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Management of post-traumatic long bone defects: A comparative study based on long-term results*

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ABSTRACT

Background: Reconstruction of post-traumatic long bone defects is a formidable problem. To date, the approaches for bony reconstruction remain controversial. Thus, we aimed to compare the different methods in the treatment of patients with post-traumatic long bone defects, based on the long-term functional and self-evaluation results.
Methods: We retrospectively reviewed data on patients with post-traumatic long bone defects of the lower extremities from January 2006 to January 2015. The patients were divided into three groups according to the surgical method used to treat the defects (group 1, free vascularized fibular transfer; group 2, distraction osteogenesis; group 3, the induced membrane technique). Data including the complication rates, entire treatment period, long-term visual analog scale scores, and Sickness Impact Profile (SIP) scores during follow-up were recorded.
Results: A total of 317 patients were included, with 106, 132, and 79 patients in groups 1, 2, and 3, respectively. The major complication rates were 22.6%, 25.8%, and 26.6% for the groups ($P > 0.05$), respectively. The mean treatment durations for bony defects, from surgery to non-protected weight-bearing, were 65.1, 46.5, and 56.6 weeks for each group, respectively. At 2 years postoperatively, the average SIP scores for each group were 10.5, 11.7, and 11.5, respectively ($P > 0.05$).
Conclusion: Patients who sustained long bone defects can be advised that either one of these three methods which typically results in long-term outcomes equivalent to others.
Level of evidence: retrospective study

Introduction

Reconstruction of post-traumatic long bone defects is a formidable problem. As the techniques for microsurgery and distraction osteogenesis have evolved, the techniques for reconstructing long bone defects have also evolved. Tissue transfer has been proven to be effective not only for ensuring an adequate soft tissue envelope through pedicled or free-tissue transfer but also for reconstructing bony defects with free vascularized bone grafts. Even in the presence of complex defects in soft tissue and bone, microsurgical techniques can be used to create vascularized composite osteocutaneous flaps in a single procedure. [1,2] The Ilizarov technique has also been widely used for treating bone defects, bone nonunion, and nonunions that are associated with poor soft-tissue coverage [3–5].The technique of induced membrane was first described in 2000 by Masquelet et al., and many further reports have confirmed its clinical validity [6,7].

To date, the approaches for bony reconstruction remain controversial. Vascularized fibular or iliac crest transplants, including the use of double barrel or two-strut fibular grafting, require compensatory hypertrophy before protected weight-bearing can be attempted. [21] It usually takes 12–18 months and is often not feasible [8]. However, there is a high rate of refracture when large, segmental, vascularized bone transfers are used in the lower extremities [8]. In the distraction osteogenesis method, the complications, which include pin-tract infection, docking-site nonunion, prolonged rehabilitation time, and anchyloses, increased when the frame-wear duration was longer than 6 months. The induced membrane technique, known as the Masquelet technique, is now well recognized for treating osteomyelitis, but it also has several drawbacks, including prolonged period for consolidation, secondary deformity, and leg length discrepancy (LLD). [9,10] Hence, we conducted this

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retrospective study to compare these different reconstructive strategies for post-traumatic long bone defects of the lower extremities, based on the short-term complications and long-term functional self-evaluation results.

Methods

The study was approved by the Ethics Committee of Shanghai Jiaotong University Affiliated Sixth People's Hospital. Informed consent was obtained from all authors. All study methods were in accordance with the Declaration of Helsinki.

Patients

We retrospectively reviewed data on 317 patients who sustained post-traumatic long bone defects of the lower extremities between January 2006 and January 2015 at a single institution. There were 186 men and 131 women, with a mean age of 42.3 years (range: 19–62 years). The injuries were mostly caused by traffic accidents. Many patients had undergone multiple procedures at other institutions.

Sixty-nine cases involved infected fractures or osteomyelitis. Eight patients in particular presented to us over 3 years after their initial injury. Hence, information on these patients was not available when we reviewed their records.

