

# Masquelet technique combined with microsurgical technique for treatment of Gustilo IIC open distal tibial fractures: a retrospective single-center cohort study

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## Abstract

**Objective:** This study was performed to investigate the clinical effects of the Masquelet technique combined with a microsurgical technique for treatment of Gustilo IIC open distal tibial fractures.

**Methods:** Fifteen patients with a mean age of  $39.3 \pm 7.9$  years (range, 21–43 years) with Gustilo IIC open distal tibial fractures were treated by the Masquelet technique combined with a microsurgical technique from May 2013 to January 2017. The mean length of the bone defect was  $6.9 \pm 2.2$  cm (range, 5.2–10.7 cm). The mean area of the wound defect was  $129.3 \pm 41.4$  cm<sup>2</sup> (range, 83.7–180 cm<sup>2</sup>). Complications and fracture healing were recorded. At the last follow-up, the functional outcome was measured using the lowa ankle score.

**Results:** All 15 patients achieved bone healing, and the median healing time was about 6.1 months (range, 5–8 months). No complications such as infection or nonunion occurred. At the last follow-up, the median lowa ankle score was 82 (range, 68–88). The rate of an excellent and good lowa ankle score was 86.6%.

**Conclusions:** Application of the Masquelet technique combined with a microsurgical technique is an effective strategy for the treatment of Gustilo IIC open distal tibial fractures.

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## Keywords

Masquelet technique, microsurgical techniques, bone defect, Gustilo IIIC open distal tibial fractures, comminuted fractures, bone healing

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## Introduction

In developing nations, one of the most common causes of open tibial fractures is firearm or war weapon trauma. A Gustilo IIIC open comminuted fracture is one of the most serious injuries seen in the clinical setting. Such fractures are accompanied by blood vessel rupture, skin and soft tissue defects, and bone exposure. The complication of floating knee (flail knee joint) occurs with a particularly high incidence.<sup>1</sup> In the later stages, Gustilo IIIC open comminuted fractures are prone to serious complications such as limb blood supply disorders, bone nonunion and infection, and amputation.<sup>2-4</sup> The rapid development of microsurgical techniques has provided better treatment options for Gustilo IIIC open fractures.<sup>5</sup> Gustilo et al.<sup>3</sup> reported that the infection rate was as high as 42% for Gustilo IIIC fractures. Bone nonunion and osteomyelitis are often the major causes of amputation in the later stages. Moreover, large bone defects are often associated with severe Gustilo IIIC open fractures, introducing new difficulties into limb salvage treatment. If limb ischemia lasts longer than 4 to 6 hours, muscle loss affects more than two compartments, or bone loss exceeds one-third of the tibial length, primary amputation is considered an effective option.<sup>6</sup>

The treatment of a large bone defect with a concurrent soft tissue defect is very difficult. The Ilizarov bone transport technique is used for bone defects larger than 4 cm.<sup>7</sup> However, Ilizarov bone transport technology adopts the method of distraction osteogenesis, which is often intolerable for

patients with a long bone healing time. Early in the clinical course of Gustilo IIIC tibial fractures, the use of bone transport techniques may result in secondary damage to the repaired vessels. A common treatment strategy is the placement of an autogenous bone graft with blood vessels. However, the shortcomings of this technique include a long healing time and potential risk of failure.<sup>8</sup> Masquelet et al.<sup>9,10</sup> reported a technique for the treatment of segmental bone defects (i.e., the membrane induction technique or Masquelet technique). Induced membrane formation is accomplished by a bone cement spacer in the first stage, and bone grafts are then adopted to repair the bone defect in the second stage. This technique has been widely recognized and is currently used in clinical practice.<sup>11-14</sup> However, the clinical effect of this technique for treatment of Gustilo IIIC open distal tibial fractures is not clear. In the present study, we analyzed the results of Gustilo IIIC open distal tibial fractures treated with the Masquelet technique combined with a microsurgical technique. The Injury Severity Score (ISS) and the Mangled Extremity Severity Score (MESS) were used to evaluate the severity of the injury, and the Iowa Ankle Score was used to evaluate the function of the injured limb.

