Masquelet technique combined with modified Sauve-Kapandji, negative pressure drainage and flap transplantation for the treatment of a Gustilo-Anderson III type C open fracture of the forearm: A case report

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Abstract. Gustilo-Anderson III Type C open fracture is a high-energy injury with severe bone defects and extensive soft-tissue and vascular damage. Successful limb salvage remains challenging for surgeons due to the inherent risks of vascular damage, infection, nonunion and even amputation. The present case study reports on a 55-year-old male who presented with a Gustilo-Anderson III type C open fracture, which was successfully salvaged by a combined Masquelet and microsurgical approach. The modified Sauve-Kapandji technique was used to improve wrist mobility. Sufficient preoperative evaluation, a detailed surgical plan, positive revascularization, thorough debridement and prevention of complications are key to successful limb salvage. The range of motion test was excellent one year after surgery. The patient was able to take care of their daily life, return to performing a light-labor job and is satisfied with the function of the limb. Therefore, the Masquelet technique combined with modified Sauve-Kapandji technique, negative pressure drainage and skin-flap transplantation may be a reasonable and effective treatment for Gustilo-Anderson III type C open forearm fracture.

Introduction

Muscle and bone injuries have greatly increased the global burden, and open fractures are the leading cause (1). Gustilo-Anderson III fracture is commonly caused by a high-energy mechanism, which frequently involves a comminuted fracture, segmental skeletal defect and soft tissue damage, and requires vascular and nerve repair. Hence, it remains a Gordian knot (2,3). There is ongoing controversy regarding limb salvage or amputation (4,5). Amputation used to be common in patients with serious Gustilo-Anderson III C fractures (6). Open injury represents a wide spectrum of pathology and Morbidity, Mangled Extremity Severity Score (MESS) ≥7 was identified as an independent predictor of limb amputation. In particular, Gustilo-Anderson IIIC open fractures present high rates of infection and amputation (3,4). The current report presents a successful limb salvage case of a patient with a MESS of 7 points (7), Gustilo-Anderson Grade III type C and Orthopaedic Trauma Association and American Academy of Orthopaedic Surgeons classification 2R3A3.3 (8) open fracture of the forearm after treatment by a combination of Masquelet technique, modified Sauve-Kapandji, negative pressure suction drainage and microsurgical therapy.

Case report

Clinical data. In August 2020, a 55-year-old male was hospitalized at the Kunming 311 Hospital (Kunming, China) 6 h after machine strangulation of the right upper limb. The patient presented with anemia, low blood pressure, increased heart rate, deformity of the right forearm, dorsal and radial skin degloving (18x6 cm), partial defect of the distal end of skin degloving and dissociated fragments of the ulnar and radius fractures. The extensor carpi radialis longus and extensor carpi radialis brevis tendons were ruptured in the dorsal distal forearm. The extensor carpi ulnaris, extensor pollicis longus muscle, extensor indicis proprius, abductor pollicis longus and extensor pollicis brevis tendons were ruptured in the lower third of the dorsal distal forearm. The extensor digitorum tendon was pulled out from the proximal muscle abdomen of the extensor digitorum, and the extensor digitorum and extensor carpi ulnaris were damaged in the tendon-muscle belly transition area. The radial artery and its accompanying