All of the patients were divided into three groups based on their therapeutic regimens. Patients in group 1 (FVFG group) were treated with free vascularized fibular graft, those in group 2 (DO group) were treated with distraction osteogenesis, and those in group 3 (IM group) were treated with the induced membrane technique.

Data collection and evaluation

All patients' preoperative data were collected through a review of their charts, except for patients who presented to us over 3 years after their initial injury. The preoperative information included smoking history, diabetes history, movement function, and sensation of the affected limb.

The patients were evaluated at 3, 12, 24, and 36 months after undergoing reconstructive surgery (or after frame removal for patients who wore frames). At each point, patients were evaluated by an orthopedic surgeon and physical therapist to ascertain their limb's status and the presence or absence of major complications. Major complications were defined as the existence of one of the following: late amputation, nonunion of the transplanted bone, refracture without a second injury, hardware failure, massive infections, recurrent osteomyelitis, donor-site morbidity, and residual deformities that required additional surgery. The durations of treatment from surgery to weight bearing and the final walking status were recorded with respect to functional outcomes.

The visual analogue scale (VAS) and Sickness Impact Profile (SIP) scores were also evaluated at each point postoperatively. [11] The reliability and validity of the SIP have been well tested, especially with respect to after the outcomes of injuries [12]. The overall SIP scores range from 0 to 100; scores greater than 10 suggest severe disability in daily life, and differences in scores of 2 to 3 points represent significantly impaired function. [13] The general scores in a nationwide population (the US) were 2 to 3 points [14,15]. Because most of the reconstructive regimens were decided by the senior orthopedic and reconstructive surgeons in our group, and because we wished to avoid examiner bias in the evaluation of functional outcomes, the data were collected and analyzed by another surgeon in our study group.

Statistical analysis was performed using SPSS 22.0 software. A P value of < 0.05 was considered to be statistically significant. Data were presented as mean $\pm$ standard deviation. Student's test and chi-square test were used to compare numeric and nonnumeric variables respectively.

Surgical technique

The surgical technique for free vascularized fibular flap has been well illustrated by Taylor et al. in 1975. [16] Reports in recent decades have made modifications to both the flap design and elevation technique, which have widened the indications for the fibular flap [16–20].

The procedures for external fixator assembly and corticotomy were illustrated by Paley and Solomn. [21,22] Monolateral external fixators were mainly used in midshaft bony defects, while Ilizarov ring fixators were used in the other cases.

The induced membrane technique was a two-stage procedure. Masquelet describes an initial debridement of soft tissue and necrotic bone to bleeding healthy tissue and the use of a polymethyl methacrylate cement spacer placed in the bony defect, which is stabilized with a temporary external fixator. After 6–8 weeks, the second step is undertaken. The induced membrane is carefully incised and the spacer removed. Morcellized cancellous bone from the iliac crest is implanted and the membrane closed with definitive fixation. [6,23,24]

Results

The demographic and injury characteristics of the 317 patients in this study are shown in Table 1. There were 106, 132, and 79 patients in groups 1, 2, and 3, respectively. The major etiology was road traffic accident. There were 29, 37, and 39 patients who sustained infected nonunion and/or osteomyelitis in each group. The most frequently cultured organisms were *Staphylococcus aureus* and *Pseudomonas*

Table 1
Demographics Characteristics.

	Group 1 Free vascularized fibular transfer N = 106	Group 2 Distraction osteogenesis N = 132	Group 3 The induced membrane technique N = 79
Male Sex	69.8% (N = 74)[a]	73.4% (N = 97)[a]	67.1% (N = 53)[a]
Age (yrs)	36.5 ± 5.9[a]	35.7 ± 5.6[a]	35.2 ± 5.0[a]
Mean follow-up (mos)	27	29	24
lengths of bone defects (cm)	11.0 ± 8.7[a]	10.5 ± 8.4[a]	11.5 ± 9.1[a]
Number of patients who sustained infected nonunion and/or osteomyelitis	27.4% (N = 29)	28.0% (N = 37)	49.4% (N = 39)[b]
Number of patients who received Soft tissue coverage	11.3% (N = 12)	12.9% (N = 17)	5% (N = 4)[b]

