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Long-Term Efficacy and Surgical Outcomes of Sural Neurovascular Flap Applications in Distal Lower Limb Wound Reconstruction: A Single-Center Retrospective Study of Patients Treated in Jingzhou City From 2012 to 2018

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ABSTRACT

Background and Aim: The sural neurovascular flap has been effectively used to reconstruct complex tibial and soft tissue defects caused by severe trauma, promoting successful wound repair and healing. Proactive management is essential in minimizing postoperative complications and achieving optimal outcomes. This study evaluates the efficacy and long-term outcomes of sural neurovascular flap applications in distal lower limb wound reconstruction.

Methods: Our institution's ethics committee approved this retrospective study numbered YJ202457 involving 47 participants. Informed consent was obtained from all subjects. Data collected included demographic details, injury mechanisms and sites, mode and size of soft tissue defects, complications, cosmetic outcomes, and functional outcomes of the lower limb and ankle. All flaps were performed by a single surgeon, with follow-up from January 2012 to February 2018.

Result: The study observed minor complications, primarily superficial necrosis. Over 95% (45) of flaps survived, and less than 5% (2) required reoperations due to superficial necrosis. Patient satisfaction was high, with over 50% (24) achieving excellent cosmetic results and over 40% (20) good cosmetic results. The study recorded improved Functional Recovery and Quality of life.

Conclusion: Sural neurovascular flap applications show significant promise in reconstructing distal lower limb wounds. Our findings highlight the procedure's efficacy, demonstrated by high patient satisfaction, excellent cosmetic outcomes, and favorable functional results. Critical factors for success include meticulous patient selection, thorough debridement, and careful planning to mitigate risks and optimize outcomes. The patients with diabetes and hypertension were not included to minimize factors that could interfere with the study's results.

Abbreviation: NV, neurovascular.

1 | Introduction

Reconstructing wounds in the distal lower limb presents substantial challenges due to its complex anatomy and limited vascularity [1–3]. Various surgical procedures have been investigated to overcome these issues, with the sural neurovascular flaps emerging as a potential option. [4–8] The sural neurovascular flap, encompassing the sural nerve and surrounding arteries, has emerged as a viable option, offering consistent vascularity and flexibility in flap design [2, 9–11]. This flap provides robust soft tissue coverage while preserving functional integrity, making it ideal for reconstructive surgery in the ankle and foot areas [1, 3, 9, 12–17]. Additionally, this technique's low donor site morbidity enhances its appeal. However, successful application requires a thorough understanding of anatomy and surgical proficiency [1, 3, 18].

Over time, the sural neurovascular flap has been used to treat complicated tibial and soft tissue anomalies caused by severe trauma, resulting in successful wound repair and healing [6, 11, 19–21]. Proactive management efficiently controls postoperative complications, resulting in the best results. While complications such as partial necrosis, deep infection, and flap ischemia may occur, overall clinical results are favorable, with donor sites healing well and mild paresthesia reported. [6] Valuable insights into surgical technique and aftercare help to improve the procedure's effectiveness and reduce risks.

While previous studies have focused on immediate surgical outcomes [22–24], more data must be collected on the long-term functional and patient-reported outcomes of sural neurovascular flap reconstruction for distal lower limb wounds. Evaluating parameters such as range of motion and patient satisfaction over extended periods can provide valuable insights. Furthermore, there is a need to investigate the impact of this reconstruction technique on patients' quality of life and esthetic satisfaction.

This study uses a single-center retrospective study design to evaluate the efficacy and long-term outcomes of sural neurovascular flap applications in distal lower limb wound reconstruction. At the end of this study, we hope to thoroughly understand the esthetic and functional outcomes and the clinical and efficacy findings of using sural neurovascular flaps to reconstruct severe wounds in the distal lower limbs.

2 | Patients and Methods

2.1 | Study Design and Setting

This retrospective single-center study, approved by our institution's ethics committee and numbered YJ202457, was conducted at an urban central hospital's orthopedic trauma center.

2.2 | Patients

The study included 47 participants, selected based on predetermined inclusion and exclusion criteria. A single surgeon performed all surgeries from January 2012 to February 2018. Data collected included demographic information, injury characteristics, defect size, complications, cosmetic outcomes, and functional outcomes of the lower limb and ankle. Statistical analysis was conducted using IBM SPSS Statistics 27.0.1, with a p value of 0.05 considered statistically significant.

