Am J Transl Res 2020;12(9):5836-5843
www.ajtr.org /ISSN:1943-8141/AJTR0116264

Original Article

Outcomes of free anterolateral thigh perforator flaps versus free modified latissimus dorsi myocutaneous flaps for Gustilo type IIIB open tibial fractures with necrosis and infection

Xiaoyang Pang, Zheming Cao, Panfeng Wu, Juyu Tang, Zhengbin Zhou, Fang Yu, Lei Zeng, Yongbin Xiao, Ding Pan, Rui Liu

Department of Orthopedics, The Xiang-Ya Hospital of Central South University, 87# Xiangya Road, Changsha 410008, Hunan, People's Republic of China

Received June 14, 2020; Accepted July 17, 2020; Epub September 15, 2020; Published September 30, 2020

Abstract: Background: Infection and non-union of fractures are potential complications of Gustilo type IIIB open tibial fractures. It is important to choose the most effective type of flap to reduce the incidence of infection and non-union. Method: This study reviewed outcomes of 44 patients (aged 16-65 years) who underwent reconstruction of Gustilo type IIIB tibial fractures from January 2004 to January 2017. Patients received a free anterolateral thigh perforator flap (ALTP; n = 23) or modified latissimus dorsi myocutaneous flap (MLD; n = 21). Demographic data, intraoperative data, postoperative complications, and long-term outcomes were compared between groups. Results: Flap complications occurred in 8 patients (18.2%) after flap reconstruction: 6 in the ALTP group and 2 in the MLD group ($P < 0.05$). No patient developed total flap necrosis. Rates of erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) normalization were higher in the MLD group than in the ALTP group at 2 and 4 weeks after flap transfer ($P < 0.05$). By 6 months, fracture union occurred in 52.4% of patients in the MLD group and 30.4% of those in ALTP group ($P < 0.05$). By 9 months, union occurred in 85.7% of MLD group patients and 52.2% of MLD group patients ($P < 0.05$). Conclusion: MLD was associated with fewer flap complications, shorter time to ESR and CRP normalization, and higher union rates by 6 and 9 months, compared with ALTP. These results suggest that MLD may provide a better environment for reducing susceptibility to infection and promoting fracture healing in Gustilo type IIIB tibial fractures with necrosis and infection.

Keywords: Open tibia fractures, anterolateral thigh perforator flap, modified latissimus dorsi myocutaneous flap, reconstruction, infection, bone healing, gustilo type IIIB

Introduction

Orthoplastic surgery is best surgery procedure for treating of gustilo type IIIB open tibial fractures, as it combines both salvage and reconstruction of the lower extremity, thereby improving quality of life [1]. However, successful orthoplastic surgery requires not only an experienced orthopedic surgeon but also an experienced plastic surgeon, and most patients with these fractures initially present to a local hospital where a plastic surgeon is unavailable [2]. The opportunity to perform orthoplastic surgery is often lost if a substantial delay occurs while evaluating neurovascular status or function of other organs or while transferring the patient to another facility. Thus, patients with Gustilo type IIIB open tibial fractures have high rates of necrosis and infection and may even require amputation.

When necrosis and infection occur in the setting of Gustilo type IIIB tibial fractures, management becomes a major challenge. Controversy exists regarding the best type of flap for reconstructing the defect after debridement. Local pedicle flaps, such as gastrocnemius or soleus flaps [3-5], may be used to repair lower limb defects in accordance with the principle of "like-with-like" [6, 7]. Transplantation with free flaps, including anterolateral thigh perforator flaps (ALTP) [8-11], latissimus dorsi myocutane-

