



OPEN Local muscle or myocutaneous flap transfer for emergent repair of Gustilo IIIB open tibiofibular fractures

Gang Zhao[✉], Wenming Luo, Da Huo, Xingzhen Shi, Qi Wang, Xuecheng Sun, Zhen Liu, Xiaoming Yang, Jie Zhao & Yongqiang Zhang

This study aimed to investigate the clinical outcomes of local muscle or myocutaneous flap transfer for emergent repair of Gustilo IIIB open tibiofibular fractures. This retrospective case series study included patients with Gustilo IIIB open tibiofibular fractures treated by local muscle or myocutaneous flap transfer in Weifang People's Hospital between May 2016 and April 2021. Fifteen patients (11 males aged 19–72 years) were included. The follow-up ranged from 8 to 24 months. The ranges of bone healing time and wound healing time were 6–17 months and 1–3 weeks, respectively. The length of hospital stay was 26 days (11–50 days). All patients reported acceptable functional recovery and satisfactory leg appearance, with Johner-Wruhs scores of excellent, good, and fair in 10, four, and one patients, respectively. The excellent-good rate was 93.3%. The complications included one case of infection and one case of nonunion. In conclusion, local muscle or myocutaneous flap transfer for emergent repair of Gustilo IIIB open tibiofibular fractures may be useful in providing adequate soft tissue coverage and fracture healing with low complication and infection rates.

Keywords Tibiofibular fracture, Gustilo IIIB, Muscle flap, Retrospective case series study

Gustilo IIIB open tibiofibular fracture is a severe type of lower extremity injury that involves extensive soft tissue damage, periosteal stripping, and exposed bone^{1–3}. It is usually caused by high-energy trauma and is often associated with infection, necrosis, and vascular impairment⁴. Managing this complex injury remains challenging for orthopedic and plastic surgeons⁵. Therefore, finding an effective treatment to provide adequate fracture stabilization, debridement, and soft tissue coverage is important.

The current treatment options for Gustilo IIIB open tibiofibular fracture include split-thickness skin grafts, local flaps, and free tissue transfer^{5–7}. However, each of these methods has its limitations and drawbacks. Split-thickness skin grafts may not provide sufficient coverage for large defects and may result in poor aesthetic and functional outcomes⁸. Local flaps are limited by the availability and quality of the surrounding tissue and may compromise the blood supply of the donor site⁹. Although free tissue transfer provides the best coverage and versatility, it is technically demanding, time-consuming, and associated with higher complication rates¹⁰. Therefore, there is a need for a novel technique that can provide reliable and effective soft tissue reconstruction for Gustilo IIIB open tibiofibular fractures. One such technique is the local muscle or myocutaneous flap transfer, which involves the transfer of a muscle or a composite flap from the same extremity to the defect site. This technique has several advantages over the conventional methods, such as preserving the blood supply of the flap, reducing the operative time and morbidity, and improving the functional and aesthetic outcomes¹¹. Therefore, this study aimed to evaluate the local muscle or myocutaneous flap transfer for emergent repair of Gustilo IIIB open tibiofibular fracture.

Methods

Study design and participants

This retrospective case series included patients who underwent surgical repair for Gustilo IIIB open tibiofibular fractures using local muscle or myocutaneous flap transfer at the Weifang People's Hospital (China) between May 2016 and April 2021.

Department of Orthopedics and Trauma, Weifang People's Hospital (First Affiliated Hospital of Shandong Second Medical University), Weifang 261000, China. ✉email: 15865361913@163.com

The inclusion criteria were (1) patients with Gustilo IIIB open tibiofibular fractures and (2) underwent repair using local muscle or myocutaneous flap transfer. The exclusion criteria were (1) patients with damaged muscles around the fracture and the impossibility of transferring the muscle myocutaneous flaps or (2) patients with incomplete medical records.

This study was approved by the Ethics Committee of Weifang People's Hospital (No: KYLL20231031-3). Due to the retrospective nature of this study, written informed consent was waived.