2.3 | Patient Selection

Patients are selected based on predetermined inclusion and exclusion criteria, as illustrated in Figure 1. All patients are selected from our department's database with a strict follow-up protocol stipulated by our institution's ethics committee. The inclusion criteria were: (1) Patients with Distal Lower Limb Wounds include individuals with open wounds or soft tissue defects in the distal lower limb region. (2) Cases where the primary method of reconstruction involved using a Sural Neurovascular Flap. (3) Age Range: 18 years and above.

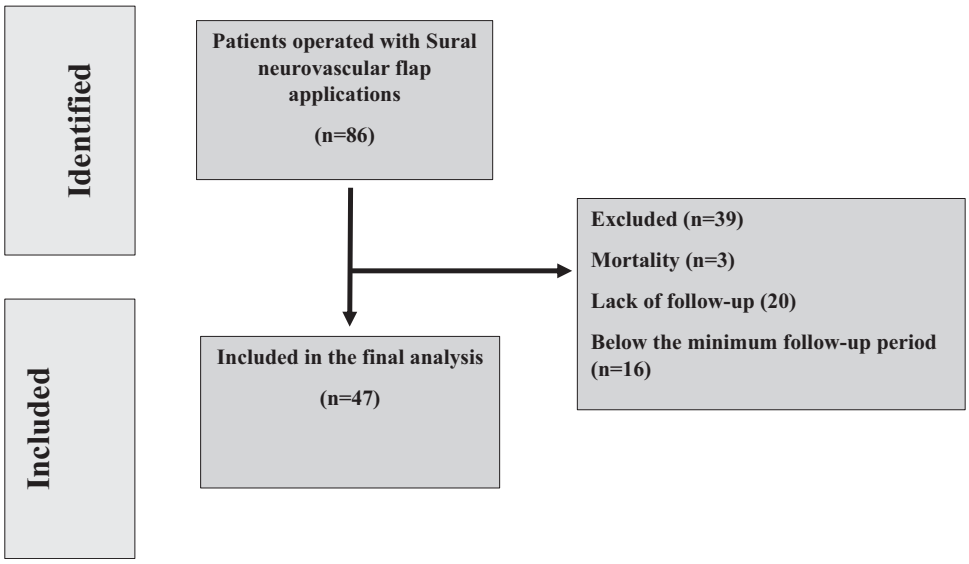

FIGURE 1 | This chart shows the patient inclusion process for this study.

Exclusion criteria were: (1) Cases where Sural Neurovascular Flap was not the primary or sole reconstruction method. (2) Pediatric patients were excluded. (3) Cases with severe systemic conditions like diabetes that may significantly impact wound healing independently of the surgical procedure. (4) Previous Failed Flap Reconstruction cases where the patient had prior unsuccessful attempts at flap reconstruction to isolate the impact of the Sural Neurovascular Flap. (6) Non-Distal Lower Limb Injuries cases involving wounds or injuries outside the distal lower limb region.

Preoperative evaluation

A routine preoperative examination: This comprises clinical consultation, physical examination, and laboratory preoperative tests to determine the patient's readiness for surgery.

Vascular ultrasound: Conducted to determine the condition of the blood vessels and the circulation to the injured limb, particularly after severe damage to soft tissues or suspected vascular trauma.

Radiographic imaging: Simple X-ray pictures were taken to check the fracture type and its location relative to the bone to assess the amount of displacement.

Computed tomography (CT) scans: Obtained to evaluate the extent of complex fractures and assist in planning surgery to define the position of fracture fragments after surgery.

2.4 | Surgical Techniques

Following the successful administration of spinal anesthesia, a patient is carefully positioned appropriately. Preparation ensued as the affected limb underwent thorough disinfection using 1% iodine, followed by applying sterile wipes. The thigh airbag tourniquet pressurized at 500 mmHg is applied to ensure proper circulation control.

Upon assessment, a skin defect approximately 10 cm^2 in size is identified on the lateral aspect of the left calcaneus, revealing the calcaneus with visible milky white inflammatory exudation. Surrounding soft tissues appeared healthy, with the fibular tendons securely in place.