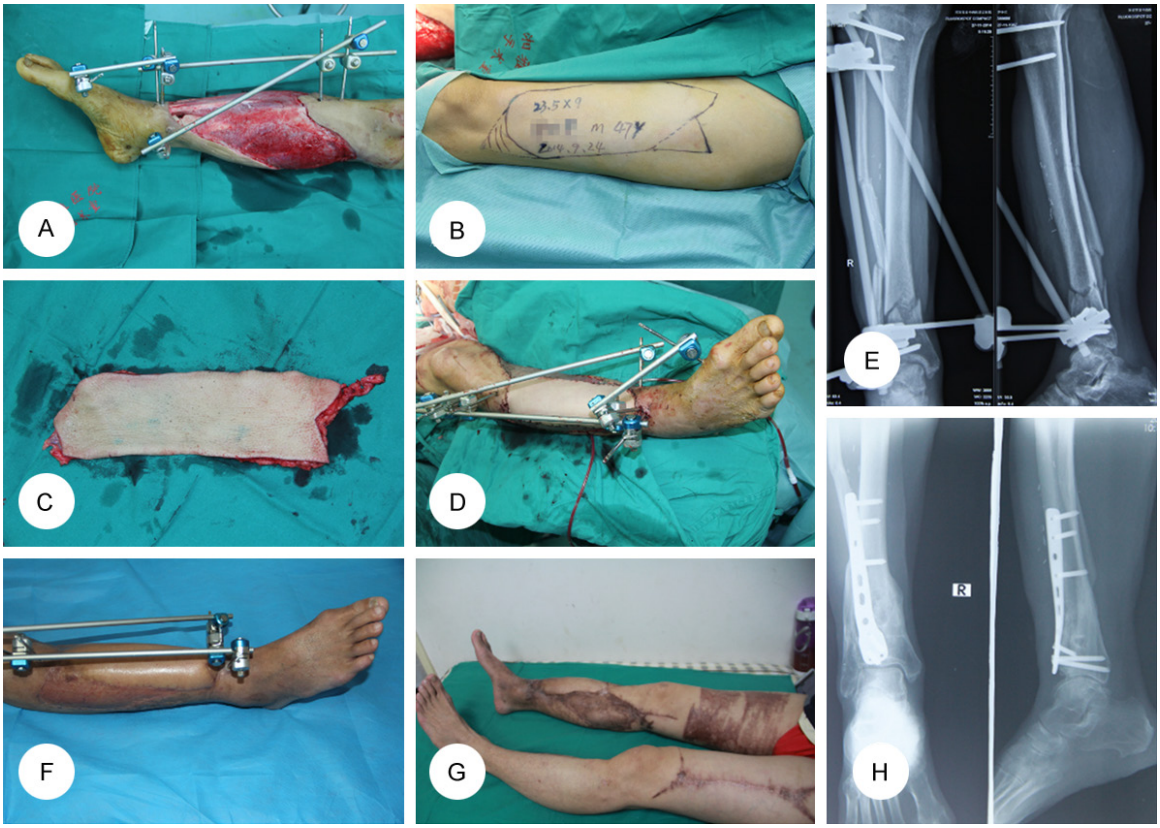

Figure 1. (A) 47-year-old male presented with a Gustilo type IIIB open tibial fracture at the distal tibia secondary to a traffic accident. The wound site was infected with *Escherichia coli*. Seven days after debridement (A), a left anterolateral thigh perforator flap (23.5 cm × 9 cm) was used to cover the fracture and anterior tibial defect (B-D). The flap survived well, and erythrocyte sedimentation rate and C-reactive protein values returned to normal within 4 weeks. External fixation was replaced with internal fixation 5 weeks after the flap surgery (E, F). Bone healing was observed 9 months after flap surgery, with no evidence of osteomyelitis (G, H).

ous flap [12], thoracodorsal artery perforator flap [13], deep inferior epigastric perforator flap [14], is also popular. At present, ALTP and latissimus dorsi flaps are the most commonly used flaps for repairing composite soft-tissue defects in the lower extremities.

The aim of this study was to compare outcomes between ALTP and modified latissimus dorsi myocutaneous (MLD) flaps for reconstruction of Gustilo type IIIB open tibial fracture defects, with the ultimate goal of determining which type of flap provides the best results.

Patients and methods

After receiving institutional review board approval, we reviewed the medical records of 44 adults with Gustilo IIIB tibial fractures who were transferred to our institution from a local hospital between January 2004 and January 2017. All patients were initially treated with debridement and external fixation at the local hospital and then transferred approximately 5-7 days after the initial trauma because of infection and necrosis. The study inclusion criteria were 16 to 65 years of age, presence of a Gustilo IIIB tibial fracture, and agreement to undergo one-stage reconstruction surgery with an ALTP flap (**Figure 1**) or MLD flap (**Figure 2**), based on the recommendation of the primary treating surgeon. If more than one flap was used to close the defect, the patient was excluded from the study. Written informed consent was obtained from all patients or their guardians. All operations were performed by the same surgeon with his team.