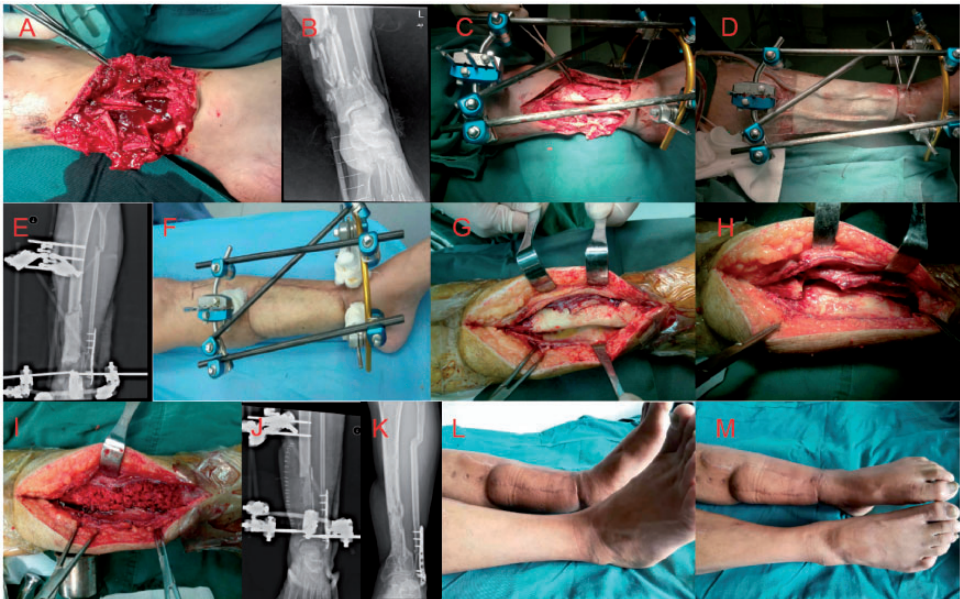
## Methods

We retrospectively evaluated the data of patients with Gustilo IIIC open distal tibial fractures treated by the Masquelet technique combined with a microsurgical

technique from May 2013 to January 2017. The inclusion criteria were a Gustilo IIIC open tibial fracture with a length of  $>2.5$  cm (Figure 1(a), (b)), an absence of complete tibial nerve injury, age of 18 to 70 years, time since injury of  $<6$  hours, and follow-up time of  $>1$  year. The exclusion criteria were severe head, chest, and abdominal injuries; serious diabetes, cardiovascular and cerebrovascular diseases, and other basic diseases; and an ISS of  $>25$  or MESS of  $\geq 8$ . The study was approved by the institutional review board, and informed consent was received from each patient.

Comprehensive anti-shock therapy including blood transfusion, infusion of saline or plasma, and administration of medications that support blood pressure

and microcirculation, was performed as needed. In such patients, external fixation of the injury was performed with a pressure dressing splint, and X-ray examination was performed to determine the degree of fracture crushing and the length of the bone defect. In all patients, treatment was divided into three stages. The first stage involved debridement, placement of an external fixator, vascular repair, nerve repair, tendon repair, and wound closure by vacuum sealing drainage (VSD). Second, 5 to 7 days after the operation when the condition had gradually stabilized, a free anterolateral femoral flap or musculocutaneous flap was used to repair the wound. Third, the bone cement was removed and autologous bone grafting was performed.



**Figure 1.** A 43-year-old man with a left Gustilo IIIC open tibial fracture. The length of the bone defect was 10.0 cm, and the soft tissue defect measured about  $7.5 \times 15.0$  cm. (a) Preoperative photograph. (b) Preoperative radiograph. (c) After debridement, the defect was filled with bone cement and an external fixator was applied. (d) The wound surface was covered by vacuum sealing drainage. (e) Postoperative radiograph of stage one. (f) Preoperative photograph 2 months after stage one. (g) Intraoperative incision in stage two. (h) Removal of bone cement. (i) Implantation of autogenous cancellous bone. (j) Postoperative radiograph. (k) Eight months after removal of external fixation device. (l), (m) Hip motion photographs after 18 months.

