RESEARCH ARTICLE

Radical treatment of severe open fractures of extremities by orthoplastic surgery: a 10-year retrospective study

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Abstract

Objective: This study aimed to retrospectively analyze clinical data of a series of patients with severe open fractures of extremities (Gustilo IIIb or IIIc), who achieved a satisfactory outcome through radical orthoplastic surgery, so as to provide a reference for determining the treatment of severe open fractures of extremities.

Methods: The clinical data of 41 consecutive patients with severe open fracture (Gustilo IIIb or IIIc) of the limb, who underwent successful surgical debridement, fixation, and soft tissue reconstruction in one stage between January 2008 and January 2019, were retrospectively reviewed. Postoperative indicators, including infection rate and union time, were acquired by a regular follow-up and analyzed.

Results: The mean (±SD) age of the patients was 38 ± 16 years. A total of 90 open fractures and severe soft tissue damages were analyzed. The soft tissue cover was achieved within 72 h. The overall rate of infection was 14.6% (6/41). Sex and the Mangled Extremity Severity Score were associated with infection. The median union time of 40 patients (one amputation) was 32 weeks.

Conclusion: The overall rate of infection exhibited a lower tendency in this study compared with previous studies on high-grade open fractures following a two-stage orthopedic approach. The consequence of infection rate and union time was similar to that in previous studies. These results indicated that the single-stage radical orthoplastic treatment was an effective and reliable option for reconstructing severe open fractures.

Keywords: Soft tissue reconstruction, Severe open fractures, Orthoplastic, Masqualet

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Introduction

It has been 20 years since Gopal and Smith et al. [1] published their remarkable achievements in dealing with severe open fractures of the tibia by radical orthoplastic approach. However, similar studies have rarely been reported in recent years. This is mainly because severe open fractures (referred to as Gustilo IIIb or IIIc injuries), which often lead to large soft tissue defects and high risk of infection, are still a challenge for reconstructive surgeons [2, 3]. Although various methods and standards have been used for managing open fractures in the lower limb [4–6], the salvage treatment is still debatable in severe cases [7].

The present popular concept of severe open fracture management aims to achieve soft tissue coverage in an early stage. It is based on the collaboration of orthopedic and plastic (microvascular) surgeons in an “orthoplastic” central unit [8]. Compared with the traditional orthopedic approach in which the primary stabilization of the fracture and delayed wound closure are completed in two stages, the combined “orthoplastic” treatment has advantages such as fewer flap failures, lower infection rate, decreased bone-healing time, and short hospital stay [1, 4].

Despite remarkable superiority, orthoplastic treatment is not used worldwide yet. Especially in Mainland China, the traditional orthopedic approach is generally accepted to deal with severe limb trauma. However, several surgeons in the orthopedic department of Mainland China can handle both fixation and microsurgery. This is quite different from the “orthoplastic center” mode in the UK [6].

Besides, the orthoplastic approach proposed by Gopal et al. [1] is relatively radical compared with the “orthoplastic” treatment recommended by the British Orthopaedic Association and the British Association of Plastic Reconstructive and Aesthetic Surgery [6]. The major difference is whether the soft tissue cover is achieved in a single primary procedure. The current popular opinion holds that immediate soft tissue cover is not safe [3, 9]. In contrast, staged surgery for early coverage within 72 h is relatively safe and stable [10]. Nevertheless, Gopal et al. [1] showed excellent union and low rates of infection in aggressive management, proving its effectiveness and operability.

Based on the aforementioned findings, our department made a series of attempts in dealing with severe open fractures of limbs using the “radical orthoplastic” treatment [1] since September 2008. This study aimed to evaluate the infection rates and union time retrospectively in patients who had Gustilo-Anderson grades IIIb and IIIC open fractures of limb and accepted a single-stage orthoplastic treatment. It was hypothesized that the “radical orthoplastic” approach would be an effective treatment.