The surgical area undergoes meticulous cleansing with hydrogen peroxide, diluted iodine, and physiological saline. Subsequent procedures included debridement, which is crucial in preparing the wound bed because it eliminates necrotic tissue, foreign objects, and any biofilm that could foster infection, wound margin trimming, and removal of compromised tissues, with intermittent rinsing of the surgical site using the solutions above. The ankle joint wound is closed using Johnson & Johnson Line 1 oblique sutures, followed by vacuum sealing drainage (VSD) excipients to facilitate wound healing while maintaining negative pressure. The patient safely returns to the ward following the surgery.

2.5 | Flap Design

When performing traditional sural neurotrophic vascular flap surgery, we opt for the “retrograde method.” For flap design, the focus is on positioning it at the upper 1/3 of the posterior midline of the calf, aligning with the axis formed by the sural nerve, superficial peroneal artery, and small saphenous vein. This alignment follows a body surface projection from the midpoint of the popliteal fossa to the midpoint of the lateral malleolus and Achilles tendon, ensuring that neither side extends beyond the lateral midline. The retrograde sural neurovascular flap's transfer point lies at the ankle, making it suitable for addressing soft tissue defects in the heel, ankle, and lower 1/3 of the calf. We locate the flap rotation point 5–7 cm posterior and superior to the lateral malleolus to determine the flap rotation point. Subsequently, we symmetrically drew the excision area of the flap on the flap axis, considering the required pedicle length for the recipient area, as shown in Figures 2 and 3.

The blood supply to the distal pedicle flap is primarily sourced from the lowermost intermuscular perforator of the peroneal artery, located approximately 5 cm behind and above the lateral ankle, within a range of 4–7 cm. This crucial vascular pathway typically exhibits an outer diameter of approximately 1.2 mm, as demonstrated in Figure 4.

3 | Postoperative Management

Following surgery, antibiotics were administered intravenously to patients for at least 48 h. The wounds are always kept clean and dry, as dressings are frequently changed to prevent infections. We constantly monitor the wound for signs of infection like increased redness, swelling, warmth, or drainage. We regularly monitor the flap for signs of ischemia or necrosis, such as changes in temperature, color, or capillary refill time. A Doppler ultrasound was used to evaluate lap perfusion. Functional exercise was initiated 3–5 days after the operation to avert muscle atrophy and joint stiffness. Patients were permitted to resume weight-bearing activities 3–5 weeks following surgery.

4 | Follow-Up Protocol

After discharge, strict outpatient follow-ups were conducted per hospital protocols to assess the healing process. During these follow-up periods, a nurse was permanently assigned to assess and record Patients' Reported Outcomes (PROs) using the VAS score and SF-36 questionnaires. Four domains of the SF-36 were used, including the Physical Functional domain, Mental Health domain, Role Limitation domain, and General Health domain. After 1 year of Postoperation, the participants were contacted through cell phones or during outpatient visitation for follow-up.

Initial Postoperative Visit: Within 7 days after discharge, the patient is assessed for the surgical site, pain levels are recorded using VAS, and appropriate wound healing is evaluated.

Three-month follow-up: Patients' quality of life, functional outcomes (SF-36), and pain level (VAS) are further evaluated. Radiological imaging of bone healing progress is also conducted through X-rays or CT scans.