[a] $P > 0.05$ for the overall comparison between groups.
[b] $P < 0.05$ for the comparison with other two groups.

aeruginosa. Mean lengths of bone defects were 11.0 ± 8.7 cm, 10.5 ± 8.4 cm, and 11.5 ± 9.1 cm for each group (P > 0.05). In total, 12, 17, and 4 patients required soft-tissue repair in groups 1, 2, and 3, respectively.

Radiographic results

The radiologic healing/consolidation times were 18.2 ± 7.5, 44.7 ± 19.5, and 38.1 ± 21.2 weeks for groups 1, 2, and 3, respectively. (Table 2)

Clinical results

The mean follow-up duration was 27 months, 29 months, and 24 months for groups 1, 2, and 3, respectively

The time from surgery to total non-protected weight bearing was 65.1 ± 22.4 weeks, 46.5 ± 19.2 weeks, and 56.6 ± 18.9 weeks for the groups, respectively. (Table 2)

The percentage of patients with an unrestricted walking distance and percentage of patients with monopedal weight bearing are illustrated in Table 2. No significant statistical difference was noted among the groups.

Complications

Major complications in the FVFG group comprised hardware failure and/or refracture (7 cases), nonunion (5 cases), joint ankylosis or fusion (6 cases), > 3 cm LLD (3 cases), and residual deformity requiring secondary procedures (3 cases).

Complications in the DO group comprised pin-site infection (8 cases), premature or poor quality of consolidation (6 cases), deep infection (1 case), joint ankylosis or fusion (8 cases), > 3 cm LLD (3 cases), clubfoot or dropping foot (6 cases), and residual deformity requiring secondary procedures (2 cases).

Complication in the IM group comprised hardware failure (3 cases), joint ankylosis or fusion (6 cases), > 3 cm LLD (5 cases), clubfoot or dropping foot (3 cases), and residual deformity requiring secondary procedures (4 cases).

The overall complication rates were 22.6%, 25.8%, and 26.6% for each group (P > 0.05), respectively. (Table 2)

Self-evaluation

In a long-term survey, the average VAS scores at 1 year postoperatively were 3.57, 3.71, and 3.83 in groups 1, 2, and 3, respectively (P > 0.05). The average VAS scores at 2 years postoperatively were 2.67, 2.78, and 2.67 in groups 1, 2, and 3, respectively (P > 0.05). The average SIP scores at 1 year postoperatively were 11.5, 12.3, 12.5 in groups 1, 2, and 3, respectively (P > 0.05), and the average SIP scores at 2 years postoperatively were 10.5, 11.7, and 11.5 in groups 1, 2, and 3, respectively (P > 0.05) (Table 2).

Discussion

Our results overall showed that the three methods had similar complication rates and functional results in the treatment of post-traumatic long bone defects.

Table 2
Complications and long-term outcomes of each group.