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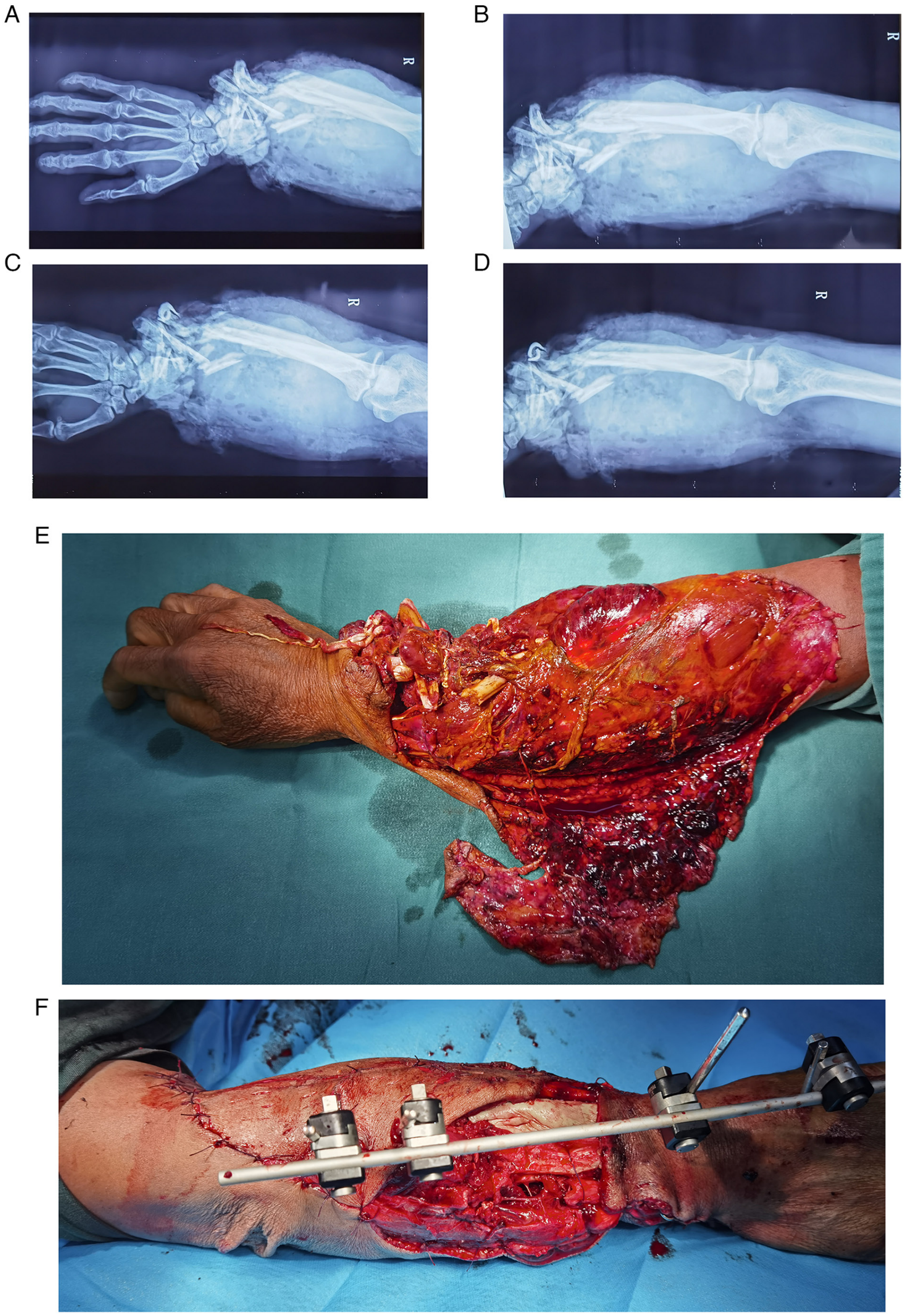

Figure 1. (A-D) Preoperative radiography imaging examination. (A) The patient's right forearm had been wounded by a machine, causing comminuted fracture of the distal radius and the right ulna, and broken ends of the ulna and radius had caused tissue puncture. (B) The distal wrist joint was intact with no obvious fracture signs. Forearm soft-tissue swelling was observed with distal radius bone residue of ~2.5 cm. (C) Soft-tissue swelling was obvious in the far distal joint but there was no significant fracture in the elbow joint. (D) The distal ulna and radius fractures were crushed and certain fragments protruded out of the soft tissue. (E) Image of the wounded arm after cleaning, hemostatic strap bleeding and disinfection; the patient had forearm soft-tissue swelling, skin degloving, degloved skin contusion and distal dorsal forearm defect, distal dorsal muscle rupture, exposed fracture fragments, residual tendon and an intact distal wrist joint. (F) Intraoperative image. The forearm was fixed with an external fixator for a short duration during the *in situ* replantation of the degloved skin. Distal dorsal soft-tissue defect wounds were observed. Polymethyl methacrylate was used to fill the distal radius defect. A Kirschner wire is visible on the ulnar side of the forearm, which was used to fix the distal radioulnar joint. The free fragments of the ulna fracture were removed and discarded, and obvious ulna bone defects are visible.

Table I. Timelines.

