BMC Musculoskeletal Disorders

RESEARCH Open Access

A minimally invasive technique for correcting extra-articular malunions of metacarpal fractures

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Abstract

Purpose This study aimed to assess the efficiency of a minimally invasive technique for correcting malunions of extra-articular metacarpal fractures, followed by percutaneous fixation using a cemented K-wire frame.

Methods From January 2018 to January 2022, 31 patients (31 malunions of extra-articular metacarpal fractures) were treated. The mean age of the patients was 32 years (range, 21–52 years). There were 25 fifth, 4 fourth, 1 third, and 1 second metacarpal malunion. Range of motion of the fingers was assessed based on the total active motion scoring system of American Society for Surgery of the Hand. Range of motion of the joint was graded as excellent (85–100%), good (70–84%), fair (50–69%), and poor (< 50%) by comparing to the opposite uninjured finger. The aesthetic appearance of the hand was evaluated based on the 10-cm visual analogue scale. Patient satisfaction was assessed using the Short Assessment of Patient Satisfaction (0–10, very dissatisfied; 11–18, dissatisfied; 19–26, satisfied; and 27–28, very satisfied).

Results Bone healing was achieved in all patients after a mean of 5.4 weeks (range, 4–10 weeks). The mean follow-up period was 27 months (range, 24–33 months). The mean preoperative total active motion scale was 233° (range, 185°–288°), and the postoperative scale was 263° (range, 235°–290°). There were 8 excellent, 19 good, and 1 fair result. There were 15 very satisfied and 13 satisfied with the results. The mean preoperative aesthetic appearance of the hand was 7 cm (range, 5–8 cm), and the postoperative appearance was 10 cm (range, 9–10 cm).

Conclusion The minimally invasive technique is effective for correcting extra-articular malunions of metacarpal fractures. Rigid fixation allows fracture healing and early joint motion of the injured hand. The technique improves hand function, patient satisfaction, and aesthetic appearance.

Level of evidence Therapeutic study, Level IVa.

Keywords Minimally invasive technique, Metacarpal fracture, Extra-articular malunions, Percutaneous fixation, Cemented K-wire frame

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Introduction

Metacarpal fractures comprise approximately 36% of cases in daily emergencies, mostly due to road traffic accidents, falls, and assaults [1, 2]. Most metacarpal fractures are extra-articular and treated conservatively using closed manual repositioning and immobilization [3]. However, malunion is the most common complication, and the optimal treatment strategies are still controversial [4].

Malunions of extra-articular metacarpal fractures (MEAMFs) are defined as healing of an extra-articular metacarpal fracture in an abnormal position, including bone shortening, angulation, malrotation, etc. MEAMFs present a combination of functional and aesthetic problems [5]. Hoigne et al. [6] corrected the angular malunions using dorsal closing wedge osteotomy, followed by fixation with a plate and screw system. The outcomes were acceptable, but the major drawback is metacarpal shortening. Thurston [7] developed pivot osteotomy combined with open and closed wedge osteotomy. Although angular malunion was corrected successfully, the length of the metacarpal was not completely restored. Del Piñal et al. [8] corrected 16 MEAMFs with an open or closed osteotomy though 2-cm incision, followed by bone grafting. However, placing a longitudinal cannulated screw through the metacarpal head damaged the articular surface.

This retrospective study aimed to assess the efficiency of a minimally invasive technique for correcting MEAMFs through a 3-mm incision, followed by percutaneous fixation using a cemented K-wire frame.

Materials and methods

The institutional review boards of the participating hospitals approved the study (Number K2024-129-1). Informed consent was obtained from each patient.

From January 2018 to January 2022, 31 patients (31 MEAMFs) were treated in our hospitals. Preoperative X-rays were obtained in all patients (Fig. 1A, B). The inclusion criteria of the study were (1) a confirmed MEAMF with angulation > 45°; (2) bone shortening > 5 mm; (3) rotational deformity; and (4) a patient's cosmetic unhappiness due to a depressed fifth metacarpophalangeal (MCP) joint. The exclusion criteria included (1) unwillingness to correct the malunion; (2) minor deformities; (3) the need for excision of fibrous scar tissue at the nonunion site; (4) uncooperative patients, and (5) infectious condition, rheumatoid arthritis, or gout.