Methods

Patients

The data of 41 patients suffering from severe limb injury and undergoing successful surgery, including debridement, fixation, and soft tissue reconstruction, in one stage in the Xijing Hospital between January 2008 and January 2019, were retrospectively reviewed using the medical and follow-up records. The injury was confined to upper and lower limbs, including 90 open fractures and severe soft tissue damage (mainly types IIIb and IIIC, according to Gustilo criteria) [3]. These cases were followed up consistently. Unfortunately, one patient came to an end of amputation due to personal economic reasons.

Treatment protocol

The treatment protocol was as follows: Patients underwent temporary stabilization with cast and life-supporting treatments as appropriate on arrival at the emergency department of the Xijing Hospital. Further procedures in the orthoplastic approach were started as quickly as possible when the patient was transferred to our department of orthopedic surgery. Immediate radical wound debridement and transitional fixation were performed for those with grade IIIb injury. Profuse lavage was used, and the debridement area exceeded the injury zone. Skeletal stabilization was achieved with a transitional plate (usually a short and thin tubular plate is used to reduce the infection risk) or external fixation or screw or a combination of these depending on the anatomy of the fracture. More critically, the soft tissue defect was immediately reconstructed using a vascularized muscle flap with a split skin graft or a local transfer flap according to the anatomy of the injury rather than by temporary negative pressure dressing. For the grade IIIC injury, the vascular reconstruction was accomplished first, and the protocol followed was the same. Masquelet or bone-shortening methods were used for solving bone defect problems in some patients. A delayed operation of bone graft and plate replacement (with a rigid reconstruction plate) was done 7–29 weeks (at a mean time of 13 weeks) later when all infection indicators were normal.

Postoperative rehabilitation included intravenous antibiotics (cefoperazone sodium and metronidazole), which were administered for the first 5 days. Furthermore, antibiotic treatments were adjusted according to the indications from cultures from the areas of the superficial skin graft. All patients were advised for joint movements on bed. A routine postoperative anticoagulant, anticonvulsant, anti-infective therapy was performed to ensure the survival of the flap. Partial weight-bearing was permitted until 12 weeks postoperatively after early bony stability was obtained. External fixation was removed 3 months after the surgery as appropriate.
Besides, the Masqualet bone cement technique was introduced since August 2017, which provided not only defect fillings but also an antibacterial effect on the fracture site.

Follow-up
Patients discharged from the hospital were appointed in the orthopedic clinic for subsequent follow-ups until the union of the fracture. All participants were interviewed and checked by the surgeon responsible for the whole medical process. The examinations included the following: X-ray for bone-healing observation, status of soft tissue recovery, and any abnormal appearance of the reconstructed limb. Due to clinical suspicion, positive skin and bone tissue cultures and routine blood tests were performed, and high-sensitivity C-reactive protein level and erythrocyte sedimentation rate were determined. Hybrid positron emission tomography-computed tomography (PET/CT) bone scanning was used in the case of suspected osteomyelitis. The follow-up time ranged from 6 to 36 months postoperatively according to the rehabilitation of the patient (Figs. 1, 2, and 3).

Data collection
Injury details included Mangled Extremity Severity Score (MESS), open fracture classification, AO fracture classification, device of stabilization, flap type, initial antibiotic timing, and the timing of flap. The results were obtained from the surgeon who was responsible for the entire operation.

Statistical analysis
Quantitative variables were presented as means ± standard deviation. Medians with interquartile range (IQR, presented as the upper and lower quartiles) were used when the data were skewed, and qualitative variables were expressed as frequency and percentages [n (%)]. Fisher’s exact probability test was used for categorical variables (Table 4). Moreover, t tests were used for continuous variables with normal distribution in the two groups; Mann–Whitney U test was used for continuous variables when the data were skewed (Table 4). All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) 16.0 (SPSS, IL, USA). A P value less than 0.05 was considered statistically significant.

Results
A total of 41 patients with 90 severe open fractures [89 IIb (98.9%) and 1 IIIc (1.1%)] were examined. The mean (± SD) age was 38 ± 16 years, 75.6% (31 cases) were men, and the injuries were due to traffic accidents (28 cases, 68.3%), blunt trauma (9 cases, 22%), drifting-down injury (3 cases, 7.3%), and twist trauma (1 case, 2.4%). All the patients were followed up to a minimum of 2 year since the end of their clinical course. One patient, unfortunately, selected amputation 4 weeks after the primary surgery because of economic reasons. The description of the demographics and injury details are shown in Table 1. Injury details, including MESS, open fracture classification, AO fracture classification, device of stabilization, flap type, initial antibiotic timing, and the timing of flap, were analyzed.

