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ORIGINAL RESEARCH

Comparison of Clinical Effects of the Modified Masquelet Technique and Kirschner Wire External Fixation-Assisted Autogenous Bone Transplantation in the Treatment of Segmental Metacarpophalangeal Bone Defects

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Objective: The present study aims to explore the (1) clinical effects of the modified Masquelet technique, whose improved Masquelet technique innovates the in vitro plasticity of the bone cement module and prefabricated hollow design, and the Kirschner wire external fixation-assisted autologous bone transplantation technique in the treatment of segmental metacarpophalangeal bone defects and (2) the differences between the two techniques.

Methods: The clinical data of 32 patients with segmental metacarpophalangeal bone defects (15 patients treated with the modified Masquelet technique and 17 patients treated with the self-made Kirschner wire external fixation technique) admitted to our department between January 2012 and January 2020 were retrospectively analyzed. The postoperative bone healing time, hand function, and complications were compared between the two groups.

Results: The two groups were comparable; there were no significant differences in age, sex, length of bone defect, and time from injury to operation between the two groups ($P > 0.05$). All patients were followed up with for 6–24 months (average = 13.7 months), and all patients with segmental metacarpophalangeal bone defects achieved fracture healing. The postoperative hospital stay, fracture healing time, functionary scores of the affected limb, and incidence of severe complications were better in the modified group than in the external fixation group ($P < 0.05$).

Conclusion: Compared with the Kirschner wire external fixation stent assisted autologous bone transplantation, the improved Masquelet technique has the advantages of simple operation, fast healing, accurate effect, wide indications, and less complications, making it more worthy of clinical promotion.

Keywords: segmental metacarpophalangeal bone defect, modified, Masquelet technique, curative effect

Introduction

The number of metacarpal and phalangeal bone defects caused by high-energy hand trauma,[1] hand infection and osteomyelitis,[2] long segment metacarpal and phalangeal bone tumor resection,[3] and various complex hand deformities[4] has recently been increasing year by year.

A metacarpal and phalangeal bone defect that is long, heavily polluted, or even combined with infection or osteomyelitis has a difficult treatment, long treatment process, high number of complications, and poor effect.[5] This is especially true in metacarpophalangeal bone defects with a length of >1.5 × its diameter; these are called large metacarpophalangeal bone defects,[6] and they are a hot point and difficult problem for surgeons.

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At present, there are many treatment schemes for large metacarpophalangeal defects with different curative effects. Since 2012, our hospital has used the self-made Kirschner wire external fixation stent combined with autologous bone transplantation to treat large metacarpophalangeal bone defects. Since 2015, the hospital has innovatively designed and improved Masquelet technique to treat large metacarpophalangeal bone defects that meet the surgical indications, and good clinical results have been achieved.

In the present research, the clinical data of 32 cases of large metacarpal and phalangeal bone defects treated with either modified Masquelet technique or self-made Kirschner wire external fixation stent combined with autologous bone transplantation in our hospital from January 2012 to January 2020 were retrospectively analyzed by comparing the postoperative efficacy and complications of the two treatment schemes; this was used to prove the feasibility, advantages, and disadvantages of the two schemes in the treatment of large metacarpophalangeal bone defects as well as to provide reference guidance for the selection of clinical treatment schemes.

Information and Methods

Inclusion and Exclusion Criteria

Patient inclusion criteria: (1) The metacarpophalangeal bone defect length was >1.5 × its diameter; (2) the wound inflammation was controllable, and the skin and soft tissue defects were repaired using a skin flap; (3) the blood supply of the affected finger or limb was good, and the patient could tolerate the operation so that the affected finger would not develop ischemic necrosis; and (4) the patient did not have bone cement allergies.

Patient exclusion criteria: (1) The blood supply of the injured finger or limb was poor due to neurovascular injury, easily inducing ischemic necrosis; (2) the patient had poor compliance and would not cooperate with the treatment; (3) the patient had a systemic disease affecting treatment and fracture healing or a serious disease of the heart, lung, liver, kidney, or other vital organs; (4) the patient had abnormal coagulation; and (5) the patient had a long-term history of hormone drug use.

General Data

In recent years, our hospital has conducted relevant research, with some patients failing to complete the follow-up due to various reasons. A total of 32 patients (23 males and 9 females) aged 19–57 years (average age = 41.3 years) and no underlying diseases were included in the present study. The patients were divided into two groups according their treatment technique: the modified group and the external fixator group.

(1) The modified group comprised 15 patients (11 males and 4 females). The causes of bone defects included high energy injury in 12 cases, debridement due to osteomyelitis in 2 cases, and long bone tumor resection in 1 case. The affected fingers included five thumbs, four index fingers, two middle fingers, two ring fingers, one little finger, and 2 cases involving the metacarpal bone; this included 1 patient with multiple metacarpal fractures and 1 patient with thumb and phalangeal defects, which were treated with modified therapy.

(2) The external fixator group comprised 17 cases (12 males and 5 females). The causes of bone defects included high energy injury in 13 cases and debridement due to osteomyelitis in 4 cases. The affected fingers included eight thumbs, five index fingers, two middle fingers, one ring finger, and one little finger.

Bone defect classification: A total of 13 cases were infectious and 4 cases were non-infectious, the length of bone defect was 1.5–4.5 (2.99 ± 0.92) cm, and there were 5 cases of a bone defect combined with other injuries. In emergency cases where the wound was heavily contaminated and could not be closed directly, vacuum sealing drainage was performed. In 9 cases, the wound could be closed directly, and 23 cases were repaired using a skin flap when the wound condition was stable. The two groups were comparable; there were no significant differences in age, sex, length of bone defect, and time from injury to operation between the two groups ($P > 0.05$).

Therapeutic Methods

Surgical Methods

Preoperative Assessment

The patients received routine preoperative examination after admission and underwent X-ray examination of the hands to

ensure understanding of the metacarpophalangeal bone defects. The patient's general condition and hand lesions were comprehensively evaluated to determine whether he/she met the diagnostic criteria of segmental metacarpophalangeal bone defects and the indications of the operation plan. For patients who met the requirements and were included in the study, the patients and their families were fully and effectively communicated with before the operation in order to determine the operation plan, specific process, and possible risks and complications as well as objectively evaluate surgical efficacy. Informed consent was signed after the patients selected the treatment plan.

Surgical Methods

Anesthesia was performed through a brachial plexus block or general anesthesia. An inflatable tourniquet was applied at the upper third of the arm to completely stop bleeding. Thorough debridement was performed, and necrotic and inorganic tissues were removed. Attention was paid to protecting the blood vessels and nerves of the affected hand and fingers to ensure blood supply to the fingertips. The broken ends of the bone defects were trimmed, bloodless and/or ossified bones were removed, and the bone marrow cavity was recanalized.

If the metacarpal and phalangeal bones were extensively involved with segmental osteomyelitis or a long segment bone tumor, the damaged bone was removed thoroughly. The wounds were washed with a large volume of normal saline and iodophor, and thorough hemostasis was performed. In severely contaminated wounds, samples were obtained after debridement for bacterial culturing and drug sensitivity testing. If the wound could not be closed directly, a skin flap was used for repair.

During the first stage of operation in the modified group, antibiotic bone cement was prepared by mixing 40 g of bone cement with 2 g of vancomycin after thorough debridement of the wound and satisfactory treatment of the broken ends of the bone defect. A hollow polymethyl methacrylate bone cement segment containing vancomycin was prepared in vitro according to the shapes and sizes of the phalangeal defects (Figure 1). The appearance of the segment was smooth, its circumference was slightly larger than that of normal bone, and both ends of the bone cement were wrapped around the proximal and distal fracture ends.

The bone cement was placed on the bone defect area after it was cooled and solidified in order to avoid scalding the adjacent nerves and blood vessels by thermogenesis, thus influencing the blood supply and sensation of the affected finger after the operation. Thorough hemostasis was performed, and the skin and subcutaneous tissues were sutured layer by layer to close the wound.

If the wound was severely contaminated and complicated with skin and soft tissue defects (Figure 2), one-stage debridement and vacuum sealing drainage were performed. After the condition of the wound became suitable, the bone cement module was implanted, and the wound was repaired and closed. Poor condition of the skin and soft tissue at the operation site could cause scars or inflammatory issues, possibly affecting subsequent treatment.