Orthoplastic repair

The orthoplastic repair was conducted in two stages. In the initial stage, the patients underwent a thorough physical examination and received intravenous antibiotics upon admission to the emergency room. Orthoplastic repair was planned after ruling out contraindications. The wound was debrided to remove any dead or contaminated soft tissue and free bone fragments. The resulting bone defects were filled with bone cement. The exposed bone parts were appropriately covered with nearby muscle using one of three types of flap surgery: medial gastrocnemius myocutaneous flap, medial gastrocnemius muscle flap, or soleus muscle flap. The distal and proximal ends of the fractures were fixed externally to maintain satisfactory lower extremity alignment. The wound was covered by a soft hydrophilic fiber dressing. Patients were administered second-generation cephalosporin antibiotics for 72 h postoperatively. The granulation tissues in the wounds were evaluated 3–10 days later to determine when the second stage surgery should occur to complete the wound closure or free skin grafting.

In the second stage of surgery, bone cement was replaced with autologous cancellous bone, or bone repair was performed using the Ilizarov technique, depending on the extent of the bone defect.

Data collection

Age, sex, causes of fracture, location of defect (left and right), mangled extremity severity score (MESS), soft tissue cover, hospital stay, vacuum-assisted closure (VAC), definitive fixation method, bone defect length (cm)/volume (cm³), skin defect area, and surgical repairs were reviewed. After hospital discharge, the patients were followed up in the clinic for up to 24 months. The survival of the flaps, the time required for fracture and wound to heal, complications, and lower extremity functional assessment using the Johner-Wruhs scoring system were documented. During the follow-up evaluations, complete bone healing was determined when the patients had full weight bearing.

Statistical analysis

Categorical data were presented as numbers or percentages, and continuous data were presented as medians (range). Only descriptive statistics were used.

Results

Baseline characteristics of study participants

Fifteen patients (11 males aged 19 to 72 years) were enrolled. Six patients were injured by heavy objects, and nine were in traffic accidents. The areas of the soft tissue defects ranged from 3 × 6 cm to 21 × 10 cm. The length of the tibial defect was between 0 and 13 cm (mean length of 5.1 cm). The MESS value was between 4 and 7. The mean time elapsed from injury to debridement was 5.3 h (2–13 h). After thorough debridement, all patients received first-stage surgery, which included covering the fracture wound with a local muscle or myocutaneous flap transfer (or combined with the Masquelet technique). After the muscle or myocutaneous flap transfer, three patients received skin grafting, and 12 patients received simple sutures to close the wound during the second-stage surgery. All local flaps transferred were able to completely cover the exposed bone wounds. Three patients received a medial gastrocnemius myocutaneous flap, eight received a medial gastrocnemius muscle flap, and four received a soleus muscle flap. During the second stage of surgery, three patients received skin grafting, and 12 patients received simple suturing to close the wound (Table 1).

Surgical outcomes

The follow-up ranged from 8 to 24 months. All fractures and wounds healed. The range of bone healing time was 6–17 months, and the range of wound healing time was 1–3 weeks. The flaps were soft, although with varying degrees of pigmentation. The length of hospital stay was 11–30 days (mean 26 days). The Ilizarov technique initially failed in two patients, but treatment was successful after the fracture ends were debrided. All patients reported acceptable functional recoveries and satisfactory leg appearance, with Johner-Wruhs scores of excellent, good, and fair in 10, four, and one patients, respectively. The excellent-good rate was 93.3%. Complications were found in four of 15 patients, including one case of infection and one of nonunion. These complications were managed successfully by appropriate interventions, such as debridement, antibiotic therapy, bone grafting, and revision surgery. No cases of flap loss, deep vein thrombosis, or amputation were reported in this study.

Case 1

A 33-year-old male was injured by a heavy object, resulting in an open left tibiofibular comminuted fracture (42-C3.2, Gustilo type IIIB). He had no other injury. The distal extremity had normal blood circulation but mild nerve contusion. Physical examinations showed an open wound to the left lower leg (Fig. 1A). A large segment of the fractured tibia was exposed, with periosteal stripping. After debridement, the free bone fragments were without blood supply. The anteroposterior and lateral radiographs of the tibia and fibula revealed a comminuted fracture of the tibia with local bone loss. The fibula exhibited a multi-segmental comminuted fracture. The ankle joint was aligned and stable (Fig. 1B, C). The patient was diagnosed with Gustilo IIIB open tibiofibular fracture.