Fixation
Table 2 exhibits the kind of fixation device chosen for different patients and associated results. Nine options were chosen for different fractures and 7 of them were applied in a multiple fixation devices combinational way rather than used solely.

Soft tissue reconstruction
The soft tissue cover was accomplished by two kinds of local transfer flaps (10 gastrocnemius and 12 soleus) and...
free anterolateral thigh flap (19 cases) according to the characteristic of injury (Tables 1 and 5). All flaps survived in all patients uneventfully and showed better appearance, color, and texture as well as satisfactory sensation. More significantly, the soft tissue cover was achieved within 72 h in all 41 patients, and the median (IQR) time was 22 (18–32) h. Furthermore, 22 cases were covered immediately (≤ 24 h), while the remaining as early as possible (24–60 h). The associated results between immediate and early coverage are shown in Table 3.

Infection
The overall rate of infection was 14.6% (6/41), which included one acute flap infection and five chronic fracture site infection. The rate of infection was 28.6% (4/14) in the first 6 years (September 2008 to July 2014), and 7.4% (2/27) in the next 5 years (August 2014 to April 2019).
| Age (years) | Gender | MESS score | Gustilo classification | AO classification | Fixation | Flap | Initial antibiotic timing (h) | Flap timing (h) | Secondary procedures | Union (weeks) |
|------------|--------|------------|------------------------|-------------------|----------|------|---------------------------|----------------|---------------------|----------------|
| 20         | F      | 6          | IIIB                   | 42B3(b), 4F2A(b)  | EF       | ALT | 12                        | 18             |                     | 45             |
| 54         | M      | 10         | IIIB                   | 43C3.3, 4F2B(b), 44B3.3 | ORIF     | ALT | 8                        | 14             | Plate replacement   | 52             |
| 42         | F      | 7          | IIIB                   | 13C3.3, 2U1B1     | ORIF     | ALT | 24                        | 35             | Skin graft          | 43             |
| 34         | M      | 7          | IIIB                   | 43A3.2, 4F3A      | EF       | ALT | 9                        | 18             |                     | 15             |
| 31         | M      | 8          | IIIB                   | 42C3(a), 4F2B(b)  | ORIF + Screw | ALT | 13                        | 56             | EF 6 weeks          | 84             |
| 44         | M      | 6          | IIIB                   | 2R3A3.1, 2U3A2.3, 77.2.1A, 77.3.1A | ORIF     | ALT | 4                        | 18             |                     | 29             |
| 9          | F      | 6          | IIIB                   | 43A1.2, 4F2A(c), 87.1.3C | EF + Screw | ALT | 22                        | 37             |                     | 16             |
| 47         | M      | 10         | IIIB                   | 42B2(b), 4F2A(b)  | EF + Screw | GAS | 6                        | 16             |                     | 35             |
| 51         | F      | 11         | IIIB                   | 42B3(a), 4F1B(n)  | EF       | GAS | 20                        | 30             | Skin graft          | 35             |
| 62         | F      | 10         | IIIB                   | 42B3(a), 4F2A(a)  | EF       | GAS | 12                        | 18             |                     | 39             |
| 59         | M      | 11         | IIIB                   | 42C3(i), 4F2A(b)  | EF       | SOL | 14                        | 20             | Bone graft + plate replacement + flap | 40             |
| 32         | M      | 11         | IIIB                   | 42C2(j), 4F3A     | EF + Screw | ALT | 11                        | 24             | Flap 12 days        | 70             |