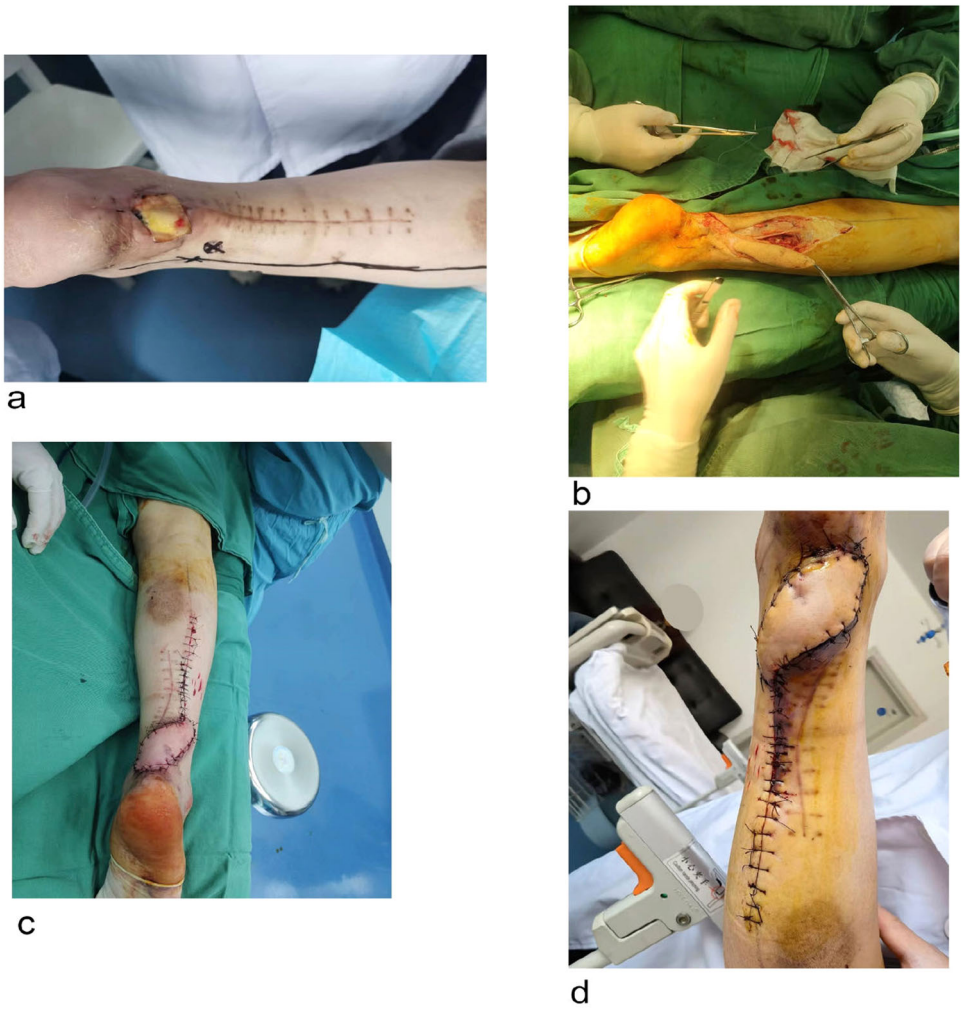

FIGURE 2 | A 33-year-old male patient with an Achilles tendon rupture from severe trauma. (a) shows preoperative examination and planning, (b) during the operation, (c) shows the end of the operation, and (d) 3 days postoperation.

Six-Month follow-up: Quality of life and functional outcomes are assessed. Pain levels and complication status are evaluated. If necessary, more imaging studies will be done.

Annual follow-ups (up to 5 years): Quality of life, functional recovery (SF-36), amount of pain (VAS), and dissatisfaction due to physical appearance are evaluated for more long-term periods.

5 | Statistical Analysis

The data analysis was performed using IBM SPSS Statistics 27.0.1 software. A p value of 0.05 indicates statistical significance. The demographic variables of age were presented as Mean $\pm$ SD, and sex was presented as frequency and percentage. Functional recovery and Quality of Life variables were computed using a One-Sample t-test.

6 | Sample Characteristics

A Shapiro-Wilk test determined the normality of the age distribution and follow-up time between males and females. It demonstrates that they are both approximately normally distributed, with a p value greater than 0.05. Visual examination of their histograms, standard Q-Q plots, and box plots revealed that the age and follow-up duration were approximately normally distributed for males and females, as shown in Table 1.

7 | Result

7.1 | Descriptive Data

Data from 89 patients who underwent sural neurovascular flap applications in distal lower limb wound reconstruction were collected, but only 47 met the follow-up and inclusion criteria. Of the 47 analyzed patients, 31 were males and 16 were females, with a mean age of 50.66 ± 10.10 years. The wounds average an area of 96 cm^2. The detailed patient characteristics are in Table 1 of the supplementary files. The major mechanism of injury of our participants is trauma followed by Tumor resection, Achilles tendon rupture, dog bite, and burns.

The study found minor complications, the majority of which were superficial necrosis. Most of the flap survived with less than 5% (2) requiring reoperations due to superficial necrosis.