Date	Procedure
Aug 2020	The patient was admitted to the hospital and completed preoperative checks. Physicians performed fluid rehydration, blood preparation, communicated with the patient and the patient's family to finalize planning of treatment details, corrected anemia and performed emergency surgery (First operation) simultaneously.
Aug 2020 (first day after the first operation)	Laboratory checks revealed low levels of blood cells and low hemoglobin, and blood transfusion was performed to correct the anemia.
Aug 2020 (seventh day after the first operation)	The Digital X-ray film of the right forearm was reviewed, the vacuum sealing drainage device was removed and skin survival was checked under direct vision.
Aug 2020 (eighth day after the first operation)	The dressing was changed and a vacuum sealing drainage device was placed on the wound.
Sep 2020 (24 days after the first operation)	The vacuum sealing drainage device was removed, the open dressing was changed and a date for repair surgery of the injured area was selected.
Sep 2020 (26 days after the first operation)	The wound surface of the forearm was repaired with an abdominal flap (Second operation).
Oct 2020 (35 days after the second operation)	Surgery to cut off the flap of the pedicle (Third operation).
Dec 2020 (62 days after the third operation)	The external fixator of the patient's forearm was removed and replaced with. plaster fixation
Dec 2020 (67 days after the third operation)	Surgery: Bone graft, radius fixation and wrist reconstruction (The last operation).
Dec 2020 (4 days after the last operation)	X-ray films indicated the distal radius of the right ulna defect, internal fixation of the right radius with a plate and the right radioulnar joint with screws.
Jan 2021 (13 days after the last operation)	After the wound had healed, all sutures were removed. The patient was instructed to perform functional recovery exercises, precautions were explained to the patient and he was subjected to the discharge procedure.
Dec 2021 (1 year and 4 months after the firist operation)	Review and functional assessment.

vein were lacerated in the distal forearm. Displaced fracture fragments were present around the lacerated blood vessels. Furthermore, contusions surrounded the ulnar artery and accompanying vein. The blood vessels in the injured site were tortuous and without fracture; however, distal blood flow was interrupted at the injured site. There was no obvious injury to the median nerve and ulnar nerve, and the main radial nerve was not ruptured. The dorsal branch of the ulnar nerve and the superficial branch of the radial nerve were torn. The distal wrist was intact. As presented in the radiographs in Fig. 1, the distal ulnar and radius fractures were crushed; the MESS score was 7 (7) and the fracture was classified as Gustilo-Anderson type III C (9). The patient strongly desired limb salvage; hence, this was considered.

Diagnosis and treatment process. The time-course of the treatments of the patients is provided in Table I. After admission, emergency surgery was performed to remove contaminants, necrotic tissue and free bone. The external fixator (Combined external fixator; Jiangsu Guoli Medical Instrument Co., Ltd.) was used to support and fix the fracture, and the force line was maintained. Masquelet's induced membrane technique was applied with antibiotic-free polymethyl methacrylate (PMMA; Bone Cement; specification model, PALACOS® R+G; Heraeus Medical GmbH) as a spacer to treat distal radius damage. No special treatment was performed for proximal ulna fractures after ulnar fracture fragments had been removed. Due to fixing the forearm force line and debridement of the ulnar artery, the vascular tortuosity and spasm were relieved and the blood circulation was re-established. Bones in the region of 2.5 cm proximal to the ulnar styloid process were retained and the joint was temporarily fixed with a Kirschner wire through the ulnar margin of the inferior radioulnar joint to the radial side. Next, all ruptured tendons were repaired from deep to superficial regions, except for the extensor digitorum tendon, extensor indicis proprius and extensor pollicis longus tendon, due to the defects. The avulsed skin was thinned and replanted with holes for drainage and the defect of the dorsal distal end and the site of the replanted avulsed skin was sealed with negative pressure (first operation; Table I). The distal forearm wound was repaired with a pedicled abdominal flap (second operation; Table I) after replacement of the negative pressure drainage. Until the wound healed completely, the radial fracture was slightly angulated upon fixing the unilateral external fixator of the forearm with the pedicled flap (Figs. 2 and 3). At about one month after the pedicled abdominal flap surgery, the pedicle of the flap was cut (third operation; Table I). After two months, the spacer was removed under general anesthesia