Surgical technique

The operation was performed under local anaesthesia without tourniquet control. First, we percutaneously stabilized the proximal portion of the metacarpal to the adjacent metacarpal using a 1.5-mm transversal K-wire. Based on the initial fracture pattern, present deformity, and anatomy, the osteotomy site was selected with fluoroscopic guidance. Second, we made a 3-mm longitudinal incision at the osteotomy site where there were no nerves, vessels, or tendons. Through this small incision, we created multiple drill holes in different directions using a 1.0- to 1.2-mm K-wire along the osteotomy plane (Fig. 1C). We inserted a miniature bone elevator into the osteotomy plane and rotated it to fracture the metacarpal (Fig. 2D). Third, we inserted a 1.5-mm K-wire as a joystick into the distal fragment to correct the deformity. We manually inserted a 1.5-mm axial K-wire into the surrounding soft tissue of the metacarpal to stabilize the reduction temporarily. We inserted 2 to 3 1.5-mm transversal K-wires into the distal fragment and one 1.5-mm K-wire into the proximal fragment. Desired reduction and wire position were confirmed with fluoroscopy. We confirmed that there was no rotational deformity based on the finger flexed toward the scaphoid tubercle and no existence of overlapping fingers. Bone shortening was compared to the adjacent metacarpal. Angulation was measured by the dorsal cortical line of the distal and proximal fragments [9]. Fourth, the K-wires were bent at a level about 1.5 cm distal to the skin, toward the fracture site. We mixed Monomer (liquid) and polymer (powder) of bone cement (Single dose 40 g, US$170; PALACOS®, Hanau, Germany). When the bone cement viscosity changed over time from a runny liquid into a dough-like state, we applied it to the bent K-wire ends, and then waited for it to harden into solid material. The axial K-wire for provisional fixation was removed. Fifth, satisfactory alignment of the fracture was confirmed with fluoroscopy. Finally, small bone allografts were inserted into the fracture site through a small wire guide placed at the incision (Fig. 1E). The incision was closed with one stitch.

Postoperative management

After surgery, we used a dorsal splint to protect the system, but there was no restriction to joint motion. Active motion of the fingers started on the second postoperative day as tolerated. Pin care was done every 3–5 days as needed. Once bone healing with callus formation was observed on X-rays, the K-wires were cut off and removed.

Outcome evaluation

All assessments were performed by a senior hand surgeon (YY) who did not attend the treatments. Bone healing was confirmed when we observed a bridging callus across the fracture line on X-rays. Nonunion was defined as no evidence of bone healing observed 3 months after surgery. Bone shortening was measured by comparing