### Surgical protocol

**Stage one.** After adequate anesthesia, the patient lay supine on the operating table under an airbag tourniquet (without bleeding). After conventional disinfection, the wound was thoroughly debrided and expanded. Severely contaminated bone fragments were thoroughly removed, and the less severely contaminated and larger bone fragments were retained. Repeated debridement and irrigation of the wound were performed. Contaminated soft tissue was taken from the wound for bacterial culture. Tibiofibular fixation was performed after debridement. The relative length of the lower leg was first fixed with a fibula plate, and the external fixator of the tibia was then fixed (Figure 1(c)). Intraoperative C-arm fluoroscopy showed that the tibia and fibula were in good alignment and that the axis of the knee joint and ankle joint were well adjusted. According to the length of the vascular defect, the root of the residual vessel was dissociated to facilitate direct anastomosis. Eight "0" vascular anastomosis lines were performed under microscopy

to repair one artery with a small amount of tension. Two long vascular defects were repaired by bridging of the great saphenous vein. The ruptured deep peroneal nerve and tendon tissue were also repaired. Finally, bone cement implantation and VSD closure were performed. According to the length of the bone defect, an appropriate amount of gentamicin sulfate-containing bone cement, the main component of which was polymethyl methacrylate, was molded in vitro and then used to partially fill the bone defect. The cement was wrapped around the proximal and distal ends of the bone defect to ensure that the length of the bone defect was completely covered for formation of the induced film. The wound surface was narrowed by suturing the surrounding tissue appropriately and closed by VSD (Figure 1 (d)). After the operation, the patients were treated with anti-infection therapy, fluid replacement therapy, correction of systemic nutrition, and prevention of thrombosis-related complications. Sensitive antibiotics were given if a culture indicated infection (Table 1).

**Table 1.** Patient demographics.

Case	Sex/age (years)	Injury factor	Injury time (hours)	Location	Bone defect length (cm)	Wound area (cm <sup>2</sup> )
1	M/20	Traffic accident	2.0	Metaphyseal	5.5	6.5 × 15.0
2	M/26	Traffic accident	3.0	Metaphyseal	6.0	6.2 × 13.5
3	M/43	Traffic accident	5.0	Diaphyseal	10.0	10.0 × 18.0
4	F/42	Fall injury	4.0	Metaphyseal	7.0	6.8 × 16.0
5	F/38	Traffic accident	1.5	Diaphyseal	6.5	7.5 × 15.0
6	M/55	Blunt trauma	3.0	Metaphyseal	6.0	8.5 × 16.0
7	M/45	Fall injury	1.0	Diaphyseal	5.0	7.0 × 18.0
8	M/36	Traffic accident	6.0	Diaphyseal	8.0	9.0 × 12.0
9	F/34	Traffic accident	1.5	Diaphyseal	7.5	6.9 × 15.8
10	M/65	Fall injury	2.0	Metaphyseal	8.5	8.6 × 16.5
11	M/33	Blunt trauma	3.5	Metaphyseal	5.5	10.0 × 17.0
12	M/29	Traffic accident	4.0	Metaphyseal	5.0	6.6 × 15.5
13	F/46	Traffic accident	3.5	Metaphyseal	6.5	7.8 × 16.0
14	F/35	Traffic accident	4.5	Diaphyseal	8.0	8.1 × 14.0
15	M/41	Traffic accident	5.0	Diaphyseal	9.0	9.0 × 15.0

M, male; F, female.

**Stage two.** Free anterolateral femoral flap transplantation was performed 5 to 7 days after surgery to repair the wound. In two patients, the tendon and other soft tissues of the anterior tibial wound were severely damaged. The free anterolateral femoral myocutaneous flap was used to fill the cavity. The muscle tissue and the damaged proximal and distal tendon tissue were sutured together to restore partial muscle function. We expanded the size of the flap by 20% according to the area of the defect. One of the thicker perforator vessels was usually selected in the process of flap excision. Reverse separation was performed along the vessels to the proximal descending branch of the lateral circumflex femoral artery. Because the proximal vascular diameter is larger, it is more consistent with the pretibial or posterior tibial artery diameter in the recipient area. In this study, the anterior tibial artery was used as the donor artery in nine cases, and the posterior tibial artery was used as the donor artery in six cases. The anterior or posterior tibial artery and its vein were anastomosed with the two veins at the pedicle of the flap. After the operation, multiple drainage tubes were placed at the pedicle and under the flap for fluid drainage. Skin grafting was performed after the donor site was sutured to reduce the wound. After surgery, the patients were intramuscularly injected with papaverine for prevention of smooth muscle spasm, subcutaneously injected with low-molecular-weight heparin sodium for anticoagulation therapy, and intravenously injected with antibiotics and blood vessel-nourishing drugs. The prothrombin time, activated partial thromboplastin time, fibrinogen concentration, D-dimer concentration, C-reactive protein concentration, and leukocyte count were monitored. The patients were instructed to perform lower limb muscle contraction exercises and toe flexion and extension exercises postoperatively. According to the re-examination