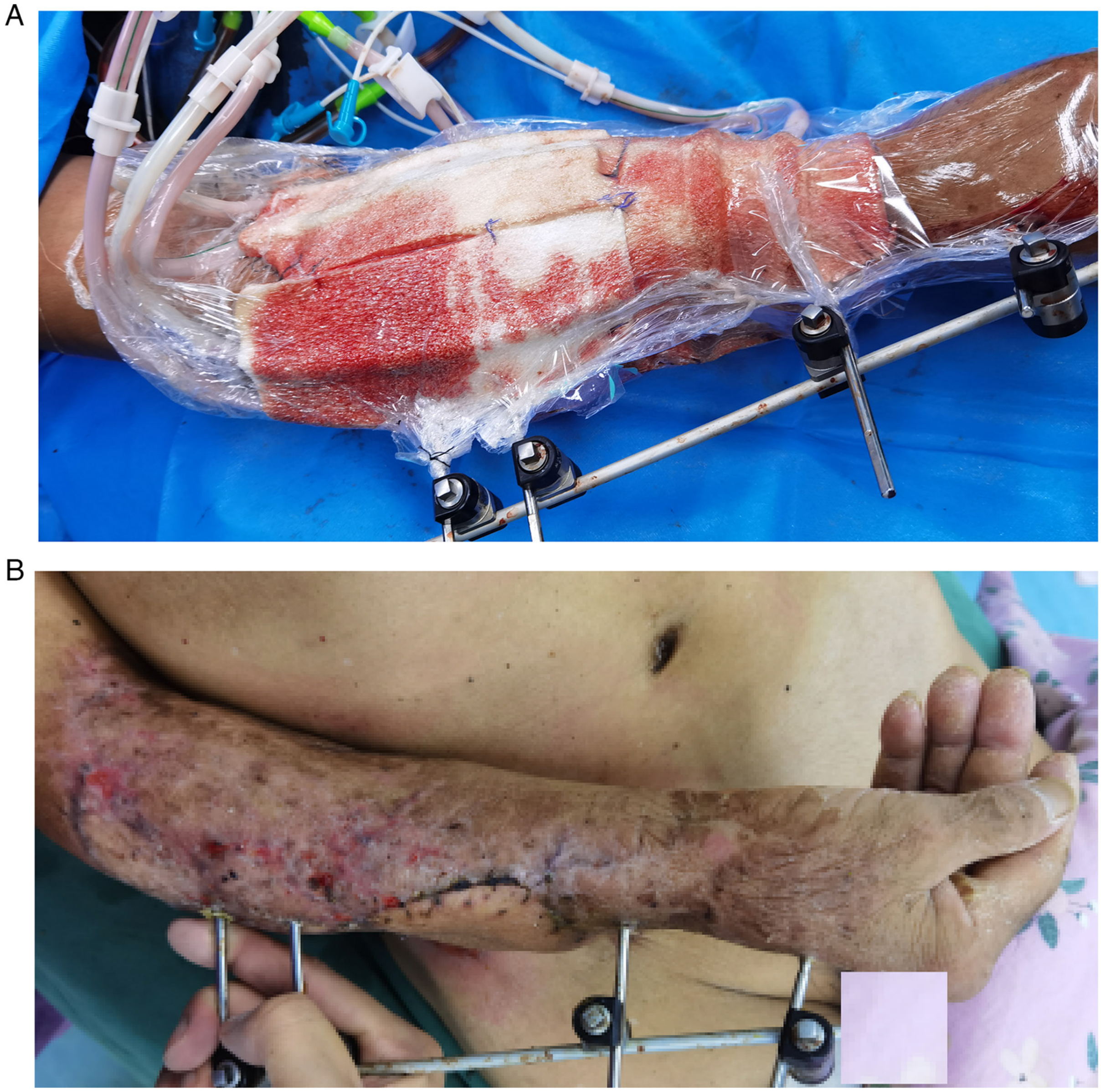

Figure 2. (A) After the first operation, continuous vacuum sealing drainage was used at the site of tissue defects and skin *in situ* replantation. (B) Appearance one and a half months after the first operation; flaps and skin *in situ* replantation had healed well and blood circulation was established between the flap and forearm.

after the external fixation needle had healed; bilateral iliac bone was added with allograft bone (Allogeneic bone repair material; Chongqing Daqing Co., Ltd.) to fill the radius defect (10). The proximal and distal fractures of the radius were fixed with a steel plate (Metal Locking Plate System; Jiangsu Guoli Medical Instrument Co., Ltd.), the distal ulna was fixed with a screw (11,12) and modified Sauve-Kapandji surgery was performed (last operation; Table I; Fig. 4). Throughout the course of treatment, the patient was given cephalosporin antibiotics half an hour before the first operation to prevent infection. Cephalosporin antibiotics were applied after the operation until one week after the operation and the patients' blood indexes were normal after one week. In the later period, the cephalosporin antibiotics were applied after each operation until 1-3 days after the operation and no wound infection occurred during the entire treatment process (including two hospitalizations, spanning over two months; Table I). The patient was injected with low-molecular-weight heparin calcium subcutaneously once a day 24 h after the first operation until the drug was discontinued one week after the operation. In the later stage, the time of bed rest for each operation was short and the patient was able to get out of bed for activities and perform limb flexion and extension exercises, and did not use any drugs for thromboprophylaxis. During the hospitalization, the patient began to exercise 3 days after the operation, including active small arc flexion and extension of fingers, elbow and shoulder joint movement. After stable limb blood circulation was achieved, upper limb muscle isometric contraction exercise and mild strength training were performed. At four weeks after the first stage of the operation, muscle isotonic contraction exercise and moderate strength training were performed. Prior to and after the last operation, functional exercise was performed at the Department of Rehabilitation (Kunming 311 Hospital, Kunming, China)