Upon arrival at our institution, a sample of wound secretions was sent to the laboratory for bacterial culture and drug sensitivity analysis. Subsequently, an experienced plastic surgeon

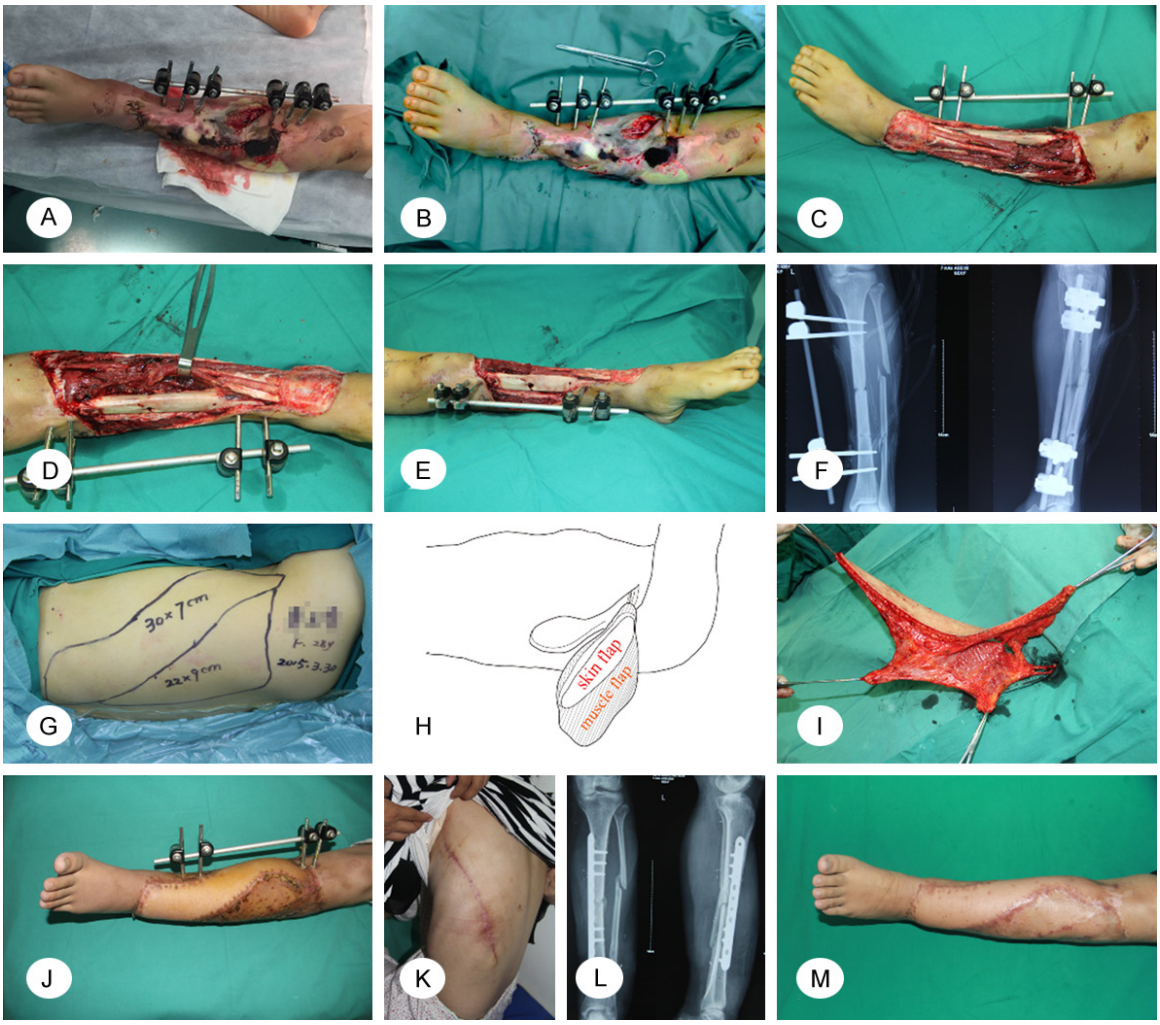

Figure 2. A 28-year-old female patient with Gustilo type IIIB open tibia fractures secondary to a traffic accident. She was transferred to our institution because of necrosis and Staphylococcus aureus infection (A, B). After meticulous debridement, the long segment of the tibia is exposed without periosteum (C-F), a modified latissimus dorsi myocutaneous flap was used to reconstruct the defect (G). With this technique, the whole latissimus dorsi muscle and part of the nearby fasciocutaneous tissue were harvested, and the donor site was closed primarily (H, I). All flap survival well (J), and the donor site closed directly, retaining linear scars (K). By 4 weeks after flap surgery, the erythrocyte sedimentation rate and C-reactive protein had returned to normal, so external fixation was replaced with internal fixation (L). Bone union was achieved by 6 months after flap surgery (M).