The damaged skin and soft tissue were removed via debridement, and the skin flap was used to repair and close the wound (Figure 3). The Kirschner wire was inserted through the hollow bone cement module and fixed the fracture ends. An X-ray examination of the hand was performed after surgery to check the cement filling (Figure 4).

In the second stage of operation, if no infection occurred or the inflammatory index decreased to a normal range at 4–6 weeks after the first stage and wound healing, the skin and soft tissue were cut along the original surgical incision, a longitudinal incision of the cement-inducing membrane was made, and the bone cement implanted during the first stage of surgery was cautiously removed (Figure 5); the surgeon was careful to avoid damaging the developing membrane.

Calcified or inorganic bone tissue at the ends of the fracture was removed, and the medullary cavity was recanalized. According to the volume of the bone defect, sufficient autogenous cancellous bone and ≤1/4 cortical bone or artificial bone were filled. Kirschner wire or a plate and screws were used to internally fix the bone graft and fracture ends to maintain the shape and appearance of fingers or palms (Figure 6). The incision was sutured layer by layer.

The external fixator group: After thorough debridement and removal of the non-reserved bone (Figure 7) or satisfactory cleaning of the broken end of the bone defect, the self-made Kirschner wire external fixator (Figure 8) was installed to fix the proximal and distal bones of the defect. The tension of the external fixator was adjusted to restore and maintain the force line and length of the metacarpophalangeal bone.

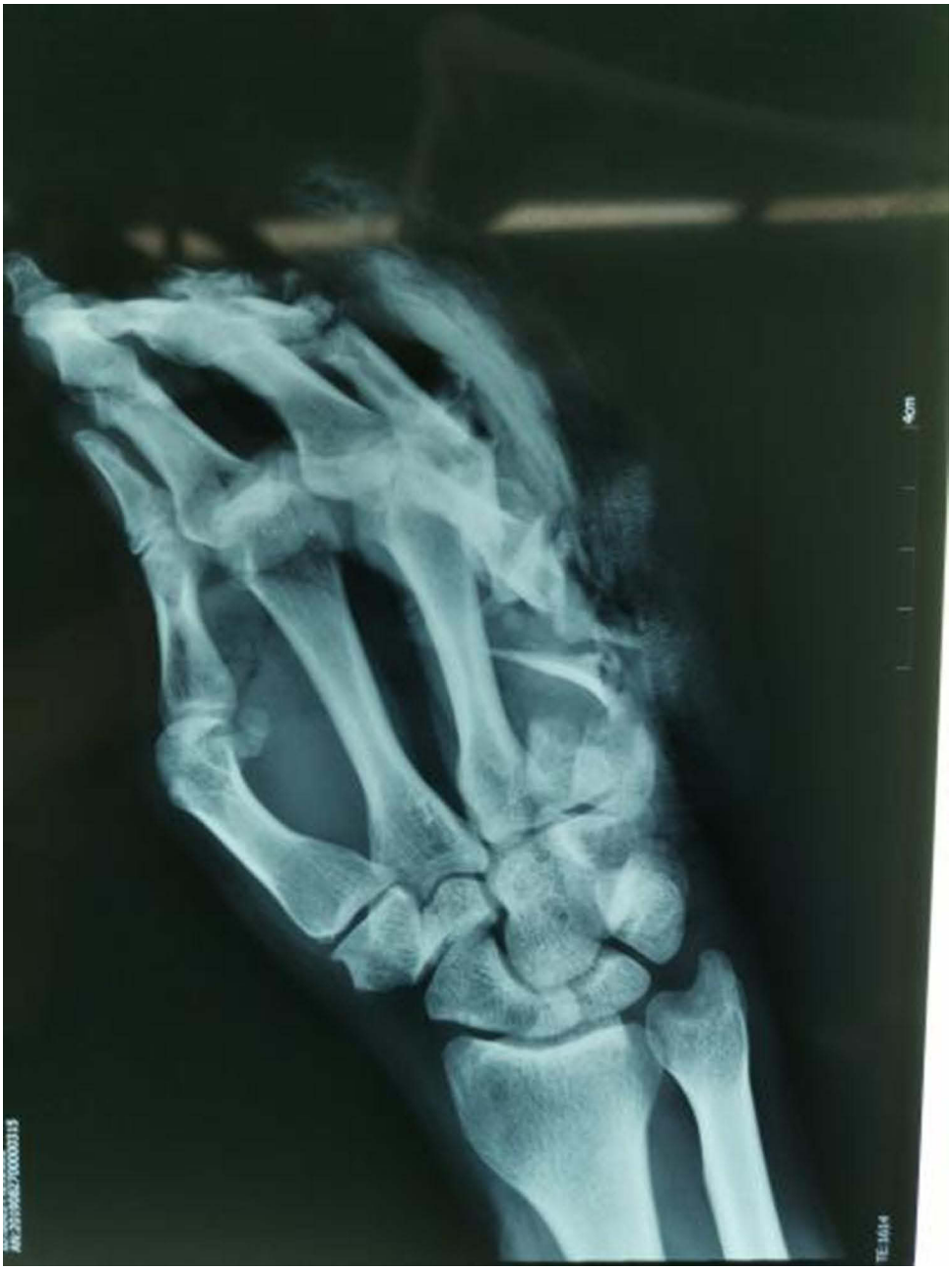

Figure 1 Preoperative X-ray film of the affected hand displaying multiple segmental metacarpal bone defects.

In patients with a skin or soft tissue defect of the affected finger that could not be closed directly, the corresponding dorsal metacarpal artery island flap or other flaps were designed to repair and close the wound.

After the condition of the affected finger's soft tissue was stable and the inflammatory indexes were normal, the Kirschner wire external fixator was removed. The skin and soft tissue were cut along the original surgical incision, thorough debridement was conducted, and the scar and fibrotic tissue of the bone defect were removed.

During this process, attention was paid to protecting the nerves and blood vessels to avoid injury and prevent postoperative ischemic necrosis or sensory disturbance. According to the length and circumference of the bone defect, the corresponding iliac bone-block was taken and transplanted in the defected area in a free pattern. Internal fixation of fractures was performed with metal plates and screws or Kirschner wires (Figure 9). The incision was sutured layer by layer.