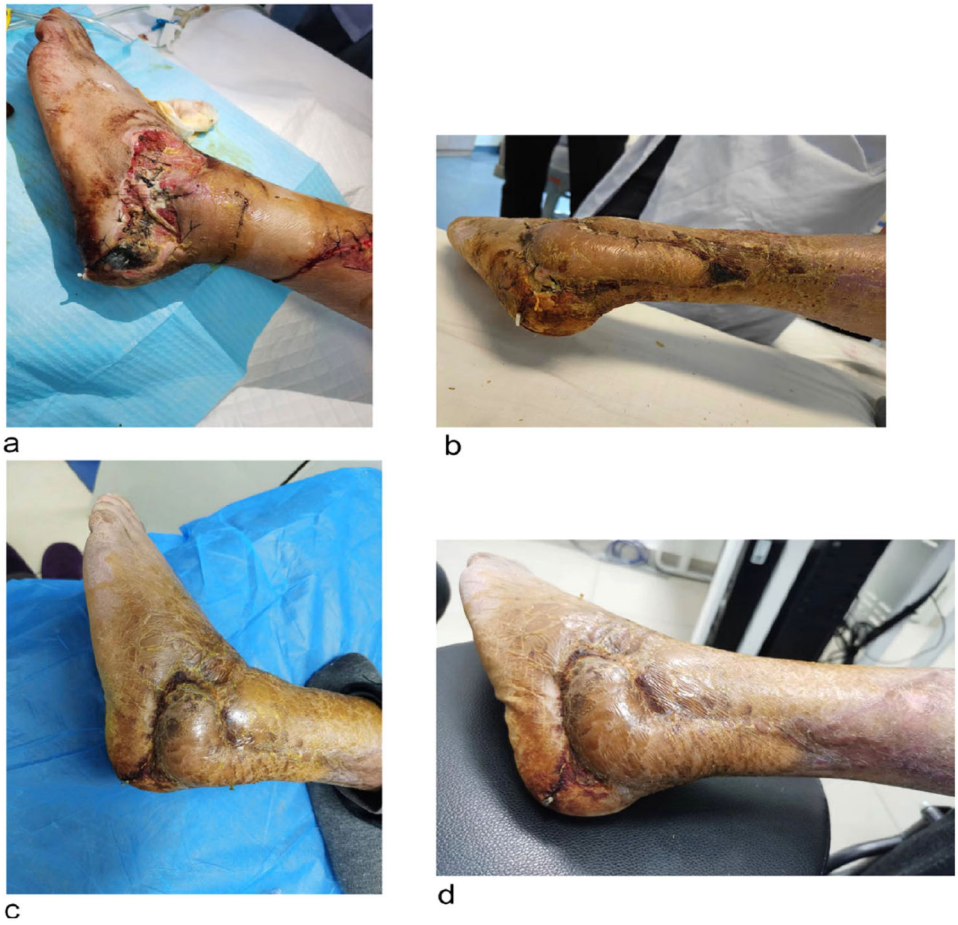

FIGURE 3 | A 55 years old male patient with left ankle trauma resulting in severe soft tissue damage, (a) preoperative, (b) 9 days postoperative, (c) 21 days post operation, and (d) 8 weeks postoperation.

The average clinical healing time is slightly above 16 days. After a follow-up period of over 67 months, most participants were delighted, with 24 (over 50%) having excellent cosmetic appearances and 20 (over 40%) having good cosmetic appearances, as shown in Table 2. The cosmetic appearance was graded according to Dr. Pervaiz Hashmi's grading [25] from excellent to poor with scores of 5, 4, 3, and 2, as indicated in Table 3. Participants' Functional Recovery and Quality of life were recorded using the Short Form (SF)-36 questionnaire with a score of 0–100, zero being the worst outcome and 100 being the best outcome. Four domains of the SF-36 were used with Physical Functioning, Mental Health, Role Limitation, and General Health recorded from the preoperative period to the last follow-up period as shown in Table 4. The VAS score also recorded progressive improvement over the period, as in Table 4.

8 | Discussion

The main objective of this study was to investigate factors influencing success rates, clinical healing timing, the impact of preoperative recipient site conditions, the choice of sural neurovascular flap, and their correlation with long-term functional outcomes. To contextualize our investigation, we meticulously reviewed previous research on superficial neurovascular flap applications in distal lower limb wound reconstruction [1–21, 25–27].