Figure 3. (A) When preparing for surgery to cut off the pedicle of the flap, the external fixator was fixed in place and there was no infection around the needle track. (B) Digital X-ray display: The external fixator was fixed in place and polymethyl methacrylate was used as a spacer to fill the distal radius defect. (C) The pedicle of the flap was cut off half a month later. The abdominal flap at the donor site and the forearm flap at the recipient site were healed.

under the guidance and assistance of professional doctors. The treatment included joint mobilization treatment, intermediate frequency electrical stimulation therapy and infrared therapy.

Outcomes. The injured limb was successfully saved with obvious scarring on the forearm; Fortunately, the patient is a left-handed person, and the patient returned to the original company, replacing a not more labor-intensive job than the original work. At the 1-year postsurgical follow-up, the range of motion of the elbow joint was similar to that of the healthy contralateral joint; rotation of the forearm was unrestricted; active wrist extension was partly limited, active back extension reached 15˚ (normal, 80˚) and passive wrist extension was not limited; active palmar flexion and passive palmar flexion of the wrist joint reached 55˚ and 70˚ (no difference from healthy side), respectively; no significant limitation of thumb abduction was observed; active dorsiflexion of metacarpophalangeal and interphalangeal joints was limited, but

Figure 4. (A) Bone grafting and plate fixation were performed at the radial defect. The distal ulna and distal radius were fixed with a screw and the modified Sauve-Kapandji operation was performed to restore the stability of the wrist. (B) The sufficient bone graft in the forearm radial defect was observed by digital X-ray lateral film. (C) The successful outcome of forearm limb salvage.

the thumb metacarpophalangeal joint passive flexion range of 0-60˚ (normal range, 0-60˚), other metacarpophalangeal joint passive flexion range of 0-85˚ (normal range, 0-90˚), thumb interphalangeal joints flexion range of 0-80˚ (normal range, 0-90˚), other proximal interphalangeal joint flexion range of 0-90˚ (normal range, 0-100˚) and distal interphalangeal joint flexion range of 0-60˚ (normal range, 0-100˚). Finger and wrist extensions were not restored by surgery. The Disability of the Arm, Shoulder, Hand score was 33.33 (13).

Discussion

Gustilo-Anderson III open fractures are associated with extensive soft-tissue injuries and Gustilo-Anderson III C open fractures frequently require microsurgical techniques, such as vascular nerve anastomosis and flap transplantation (9,14,15). MESS is a recognized severity evaluation standard for limb damage (7). Traditionally, most patients with Gustilo-Anderson III Type C open fracture (MESS ≥7) underwent amputation, particularly when the time of blood supply disturbance in the injured limb was >24 h (16), while limb preservation was attempted in a small proportion of the patients. The treatment was required to include the following steps: Debridement and reconstruction of blood supply were the main parts of the first stage. Soft-tissue coating was carried out in the first or second stage according to the situation. Bone continuous reconstruction was performed in the third stage and limb function reconstruction in the last stage, but the treatment results were frequently disappointing. Furthermore, injured limb salvage may lead to serious complications. The amputation of injured limbs is frequently delayed due to infection, bone nonunion and muscle necrosis, which may result in long-term limb ischemia, massive muscle necrosis, toxin absorption, liver and kidney function decline and even organ failure leading to death (17). However, with the development of microsurgery, the evaluation of the progress of internal fixation materials may be appropriately relaxed according to the situation (18). In the present case, through four surgeries (Table I) with multidisciplinary cooperation and multi-technical application, combined with various synergistic treatment strategies, and with consideration of the most favorable timing of the surgeries, making the most of strengths and avoiding weaknesses, it was possible to preserve the integrity of the limb and reconstruct most of the functions of the injured limb, resulting in a good functional assessment outcome. Sufficient preoperative evaluation, a detailed surgical plan, positive revascularization, thorough debridement and prevention of complications are key to successful limb salvage. As an injured limb that only preserves integrity without function is a burden for living (19), the last operation was performed after complete wound repair, which ingeniously integrated the internal fixation operation and the functional reconstruction operation and saved one treatment cycle, reducing pain and ensuring excellent results.