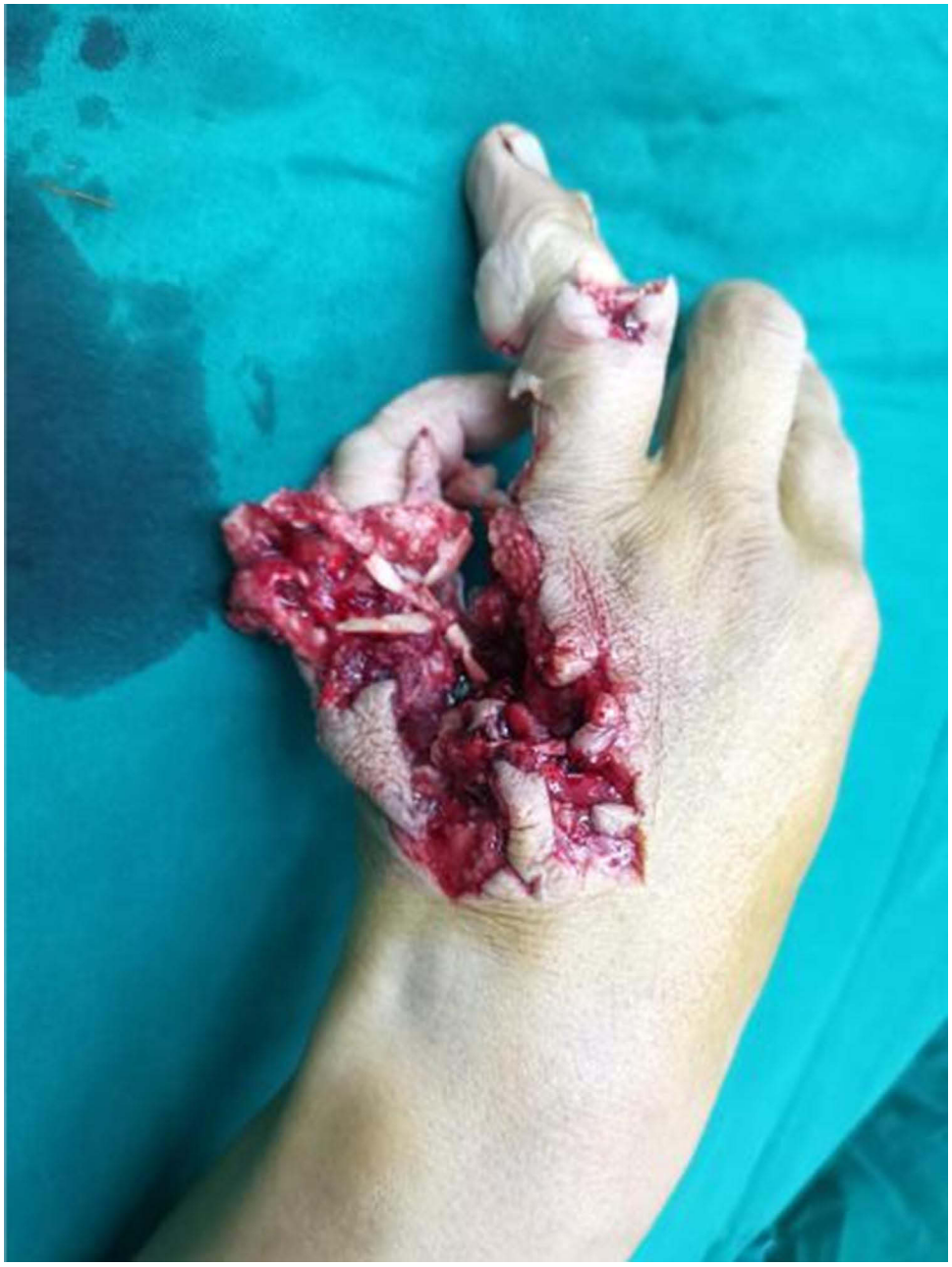

Figure 2 Wound and bone defect of an affected hand before the operation.

Postoperative Measures

Prophylactic or therapeutic antibiotics were administered after the operation, and wound care was strengthened. In patients with Kirschner wire exposure and an external fixator, attention was paid to the nursing of the nail path, and the tension of the external fixator was adjusted to prevent over-traction. The blood supply of the fingertip or flap was observed.

Fracture healing after bone grafting was regularly rechecked (Figures 10 and Figures 11). Under the guidance of rehabilitation doctors, the patients underwent function exercises of the affected finger or hand. The internal fixation was removed after fracture healing, and the patients were followed up with regularly until the end of rehabilitation training.

Evaluation Criteria for Postoperative Efficacy

The bone grafts of the affected hands healed completely, and the segmental metacarpophalangeal bone defects were

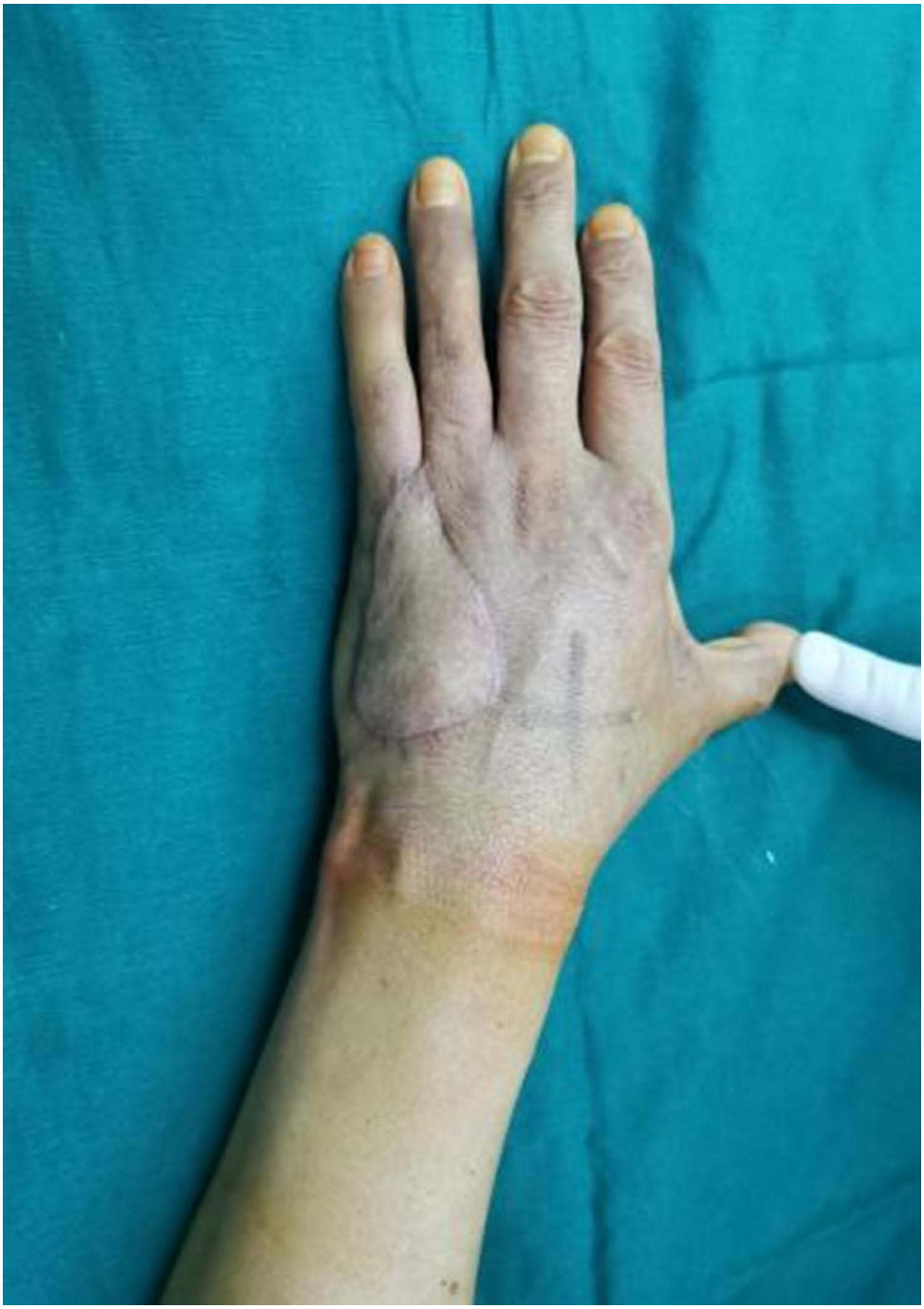

Figure 3 Repair of closing wounds using flaps.

completely repaired. After the end of rehabilitation training of the affected hand, the patient postoperative function was evaluated objectively (Appendix 1) according to the trial standard of hand function evaluation formulated by the Hand Surgery Society of the Chinese Medical Association in 2000.[7] By comparing excellent and good rates, postoperative hospital stay, fracture healing time, and total adverse events between the two groups, the curative effects, advantages, and disadvantages of the two methods in treating segmental metacarpophalangeal bone defects were evaluated.