findings 4 to 6 weeks after surgery (Figure 1(e)), the plaster was removed for non-weight-bearing joint functional exercises. Nursing measures such as alcohol disinfection of the nail hole in the external fixator were performed to prevent infection.

**Stage three.** About 8 weeks after the skin flap repair surgery, the skin flap and surrounding tissues had healed well (Figure 1(f)). Routine blood tests were performed after admission, including measurement of the C-reactive protein concentration, erythrocyte sedimentation rate, and procalcitonin concentration. A longitudinal incision was made from the middle or edge of the flap to avoid injuring the induced membrane (Figure 1(g)). The bone cement was completely removed, and the bone wound at the proximal and distal ends of the fracture were freshened (Figure 1(h)). Sufficient autologous iliac cancellous bone was implanted, and the induced membrane was sutured completely to ensure the "periosteal" structure (Figure 1(i)). In two cases, the thick external fixation needle was replaced because its distal end had become loose. An external fixator was installed, and a negative-pressure drainage tube was placed in the wound. The affected limb was externally fixed with plaster for 4 to 6 weeks (Figure 1(j)). After wound healing, the patients were discharged from the hospital for regular follow-up. All 15 patients were followed up by regular outpatient re-examinations. Radiographic examination or computed tomography was performed to assess fracture healing. We defined radiographic healing as bridging of the callus on three of four cortices and clinical healing as pain-free and full weight bearing. The fracture was reviewed monthly until it healed. After fracture healing, the patient was re-examined every 3 to 6 months until functional recovery was attained. Follow-up and evaluation included observation of the wound and external fixation nail hole for

signs of infection, assessment of flap survival and limb shortening, and monthly radiographic or computed tomography examinations to evaluate the fracture healing time (Figure 1(k)). The Iowa ankle questionnaire and ankle ranges of motion were measured during the final follow-up (Figure 1(l), (m)). The Iowa ankle clinical rating system has separate scores for pain and function. A score of 85 to 100 represents an excellent result, 70 to 84 represents a good result, 60 to 69 represents a fair result, and <60 represents a poor result.

## Results

Fifteen patients with Gustilo IIIC open distal tibial fractures were evaluated in this study. The patients' demographic characteristics are shown in Table 1. They comprised 10 men and 5 women with a mean age of  $39.3 \pm 7.9$  years (range, 21–43 years). The cause of the injury was a traffic accident in 10 patients, a fall in 3 patients, and crushing by a heavy weight in 2 patients. The mean length of the bone defect was

$6.9 \pm 2.2$  cm (range, 5.2–10.7 cm). The mean area of the wound defect was  $129.3 \pm 41.4$  cm<sup>2</sup> (range, 83.7–180 cm<sup>2</sup>). Two patients had an ISS of 17, eight patients had an ISS of 14, and five patients had an ISS of 13. Two patients had a MESS of 6 and the remaining patients had a MESS of 7 (Table 2). Six patients exhibited different degrees of shock as evidenced by a pale complexion, decreased blood pressure, rapid pulse rate, and clammy, cold limbs. All fractures were associated with anterior tibial and posterior tibial blood vessel rupture. According to the length of the vascular defect, the root of the residual vessel was dissociated to facilitate direct anastomosis. The tibial posterior artery was repaired in nine cases and the tibial anterior artery was repaired in six cases (Table 2). The time from injury to admission ranged from 1 to 6 hours. All patients underwent emergency surgery.