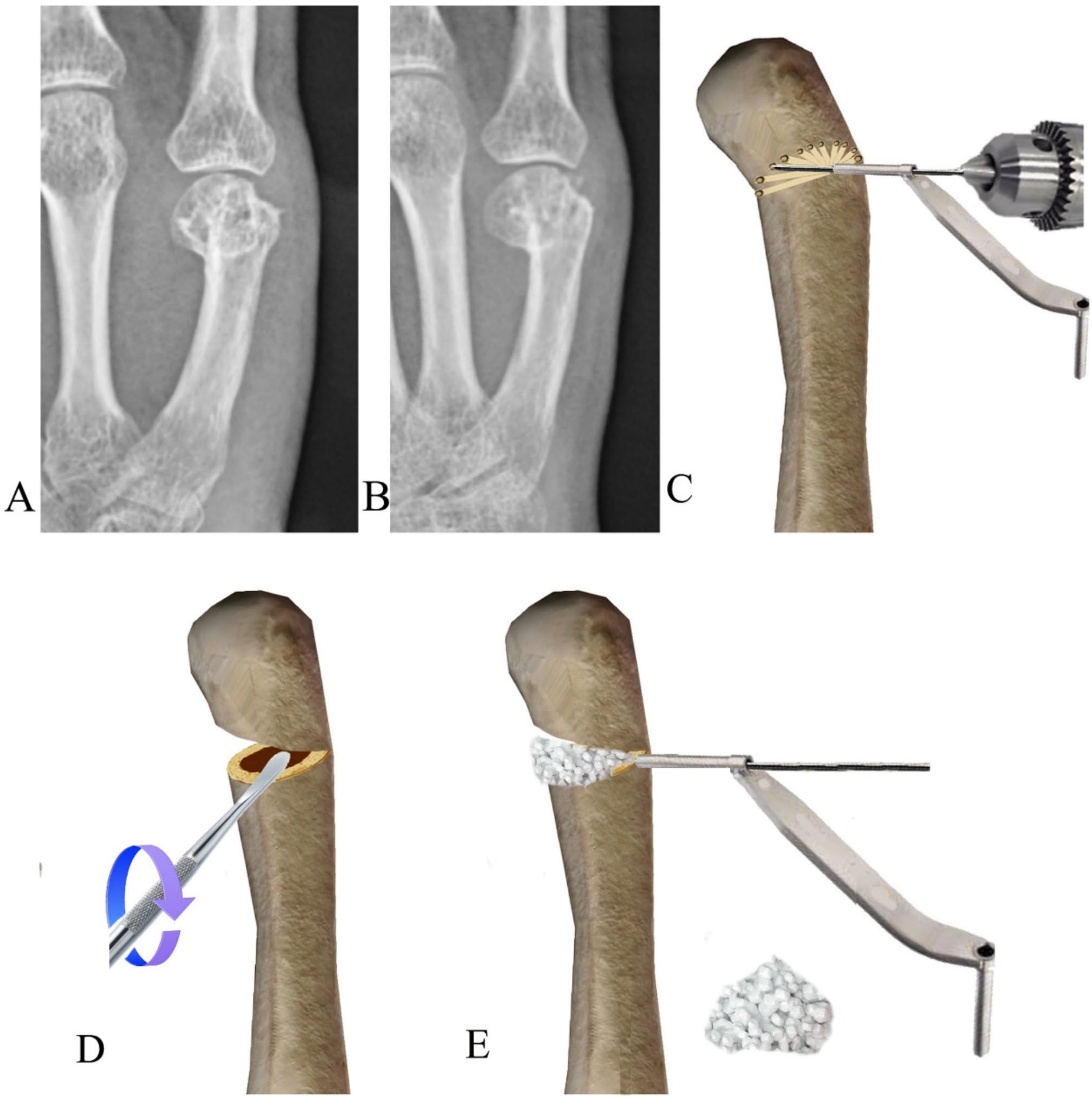

Fig. 1 **A** posteroanterior (PA) X-ray shows a malunion of the fifth metacarpal neck fracture 3 months after injury. **B**. Oblique X-ray. **C**. A 1.0 to 1.2 mm K-wire with a guide is inserted through a 3-mm incision made over the ulnar aspect of the fifth metacarpal, and multiple drill holes are made in the osteotomy plane. **D**. The fifth metacarpal is fractured by inserting and rotating a mini-bone elevator (arrow). **E**. The void is filled with allografts inserted through a guide

the axial of the opposite fifth metacarpal on posteroanterior X-rays. We evaluated the angulation of the metacarpal on lateral X-rays by measuring the angle created by the dorsal cortical line of the distal and proximal fragments [9]. Rotational deformity was clinically assessed by observing the alignment of the nail plate of the injured finger, compared to the adjacent finger [10, 11]. We evaluated the range of motion of the finger based on the total active motion scoring system of American Society for Surgery of the Hand [12]. The motion is calculated by adding the active range of motion of the MCP, proximal interphalangeal, and distal interphalangeal joints. Joint motion was graded as excellent (85–100%), good (70–84%), fair (50–69%), and poor (<50% by comparing to the opposite finger). To exclude the strength discrepancy between the dominant and non-dominant hands, grip