Statistical Analysis

Data were analyzed using the SPSS 19.0 software. Measurement data, such as the length of hospital stay, fracture healing

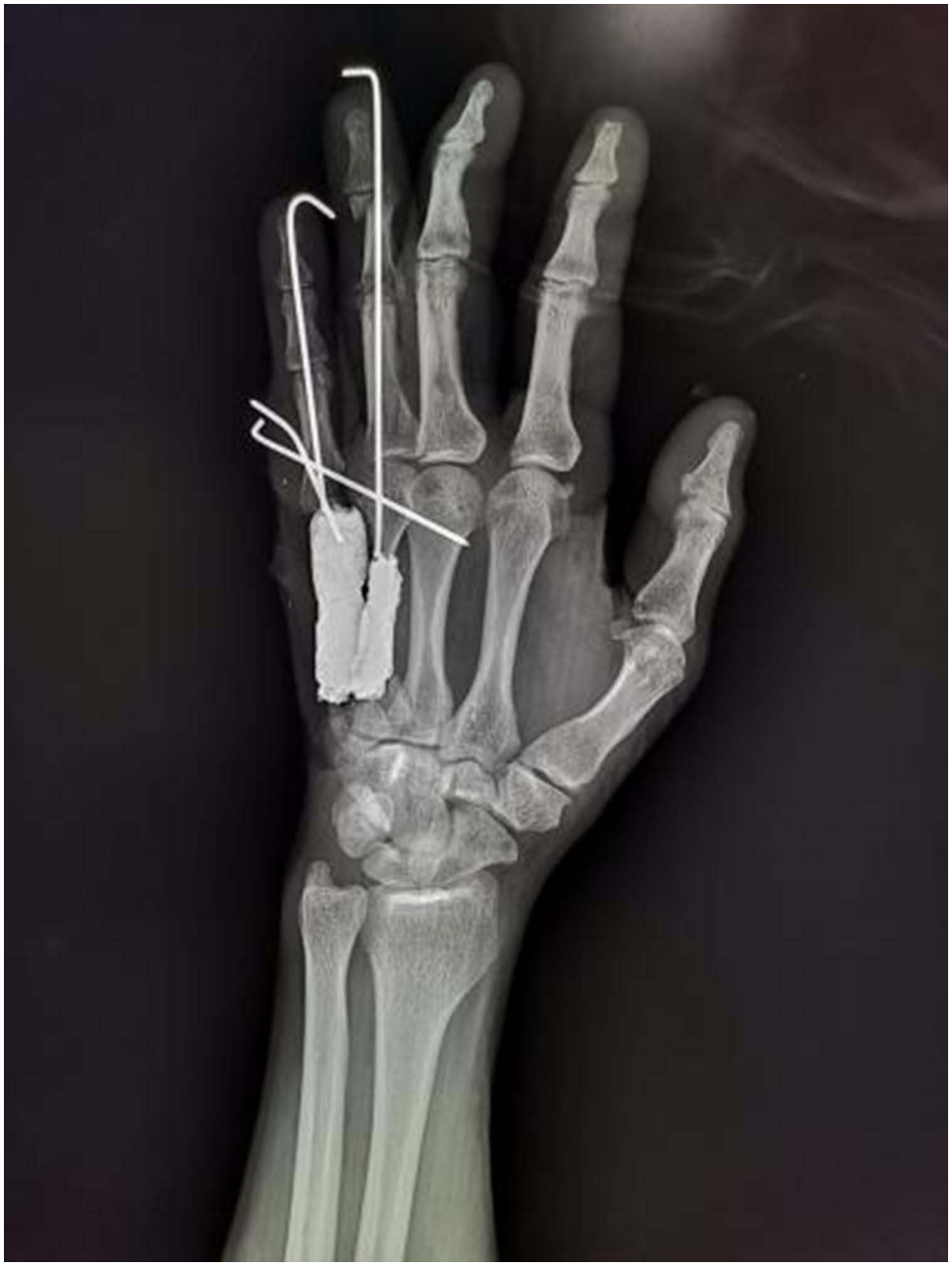

Figure 4 Postoperative reexamination of an X-ray displaying that the bone cement component is filled in the segmental metacarpal bone defect area.

time, and the functional score of the affected limb, were expressed as mean ± standard deviation (x ± SD) and compared between groups using a *t*-test. Count data, such as major and minor adverse events and the incidence of the total adverse events were expressed as (n [%]) and compared between groups using a chi-square test. A P value of <0.05 was considered statistically significant.

Results

All patients were followed up with for 6–24 months (average = 13.7 months). At the last follow-up, hand function was assessed objectively according to the trial standard of the hand function assessment in the standard of upper limb function assessment formulated by the Hand Surgery Society of the Chinese Medical Association in 2000.

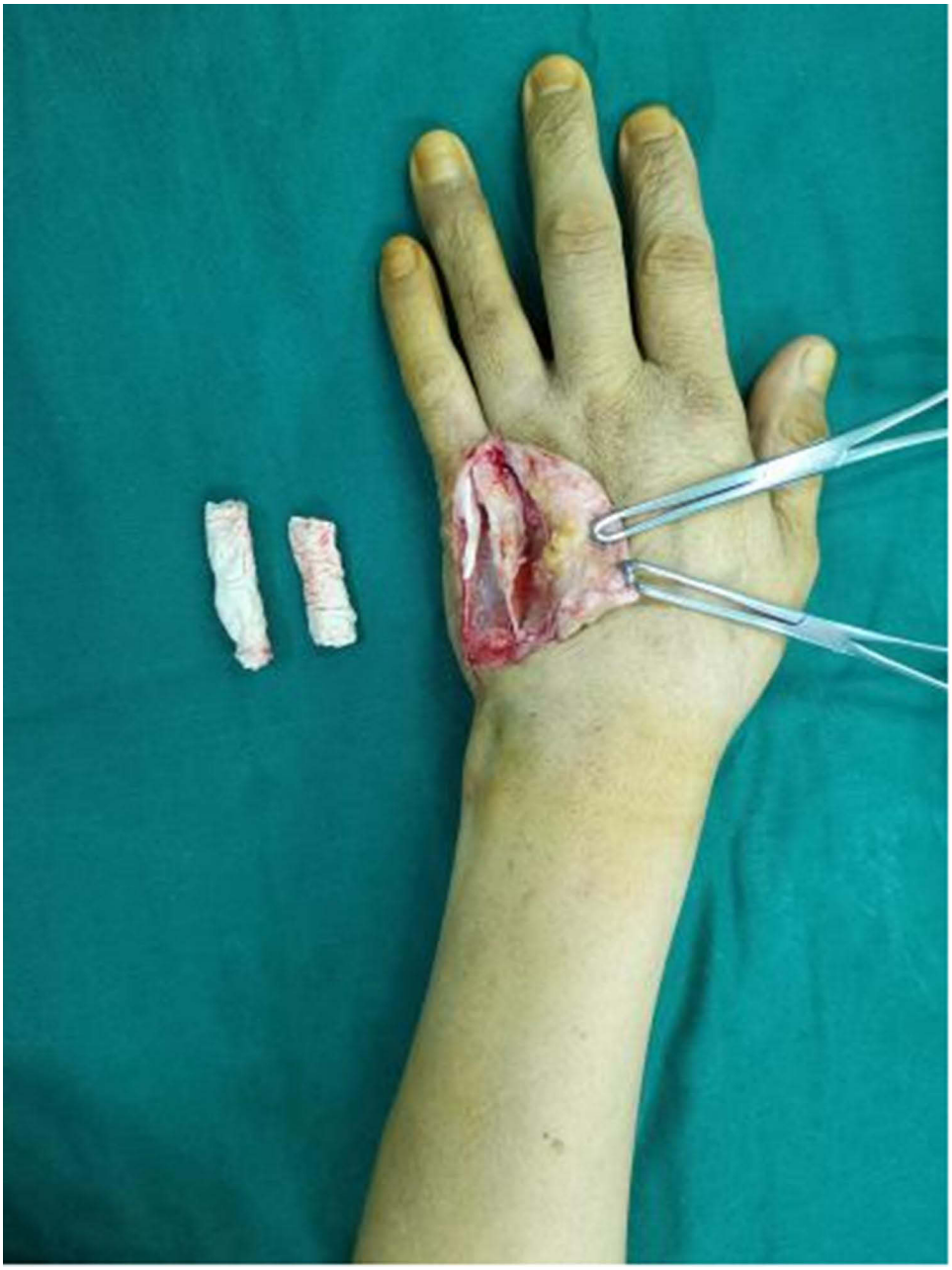

Figure 5 Removal of the bone cement unit in the second operation to protect the integrity of the induction membrane.

There was no significant difference between the two groups in terms of age, gender, function of affected hands and fingers, operation times, causes of bone defect, fingers, and other clinical data ($P > 0.05$) (Table 1); hence, the two groups were comparable.

Delayed healing of segmental bone defects was found in 1 patient in the modified group and in 3 patients in the external fixation group, and non-healing with bone resorption was found in 2 patients in the external fixation group. All 6 patients achieved bone healing after bone replantation and shock-wave therapy.