	Group 1 Free vascularized fibular transfer n = 106	Group 2 Distraction osteogenesis n = 132	Group 3 The induced membrane technique n = 79
Complication rates	24 22.6%[a]	34 25.8%[a]	21 26.6%[a]
Detailed incidence of specific complication	Hardware failure and/or refracture (7 cases), nonunion (5 cases), joint ankylosis or fusion (6 cases), > 3 cm LLD (3 cases), and residual deformity requiring secondary procedures (3 cases)	Pin-site infection (8 cases), early or failed consolidation (6 cases), deep infection (1 case), joint ankylosis or fusion (8 cases), > 3 cm LLD (3 cases), clubfoot or dropping foot (6 cases), and residual deformity requiring secondary procedures (2 cases)	Hardware failure (3 cases), joint ankylosis or fusion (6 cases), > 3 cm LLD (5 cases), clubfoot or dropping foot (3 cases), and residual deformity requiring secondary procedures (4 cases)
Radiologic healing/ consolidation times (weeks)	18.2 ± 7.5[b]	44.7 ± 19.5	38.1 ± 21.2
Time from surgery to total non-protected weight bearing (weeks)	65.1 ± 22.4[a]	46.5 ± 19.2[a]	56.6 ± 18.9[a]
Percentage of patients with unrestricted walking distance	82.1%[a] (87 patients)	81.8%[a] (108 patients)	81.0%[a] (64 patients)
Percentage of patients with monopedal weight bearing	6.6%[a] (7 patients)	8.3%[a] (11 patients)	6.3%[a] (5 patients)
VAS at 1 year follow-up	3.57 ± 2.56[a]	3.71 ± 2.87[a]	3.83 ± 2.67[a]
VAS at 2 year follow-up	2.67 ± 2.33[a]	2.78 ± 2.14[a]	2.67 ± 1.98[a]
SIP at 1 year follow-up	11.5 ± 8.3[a]	12.3 ± 9.3[*]	12.5 ± 8.7[a]
SIP at 2 year follow-up	10.5 ± 7.8[a]	11.7 ± 8.5[a]	11.5 ± 8.2[a]

[a] P > 0.05 for the overall comparison between groups.
[b] P < 0.05 for the comparison with other two groups.

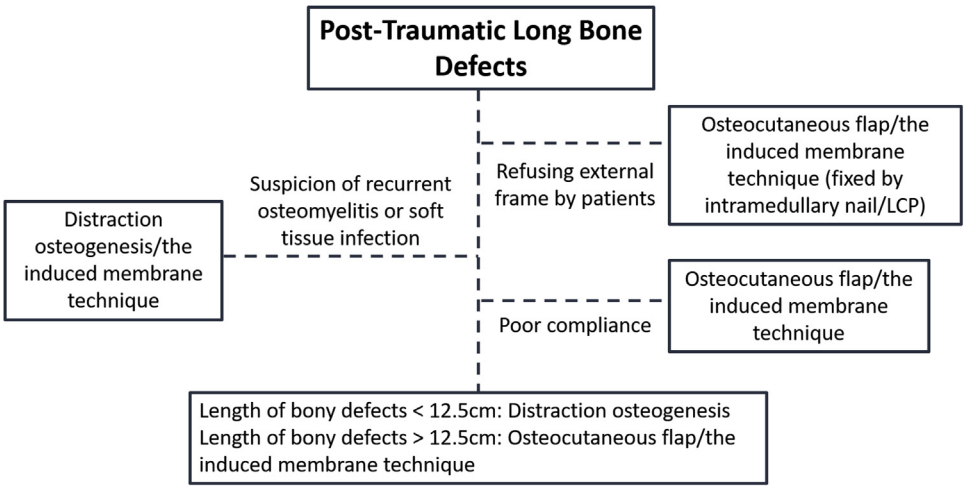

Fig. 1. A precis algorithm of choose which option based on some factors.

According to the radiographic and clinical results, although the mean radiologic healing/consolidation time of the FVFG group was lesser than that of the DO and IM groups, it took extra time for compensatory hypertrophy to develop before full weight-bearing in patients treated with the free vascularized fibular graft, and this extra time ranged from 6 to 18 months, with a mean of 11 months (the sufficient compensatory hypertrophy was defined as a 50% increase in the original caliber of the transferred fibular).