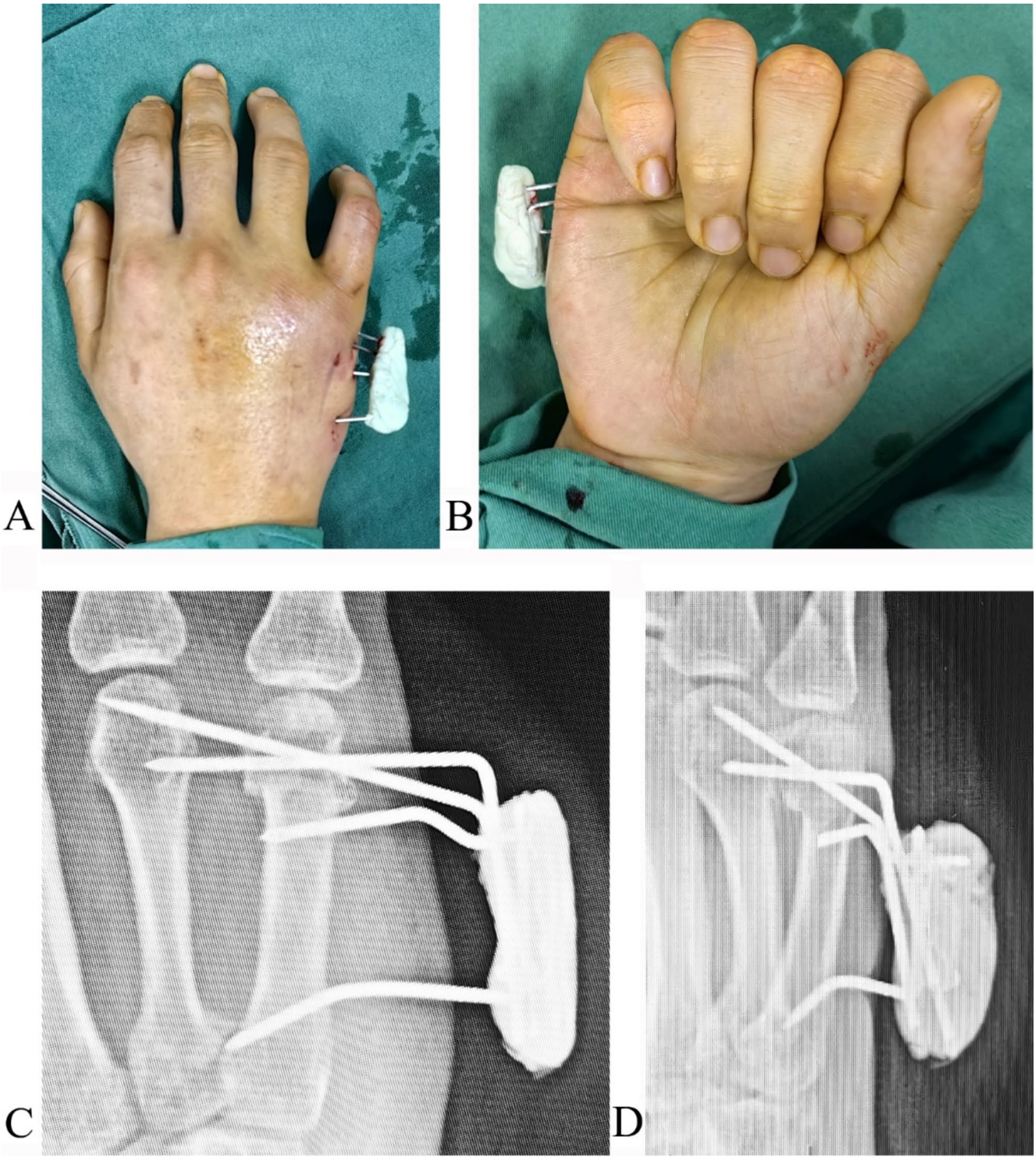

Fig. 2 The fracture is fixed with a K-wire and bone-cement frame. **A**. Dorsal view immediately after surgery. **B**. Flexion. **C**. A PA X-ray shows bone healing 1.5 months after surgery. **D**. Oblique X-ray

Table 1 Demographic and clinical characteristics for 28 patients

Age (year)	**32 (21–52)**
Sex (male : female)	26 : 2
Side (left : right)	12 :16
Metacarpals (n)	
2th	1
3th	1
4th	4
5th	25
Dominant hand (n)	17 : 11
Injury mechanism (n)	
Crushing	5
Punch	14
Rotation	6
Road traffic accident	3
Duration from injury to surgery (day)	52 (35–183)
Fracture type (n)	
Transversal	12
Oblique	9
Comminuted	7
Fracture site (n)	
Neck	21
Shaft	13
Base	4
Bone healing (week)	5.4 (4–10)
Follow-up time (month)	27 (24–33)

Data are expressed as mean and range.