Patients with multiple fractures experienced a good curative effect, and they all achieved early healing. The rate of fracture healing was 0% in the modified group and 11.76% in the external fixation group. The improved group had a shorter length of postoperative hospital stay, a shorter fracture healing time, and a higher functional score of the

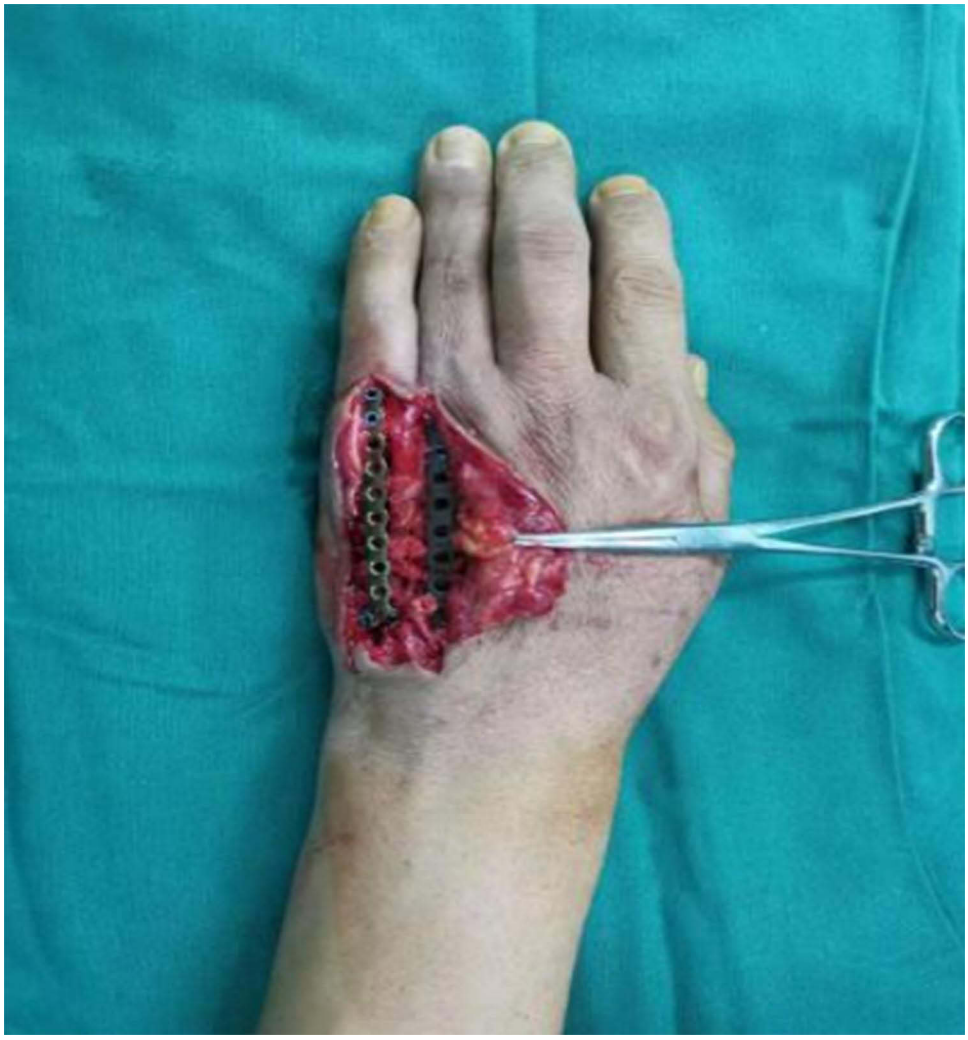

Figure 6 Fixation of the broken ends of the fracture with an autogenous cancellous bone plate implanted into the induction membrane.

affected limb (Table 2); the differences were statistically significant ($P < 0.05$). After large metacarpal and phalangeal defect repair and rehabilitation training, the functional evaluation of the affected limb in the improved group was better than in the external fixation group; the difference was statistically significant ($P < 0.05$) (Table 3). The improved group had significantly less complications than the external fixator group.

In the improved group, there were 8 cases of major complications, 2 cases of nonunion of fracture broken end absorption, 3 cases of delayed healing, and 2 cases of recurrence of surgical incision infection in the external fixator group. Secondary healing of the surgical incision was found in 1 case. Furthermore, there were 7 cases of secondary complications, including 2 cases of delayed healing of surgical incision, 3 cases of abnormal pain sensation in the autologous bone donor area, and 2 cases of finger numbness.

In the improved group, the main complications were 5 cases: 2 cases of delayed fracture end healing and 3 cases of secondary healing of the surgical incision and flap edge. There were 11 cases of secondary complications (including 4 cases of nail canal infection, 3 cases of excessive tension of the external fixation stent elastic device, and 2 cases of delayed healing of the surgical incision; 1 patient suffered from finger numbness, and 1 patient suffered from abnormal pain sensation in the autologous bone donor area).

The difference between the two groups was statistically significant ($P < 0.05$) (Table 4).

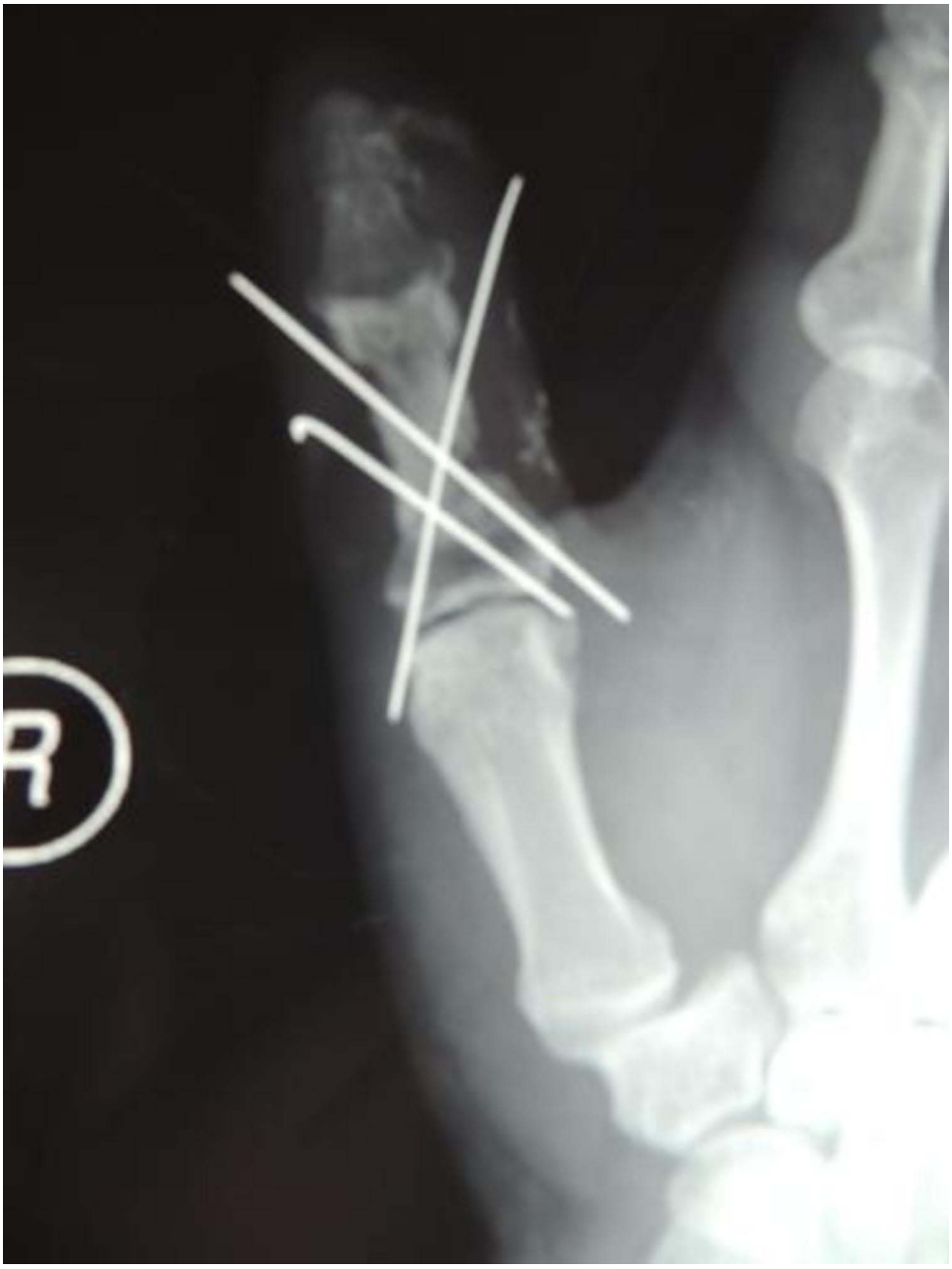

Figure 7 Extensive vermiphagocytic destruction of osteomyelitis with bone resorption after an operation of the proximal phalanx fracture of the right thumb.