meticulously and thoroughly debrided the defect, obtained another sample for bacterial culture and drug sensitivity, and then covered the defect with vacuum-closed drainage. Antibiot ics were prescribed based on the sensitivity results. One week later, the lower extremity soft tissue defect was repaired with an ALTP or MLD flap. The MLD flaps (**Figure 2**) differed from traditional latissimus dorsi flaps. Part of the latissimus dorsi muscle does not carry fasciocutaneous, so the muscle flap is larger than the fasciocutaneous [15]. External fixation was replaced by internal fixation within 4-8 weeks after flap transplantation. This was performed when the flap was healing well and inflammatory markers (erythrocyte sedimentation rate [ESR] and C-reactive protein [CRP]) returned to normal. All patients underwent rehabilitation training in accordance with the post-fracture rehabilitation program at our institution.

Demographic data, intraoperative data, early complications, and long-term follow-up results were collected. We also recorded flap complications (with the corresponding reasons), donor site morbidity, and ESR and CRP values.

Table 1. Demographic data

Variable	ALTP group (n = 23)	MLD group (n = 21)	*P* Value#
Age (year)	43.8 ± 11.0	45.1 ± 10.5	0.688
Sex			0.289
Male	15	11	
Female	8	10	
BMI (kg/m^2)			0.828
< 25	13	10	
≥ 25-29.9	6	7	
≥ 30	4	4	
Injury location			0.958
Proximal	2	1	
Proximal/middle	2	3	
Middle	5	4	
Middle/distal	6	5	
Distal	8	8	
Bacterial culture			0.974
Staphylococcus aureus	6	5	
Escherichia coli	5	6	
Klebsiella pneumoniae	8	7	
MRSA	2	1	
None	2	2	
Defect size (cm^2)	151.7 ± 21.0	153.5 ± 22.9	0.784

Data represent mean ± standard deviation or number. ALTP, anterolateral thigh perforator flap; BMI, body mass index; MLD, modified latissimus dorsi musculocutaneous flap; MRSA, Methicillin-resistant Staphylococcus aureus. #Two-sided Fisher's exact test or Student's t-test.

Table 2. Intraoperative data

Variable	ALTP group (n = 23)	MLD group (n = 21)	*P* Value#
Flap size (cm^2)	181.7 ± 22.6	183.8 ± 24.9	0.769
Operation time (min)	208.3 ± 21.5	210.0 ± 21.9	0.792
Flap harvested time (min)	55.0 ± 7.8	56.4 ± 7.7	0.557
Blood loss (ml)	204.3 ± 42.4	214.3 ± 47.8	0.469

Data represent mean ± standard deviation. ALTP, anterolateral thigh perforator flap; MLD, modified latissimus dorsi musculocutaneous flap. #Student's t-test.

Fracture healing time was determined during follow-up visits according to the modified Radiographic Union Scale for Tibia scoring system [16].

Quantitative data were expressed as mean ± standard deviation and compared using Student's t-test. Qualitative data were expressed as number or percentage and compared using the χ^2 test and Fisher's exact test. Statistical analysis was performed using SPSS 20.0 software (SPSS Inc., USA). *P* values < 0.05 were considered statistically significant.

Results

Forty-four patients were included in the study: 23 in the ALTP group and 21 in the MLD group. There were no statistically significance differences between groups for any demographic data, including age, sex, body mass index, fracture location, bacterial culture results, or soft tissue defect size (*P* > 0.05; **Table 1**). Bacteria were detected in 90.9% (40/44) of patients, with methicillin-resistant *Staphylococcus aureus* (MRSA) detected in 3 patients. Intraoperative data, including flap size, operation time, flap harvesting time, and blood loss, also did not differ significantly between groups (*P* > 0.05; **Table 2**).