Our findings revealed a remarkable flap survival rate of 45, exceeding 95%, with 2 (less than 5%) necessitating reoperation. The overall results remained commendable despite complications such as partial superficial necrosis, infection, and occasional venous congestion. Korompilias et al. conducted a retrospective analysis of 10 participants, demonstrating over 90% flap success, notwithstanding challenges posed by diabetes and smoking [1]. However, the limited participant pool might impinge on the statistical reliability of their conclusions. Similarly, Cang ZQ et al. examined 29 patients undergoing medial plantar flap reconstruction for lower leg and foot soft tissues, yielding a success rate exceeding 96%. However, one flap succumbed to partial necrosis, potentially attributable to diabetes [26]. A retrospective study conducted by Burusapat C. and colleagues showcased encouraging outcomes yet encountered venous congestion in over 37% of patients, contrasting our findings [27]. Al-Himdani S. et al. emphasized the significance of careful flap selection. However, venous congestion remains the most common complication, highlighting the need for careful planning to reduce risks [3]. The low incidence of complications substantially influences the procedure's success.

Notwithstanding variations in flap sizes, clinical healing times appear congruent (within 16 days), barring those necessitating reoperations. Our investigations evince those complications warranting reoperation and influencing healing times 16.30 ± 3.84 days ($p < 0.001$). Di Summa et al. reported a

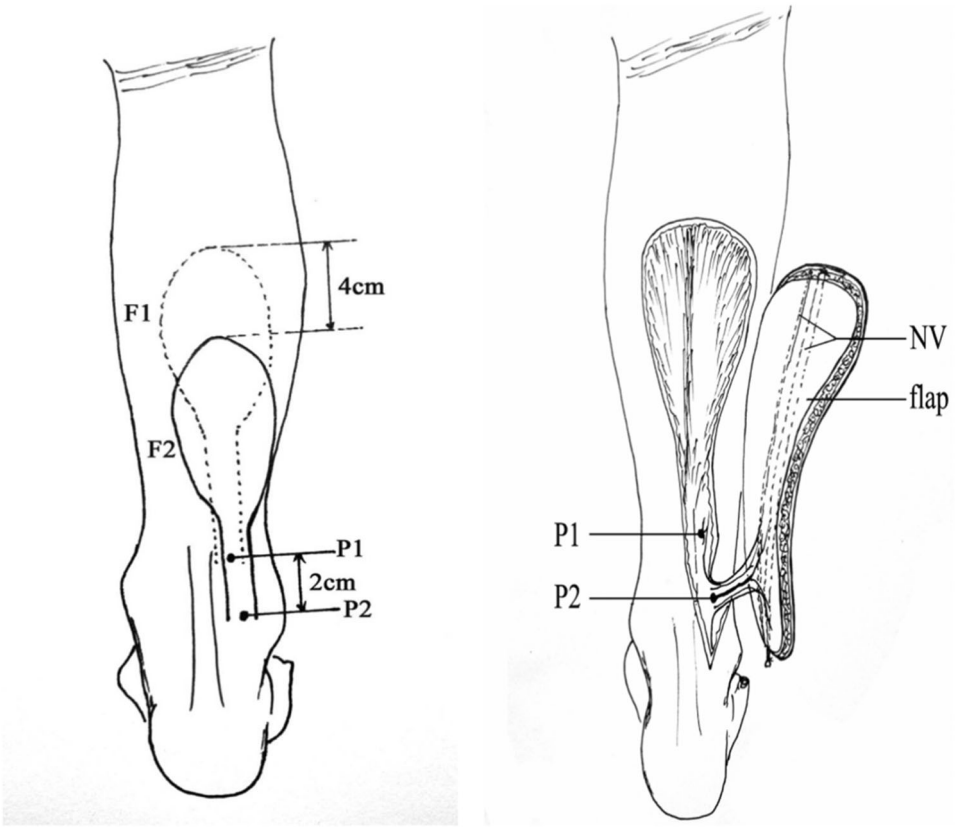

FIGURE 4 | A schematic drawing of distal and proximal pedicle flap blood supply. NV, neurovascular; P1, vascular puncture point1; P2, vascular puncture point2; F1, proximal flap; F2, distal flap.

TABLE 1 | Test for normality.

		Age		Follow-up period	
		Male	**Female**	**Male**	**Female**
Shapiro-Wilk	*p* values	0.082	0.222	0.008	0.088

complete healing time of 19 days, aligning closely with our observations. In contrast, Korompilias et al. documented a protracted healing period averaging over 3 weeks, possibly attributable to challenges posed by diabetes and smoking, and excluding patients with comorbidities such as diabetes and hypertension yielded relatively favorable healing outcomes, underscored by the high flap survival rates. Although studies on preoperative recipient site condition effects on wound healing remain scarce, variations in wound healing between diabetic and nondiabetic patients have been delineated [1, 5]. The recipient site's condition emerges as pivotal to procedural success, thus accentuating the indispensable role of thorough debridement in averting complications like infections.