Discussion

In recent years, the number of patients with large metacarpophalangeal bone defects has been increasing. From 2015 to 2020, the number of patients with large metacarpophalangeal bone defects increased by nearly 10% yearly.The treatment of large segment metacarpal and phalanx bone defects in complex conditions is relatively difficult, with long course of treatment, many postoperative complications and poor effect. It is a hot spot and difficult point for hand surgeons.[8] In view of the diagnosis and treatment status of large metacarpal and phalanx bone defects, many treatment plans have been designed, but none of these treatment plans can perfectly solve all the problems of large metacarpal and phalanx bones.[9]

Use of the traditional Kirschner wire external fixation bracket combined with autologous bone transplantation has achieved good therapeutic results in the treatment of large metacarpal and phalangeal bone defects.[10] However, the

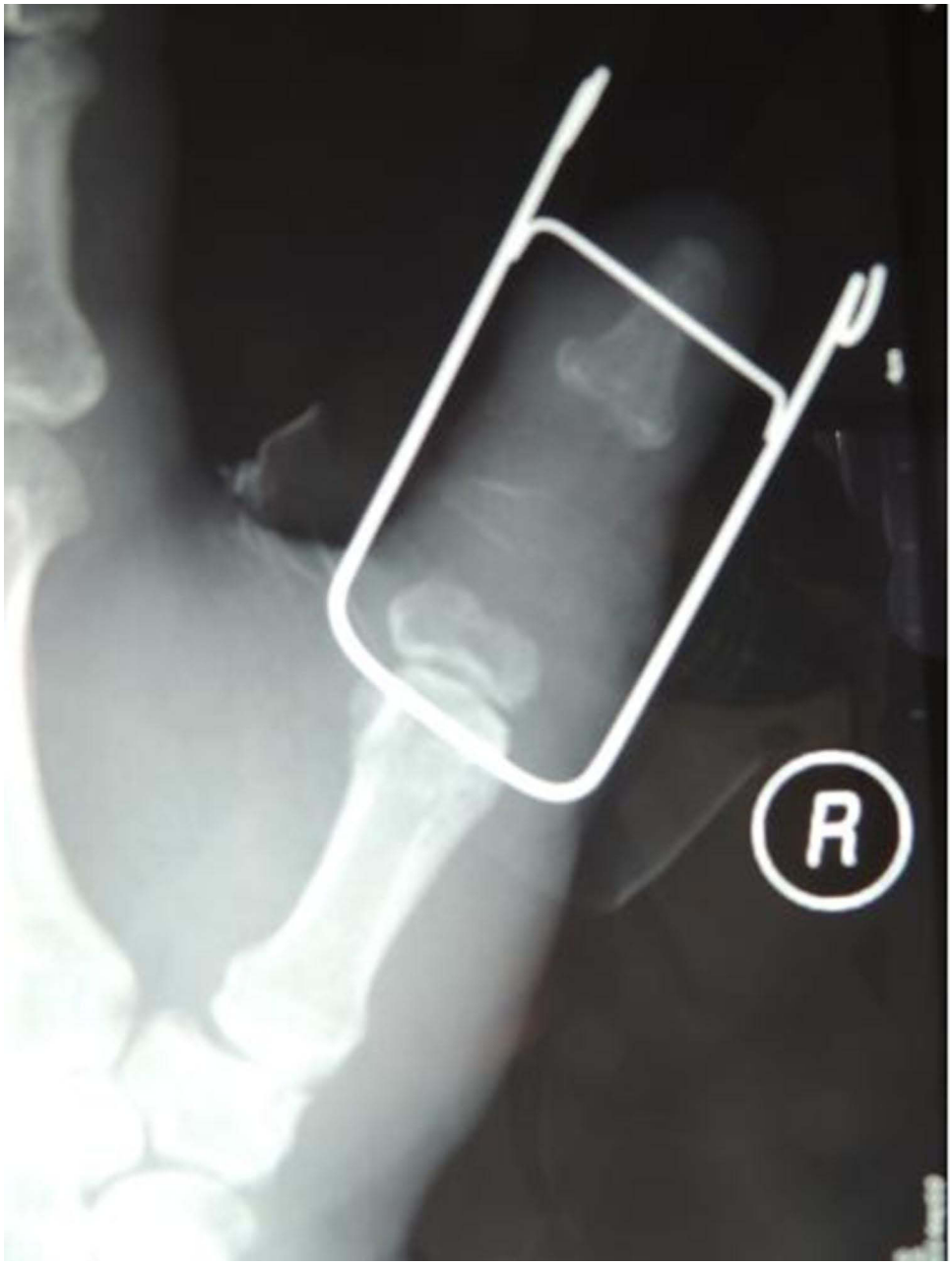

Figure 8 Cleaning and destruction of the bone and installation a self-made Kirschner wire external fixator in the broken ends of segmental bone defects.

incidence of nail canal infection of the external fixation stent, which requires regular nursing, is high. Tension adjustment of the external fixation stent can easily become low or high, and the course of disease is relatively long; thus, autologous bone transplantation is still needed.

Traditional bone transplantation for long bone defects has certain limitations and deficiencies.For example, the fracture healing process is slow and only suitable for the treatment of small bone defects, once the length of bone defects is large, the risk of graft absorption and fracture non-union is high.[11] Although an external fixator can maintain the bone defect length, the bone defect is filled with scar tissue and needs to be completely removed during secondary bone grafting; this increases the risk of neurovascular injury. There are also certain limitations in the treatment of large metacarpal bone defects and distal segment bone defects.[12]

