malleolar perforator of the posterior tibial artery offers several advantages, including the preservation of the main blood vessel, direct suturing of both donor and recipient sites, simplicity of operation, reliable blood supply, favorable functional recovery, and the attainment of a healthy, aesthetically pleasing appearance. Therefore, this technique represents an ideal and effective approach for repairing small skin defects in the Achilles tendon region.

Conclusion

Based on walking time, hospital stay, average time of first weight-bearing walking, average time of full weight-bearing activity, VAS, AOFAS, and ROM score, applying a medial superior malleolar perforator flap from the posterior tibial artery plus a VAC dressing demonstrated superior outcomes than using a flap alone. Our data support the use of the medial superior malleolar perforator flap from the posterior tibial artery as an ideal method for repairing small and medium-sized skin defects in the Achilles tendon area. Advantages of this method include a reliable blood supply, simple operation, reduced damage to the donor site, healthy appearance, and a decreased incidence of postoperative complications.

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Disclosure of conflict of interest

None.

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