Patient ID	Age (yrs)	Sex	Cause	Location of defect	MESS score	Soft tissue cover	Hospital stay (days)	VAC	Definitive fixation method	Bone defect length (cm)/volume (cm ³)	Skin defect area (cm)	Complication	Johner-Wruls score
1	19	M	Traffic accident	R	6	MGMF	23	Y	E-X	5/21.5	10×6	None	Excellent
2	35	M	Machine crush injury	R	5	SMF	11	N	IMN	0	5×4	None	Excellent
3	46	M	Machine crush injury	L	5	MGF	33	N	E-X	2/11	7×3	None	Excellent
4	28	F	Traffic accident	L	6	MGF	25	N	E-X	4/21.4	3×6	None	Excellent
5	40	M	Traffic accident	L	6	SMF	26	Y	E-X	5/25.6	13×5	None	Excellent
6	59	F	Machine crush injury	L	5	MGF	35	N	E-X	3/13	14×6	None	Good
7	43	F	Machine crush injury	R	7	MGF	50	N	E-X	11/37.3	20×7	Poor bone healing	Fair
8	33	M	Traffic accident	R	5	SMF	25	Y	LCP	0	11×6	None	Excellent
9	39	M	Machine crush injury	L	6	MGMF	27	Y	E-X	5/25.9	18×7	None	Good
10	45	M	Traffic accident	R	4	MGMF	21	N	E-X	6/28.1	15×7	None	Excellent
11	31	M	Machine crush injury	R	5	MGF	19	N	E-X	11/24.7	20×6	None	Excellent
12	25	M	Traffic accident	L	4	MGF	13	N	E-X	7/33.9	13×8	None	Excellent
13	58	M	Traffic accident	R	4	MGF	14	Y	LCP	0	5×6	None	Good
14	72	M	Traffic accident	R	7	MGF	42	Y	E-X	13/37.9	16×7	Poor bone healing	Good
15	60	F	Traffic accident	R	5	SMF	26	N	E-X	5/24.6	21×10	None	Excellent

Table 1. Baseline characteristics of the patients. *MGMF* medial gastrocnemius myocutaneous flap, *MGF* medial gastrocnemius muscle or mucocutaneous flap, *SMF* soleus muscle or mucocutaneous flap, *IMN* intramedullary nail, *E-X* external fixator, *LCP* locking compression plate, *VAC* Vacuum Assisted Closure, *MESS* Mangled Extremity Severity Score.



Fig. 1. A 33-year-old male sustained a comminuted fracture of the left tibia and fibula (classified as 42-C3.2, Gustilo IIIB type) after being struck by a heavy object. (A–C) A comminuted fracture of the left tibia and fibula (classified as 42-C3.2, Gustilo IIIB type); (D,E) After thorough debridement, an external fixation frame was applied temporarily to the tibia, with the exposed bone covered by a soleus muscle flap to protect the wound surface; meanwhile, free skin grafting was performed to cover the muscular tissue; (F,G) The external fixator was removed, the skin graft survived stably and the wound healed; (H–K) Plate fixation.

Debridement, internal and external fixation, local muscle or myocutaneous flap transfer, and reconstruction of the bone defect with an autogenous bone graft from the iliac crest were performed.

During the first stage of surgery, the free devascularized bone fragments were removed after debridement. A memory alloy fixator was used for fixation. The bone defects were temporarily stabilized with an external fixator (Fig. 1D). The medial head of the soleus muscle was used to cover the defect area. The surrounding skin was closed using tension sutures (Fig. 1E). The area of the wound was 12×6 cm. The granulation tissue grew well before the skin grafting, and the skin graft survived. Three weeks after wound closure, an intramedullary plate was inserted for fixation, and a small amount of autogenous iliac bone was grafted. The fracture site was healed 6 months later, with soft tissue coverage (Fig. 1F, G) and good fixation (Fig. 1H–K). The patient was followed up in the clinic for 22 months with satisfactory functional recovery.