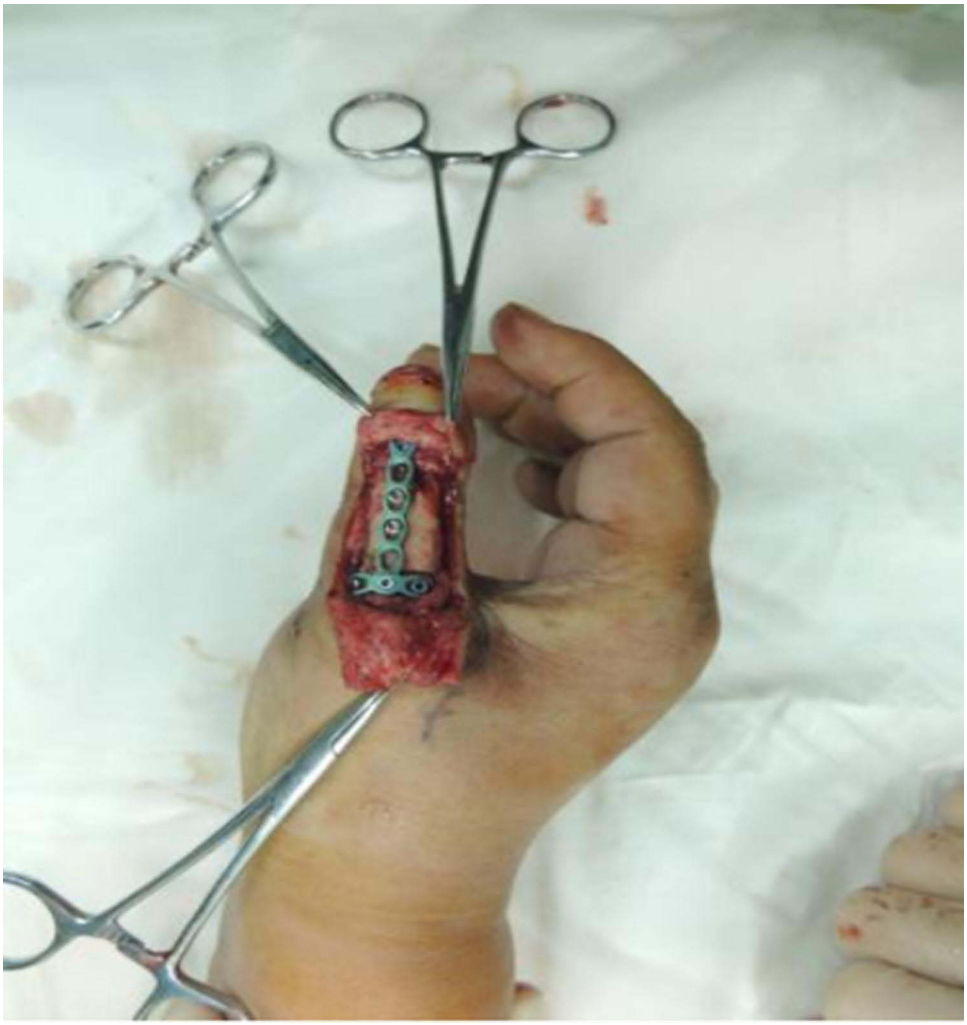

Figure 9 Bone defect filled with iliac bone graft and internal fixation with a plate after wound infection control.

At present, Masquelet technique is an ideal scheme for the treatment of large bone defects. It has the advantages of a simple surgical method, short treatment cycle, accurate effect, low cost, wide indications, and low requirements for surgical conditions and instruments.[13] However, Masquelet technique is mainly used for long bone defects of limbs, such as tibiofibula,[14] and has not been widely applied in the treatment of hand bone defects.[15] In view of the anatomical characteristics and surgical requirements of the hand, we have innovatively improved the Masquelet technique and used it to treat various forms of large metacarpophalangeal bone defects; satisfactory therapeutic results have been achieved.

The operation method improvement is reflected in the module's adoption of in vitro plastic to make a hollow bone cement cylinder in order to avoid high heat temperature in the plastic process of bone cement and damage to the adjacent blood vessels and nerve bundles, which can affect the blood supply as well as the feeling in the affected fingers after operation.

In addition, the in vitro operation is convenient and easy to conduct; this can ensure the smooth appearance of the created bone cement and avoid the difficulties of secondary removal so as to damage the induction membrane.

The bone cement cylinder is reserved and made into a hollow shape in advance to facilitate the internal fixation of Kirschner wire through the bone cement module; this is used to fix the broken end of the proximal and distal fracture.

Modified Masquelet technique uses a hollow bone cement module to fill the bone defect; this not only maintains the length of the bone defect but also avoids the bone graft cavity being filled and narrowed by scar tissue secondary to the traditional

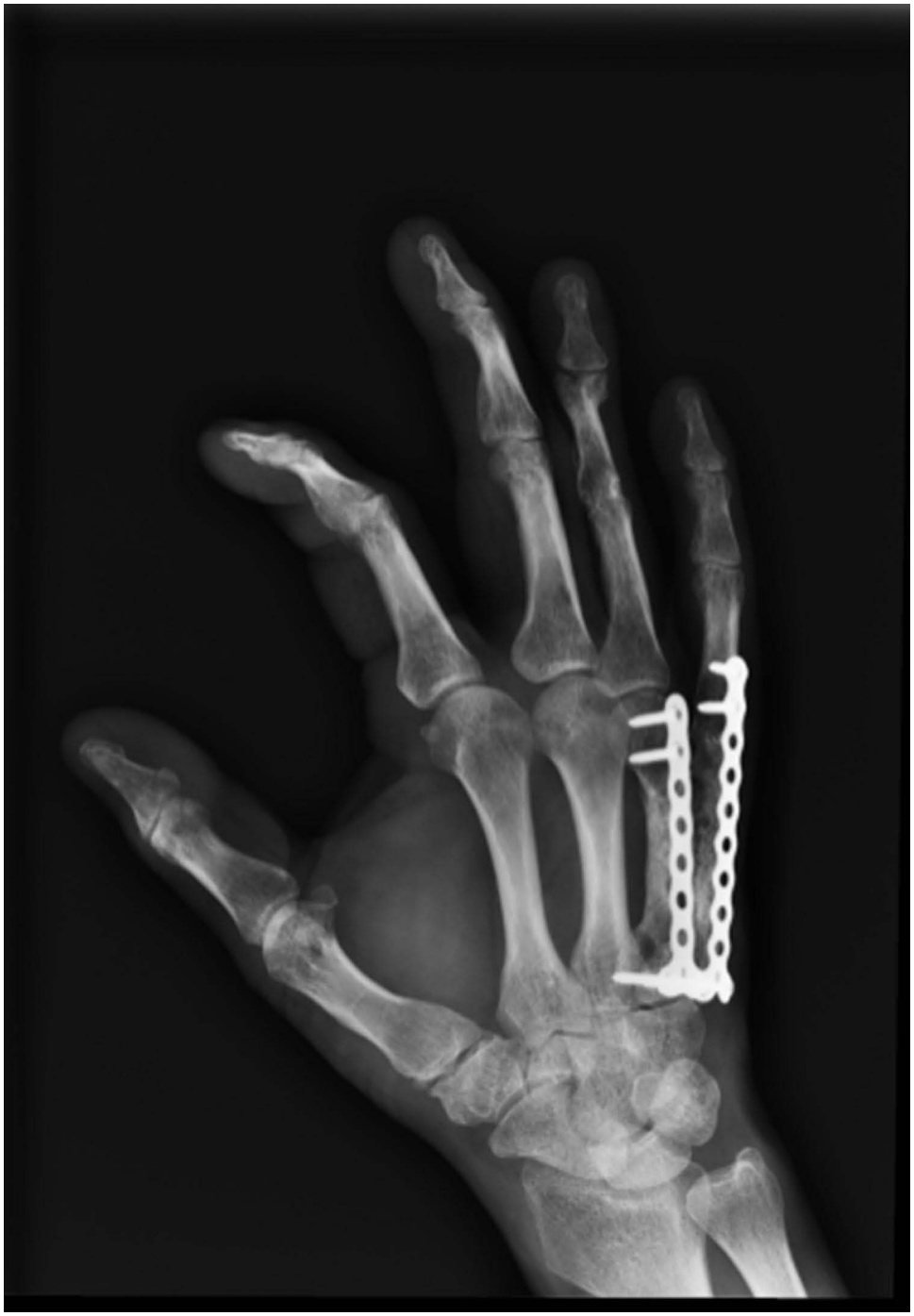

Figure 10 Healing of free and grafted cancellous bone and broken ends of the fracture.

external fixation stent and bow needle technology. In addition, the modified Masquelet technique for the treatment of large metacarpal and phalangeal bone defects is not limited by the length of the defect, and the indications are relatively wide.

Moreover, the transplanted bone can use autologous bone or the mixed bone of autologous bone and allogeneic bone; this reduces the dosage of autologous bone to a certain extent, lowering the risk of complications in the donor area.

The induced membrane formed using the Masquelet technique is similar to periosteum in structure and function,[16] as it reduces the bone resorption and promotes the healing speed of bone graft; hence, it not only ensures the curative effect but also reduces the treatment cycle.