Table 2 Correction of the malunions after bone healing

	Pre-operation	**Immediately after surgery**
Angulation on X-rays (°)	46 (12–66)	1 (0–6)
Shortening on X-rays (mm)	5 (2–8)	1 (0–3)
Rotation (°) *	9 (0–17)	0 (0–4)

*, measured using the angle between the middle and ring fingernail during extension

strength of the dominant hand was 15% higher than that of the non-dominant hand [13]. Dorsal prominence, the pain of the injured site, and aesthetic appearance of the hand were evaluated based on the 10-cm visual analogue scale. Patient satisfaction was assessed using the Short Assessment of Patient Satisfaction (SAPS; 0–10, very dissatisfied; 11–18, dissatisfied; 19–26, satisfied; 27–28, very satisfied) [14].

Results

The mean age of the patients was 32 years (range, 21–52 years). The mean duration from injury to surgery was 52 days (range, 35–183 days). There were 25 fifth, 4 fourth, 1 third, and 1 second metacarpal malunions. The initial fractures were transversal ($n=12$), oblique ($n=9$), and comminuted fractures ($n=7$). The fracture sites were neck ($n=21$), shaft ($n=13$), and base ($n=4$) of the metacarpals (Table 1).

Table 3 Outcomes of 28 patients at the final follow-up

	Injured side	**Opposite side**
Active ROM (°, mean, range)		
MCP joint	54 (32–84)	78 (68–85)
PIP joint	96 (80–117)	104 (94–118)
DIP joint	81 (70–87)	83 (73–87)
TAM scale (°, mean, range)	233 (185–288)	263 (235–290)
Excellent (100% normal, n)	8	
Good (75-99% normal, n)	19	
Fair (50-74% normal, n)	1	
Poor (< 50% normal, n)	0	
Grip strength (kg)*	41.2 (32.4–47.6)	44.5 (37.1–48.9)
Dorsal prominence (VAS, mean, range)	0 (0–1)	
Pain (cm, mean, range)	0 (0–1)	
Satisfaction (SAPS, n)		
Very satisfied (27–28)	15	
Satisfied (19–26)	13	
Dissatisfied (11–18)	0	
Very dissatisfied (0–10)	0	
Appearance (VAS, mean, range)	10 (9–10)	

ROM, range of motion; TAM, total active motion; MCP, metacarpophalangeal; PIP, proximal interphalangeal;

DIP, distal interphalangeal; VAS, 10-cm visual analog scale; SAPS, Short Assessment of Patient Satisfaction

The mean preoperative apex angulation of metacarpals was 46° (range, 12°–66°), and the mean postoperative angulation was 1° (range, 0°–6°). The mean preoperative bone shortening was 5 mm (range, 2–8 mm), and the mean postoperative bone shortening was 1 mm (range, 0–3 mm). The mean rotation of the fifth metacarpal was 9° (range, 0°–17°), and the mean postoperative rotation was 0 mm (range, 0°–4°) (Table 2). No apparent complications were observed. All K-wires stayed at the primary locations until bone healing was achieved. No wire loosening or migration occurred. No pin site infection was observed. Bone healing was achieved in all patients after a mean of 5.4 weeks (range, 4–10 weeks). No special rehabilitation therapy was performed.

The mean follow-up period was 27 months (range, 24–33 months). The mean preoperative TAM scale was 233° (range, 185°–288°), and the postoperative scale was 263° (range, 235°–290°). There were 8 excellent, 19 good, and 1 fair result. The mean grip strength of the injured and opposite hands were 41.2 kg (range, 32.4–47.6 kg) and 44.5 kg (range, 37.1–48.9 kg), respectively. There were 15 very satisfied and 13 satisfactory results. The mean preoperative aesthetic appearance of the hand was 7 cm (range, 5–8 cm), and postoperative appearance was 10 cm (range, 9–10 cm) (Table 3). Figures 3A-C and 4A-J show another neck malunion. Figure 5A-K shows a shaft malunion.