The Masquelet periosteum induction technique (20) and Ilizarov technique (21) are both commonly used in the clinical treatment of large segmental bone defects or infections (22). The Ilizarov technique is applied for the treatment of bone defects. The external fixation ring frame brings discomfort to daily life. Needle channel nursing brings a great challenge for patients themselves and is associated with a negative experience, as continuous distraction osteogenesis causes long-term unbearable pain in the injured limbs of patients. The Masquelet technique is better in terms of cost-efficiency in treating traumatic bone defects and has a higher success rate and patient satisfaction (23). Ilizarov was the first to propose its application in treating bone defects. It was found that the Masquelet technique had a better success rate of limb preservation in treating chronic bone infection (10). In the present case, antibiotic-free PMMA was used as a spacer to achieve a better result in periosteum induction than that which is typically associated with antibiotic-incorporated PMMA. When PMMA is used as a spacer, it should exceed the defect and cover the proximal and distal parts of the normal bone. After the periosteum was formed, the same treatment method (as it should) was used when the spacer was removed for bone grafting, which was conducive to the connection between the two ends of the defect and the original bone during bone grafting. The same treatment was used in this case.

The modified Sauve-Kapandji procedure was used to fuse the ulnar microcephaly with the radius, which ensured the structural integrity of the radioulnar joint (12), avoided complications caused by the change of wrist joint load transfer due to ulnar microcephaly resection, reduced the trauma caused by the distal ulnar reconstruction and improved the rotation function of the forearm (11).

Immediately after debridement, soft tissue coverage was performed, which expanded the surgical trauma. The possibility of continuing necrosis after debridement of soft tissue in Gustilo-Anderson III open fractures is high (3). Subcutaneous soft-tissue necrosis may increase the risk of infection and make the flap unable to connect with the normal soft tissue. Flap transplantation on the infected wound may increase the probability of vascular embolization in the flap, resulting in flap necrosis. First-stage debridement with negative pressure drainage and second-stage skin-flap transplantation are advantageous over traditional first-stage skin flap transplantation (14). After negative pressure sealing, negative pressure in the wound may remain unobstructed for a long time to ensure the drainage effect. Negative pressure reduces infection, cleans the environment and controls the pressure in the skin graft area, all of which are conducive to the survival of avulsed skin (24). In the present case, the degloved skin completely survived after negative pressure drainage and the granulation tissue of the skin defect wound grew well, which created conditions optimal for skin-flap transplantation.

Gustilo-Anderson III C open injury requires numerous operations with a long treatment cycle, which causes great physical and psychological trauma to the patient (4). In the present case, the patient was very satisfied with the status of limb salvage. However, the patient was afraid of surgery and chose to give up the restoration of the function of finger extension and wrist extension. This is a limitation of the treatment. Another imperfection is that when the follow-up data were collected, the focus was on the data related to the limb salvage of the patient, while ignoring the imaging data of limb function and bone healing preserved at the follow-up 1 year after the last operation, which cannot be visually examined. It was also considered to use free flaps or flow-through techniques for wound repair, which may have reduced the number of operations by one and the forearm fixation time; however, it had a limited influence on the total operation time and hospital stay and increased the surgical risks.

In conclusion, amputation was once common in patients with serious Gustilo-Anderson III C fractures. In the present case, the combination of Masquelet technology, modified Sauve-Kapandji, negative pressure suction drainage and microsurgical therapy resulted in successful limb salvage for the patient. The present report proposes new possibilities for the future treatment of Gustilo-Anderson III C fractures.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

YD, CY and SL planned the treatment. YD and WT performed treatment. ZP and YL were responsible for methodology and resources. SL supervised the writing of the article. All authors wrote the manuscript. All authors have read and approved the final manuscript. YD and WT checked and confirmed the authenticity of the raw data.

Ethics approval and consent to participate

This study was approved by the Hospital's Ethics Committee (Kunming 311 Hospital, Kunming, Yunnan, China).

Patient consent for publication

The patient provided written informed consent for the publication of the case details and related images.

Competing interests

The authors declare that they have no competing interests.

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