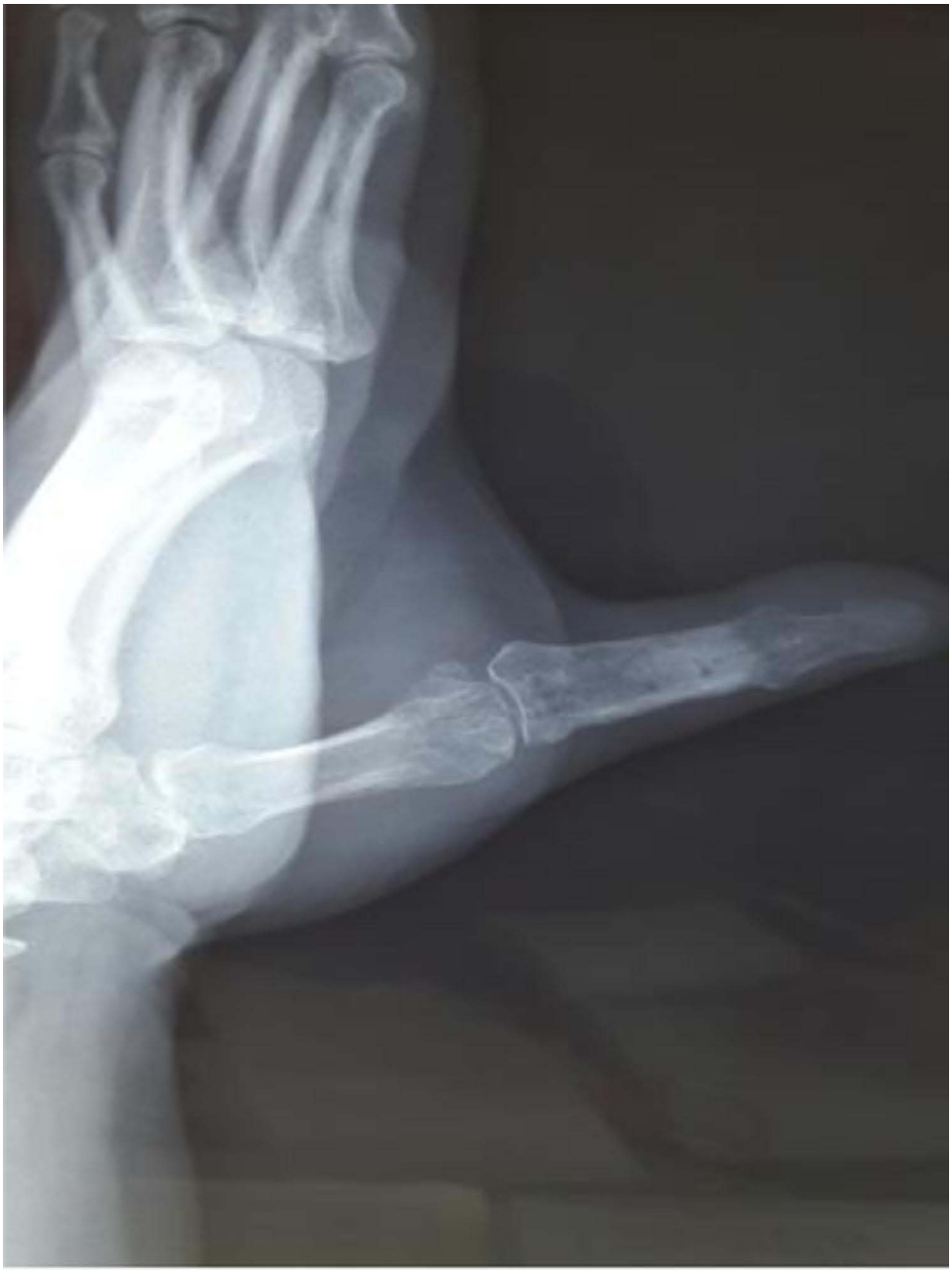

Figure 11 Healing of free and grafted iliac bone graft and broken ends of the fracture.

Bone cement module carries vancomycin, which can continuously and effectively prevent and control wound infection. It can reduce the occurrence of complications, such as infection and osteomyelitis. Controlling inflammation could promote wound healing as well as reduce secondary discomfort symptoms caused by inflammation. It can also reduce the length of hospital stay to a certain extent. At the same time, the effect of the improved Masquelet technique is reliable and more convenient; the technique avoids the life inconvenience caused by the external fixation stent and the burden of regular care of the external fixation stent. It can also ensure earlier functional exercise and better recovery of the affected limb function in patients.

In the treatment of large metacarpal and phalangeal bone defects using the modified Masquelet technique, a good blood supply to the affected hand or finger must be ensured before operation to avoid postoperative blood supply disorder

Table 1 Comparison of General Data Between the Modified Group and External Fixator Group

Group	The Number of Cases	Gender (Cases)		Age (Years)	Distribution of Injured Fingers						Bone Defect Length	Defect Type (Cases)		Combined Injury (Cases)	Skin Defect	
		Male	Female		Thumb	Index Finger	Middle Finger	Ring Finger	Little Finger	Metacarpal Bone	(cm $\overline{X} \pm S$)	Infectious	Non Infectious		No Defect	(cm2 $\overline{X} \pm S$)
Modified group	15	11	4	34.66 ±10.08	5	4	2	2	1	2	3.16±1.05	12	3	4	2	6.13 ± 0.34
External fixator group	17	12	5	37.17 ±10.97	8	5	2	1	1	0	2.99±0.92	13	4	5	7	6.25 ±0.30
Test statistics	–	0.674		−0.294	–						0.472	0.085		0.043	–	−1.95
P	–	0.86		0.51	0.63						0.55	0.26		1.00	–	0.083

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Table 2 Comparison of Postoperative Length of Hospital Stay, Fracture Healing Time and Functional Score Between the Modified Group and External Fixation Group

Group	The Number of Cases	Post-Operative Length of Hospital Stay (d)	Fracture Healing Time (w)	Functional Score (Points)
Modified group External fixator group	15 17	12.00±1.51 13.11±1.11	9.46±1.18 11.58±2.69	8.00±1.85 6.76±1.43
Test statistics P	- -	−2.4 0.023	−2.81 0.009	2.12 0.042

Table 3 Comparison of Postoperative Affected Limb Function Between the Modified Group and External Fixation Group

Group	The Number of Cases	Excellent (% (Cases))	Good (% (Cases))	Acceptable (% (Cases))	Poor (% (Cases))
Modified group External fixator group	15 17	20.00 (3) 5.89 (1)	53.33 (8) 58.82 (10)	26.67 (4) 23.53 (4)	0.00 (0) 11.76 (2)
χ^2 P	– –	1.125 0.289	0.027 0.869	0.025 0.874	1.678 0.195

Table 4 Comparison of the Incidence of Major Complications, Secondary Complications and Overall Complications in the Modified Group and External Fixation Group

Group	The Number of Cases	Incidence of Major Adverse Events (% (Cases))	Incidence of Secondary Adverse Events (%(Cases))	Incidence of Overall Adverse Events (% (Cases))
Modified group External fixator group	15 17	30.0 (5) 47.1 (8)	46.6 (7) 64.7 (11)	53.3 (8) 70.5 (12)
Test statistics P	– –	1.21 0.02	3.37 0.01	3.89 0.03

or even ischemic necrosis of the affected finger. Strict control of wound infection, good coverage of skin and soft tissue, and integrity of the induced membrane are the key to successful operation.

The prerequisite for Masquelet technique application is good skin and soft tissue coverage; otherwise, the closed wound requires repair using a flap before Masquelet operation.

Wound pollution should be removed via thorough debridement, and wound inflammation in cases of infection or osteomyelitis should be completely controlled to avoid uncontrollable infection leading to operation failure.

The improved Masquelet operation requires early perioperative rehabilitation training intervention to prevent joint stiffness and other dysfunction secondary to long-term braking or disuse. In addition, the improved Masquelet technique cannot achieve the recovery of joint function in large metacarpophalangeal bone defects involving the joint.

The operation is very detailed, and improper treatment may influence the treatment effect and even lead to operation failure. Therefore, effective communication with patients and their families before operation should take place fully and effectively.

In conclusion, the modified Masquelet technique is an effective treatment method for large metacarpophalangeal bone defects. It can meet the expected recovery of organizational structure continuity and index protection (limb). However, the number of cases in the experimental research is still small, comprising mostly single fracture cases; hence, there is a certain result bias in the clinical data.

The modified Masquelet technique still requires further study, accumulation of experience, and improvement of the operation method. It should include a higher number of multiple fracture cases, and the number of sample cases should

be increased to further verify the difference between the two treatment schemes and provide a more objective and scientific theoretical basis reference for the clinical treatment of large metacarpophalangeal defects.

Ethics Approval and Consent to Participate

The present study was conducted in accordance with the declaration of Helsinki and with approval from the ethics committee of the No. 4 People's Hospital of Hengshui. A written informed consent was obtained from all participants.

Disclosure

All authors have contributed significantly to the manuscript and declare that the work is original and has not been submitted or published elsewhere. None of the authors have any financial disclosure and all authors report no conflicts of interest for this work.

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