Fig. 3 Another malunion of the fifth metacarpal neck fracture. **A**. An oblique fracture pattern on a PA X-ray. **B**. An oblique X-ray. **C**. A lateral X-ray

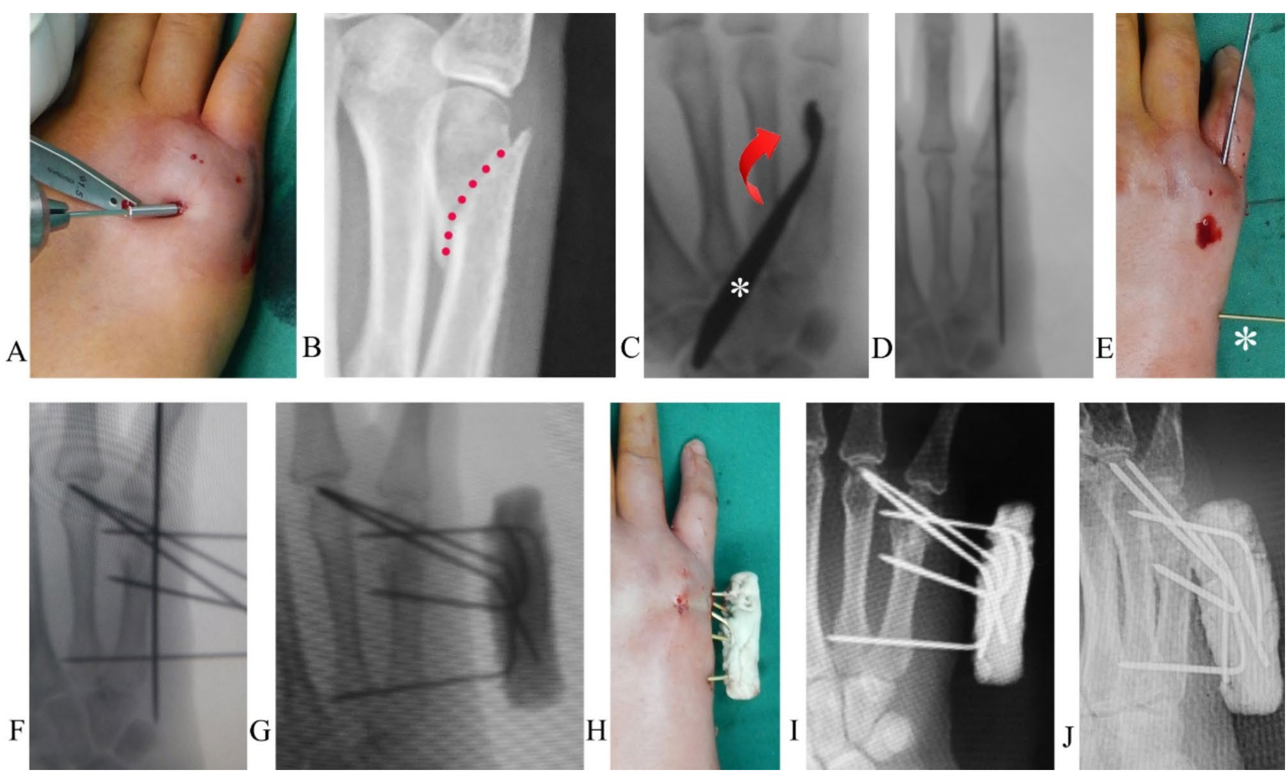

Fig. 4 Osteotomy, fixation, and bone grafting. **A**. Osteotomy through a 3-mm incision made over the dorsoradial aspect of the metacarpal. **B**. Osteotomy line marked on a PA X-ray. **C**. The fifth metacarpal neck is fractured by inserting and rotating (arrow) a mini bone elevator (*), and the distal fragment is reduced with the elevator. **D**. Reduction is temporarily maintained using a K-wire inserted manually into the soft tissues surrounding the fifth metacarpal. **E**. A The proximal fragment is stabilized to the fourth metacarpal using a 1.5-mm transversal K-wire (*). **F**. A PA X-ray shows more K-wires are added. **G**. The wire ends are bent and mounted with bone cement. **H**. Appearance. **I**. A PA X-ray shows bone healing after 6 weeks. **J**. An oblique X-ray