| 45         | M      | 6          | IIIB                   | 42B2(a), 4F2A(a)  | EF + Screw | GAS | 6                        | 16             |                     | 36             |
| 41         | M      | 11         | IIIC                   | 2R2C3(j), 2U2C3(j) | EF       | ALT | 4                        | 16             | Bone shortening + plate | 52             |
| 24         | M      | 8          | IIIB                   | 42B2(c), 4F2A(c)  | EF       | ALT | 12                        | 50             | Plate 9 days        | 38             |
| 41         | M      | 7          | IIIB                   | 42C3(j), 4F2B(a)  | EF       | SOL | 14                        | 21             |                     | 30             |
| 42         | M      | 7          | IIIB                   | 42C3(j), 4F2A(b)  | EF       | SOL | 3                         | 12             | Plate 8 weeks       | 32             |
| 8          | F      | 6          | IIIB                   | 42C2(j), 4F2B(b)  | EF + Screw | ALT | 24                        | 39             | Plate 6 weeks       | 18             |
| 39         | F      | 10         | IIIB                   | 42C3(j), 4F2B(b)  | EF + Screw + Bone shortening | F-T ALT + ALT | 26 | 29 | Bone lengthening 35 weeks | 62 |
| 17         | F      | 9          | IIIB                   | 2U2A2(b)          | EF + ORIF | ALT | 8                        | 20             |                     | 12             |
| 32         | F      | 7          | IIIB                   | 43B1.1           | EF       | ALT | 13                        | 21             |                     | 12             |
| 22         | M      | 9          | IIIB                   | 42A2(a)          | EF       | GAS | 13                        | 20             | Flap 4 weeks        | 12             |
| 37         | M      | 7          | IIIB                   | 42A3(b), 87.1.1B  | EF + Screw | SOL | 18                        | 27             |                     | 32             |
| 44         | M      | 9          | IIIB                   | 42B2(c), 4F3B    | EF + ORIF + Cement | F-T ALT | 18 | 22 | Bone graft + plate replacement 8 weeks | 22 |
| 54         | M      | 11         | IIIB                   | 42C3(k), 4F3B, 81.1.B2, 82A2 | EF + ORIF + Screw | ALT | 20 | 33 | Bone graft 7 weeks | 55 |
| 50         | M      | 10         | IIIB                   | 42C2(i), 42A2(b), 4F1A(n), 4F2A(b) | EF + ORIF + Screw | GAS | 20 | 31 | Skin graft 4 weeks | 36 |
| 65         | M      | 8          | IIIB                   | 42B2(c), 4F2A(b)  | EF + ORIF + Screw | SOL | 11 | 19 | UTN + bone graft 21 weeks | 47 |
| 9          | F      | 6          | IIIB                   | 42B2(b)          | EF + ORIF | SOL | 12 | 17 | Bone graft + plate replacement 29 weeks | 42 |
| 43         | M      | 9          | IIIB                   | 42C3(i), 4F2A(a), 87.1.1B, 87.3.2A | EF + ORIF + Screw | SOL | 30 | 42 | Amputation | - |
| 46         | M      | 7          | IIIB                   | 42C3(j), 4F2B(b)  | EF + ORIF + Screw | SOL | 18 | 26 | Bone graft + plate replacement 11 weeks | 30 |
| 33         | M      | 7          | IIIB                   | 42C2(j), 4F2A(b)  | EF + Screw | ALT | 11 | 21 | Bone graft + plate replacement 7 weeks | 23 |
These problems were resolved by antibiotics and repeated debridement. The distribution details of infection based on age, sex, MESS score, time of coverage, initial antibiotic timing, and characteristics of the injury are shown in Tables 4 and 5. Six infected fractures were found in men with a high MESS score (> 7). A comparison of the infected and noninfected fractures in Table 4 shows that males were associated with an increased rate of infection ($P < 0.001$). The same results were obtained for the increased MESS score ($P = 0.021$). However, no significant difference was found in age, time of coverage, and initial antibiotic timing between the infected and noninfected fractures.