Case 2

A 60-year-old female had an open comminuted fracture of the lower tibiofibular region due to a traffic accident. An area of the tibial periosteum, approximately 20 cm long, was exposed, as was the anterior tibial muscle (Fig. 2A, B). The free bone fragments were removed during debridement (Fig. 2C). The preoperative X-ray showed a severe comminuted fracture of the lower tibiofibular segment. The anteroposterior X-ray revealed a separation of the upper tibiofibular joint (Fig. 2D). There was no fracture in the ankle joint. The patient was diagnosed with Gustilo IIIB open tibiofibular fracture. Debridement, external fixation, local muscle or mucocutaneous flap transfer, and the Ilizarov technique were performed.

During the first stage of surgery, the soleus muscle was debrided. The anterior tibial muscle was sutured to cover the exposed tibia. Then, the area of the exposed wound was 25×6 cm (Fig. 2E–G). The tibia and fibula were shortened and fixed externally across the ankle joint (Fig. 2H–I). Two weeks later, the wound was closed after the soft tissue swelling subsided. One month later, the Ilizarov procedure was performed to lengthen the shortened tibia, with traction applied to the displaced fibula. The tibia was finally restored to its original length, and the proximal fibula returned to its normal position. The knee joint was stable. Figure 2 depicts the tibia and fibula completely healed 11 months after the Ilizarov procedure, although there was still a linear soft tissue scar in the lower leg (Fig. 2J–N). During 3 years of follow-up, repeat X-rays revealed satisfactory bone healing with normal alignment (Fig. 2O–R).

Discussion

The results showed that this technique was effective in providing adequate soft tissue coverage and fracture healing, with low complication and infection rates. The patients also reported satisfactory functional and aesthetic outcomes, with a high excellent-good rate. This technique may offer a viable alternative to the conventional reconstruction methods for this complex injury.

This study is supported by previous reports on the local muscle or myocutaneous flap transfer for defect treatment^{12–14}. The advantages of this technique include preserving the blood supply of the flap and improving the functional and aesthetic outcomes^{15–17}. The local muscle or myocutaneous flap transfer can also avoid the



Fig. 2. (A,B) Post-injury appearance of the open wound, with a substantial portion of the tibia exposed; (C) Avulsed bone fragments without blood supply; (D) Post-fracture X-ray of the tibia and fibula, demonstrating comminuted fractures at the distal ends; (E–G) Following debridement, tibial shortening is observed, with the anterior tibialis muscle flap and soleus muscle flap utilized to cover the wound site; (H,I) Follow-up X-rays after debridement and external fixation, illustrating the status of the surgical site. (J–L) Illustrates the process of tibial lengthening using the Ilizarov technique following the shortening procedure. (M,N) Represents the condition of the external fixation frame after the completion of distraction. (O,P) Demonstrates the state of the wound healing with a dry appearance. (Q,R) Shows the X-ray image upon removal of the external fixation apparatus.

potential complications of free tissue transfer, such as flap failure, donor site morbidity, and microvascular anastomosis problems^{17–19}. In the present study, the exposed bone parts of the wound were covered by a medial gastrocnemius myocutaneous flap in three patients, a medial gastrocnemius muscle flap in eight patients, and a soleus muscle flap in four patients. The medial head of the gastrocnemius muscle and a soleus muscle flap were used to cover the exposed tibia so that the bone could be covered with good tissue in the early stage, avoiding bone necrosis and bone infection caused by long-term exposure and reducing the risk of skin flap in the second operation. Satisfactory early soft tissue coverage was achieved for all patients.