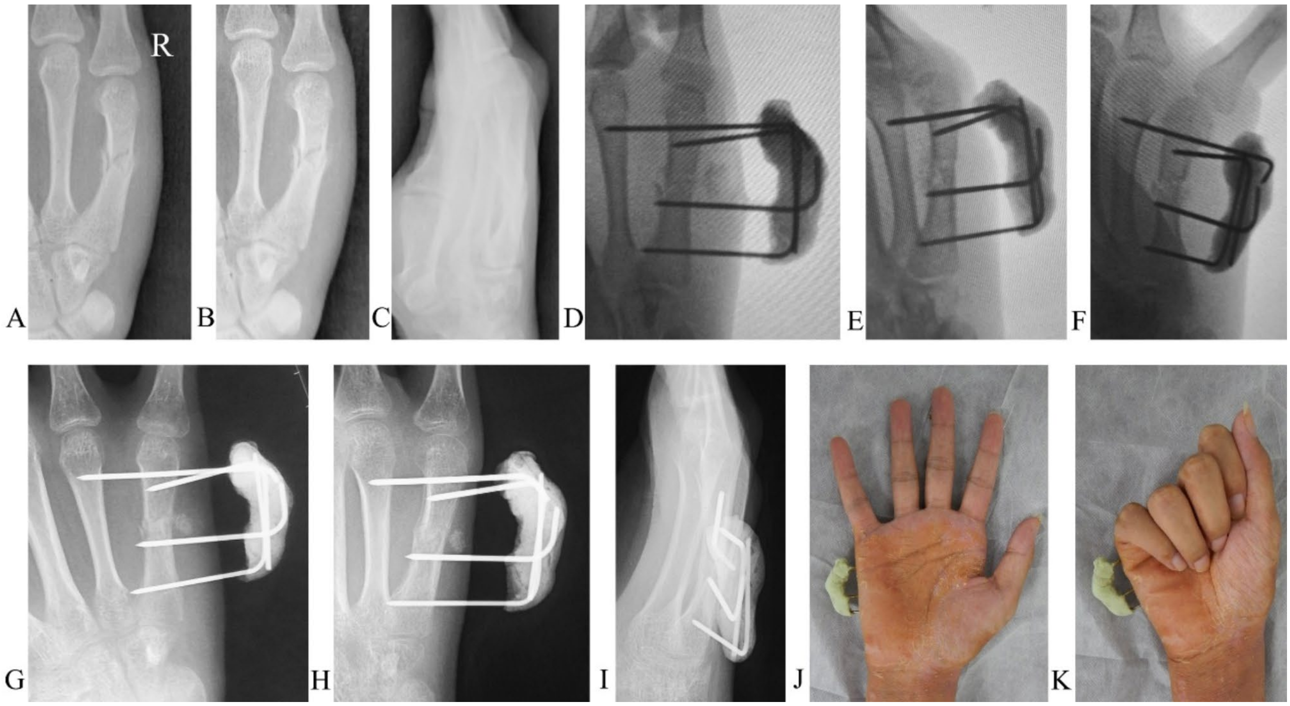

Fig. 5 A malunion of the fifth metacarpal shaft fracture. **A**. A PA X-ray. **B**. An oblique X-ray. **C**. A lateral X-ray. **D**. A PA X-ray shows that osteotomy, fixation, and bong grafting are complete. **E**. An oblique X-ray. **F**. A reverse oblique X-ray. **G**. A PA X-ray shows bone healing after 4 weeks. **H**. An oblique X-ray. **I**. A lateral X-ray. **J**. Extension of the hand 4 weeks after surgery. **K**. Flexion

Discussion

We find that this minimally invasive technique is useful and effective for correcting extra-articular malunions of metacarpal fractures. Rigid fixation allows fracture healing and early joint motion of injured hand. The technique improves hand function, patient satisfaction, and aesthetic appearance. The complications are minimal and rare.

Some cadaver studies showed that every 2 mm shortening produces 7° of extensor lag of the MCP joint [15, 16]. Kural et al. [17] suggested that shortening < 2 mm did not interfere with hand function, but more than 5 mm was not accepted. Mohammed et al. [18] suggested that metacarpal shortening > 5 mm and angulation > 30° affected the hand function. However, Westbrook et al. [19] found that MEAMFs with dorsal apex angulation may not affect hand function, but 30° was the upper limit for acceptable angulation. Trevisan et al. [20] suggested that shortening > 5 mm should be corrected surgically. Whether the need to perform an osteotomy or not is still controversial, but many surgeons agree that dorsal apex angulation produces a cosmetic issue [21]. Rotational malunion of metacarpal fractures results in overlapping of the affected finger over the adjacent finger [22]. Cosmetic deformity is often marked, and the grip is often impaired [23]. Yoneda et al. [24] precisely assessed rotation of malunion using CT imaging, but the procedure is complex and cannot be used intraoperatively.