The rate of main injured zone infection at the site of the middle forearm, middle leg, and distal leg to ankle/foot was 50% (1/2), 11.5% (3/26), and 33.3% (2/6), respectively. For soft tissue defect location, the infection rate was 40% (2/5) anteriorly, 25% (1/4) interiorly, 6.7% (1/15) anteromedially, and 50% (2/4) anterolaterally. Besides, the rate of infection was 26.3% (5/19) in the free anterolateral thigh flap group and 10% (1/10) in the gastrocnemius flap group. Nevertheless, the number in

### Table 1 Demographics and clinical details of the patients (Continued)

| Age (years) | Gender | MESS score | Gustilo classification | AO classification | Fixation* | Flap# | Initial antibiotic timing (h) | Flap timing (h) | Secondary procedures& | Union (weeks) |
|-------------|--------|------------|------------------------|------------------|-----------|------|-------------------------------|----------------|----------------------|---------------|
| 27 M        | 6      | IIIB       | 41B3.1, 42C3(j), 4F2A(a) | EF + ORIF + Cement | ALT       | 12   | 28                             | Bone graft + plate replacement 17 weeks | 30           |
| 24 M        | 4      | IIIB       | 42C3(j), 4F2A(b)        | EF + ORIF + Cement | GAS       | 23   | 31                             | Bone graft + plate replacement 17 weeks | 29           |
| 30 M        | 8      | IIIB       | 42C3(j), 4F2B(b)        | EF + ORIF + Cement + Bone shortening | GAS       | 14   | 27                             | Bone graft + plate replacement 10 weeks       | 18           |
| 42 M        | 7      | IIIB       | 42C2(j), 4F2B(b)        | EF + ORIF + Cement | SOL       | 15   | 25                             | Bone graft + plate replacement 7 weeks       | 21           |
| 77 M        | 9      | IIIB       | 32B3(c), 42B3(b)        | ORIF + Screw + Cement | GAS       | 6    | 18                             | Skin graft 2 weeks                        | 50           |
| 27 M        | 6      | IIIB       | 42C3(j), 4F2A(b)        | EF + ORIF + Cement | SOL       | 9    | 17                             | Bone graft + plate replacement 7 weeks       | 19           |
| 20 M        | 6      | IIIB       | 41C3.3, 4F2A(a)         | EF + ORIF + Screw + Cement | GAS       | 11   | 19                             | Bone graft + plate replacement 8 weeks       | 23           |
| 65 M        | 8      | IIIB       | 42C3(j), 4F2A(b)        | EF + ORIF + Cement | SOL       | 25   | 38                             | Bone graft + plate replacement 8 weeks       | 32           |
| 37 M        | 9      | IIIB       | 43A2.1, 44B3.1          | EF + ORIF + Screw | ALT       | 7    | 41                             | Skin graft 3 weeks                         | 33           |
| 39 M        | 7      | IIIB       | 41C3.1, 42C3(j), 4F2A(a) | EF + ORIF + Screw + Cement | SOL       | 20   | 33                             | Bone graft + plate replacement 18 weeks      | 32           |

* Female, M male
* EF external fixation, ORIF plating, Cement bone cement
* ALT anterolateral thigh flap, GAS gastrocnemius, SOL soleus
* UTN unreamed tibial nial

### Table 2 Details of the results according to the fixation device used

| Fixation device | Number | Amputation | Union time (median, IQR, weeks) | Acute-flap infection | Chronic-fracture site infection |
|-----------------|--------|------------|--------------------------------|----------------------|-------------------------------|
| EF              | 11     |            | 35 (15 to 40)                 | 1                    |                               |
| ORIF            | 3      |            | 43 (29 to 52)                 | 1                    |                               |
| EF + ORIF       | 2      |            | 27 (12, 42)                   | 1                    |                               |
| EF + Screw      | 8      |            | 33.5 (19.25 to 55.5)          | 1                    |                               |
| ORIF + Screw    | 1      |            | 84                            | 1                    |                               |
| EF + ORIF + Screw | 6   | 1          | 36 (31.5 to 51)               | 1                    |                               |
| ORIF + Screw + Cement | 1 |            | 50                            | 1                    |                               |
| EF + ORIF + Cement | 7   |            | 22 (19 to 30)                 | 1                    |                               |
| EF + ORIF + Screw + Cement | 2 |            | 27.5 (23, 32)                 | 1                    |                               |
each group was too small to identify a significant difference.