The mean length of hospital stay in this study was 26 days, comparable to the reported range of 18 to 35 days in previous studies using local flap transfer for open tibial fractures^{20,21}. Still, some studies using free flap transfer reported shorter hospital stays of 10 to 15 days²², suggesting that free flap transfer may have some advantages over local flap transfer in terms of hospitalization time. The survival rate of local flaps in this study was 100%, consistent with the high success rates of 95–100% reported in previous studies using local flap transfer^{12,23}. It indicates that local flap transfer is a reliable and simple method for soft tissue coverage of open tibial fractures, with minimal risk of flap failure or necrosis. The mean time for fracture healing in this study was 43.8 weeks, slightly longer than the reported range of 24 to 40 weeks in previous studies using local flap transfer^{12,24,25}. It may be related to the size and location of the bone defects, the type of bone reconstruction technique used (Masquelet or Ilizarov), and the presence of infection or nonunion. The mean time for wound healing in this study was 1–3 weeks, similar to the reported range of 2 to 4 weeks in previous studies using local flap transfer^{12,26–28}. The results suggest that local flap transfer can provide adequate and rapid wound closure without major complications such as infection or dehiscence. The complication rate in this study was 26.7%, which is in the low range of the reported 20–50% in previous studies^{12,29}. The complications in this study included two cases of Ilizarov technique failure, one case of infection, and one case of nonunion. These complications were managed successfully by appropriate interventions, such as debridement, antibiotic therapy, bone grafting, and revision surgery. No cases of flap loss, deep vein thrombosis, or amputation were reported in this study, which is consistent with the low incidence of these complications in other studies using local flap transfer^{12,30}. It indicates that local flap transfer combined with the Masquelet or Ilizarov technique can provide satisfactory functional recovery with minimal impairment of range of motion, strength, and stability. The Johner-Wruhs scoring system used in this study showed that 10 patients had excellent results, four had good results, and one had fair results, with an excellent-good rate of 93.3%. It is comparable to the reported 80–100% range in other studies using local flap transfer^{12,15}. It suggests that local flap transfer can also provide satisfactory cosmetic outcomes, with acceptable leg appearance and minimal donor site morbidity.

This study supports using the Masquelet or Ilizarov technique as a bone reconstruction option for open tibial fractures with bone loss³¹. The Masquelet technique is a two-stage procedure that involves the insertion of an antibiotic cement spacer in the first stage, followed by removing the spacer and grafting autologous bone within the induced membrane in the second stage³². The Ilizarov technique is a method of external fixation that allows a gradual distraction and compression of the fracture site and the correction of deformities and length discrepancies^{31,33}. Both techniques effectively promote bone healing and restore limb function in patients with segmental bone defects³⁴. In this study, both techniques achieved satisfactory results.

Nevertheless, this study also has some limitations that should be acknowledged. First, this single-center study has a small sample size and a short follow-up period, which may limit the generalizability and reliability of the results. Second, the study design was retrospective and lacked a control group, which may introduce selection bias and confounding factors. Third, the study did not assess the objective measures of the flap viability, such as perfusion and oxygenation, which may affect flap survival and wound healing. Fourth, the study did not evaluate the long-term outcomes of the flap transfer, such as flap contracture, hypertrophy, or atrophy, which may affect the functional and aesthetic results.

In conclusion, local muscle or myocutaneous flap transfer may be useful for treating Gustilo IIIB open tibiofibular fractures. It can provide satisfactory soft tissue coverage and fracture healing with low complication and infection rates. It can also improve the functional and aesthetic outcomes of the patients with a high excellent-good rate. Further studies with larger sample sizes, longer follow-up periods, and randomized controlled design are needed to confirm the benefits of this technique and compare it with the conventional methods of reconstruction.

Data availability

All data generated or analysed during this study are included in this published article.

Received: 3 July 2024; Accepted: 22 October 2024

Published online: 27 October 2024

References

- Myatt, A. et al. Management of Gustilo-Anderson IIIB open tibial fractures in adults—a systematic review. *Br. Med. Bull.* **139**, 48–58 (2021).
- Carver, D. C., Kuehn, S. B. & Weinlein, J. C. Role of systemic and local antibiotics in the treatment of Open fractures. *Orthop. Clin. North. Am.* **48**, 137–153 (2017).
- Singh, A. et al. Gustilo IIIB Open Tibial fractures: an analysis of infection and Nonunion Rates. *Indian J. Orthop.* **52**, 406–410 (2018).
- Hu, R. et al. Analysis of staged treatment for Gustilo Anderson IIIB/C Open Tibial fractures. *Indian J. Orthop.* **52**, 411–417 (2018).
- Ma, X., Wang, Z. & Wang, J. Clinical analysis of accelerated rehabilitation surgery for Gustilo type IIIA/B open tibio fibular fracture. *Eur. J. Trauma. Emerg. Surg.* (2022).
- MacKay, B. J. et al. Multidisciplinary application of an external tissue expander device to improve patient outcomes: a critical review. *Adv. Wound Care (New Rochelle)*. **9**, 525–538 (2020).