Fifteen patients were followed up for a mean of  $20 \pm 6.2$  months (range, 14–28 months). All skin flaps survived completely. No revision surgery was performed in

**Table 2.** ISS, MESS, and operative characteristics.

Case	ISS	MESS	Three operation times (hours)	Repaired blood vessel	Saphenous vein graft
1	14	6	3.0, 2.5, 1.5	Anterior tibial artery	
2	13	6	2.5, 3.0, 2.0	Posterior tibial artery	
3	14	7	3.0, 3.0, 2.0	Posterior tibial artery	Yes
4	14	7	2.5, 3.0, 2.0	Posterior tibial artery	
5	13	7	2.5, 3.0, 2.5	Anterior tibial artery	
6	14	7	2.5, 3.0, 2.0	Anterior tibial artery	
7	14	7	3.0, 2.5, 2.0	Anterior tibial artery	
8	14	7	3.0, 3.0, 2.0	Posterior tibial artery	
9	13	7	3.0, 2.5, 2.5	Posterior tibial artery	
10	17	7	3.0, 3.0, 2.0	Posterior tibial artery	
11	13	7	2.5, 2.0, 2.0	Posterior tibial artery	
12	13	7	2.0, 2.0, 2.0	Anterior tibial artery	
13	14	7	2.0, 2.5, 2.0	Anterior tibial artery	
14	14	7	3.0, 2.5, 2.0	Posterior tibial artery	
15	17	7	3.0, 3.0, 2.0	Posterior tibial artery	Yes

ISS, Injury Severity Score; MESS, Mangled Extremity Severity Score.

**Table 3.** Postoperative follow-up results.

Case	Follow-up (months)	Healing time (months)	Shortening of >1 cm	Iowa ankle score	Complications
1	14	5	No	85	
2	15	6	No	86	
3	28	6	No	85	Hematocele under flap
4	19	7	No	81	
5	20	5	No	88	
6	28	8	No	78	
7	19	6	No	79	
8	20	5	1.5 cm	77	Screw loosening
9	24	6	No	88	
10	17	8	1.8 cm	68	Pin tract infection and screw loosening
11	14	5	No	88	
12	15	6	No	87	
13	25	7	No	85	
14	24	6	No	86	
15	19	6	1.5 cm	69	Pin tract infection

step one. Only one patient developed a hematocele under the skin flap, which healed after dressing changes and drainage. The distal external fixation screw hole showed signs of infection in two cases. The inflammation subsided after dressing changes and administration of an oral antibiotic. The remaining patients healed without signs of infection (e.g., redness and swelling) or sinus formation. External fixators were used as the ultimate fixation devices in all patients. However, the thick external fixation needle was replaced in two patients because the distal end had become loose. The median bone healing time was 6.1 months (range, 5–8 months). Partial weight-bearing exercises were performed for 3 months postoperatively, and all patients regained their athletic ability. Three patients showed limb shortening of >1.0 cm (1.5, 1.5, and 1.8 cm, respectively). At the final follow-up, the median Iowa ankle score was 82 (range, 68–88). Eight patients had excellent scores, five had good scores, and two had poor score. The rate of excellent and good scores was 86.6%.

No patients showed obvious dysfunction in the donor area of the bone and flap (Table 3). Eight patients had an ankle joint range of motion ranging from 25° of back extension to 45° of metatarsal flexion. In five patients, the ankle joint range of motion was about 20° of back extension to 40° of metatarsal flexion, and in two patients it ranged from 5° of back extension to 30° of metatarsal flexion.

## Discussion

In the Gustilo classification system, a IIIC fracture is defined as an open fracture associated with an arterial injury requiring repair. Such fractures are often caused by high-energy injuries with large soft tissue defects and vascular injuries, the repair of which is always difficult for surgeons. In addition, secondary injuries such as ischemia, uncontrolled soft tissue infection, refractory osteomyelitis, bone nonunion, or residual deformity may even result in amputation after failure of limb salvage.<sup>15</sup> Gustilo et al.<sup>3</sup> treated 75 Gustilo III open

fractures in 1984 and reported that the infection rate of Gustilo IIB and IIC fractures was 52% and 42%, respectively, and that the amputation rate was 16% and 42%, respectively. Additionally, the authors encountered 12 cases of nonunion or delayed healing and 5 deaths.<sup>3</sup> Recent advances in therapy have improved the prognosis of Gustilo IIC open fractures. However, the amputation rate is still fairly high, especially for fractures of the medial lower tibia<sup>4,5,16</sup> because this area contains less surrounding muscle coverage and poorer blood flow.