Complications occurred in 8 patients (18.2%) after flap reconstruction. There were significantly more flap complications in the ALTP group than in the MLD group (6 versus 2; P < 0.05; **Table 3**). In the ATLP group, 4 patients developed cutaneous sinus tracts because of infection, and 2 patients developed partial flap necrosis because of vascular vascular crisis and hematoma. In the MLD group, 2 patients developed partial necrosis secondary to a subcutaneous hematoma. Total flap necrosis did not occur in either group. All donor areas were closed primarily, although 1 patient in the ATLP group exhibited delayed healing of the donor site. Two weeks after flap surgery, ESR and CRP were normal in a significantly higher percentage of patients in the MLD group than in the ALTP group (71.4% versus 21.7%; P < 0.05; **Table 3**). The proportion of patients with normal ESR and CRP was also higher in the MLD group 4 weeks after flap transplantation (100.0% versus 65.2%; P < 0.05). Most complications resolved with wound care, but 2 patients in the ALTP group with cutaneous sinus tracts and persistently elevated CRP and ESR values required debridement 6 weeks after flap transfer.

Table 3. Flap complications and inflammation marker trends

Variable	ALTP group (n = 23)	MLD group (n = 21)	*P* Value#
Reconstructed site morbidity			
Flap complications	6	2	0.032
Total flap necrosis	0	0	
Partial flap necrosis	2	2	
Cutaneous sinus tract	4Δ	0	
Factors of flap necrosis			-
Vascular crisis	1	0	
Infection	4Δ	0	
Hematoma	1	2	
Donor site morbidity			0.523
Delayed wound healing	1	0	
Inflammatory recovery*			
2 (weeks)	5/18	15/6	0.001
4 (weeks)	15/8	21/0	0.003
6 (weeks)	21/2Δ	21/0	0.489

Data are numbers. ALTP, anterolateral thigh perforator flap; MLD, modified latissimus dorsi musculocutaneous flap. #Fisher's exact test. *Erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP). ΔCutaneous sinus tracts secondary to bacterial infection occurred in 4 patients. Despite appropriate antibiotic treatment (based on drug sensitivity testing), 2 of these patients had persistently elevated ESR and CRP values at 6 weeks and required reoperation.

Table 4. Fracture healing

Variable	ALTP group (n = 23)	MLD group (n = 21)	*P* Value#
Chronic infection	2	0	0.489
Fracture union			
3 months	0/23	1/20	0.477
6 months	4/19	11/10	0.025
9 months	12/11	18/3	0.024
12 months	19/4	20/1	0.348
Reoperation	4	1	

Data are numbers. ALTP, anterolateral thigh perforator flap; MLD, modified latissimus dorsi musculocutaneous flap. #Fisher's exact test.

By 6 months, complete fracture union was observed in 11 (52.4%) of the 21 MLD group patients but only 4 (30.4%) of the 23 ALTP group patients ($P < 0.05$; **Table 4**). By 9 months, complete union was achieved in 85.7% of patients in MLD group and 52.2% of patients in the ALTP group ($P < 0.05$; **Table 4**). Nonunion occurred in 4 patients in the ALTP group and 1 patient in the MLD group. All instances of nonunion were treated with vascularized iliac bone graft, which resulted in full bone healing in all patients.

Discussion

Gustilo type IIIB open tibia fractures are caused by a high-energy trauma event. They are typically accompanied with by extensive soft tissue contusion and are susceptible to bacterial infection. Therefore, an experienced plastic surgeon is required to debride, accurately identify necrotic tissue and neurovascular compromise, and perform timely reconstruction to restore the integrity of the soft tissue. However, most patients are initially brought to a local hospitals, impossible to obtain professional treatment, where the lack of an experienced plastic surgeon prevents optimal treatment and leads to high rates of necrosis and infection. This is reflected in our study, as all patients arrived at our institution at least 5 days after their trauma, and 90.9% had confirmed bacterial infection at the wound site (**Figure 2A**, **2B**). This delay in optimal care adversely affects later management, prolonging the total healing time and increasing treatment costs [17-20].