**Bone healing**

The median union time of all 40 patients was 32 weeks (IQR, 22.25–42.75). The union time in the nine fixation device groups is shown in Table 3. The median union time in the group with immediate placement of the cover was 33.5 weeks (IQR, 21.25–45.5). However, the median union time in the group with early placement of the cover was 32 weeks (IQR, 27–39.25). The difference in union time between the two groups was not statistically significant ($P = 0.87$).

**Discussion**

The UK orthoplastic concept emphasizes that early soft tissue coverage is usually accomplished within 72 h [11]. This is largely due to the joint care by orthopedic trauma surgeons and plastic surgeons with experience in limb reconstruction in their orthoplastic specialist center. Combined procedures and appropriate support services (including microbiologists, interventional radiologists, rehabilitation specialists, limb prosthetic services, and psychologists) are provided, which is their biggest advantage [6, 12–14].

However, patients undergoing this approach still face relatively less repeated debridements and delayed reconstruction of soft tissue. Gopal et al. [1] revealed a more aggressive orthoplastic management of the severe open fracture of the tibia. Similar attempts were reported in many previous studies [4, 15]. Despite the controversy regarding safety [9, 16, 17], such radical approaches based on immediate soft tissue cover are effective with excellent union and low rates of infection. Using this concept, soft tissue coverage is accomplished as a single primary procedure.

Currently, the traditional orthopedic approach with delayed wound closure is popular in China, making the salvage treatment of severe limb injury complicated and tougher for orthopedic surgeons. Moreover, no orthoplastic center has been built in China yet. However, numerous orthopedic surgeons are available in China who can deal with not only fractures but also soft tissue reconstruction, generating orthoplastic of Chinese characteristics—“orthoplastic surgeon.” Based on radical and thorough debridement by senior qualified surgeons, the aggressive orthoplastic management reported by Gopal et al. [1] has been used since 2008. Also, satisfactory outcome results have been observed.

The infection rate is the key monitoring target of postoperative complications. Posttraumatic infection is commonly observed in severe open fractures. In this study, the overall rate of infection was 14.6%, exhibiting a lower tendency compared with the results in other previous studies on high-grade open fractures following a two-stage orthopedic approach [13, 18]. More critically, the consequence was similar to the report of Gopal et al. [1] (with an overall rate of infection of 15.9% within 72 h) and an infection rate of 14.5% in a prospective multicenter cohort study of orthoplastic surgical collaboration [8]. However, two aspects are still worth introspection. First is that a more aggressive but thorough initial debridement was carried out by senior professors of our team. Second, the introduction of induced membrane technique using bone cement and antibiotics in the orthoplastic treatment since August 2017 deserved attention. This two-step procedure was highly superior in treating bone defects and nonunions [19–21].

In common with Khan [8] and Gopal [1], the median union time largely reflected excellent results of the proposed treatment. Nevertheless, hybrid fixation devices were used in most cases, which was different from the approach of Khan and Gopal. The reason was that

### Table 3 Details of the results related to the timing of soft-tissue cover

| Timing of cover (h) | Number | Amputation | Union time (median, IQR, weeks) | Flap infection | Deep infection |
|---------------------|--------|------------|-------------------------------|---------------|---------------|
| Immediate (≤ 24)    | 22     | 0          | 33.5 (21.25 to 45.5)          | 0             | 4 (18%)       |
| Early (24-60)       | 19     | 1          | 32 (27 to 39.25)              | 1 (5%)        | 1 (5%)        |

### Table 4 Factors associated with infection

| Variable                  | Noninfected fractures (n = 35) (%) | Infected fractures (n = 6) (%) | p value |
|---------------------------|-----------------------------------|-------------------------------|---------|
| Mean age (years) (range)  | 36 (8 to 65)                      | 48 (31 to 77)                 | 0.093   |
| Male gender               | 25 (71.4)                         | 6 (100)                       | 0.0001  |
| MESS > 7                  | 15 (42.9)                         | 6 (100)                       | 0.021   |
| Lower limb fracture       | 32 (91.4)                         | 5 (83.3)                      | 0.483   |
| Median time to first coverage (h) (IQR) | 22 (18 to 31)                  | 21 (15.5 to 38.75)            | 0.592   |
| Immediate coverage (≤ 24) | 18 (51.4)                         | 4 (66.7)                      | 0.668   |
| Initial antibiotic timing (h) (range) | 14.7 (3 to 30)                 | 10.3 (4 to 20)                | 0.139   |