7. Uzun, C., Yaşar, E. K. & Alagöz, M. S. Free tissue transfer with distraction osteogenesis and Masquelet technique is effective for Limb Salvage in patients with Gustilo Type IIIB Open fractures. *Plast. Reconstr. Surg.* **148**, 853e–854e (2021).
8. He, X. et al. Clinical and radiological outcome of Gustilo type III open distal tibial and tibial shaft fractures after staged treatment with posterolateral minimally invasive plate osteosynthesis (MIPO) technique. *Arch. Orthop. Trauma. Surg.* **138**, 1097–1102 (2018).
9. Fronek, L. F. & Dorton, D. Surgical outcomes following Mohs Micrographic surgery for basal cell carcinoma on the Distal Third of the nose. *J. Clin. Aesthet. Dermatol.* **15**, 32–36 (2022).
10. Azoury, S. C., Kovach, S. J. & Levin, L. S. Reconstruction options for Lower Extremity traumatic wounds. *J. Am. Acad. Orthop. Surg.* **30**, 735–746 (2022).
11. Lee, C. H. et al. Extended use of chimeric medial sural artery Perforator Flap for 3-Dimensional defect Reconstruction. *Ann. Plast. Surg.* **82**, S86–s94 (2019).
12. Mühlhäuser, J., Winkler, J., Babst, R. & Beeres, F. J. P. infected tibia defect fractures treated with the Masquelet technique. *Med. (Baltim)*. **96**, e6948 (2017).
13. Marzouki, H. et al. Hypopharyngeal Reconstruction: Possibilities, Outcomes, and Updates for Improving the Human Health for Quality of Life. *Comput Intell Neurosci.* 6132481 (2022) (2022).
14. O'Keeffe, N. et al. Cadaveric evaluation of sternal reconstruction using the pectoralis muscle flap. *ANZ J. Surg.* **89**, 945–949 (2019).
15. Griffin, J. T. et al. Masquelet technique for the Tibia: a systematic review and Meta-analysis of contemporary outcomes. *J. Orthop. Trauma.* **37**, e36–e44 (2023).
16. Fahradyan, A., Liu, A., Taylor, L., Jones, V. & Li, W. Y. Short Stay Management of locally advanced breast Cancer using Immediate Local Thoracoabdominal Advancement Flap and enhanced recovery after surgery protocol. *Ann. Plast. Surg.* **88**, S366–s373 (2022).
17. Vathulya, M., Praveen, A. J., Barik, S., Jagtap, M. P. & Kandwal, P. A systematic review comparing outcomes of local Flap options for Reconstruction of pressure sores. *Ann. Plast. Surg.* **88**, 105–113 (2022).
18. Abula, A. et al. Reconstruction of Soft tissue defects and bone loss in the Tibia by flap transfer and bone transport by distraction osteogenesis: a Case Series and our experience. *Ann. Plast. Surg.* **84**, S202–s207 (2020).
19. Devriendt, S., Van Praet, L., Bislenghi, G., D'Hoore, A. J. L. & Wolthuis, A. M. Laparoscopic oblique Rectus Abdominis Myocutaneous Flap Harvest for Perineal Reconstruction after Abdominoperineal Resection. *Dis. Colon Rectum.* **66**, e1134–e1137 (2023).
20. Pelissier, P., Boireau, P., Martin, D. & Baudet, J. Bone reconstruction of the lower extremity: complications and outcomes. *Plast. Reconstr. Surg.* **111**, 2223–2229 (2003).
21. Thornton, B. P., Rosenblum, W. J. & Pu, L. L. Reconstruction of limited soft-tissue defect with open tibial fracture in the distal third of the leg: a cost and outcome study. *Ann. Plast. Surg.* **54**, 276–280 (2005).
22. Johnner, R. & Wruhs, O. Classification of tibial shaft fractures and correlation with results after rigid internal fixation. *Clin. Orthop. Relat. Res.* 7–25 (1983).
23. Wolff, A. Y. et al. Full-thickness skin grafting for local defect Coverage following scalp adjacent tissue transfer in the setting of Cranioplasty. *J. Craniofac. Surg.* **30**, 115–119 (2019).