When choosing the appropriate flap for reconstruction of Gustilo type IIIB tibia fractures, the surgeon must consider restoration of tissue integrity, as well as the ability of the flap to resist infection and provide an appropriate microenvironment for bone healing. Local pedicle flaps fulfill the repair principle of "like-with-like" and do not require anastomosing blood vessels, but tissues surrounding open tibial fractures are usually severely contused and contaminated with bacteria, leading to a high risk of complications. Furthermore, all patients in the current study had necrosis and previous debridements, which increased the size of the defect so that local flaps would not provide a sufficient amount of tissue to cover the defect. Free flaps not only provide an adequate amount of tissue for defect coverage but also allow three-dimensional reconstruction of the defect [21-26]. For these reasons, ALTP or MLD flaps were selected for defect reconstruction in this study.

Whether to use a muscle flap or a fasciocutaneous free flap for lower extremity reconstruction

has been the subject of considerable debate. In this study, flap complications were more common with ALTP flaps. Furth ermore, inflammatory markers normalized earlier during follow-up in the MLD group (with normal ESR and CRP levels in 100% of MLD patients at 4 weeks), suggesting that MLD flaps reduced susceptibility to bacterial infection. Cutaneous sinus tracts, which were caused by infection, were observed in 4 patients in ALTP group; 2 of these patients had persistently elevated ESR and CRP values at 6 weeks after flap surgery and required repeat debridement. Our results are consistent with previous observations that muscle flaps not only provide coverage for defects but also improve antimicrobial defenses because of their prominent vascularity [27, 28]. These superior vascular effects have been verified in animal experiments, in which blood flow to muscle in musculocutaneous flaps increased rapidly in a short period of time, whereas blood flow in fasciocutaneous flaps increased gradually over a longer time interval [29].

Despite the potential benefits of MLD flaps, ALTP flaps have been widely used to repair many types of defects and are considered "workhorse" flaps. They are characterized by a large skin area, long vascular pedicle, reliability for different flap designs, constant pedicle anatomy, and acceptable donor-site morbidity [8-11]. Some authors have reported equivalent outcomes with fasciocutaneous free flaps and muscle flaps when used for skin and soft tissue defects of the lower extremities [26, 30]. One study reported fewer complications with fasciocutaneous free flaps than with muscle flaps for foot and ankle reconstruction [25].

Bone healing must be considered, especially for patients with gustilo type IIIB fracture who are not optimally treated at initial presentation. Mehta et al [31] reported that muscle flaps reduce the time to healing for acute Gustilo type IIIB fractures, compared with fasciocutaneous flaps. Data from animal experiments have also shown shorter times to fracture healing with muscle flaps [32, 33]. We observed a higher bone healing rate in the MLD group at both 6 months (52.4%) and 9 months (85.7%), compared with the ALTP group (17.4% and 52.2% at 6 and 9 months, respectively). These results differ from those of other clinical reports [31, 34, 35]. Our findings suggest that MLD flaps not only have a good blood supply but also provide stem cells to enhance fracture healing.

All patients in our study underwent debridement by a plastic surgeon, timely flap coverage, antibiotic treatment based on drug sensitivity, and timely replacement of external fixation with internal fixation (based on normalization of ESR and CRP). However, as shown in **Figures 1A** and **2A**, the long segment of the tibia was exposed and the periosteum was exfoliated, so a prolonged period of time was required for bone revascularization and healing. MLD, with its good blood supply, accelerates revascularization of the covered tibia and reduces the time for fracture healing. This likely explains our superior results with MLD, compared with ALTP. It should be noted that 5 of our patients (4 in the ALTP group) required vascularized iliac bone graft to promote fracture healing, which may have been because of infection, trauma or other factors.

This study has some limitations. For example, it was a retrospective analysis, with the usual limitations of this study design. Additionally, the number of subjects was relatively small, and the study was conducted at one center by one surgeon, which may have limited its generalizability. Large-scale randomized controlled clinical trials are necessary to verify our results.

Conclusions

In this clinical study, we compared MLD versus ALTP flaps for repair of Gustilo type IIIB open tibial fractures with necrosis and infection. Our results demonstrated that patients with MLD flaps had fewer flap complications, shorter time to normalization of inflammatory markers (ESR and CRP), and higher union rates at 6 and 9 months, compared with patients who received ALTP flaps. These results suggest that MLD may provide a better environment for reducing susceptibility to infection and promoting fracture healing.

Acknowledgements

This publication was funded in part by the National Natural Science Foundation of China (8187081630).

Disclosure of conflict of interest

None.