The therapeutic strategy for Gustilo IIC open bone defects involves complete debridement, fracture fixation, vascular repair, wound coverage, and bone defect reconstruction. Limb salvage difficulty in the early stage is caused by recanalization of the emergency main blood vessels, which is often accompanied by different degrees of vascular defects. Stable fixation and anti-infection therapy are important. For long-segment bone defects, antibiotic bone cement is used to fill the bone defects and control infection, and this can play a key role in the recanalization of blood vessels. In our wound treatment and management strategy, VSD was used to cover the wound after thorough debridement in the early stage of the first operation, and negative-pressure drainage effectively controlled the infection.<sup>17</sup> In the later stage, an anterolateral femoral flap was used to repair the soft tissue defect. Flap coverage facilitates induced membrane formation and creates a good environment for bone grafting in the second stage of surgery. The free anterolateral femoral flap can be used to repair the soft tissue defect. A good blood supply to the flap also helps to control infection.<sup>18,19</sup> Bone transplantation with a fascia flap reportedly has the dual function of constructing blood vessels and inducing

tissue regeneration, which can enhance the repair of the bone defect.<sup>20,21</sup>

Gustilo IIC tibial fractures are often associated with large bone defects, and reconstruction of such bone defects for limb salvage is challenging. The most commonly used methods for reconstruction of large bone defects are vascularized fibular flap grafts and Ilizarov bone transfer techniques.<sup>22,23</sup> Bone resorption occurs with a high failure rate for defects of >5 cm when cancellous bone grafting is used alone.<sup>24</sup> The anterior tibial and posterior tibial vessels are both injured in Gustilo IIC tibial fractures. The repair of one main artery ensures recanalization of the vessels, and the other main artery needs to act as the recipient vessel of the free flap. Therefore, a bone flap for anastomosis of the recipient vessels is lacking. In contrast, the Ilizarov bone transfer technique requires a long time for bone healing. This technique is performed by extending the bone length by 0.75 to 1.00 mm per day. The healing time is related to the length of the bone defect. For long-segment bone defects, the bone healing time is long. The external fixation needle readily loosens after repeated extension, which may lead to failure of the operation. Early application of this technique for Gustilo IIC tibial fractures may damage the repaired main blood vessels and cause vasospasm or embolism. Another difficulty in the treatment of Gustilo IIC tibial defects is bone infection. The two-stage operation of the Masquelet technique can be used to treat both bone infections and bone defects. In the first stage, the induction membrane is formed by complete debridement followed by the implantation of antibiotic bone cement. The bone cement not only fills the cavity but can also release antibiotics locally and continuously, thus having a strong anti-infection effect. The Masquelet technique



not only repairs large bone defects but also treats bone infection. Treatment of acute open fractures with severe bone defects remains a major challenge in trauma surgery, and membrane induction is a good choice for treating such lesions.<sup>25</sup> External fixation has always been a simple and effective method for the treatment of bone defects. However, external fixators also have their own limitations, such as pinhole infection, loosening of the fixation needle, and inconvenient daily care. Wound management of the nail holes in external fixators is also important.

The application of microsurgical techniques provides ideal conditions for limb salvage. In the present study, the blood vessels were repaired directly or bridged by the great saphenous vein after being totally dissociated, and the vessels were then recanted as soon as possible to reduce the duration of limb ischemia. Gustilo IIIC open tibial bone defects are commonly seen in high-energy injuries with not only long-segment bone defects but also large-area skin and soft tissue defects. The application of a free anterolateral femoral flap can repair soft tissue defects to the largest extent, and the good blood supply of the flap also helps to control infection.<sup>18,19</sup> The good coverage provided by the flap also facilitates induction membrane formation and creates a good bone graft environment for the second-stage surgery. Moreover, application of a free anterolateral femoral musculocutaneous flap can replace the repair of tendon defects to a certain extent. In this study, an anterolateral femoral musculocutaneous flap was used in two cases to repair the wound surface and reconstruct part of the dorsiflexion function of the ankle joint.

In conclusion, the combination of the Masquelet technique with a microsurgical technique can effectively control infection,

significantly improve the bone healing rate, and facilitate good recovery of joint function in patients with Gustilo IIIC open tibial fractures.

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The authors declare that there is no conflict of interest.

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