With a high flap survival rate, the flap exhibits impeccable healing, as evidenced by 24 (over 50%) rated as excellent, 20 (over 42%) as good, and 3 (less than 7%) as fair in terms of cosmetic appearance. Encouragingly, over 51% (24) of participants expressed high satisfaction, with over 42% (20) reporting satisfaction. Al-Himdani et al. showed remarkable patient satisfaction and functional outcomes with the medial sural artery perforator flap [1]. Similarly, Hashmi et al. examined 89 patients, with over 92% reporting excellent cosmetic appearance and no instances of poor cosmetic outcomes [25]. The consistently high satisfaction rates across our study and others conducted over time attest to the procedure's reliability.

The study showed excellent Functional Recovery and Quality of Life in the four domains recorded as the Physical Functioning domain improved from 44.68 ± 7.63 at preoperative to 87.34 ± 5.60 with a $p < 0.001$. Similar improvements were also recorded in the other three domains, comparable to other studies [28, 29]. End-point assessment by Rams et al. [28] revealed that the Reverse Sural Flap delivered satisfactory outcomes 1 year after posttraumatic lower leg reconstruction. Zhong et al. [29] investigated 16 patients who received pedicle axial flaps to treat high-voltage electrical burn skin and soft tissue defects in their foot and ankle region. Functional measurements recorded during the 24-month final evaluation period revealed excellent scores between 76% and 95% for foot and ankle performance. The study also recorded a sustained improvement in VAS score from 5.02 ± 0.90 preoperatively to 0.38 ± 0.53 ($p < 0.001$) 12th-month postoperation. This is in agreement with a study conducted by Bangura et al. where patients were treated with external fixation following soft tissue reconstruction for open distal tibial fracture with severe soft tissue damage [30].

TABLE 2 | Clinical outcomes of the participants.

Serial No.	Variables		Outcomes $N = 47$	Significance p value
1	Gender	Male	31 (66%)	0.077
		Female	16 (34%)	
2	Age	Mean ± SD (years)	50.66 ± 10.10	0.67
3	Complications	Had complication	14 (29.8%)	0.005
		No complication	33 (70.2%)	
4	Flap survival	Survived	45 (95.7%)	0.05
		Reoperated	2 (4.3%)	
5	Cosmetic appearance	Excellent	24 (51.1%)	0.44
		Good	20 (42.6%)	
		Fair	3 (6.4%)	
		Poor	0	
6	Flap size	Mean ± SD	96.89 ± 68.51	< 0.001
7	Follow-up period	Mean ± SD	67.78 ± 8.29	
8	Mechanism of injury	Trauma	39 (83.0%)	
		Dog bite	1 (2.1%)	
		Archilles tendon rupture	2 (4.3)	
		Tumor resection	4 (8.5%)	
		Burns	1 (2.1%)	
9	Patient satisfaction	Highly satisfy	24 (51.1%)	0.09
		Satisfy	20 (42.6%)	
		Fairly satisfy	3 (6.4%)	
10	Clinical healing time	Days	16.30 ± 3.84	< 0.001

TABLE 3 | Cosmetic appearance grading.

Variable	Excellent (5)	Good (4)	Fair (3)	Poor (2)
Coverage	100%	90%–100%	80%–90%	70% and below
Cosmetic appearance	Highly acceptable	Acceptable with slightly raised skin margin	Acceptable with raised skin margin	Not acceptable due to thick and hairy skin
Total	15	12	9	6

TABLE 4 | Mean values of assessed functional recovery and quality of life of participants.