24. Ciclamini, D. et al. The medial femoral condyle free corticoperiosteal flap versus traditional bone graft for treatment of nonunions of long bones: a retrospective comparative cohort study. *Injury.* **50** (Suppl 5), S54–s58 (2019).
25. Granhed, H. P. & Karladani, A. H. Bone debridement and limb lengthening in type III open tibial shaft fractures: no infection or nonunion in 9 patients. *Acta Orthop. Scand.* **72**, 46–52 (2001).
26. Ren, Z. H. et al. Anterolateral thigh myocutaneous flaps as the preferred flaps for reconstruction of oral and maxillofacial defects. *J. Craniomaxillofac. Surg.* **42**, 1583–1589 (2014).
27. Elhassan, B., Karabekmez, F., Hsu, C. C., Steinmann, S. & Moran, S. Outcome of local anconeus flap transfer to cover soft tissue defects over the posterior aspect of the elbow. *J. Shoulder Elb. Surg.* **20**, 807–812 (2011).
28. Kozusko, S. D., Bird, D. & Fahey, A. L. Hyalomatrix coverage in scalp wounds with exposed cranium and dura. *J. Wound Care* **32**, 206–212 (2023).
29. Deng, L. et al. The Masquelet technique combined with the muscle flap for use in emergency management of acute Gustilo type III trauma of the lower limb with segmental bone loss: Case series. *Int. J. Surg.* **81**, 85–93 (2020).
30. Jakubietz, R. G., Meffert, R. H., Jakubietz, M. G., Seyfried, F. & Schmidt, K. Local flaps as a last attempt to avoid lower extremity amputation: an overview. *Unfallchirurg* **123**, 961–968 (2020).
31. Khaled, A., El-Gebaly, O. & El-Rosasy, M. Masquelet-Ilizarov technique for the management of bone loss post debridement of infected tibial nonunion. *Int. Orthop.* **46**, 1937–1944 (2022).
32. Klein, C. et al. The Masquelet technique: current concepts, animal models, and perspectives. *J. Tissue Eng. Regen. Med.* **14**, 1349–1359 (2020).
33. Huang, K. C. & Huang, K. C. Use of single or double local muscle flap transfers for coverage of tibia bone exposure. *Wounds* **20**, 89–94 (2008).
34. Liu, K., Shi, L., Liu, Y. & Yusufu, A. Ilizarov bone transport versus Masquelet technique for the treatment of bone defects caused by infection: a meta-analysis. *Asian J. Surg.* (2023).

Author contributions

Gang Zhao and Wenming Luo carried out the studies, participated in collecting data, and drafted the manuscript. Da Huo and Qi Wang performed the statistical analysis and participated in its design. Xingzhen Shi, Xuecheng Sun, Zhen Liu, Xiaoming Yang, Jie Zhao and Yongqiang Zhang participated in acquisition, analysis, or interpretation of data and draft the manuscript. All authors read and approved the final manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate

I confirm that all methods were performed in accordance with the relevant guidelines. This work has been carried out in accordance with the Declaration of Helsinki (2000) of the World Medical Association. This study has been approved by the Medical Ethics Committee of Weifang People's Hospital (No: KYLL20231031-3), and informed consent was obtained from each patient. The requirement for informed consent was waived by the Institutional Review Board of Weifang People's Hospital because of the retrospective nature of the study.

Additional information

Correspondence and requests for materials should be addressed to G.Z.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Open Access This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

© The Author(s) 2024