Address correspondence to: Panfeng Wu, Department of Orthopedics, The Xiang-Ya Hospital of Central South University, 87# Xiangya Road, Changsha 410008, Hunan, People's Republic of China. E-mail: wupanfeng@csu.edu.cn

References

[1] Azoury SC, Stranix JT, Kovach SJ and Levin LS. Principles of orthoplastic surgery for lower extremity reconstruction: why is this important? J Reconstr Microsurg 2019; [Epub ahead of print].

[2] Gustilo RB and Anderson JT. JSBS classics. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones. Retrospective and prospective analyses. J Bone Joint Surg Am 2002; 84: 682.

[3] Gryskiewicz JM, Edstrom LE and Dibbell DG. The gastrocnemius myocutaneous flap in lower-extremity injuries. J Trauma 1984; 24: 539-543.

[4] Chung YJ, Kim G and Sohn BK. Reconstruction of a lower extremity soft-tissue defect using the gastrocnemius musculoadipofascial flap. Ann Plast Surg 2002; 49: 91-95.

[5] Song P and Pu LLQ. The soleus muscle flap: an overview of its clinical applications for lower extremity reconstruction. Ann Plast Surg 2018; 81 Suppl 1: S109-S116.

[6] Mathieu L, Potier L, Niang CD, Rongieras F, Duhamel P and Bey E. Type III open tibia fractures in low-resource setting. Part 2: soft-tissue coverage with simple, reliable and replicable pedicle flaps. Med Sante Trop 2018; 28: 230-236.

[7] Hallock GG. Evidence-based medicine: lower extremity acute trauma. Plast Reconstr Surg 2013; 132: 1733-1741.

[8] Yildirim S, Gideroglu K and Akoz T. Anterolateral thigh flap: ideal free flap choice for lower extremity soft-tissue reconstruction. J Reconstr Microsurg 2003; 19: 225-233.

[9] Park JE, Rodriguez ED, Bluebond-Langer R, Bochicchio G, Christy MR, Bochicchio K and Scalea TM. The anterolateral thigh flap is highly effective for reconstruction of complex lower extremity trauma. J Trauma 2007; 62: 162-165.

[10] Nosrati N, Chao AH, Chang DW and Yu P. Lower extremity reconstruction with the anterolateral thigh flap. J Reconstr Microsurg 2012; 28: 227-234.

[11] Kim TG, Kim IK, Kim YH and Lee JH. Reconstruction of lower extremity complex wounds with combined free tissue transfer using the anterolateral thigh flap as a link. Microsurgery 2012; 32: 575-579.

[12] Zhu L, Wei J, Daluvoy S, Hollenbeck ST, Chuan D, Xu H and Dong J. Free partial latissimus dorsi myocutaneous flap for coverage of severe achilles contracture in children. J Plast Reconstr Aesthet Surg 2013; 66: 113-119.

[13] Jeon BJ, Lee KT, Lim SY, Pyon JK, Bang SI, Oh KS and Mun GH. Plantar reconstruction with free thoracodorsal artery perforator flaps. J Plast Reconstr Aesthet Surg 2013; 66: 406-413.

[14] Akdag O, Karamese M, Yildiran GU, Sutcu M and Tosun Z. Foot and ankle reconstruction with vertically designed deep inferior epigastric perforator flap. Microsurgery 2018; 38: 369-374.

[15] Zhang YX, Messmer C, Pang FK, Ong YS, Feng SQ, Qian Y, Spinelli G, Agostini T, Levin LS and Lazzeri D. A novel design of the multilobed latissimus dorsi myocutaneous flap to achieve primary donor-site closure in the reconstruction of large defects. Plast Reconstr Surg 2013; 131: 752e-758e.

[16] Litrenta J, Tornetta P 3rd, Mehta S, Jones C, O'Toole RV, Bhandari M, Kottmeier S, Ostrum R, Egol K, Ricci W, Schemitsch E and Horwitz D. Determination of radiographic healing: an assessment of consistency using RUST and modified RUST in metadiaphyseal fractures. J Orthop Trauma 2015; 29: 516-520.

[17] Lee ZH, Stranix JT, Rifkin WJ, Daar DA, Anzai L, Ceradini DJ, Thanik V, Saadeh PB and Levine JP. Timing of microsurgical reconstruction in lower extremity trauma: an update of the godina paradigm. Plast Reconstr Surg 2019; 144: 759-767.

[18] Karanas YL, Nigriny J and Chang J. The timing of microsurgical reconstruction in lower extremity trauma. Microsurgery 2008; 28: 632-634.