Outcome	Preoperation period	Postoperation 6 months	Last follow-up	p value
SF-36 physical functioning subscale	44.68 ± 7.63	71.53 ± 8.73	87.34 ± 5.60	< 0.001
SF-36 mental health subscale	62.02 ± 15.34	72.13 ± 11.93	86.62 ± 8.61	< 0.001
SF-36 role limitation subscale	44.68 ± 12.31	61.74 ± 9.85	79.79 ± 8.21	< 0.001
SF-36 general health subscale	56.74 ± 8.96	73.81 ± 6.72	92.34 ± 5.60	< 0.001
VAS score	Pre-operation period	Post ops 3 months	Post ops 12 months	
	5.02 ± 0.90	2.66 ± 0.64	0.38 ± 0.53	< 0.001

Note: Short Form (SF)-36 Health Survey (0–100 scale) and Visual Analog scale (VAS) score (0–7). The means are presented as Mean ± SD, standard deviation (SD).

9 | Strengths and Limitations

Our single-center study has various strengths that could benefit surgical research. The single-center strategy provides consistency in surgical techniques, follow-up protocols, and data gathering, improving the dependability and repeatability of our findings. From 5 years and beyond, sural neurovascular flap treatments' efficacy and durability are well documented, providing vital insights into

their long-term results. Excluding individuals with comorbidities like diabetes and hypertension isolates the surgical intervention's effect, lowering confounding variables and strengthening our conclusions. Our outcomes may be more reliable because the same surgeons conducted all procedures, reducing surgical technique variability.

Despite these merits, our study design has drawbacks. The retrospective study and limited sample size of 47 patients may restrict its statistical power and generalizability to other patient populations. The exclusion of people with diabetes and hypertension may also limit our findings in clinical settings. Retrospective studies are also prone to biases, inadequate data, and causality issues, which may weaken our conclusions. Despite controlling for confounding variables, unmeasured factors may still affect outcomes, affecting our study's internal validity.

We suggest many research avenues to address these limitations and improve sural neurovascular flap use. Prospective research with larger sample sizes allows for better confounding variable control and causal inferences. In addition, incorporating patients with various comorbidities and demographics would improve our external validity and reveal the procedure's efficacy in clinical practice. Comparing sural neurovascular flap applications to other surgical techniques or therapies would provide valuable data on efficacy, safety, and cost-effectiveness. Finally, multi-center collaboration would boost sample size, diversity, and generalizability, enabling validation and replication across settings. By addressing these recommendations, future research can build on our study's basis and improve our understanding of clinical sural neurovascular flap uses.

10 | Conclusion

After a thorough study of the factors that affect success rates, clinical healing times, conditions at the recipient site before surgery, and the choice of sural neurovascular flaps, along with how they relate to long-term functional outcomes, it is clear that sural neurovascular flap applications hold much promise in reconstructing wounds in the distal lower limb. Our study, supported by various findings, underscores the procedure's efficacy, as demonstrated by remarkable patient satisfaction, excellent cosmetic outcomes, and favorable functional results. Despite complications and varying healing times, meticulous patient selection, thorough debridement, and careful planning are critical factors in mitigating risks and optimizing outcomes. The consistently high satisfaction rates across multiple studies affirm the reliability and effectiveness of supravascular neurovascular flap applications in improving patient outcomes and warrant further consideration and adoption in clinical practice. The participants with diabetes and hypertension were not included to minimize factors that could interfere with the study's results. The presence of those conditions might greatly influence infection, wound healing, and recovery of surgical patients.

Author Contributions

Mohamed Lamin Bangura: conceptualization, data curation, formal analysis, investigation, methodology, software, visualization, writing – original draft, writing – review and editing. **Li An He:** data curation, formal analysis, software, supervision, validation, writing – review and editing. **Teng Zeng:** data curation, formal analysis, writing – review and editing. **Tadiwa Chiedza Chirima:** data curation, formal analysis, writing – review and editing. **Sy-Trung Tran:** data curation, formal analysis, writing – review and editing. **Wang Kang:** data curation, formal analysis, resources, writing – review and editing. **Xiang Wan:** data curation, resources, visualization. **Yong Li Jin:** data curation, formal analysis, writing – review and editing. **Minglu Wang:** data curation, formal analysis, writing – review and editing. **Huasong Luo:** conceptualization, project administration, resources, supervision, validation, visualization.

Acknowledgments

The authors have nothing to report.

Ethics Statement

The ethical committee of the First Affiliated Hospital of Yangtze University approved this retrospective study, with number YJ202457. Participants provided informed written consent. All procedures were carried out according to the relevant guidelines and regulations. All authors declared no potential conflict of interest.

Consent

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All data generated or analyzed during this study are attached as a supporting file.

Transparency Statement

The lead author Huasong Luo affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.