The entire procedure for the induced membrane technique consisted of two steps, requiring 8 to 33 weeks for temporary spacer placement (mean, 18 weeks), and 28 to 45 weeks for bony reconstruction (mean, 38 weeks). As a result, the mean time from surgery to total non-protected weight bearing for patients treated with this technique was 56 weeks, which was less than that of patients treated with the free vascularized fibular graft (65 weeks)

On the other hand, the time of distraction and consolidation was closely related to the length of bone defects in patients treated with distraction osteogenesis. Our study showed that each centimeter of bony defects requires about 31 days for distraction and consolidation, which means, the entire treatment period from first surgery (first step of the induced membrane technique) to non-protected weight bearing in patients treated with distraction osteogenesis was less than that in patients treated with the induced membrane when the length of bony defects was less than 12.5 cm. Besides, there were other factors which may affect the selection of methods, such as patients' compliance, suspicion of recurrent osteomyelitis or soft tissue infection, and acceptance of wearing external fixation (Fig. 1).

The major complications in the FVFG group comprised hardware failure and refracture, due to early weight-bearing before sufficient healing and compensatory hypertrophy. Ankle function results were relatively poor in patients treated with distraction osteogenesis and induced membrane, which is in fact due to failure to prevent ankle stiffness due to prolonged immobilization. Pin-site infection mostly occurred in patients who were not conscious of self-pin-site-care. We also noticed that poor consolidation in the DO and IM groups was highly associated with the soft-tissue condition because most patients who sustained poor consolidation also sustained delayed wound healing or partial flap necrosis. Clubfoot or dropping foot was common in patients treated with retrograde bone distraction. The rate of secondary lower limb osteotomy for a residual deformity reveals the difficulty of maintaining good alignment with a single-plane fixator. This is in fact mainly a matter of lack of vigilance in maintaining the lower limb axis. In severe defects (> 20 cm), a circular or hybrid external fixator is preferable to a single-plane model, and intramedullary nailing is not effective in this case due to the degree of stress exerted entirely on the locking screws. [25] In the DO group, docking-site revision and autogenous bone grafting became inevitable when the bone gap was over 12 cm. Thus, we regarded the method of distraction osteogenesis as the two-stage procedure when the length of bony defects was larger than 12 cm.

The overall complication rates showed no significant statistical difference among the three methods.

In the long-term survey, we used the VAS and SIP scores to evaluate the physical and psychological statuses of patients who underwent complex reconstructions. The VAS scores in group 1 were reduced at the 1-year follow-up, and those in each group were reduced to the same level at the 2-year follow-up. Analogous results were also noted in the SIP scores, which can be explained hypothetically by distraction of the pin site and inconveniences in the activities of daily life that are caused by frame wearing.

Contrary to our speculation, at two years, both percentage of patients with an unrestricted walking distance and percentage of patients with monopedal weight bearing showed no significant statistical difference among the three groups. Based on the patient's long-term life quality, chronic pain and walking statue, there was no significant indication for the selection of certain reconstructive methods.

The study has several limitations. It may be supposed that patients who responded to our invitation for assessment were those with the best results in terms of function and resumption of activities, inducing a bias. Besides that, the choice of approach was mainly determined by the surgeon's preference, and the generalizability of our results beyond level I trauma centers is uncertain. The outcomes may have been influenced by the expertise of physicians and other care givers. Moreover, this study was not a randomized controlled trial, and it is possible that superior results could be achieved if the surgeon has advanced skills and experience in performing these three methods. Further studies concerning the cost-utility analysis and long-term quality of life are needed for more comprehensive decision making for long bone defects.

Conclusion

Overall complication rates were analogous among the three methods of treatment, and special attention should be paid to alignment, external fixator stability, and care of all foot and ankle joints. Several factors may contribute to the healing or consolidation in bony reconstruction. Early radical debridement with extensive wound care and suitable coverage is a prerequisite for

continuing with reconstruction. The entire duration of treatment and times of operation may be considered among the major affecting factors for the selection of the bony reconstruction method. A circular external fixator and intramedullary nail provide better stability than a monolateral external fixator and locking plates, which may benefit early partial weight bearing, thus stimulating consolidation. For patients who treated with induced membrane, an approach worth exploring is to cross over from external to internal fixation in step 2.

Financial disclosure statement

None.

Declaration of Competing Interest

None.

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