[19] Colen DL, Colen LB, Levin LS and Kovach SJ. Godina's principles in the twenty-first century and the evolution of lower extremity trauma reconstruction. J Reconstr Microsurg 2018; 34: 563-571.

[20] Patterson CW, Stalder MW, Richardson W, Steele T, Wise MW and St Hilaire H. Timing of free flaps for traumatic wounds of the lower extremity: have advances in perioperative care changed the treatment algorithm? J Reconstr Microsurg 2019; 35: 616-621.

[21] Kozusko SD, Liu X, Riccio CA, Chang J, Boyd LC, Kokkalis Z and Konofaos P. Selecting a free flap for soft tissue coverage in lower extremity reconstruction. Injury 2019; 50 Suppl 5: S32-S39.

[22] Momeni A, Krischak S and Bannasch H. The thoracodorsal artery perforator flap with a vascularized scapular segment for reconstruction of a composite lower extremity defect. Microsurgery 2006; 26: 515-518.

[23] Song CT, Koh K, Tan BK and Goh T. Free-flap lower extremity reconstruction: a cohort study and meta-analysis of flap anastomotic outcomes between perforator and nonperforator flaps. J Reconstr Microsurg 2018; 34: 455-464.
[24] Kim SW, Kim KN, Hong JP, Park SW, Park CR and Yoon CS. Use of the chimeric anterolateral thigh free flap in lower extremity reconstruction. Microsurgery 2015; 35: 634-639.
[25] Lee ZH, Abdou SA, Daar DA, Anzai L, Stranix JT, Thanik V, Levine JP and Saadeh PB. Comparing outcomes for fasciocutaneous versus muscle flaps in foot and ankle free flap reconstruction. J Reconstr Microsurg 2019; 35: 646-651.
[26] Cho EH, Shammas RL, Carney MJ, Weissler JM, Bauder AR, Glener AD, Kovach SJ, Hollenbeck ST and Levin LS. Muscle versus fasciocutaneous free flaps in lower extremity traumatic reconstruction: a multicenter outcomes analysis. Plast Reconstr Surg 2018; 141: 191-199.
[27] Mathes SJ. The muscle flap for management of osteomyelitis. N Engl J Med 1982; 306: 294-295.
[28] Mathes SJ, Alpert BS and Chang N. Use of the muscle flap in chronic osteomyelitis: experimental and clinical correlation. Plast Reconstr Surg 1982; 69: 815-829.
[29] Gosain A, Chang N, Mathes S, Hunt TK and Vasconez L. A study of the relationship between blood flow and bacterial inoculation in musculocutaneous and fasciocutaneous flaps. Plast Reconstr Surg 1990; 86: 1152-1162; discussion 1163.
[30] Gravvanis A, Tsoutsos D, Karakitsos D, Iconomou T and Papadopoulos O. Blood perfusion of the free anterolateral thigh perforator flap: its beneficial effect in the reconstruction of infected wounds in the lower extremity. World J Surg 2007; 31: 11-18.
[31] Mehta D, Abdou S, Stranix JT, Levine JP, McLaurin T, Tejwani N, Thanik V and Leucht P. Comparing radiographic progression of bone healing in gustilo IIIB open tibia fractures treated with muscle versus fasciocutaneous flaps. J Orthop Trauma 2018; 32: 381-385.
[32] Richards RR and Schemitsch EH. Effect of muscle flap coverage on bone blood flow following devascularization of a segment of tibia: an experimental investigation in the dog. J Orthop Res 1989; 7: 550-558.
[33] Paro J, Chiou G and Sen SK. Comparing muscle and fasciocutaneous free flaps in lower extremity reconstruction--does it matter? Ann Plast Surg 2016; 76 Suppl 3: S213-215.
[34] Leow JM, Clement ND, Tawonsawatruk T, Simpson CJ and Simpson AH. The radiographic union scale in tibial (RUST) fractures: reliability of the outcome measure at an independent centre. Bone Joint Res 2016; 5: 116-121.
[35] Yazar S, Lin CH, Lin YT, Ulusal AE and Wei FC. Outcome comparison between free muscle and free fasciocutaneous flaps for reconstruction of distal third and ankle traumatic open tibial fractures. Plast Reconstr Surg 2006; 117: 2468-2475; discussion 2476-2467.