Conflicting information exists as malunited metacarpals still achieving good results in pain relief, range of motion, angulation, and rotational deformity [8]. Many osteotomy and fixation techniques have been used for MEAMFs. Open surgery includes osteotomy, plate fixation, and bone grafting. The technique allows early range of motion of the finger, but the drawbacks are extensive dissection, possible implant removal surgery, and implant-related irritation [19]. Hoigne et al. [6] corrected a malunion of the fifth metacarpal neck fracture with 45° angular deformity and internal rotation. They performed a highly precise osteotomy using a Piezosurgery Device instead of a usual oscillating saw. The drawbacks included shortening of the metacarpal due to a closing-wedge osteotomy, open surgery, long operative time, and a special and costly device required. To avoid bone shortening, Thurston [7] developed a combination of opening- and closing-wedge osteotomies using a small oscillating saw. They treated 5 neck and 5 shaft malunions with angular deformities ranging from 35° to 60°. The technique keeps the length of the metacarpal, but the procedure is complex. Del Piñal [8] treated 16 metacarpal malunions by performing an opening- or closing wedge osteotomy through a 5-mm incision, followed by fixation with a cannulated headless screw. The drawbacks are damage to the cartilage of the metacarpal head, possible bone shortening due to screw compression, and inability to control the rotation of the distal fragment. Gollamudi et al. [25]

treated rotational metacarpal malunion treated by osteotomy and plating. The outcomes were good or excellent results, but the drawbacks were open surgery and tendon irritation.

Our technique is much more minimally invasive because osteotomy and bong grafting are performed through a 2- to 3-mm incision, and fracture fixation is achieved percutaneously. During osteotomy, we use a K-wire guide to protect the tendons, nerves, and vessels. It also avoids the K-wire inserted too deep into the soft tissues. Owing to the nature of our technique, only opening-wedge osteotomy can be performed but the minimal injury to the periosteum benefits bone healing. We suggest restoring the normal length of the metacarpal, if possible. Although a between-fragment gap exists, our results show that bone grafting can effectively achieve bone healing. Like an external fixator, our cemented K-wire frame provides strong rigidity in bending, compression, and torque. The technique may be used in all patterns of MEAMFs. To avoid the loss of correction during fixation, we placed K-wires into the adjacent metacarpal, which provides reliable temporary stability. Moreover, we manually place 1 to 3 longitudinal K-wires percutaneously into the soft tissues close to the metacarpal to achieve temporary stability. This method is simple and often effective. After cement has become solid, further correction is difficult unless removing the K-wires to redo the fixation. Therefore, satisfactory reduction must be confirmed before cementing.

Indications of our technique are debated but may include almost all patterns of MEAMFs with cosmetic and functional issues, especially malunions with dorsal apex angulation > 45°, bone shortening > 5 mm, and rotational deformity. Contraindications are intraarticular fractures, minimal cosmetic and functional problems, infection, and unstable health conditions. The advantages of the technique are a minimally invasive procedure, rigid fixation, and allowing early joint motion exercise. The disadvantages are the inconvenience of the cement frame for a patient's daily life and the risk of pin site infection.

Limitations of the study are a small patient group, lack of comparison, and lack of a kinematic study. Surgeons' preference, experience, and ability may affect the treatments and outcomes.

Acknowledgements
None.

Author contributions
Zitao Han; Guisheng Zhang: Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Data, Writing – Original Draft, Writing Review & Editing, Visualizaion, Supervision.Guisheng Zhang: Project Administration, Conceptualization, Methodology.Xiaoliang Yang, Zitao Han, Yadong Yu, Wei Du: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Data Curation.Yadong Yu: Investigation.Yadong Yu, Xu Zhang: Formal Analysis, Investigation.Xiaoliang Yang, Xu Zhang: Review & Editing.

Funding
Not applicable.

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

Declarations

Ethics approval and consent to participate
The institutional review boards of the Third Hospital of Hebei Medical University reviewed the study and approved the protocol (Number W2020-020-1). Informed consent was obtained from each patient. This study adhered to the Declaration of Helsinki.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

Received: 8 September 2024 / Accepted: 23 January 2025
Published online: 04 February 2025

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