Statistically significant analyses are highlighted in bold.
greater stability reduced the risk of infection and non-union of the fracture site. Moreover, a tubular plate was used in this study, which was short and thin to reduce the infection risk in initial orthoplastic treatment, and defined it as a transitional plate. Moreover, it was replaced with a rigid reconstruction plate 7–29 weeks later, when all infection indicators are normal. This procedure reduced the risk of infection and ensured the stability of the fracture.

Khan et al. [10] pointed out that the radical “fix-and-flap” approach proposed by Gopal et al. [1] might not be pragmatic or appropriate, and staged orthoplastic surgery was more optimized. We acknowledge that the fracture fixation and vascularized soft tissue cover in the first operation was a huge challenge for reconstruction surgeons. However, delayed coverage (even within 72 h) would have been even tougher with repeated debridement and was associated with a higher rate of deep infection [18]. On the other hand, gastrocnemius and soleus transfer flaps chosen for soft tissue reconstruction were easy to handle and had a high survival rate. Free anterolateral thigh flap also had significant benefits: vascular pedicle was longer, the main artery need not be sacrificed, a flow-through blood supply was provided (a successful case 1 is shown in supplementary materials, which has been previously published in Annals of Plastic Surgery by our team) [22, 23].

### Table 5 Characteristics of the soft tissue injury and coverage

| Characteristic                  | Number | Infection (%) |
|--------------------------------|--------|---------------|
| Main injured zone              |        |               |
| Elbow joint                    | 1      |               |
| Middle forearm                 | 2      | (50%)         |
| Forearm to hand                | 1      |               |
| Proximal leg                   | 3      |               |
| Middle leg                     | 26     | (11.5%)       |
| Distal leg                     | 2      |               |
| Distal leg to ankle/foot       | 6      | (33.3%)       |
| Soft tissue defect location    |        |               |
| Anterior                       | 5      | (40%)         |
| Interior                       | 4      | (25%)         |
| Anteromedial                   | 15     | (6.7%)        |
| Anterolateral                  | 4      | (50%)         |
| Posterolateral                 | 1      |               |
| Extensive                      | 11     |               |
| Flap                           |        |               |
| ALT                            | 19     | (26.3%)       |
| GAS                            | 10     | (10%)         |
| SOL                            | 12     |               |

### Conclusion

In summary, the overall rate of infection exhibited a lower tendency in this study compared with previous studies on high-grade open fractures following a two-stage orthopedic approach. The consequence of infection rate and union time was similar to that in previous studies. This study indicated that the radical “orthoplastic” treatment was an effective and reliable option for the reconstruction of severe open fractures. The limitation of this study was that the focus was mainly on the infection rate and union time. Therefore, a prospective clinical trial was conducted to analyze the safety of the orthoplastic approach. The analysis included not only indicators used earlier but also a series of assessments for limb function and psychological states to make a comprehensive evaluation of individual recovery.

### Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13018-021-02479-2.

#### Additional file 1. Supplementary data—Case Additional file 1.

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### Authors’ contributions

Conceptualization and methodology: Dan-Min Miao, Lei Shang, and Zi-Xiang Wu. Validation: Guang-Yue Zhao. Formal analysis: Jun Li. Investigation: Ji-Wei Zou and Bao-Bao Xue. Resources: Ji-Wei Zou and Bao-Bao Xue. Data curation: Zhao Yang. Writing—original draft preparation: Zhao Yang and Chao Xu. Writing—review and editing: Zhao Yang and Chao Xu. Visualization: Zhao Yang. Supervision: Guang-Yue Zhao. Project administration: Zhao Yang, Chao Xu, and Yong-Gang Zhu. Funding acquisition: Guang-Yue Zhao. The authors read and approved the final manuscript.

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### Declarations

#### Ethics approval and consent to participate

Each author certifies that his institution approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

#### Competing interests

The authors declare no competing interests.

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