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Original article

## Treatment of comminuted fractures of the base of the thumb metacarpal using a cemented bone-K-wire frame

### Traitement des fractures comminutives de la base du premier métacarpien grâce à un cadre os-broches-ciment

W. Duan, X. Zhang, Y. Yu, Z. Zhang\*, X. Shao, W. Du

Department of Hand Surgery, Third Hospital of Hebei Medical University, Shijiazhuang, Hebei 050051, PR China



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#### ABSTRACT

We aimed to describe the treatment of comminuted fractures of the base of the thumb metacarpal using a cemented bone-K-wire frame. Between March 2010 and January 2016, 41 fractures of the base of the thumb were treated using a cemented bone-K-wire frame. The mean age of the patients was 34 years. The patients' history included a fall onto the hand in 7 cases, direct trauma in 31 cases, and polytrauma with an unclear mechanism of injury in 3 cases. At the final follow-up, hand grip and pinch strength were measured using a dynamometer. All measurements were compared with those of the opposite hand. The patients were assessed functionally using the Smith and Cooney score. All K-wires were left in place until the bone healed. Bone healing was achieved in all thumbs in an average of 5.2 weeks. Follow-up averaged 27 months. The mean hand pinch and grip strength was  $8.7 \text{ kg} \pm 2.4 \text{ kg}$  and  $38.4 \text{ kg} \pm 5.9 \text{ kg}$ , respectively. The mean measurements on the opposite side were  $9.2 \text{ kg} \pm 2.5 \text{ kg}$  and  $40.2 \text{ kg} \pm 6.6 \text{ kg}$ , respectively. Based on the Smith and Cooney score, we obtained an average score of  $87 \pm 9.3$ , with 25 excellent, 9 good, and 2 fair results. The cemented bone-K-wire frame is an external fixator alternative that can be used for treating comminuted intra-articular fractures of the base of the thumb metacarpal. The system is cheap, easy to apply, and provides rigid fixation, resulting in good functional recovery.

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#### R É S U M É

Notre objectif était d'introduire le traitement des fractures comminutives de la base du premier métacarpien à l'aide d'un cadre os-broches-ciment. De mars 2010 à janvier 2016, 41 fractures de la base du pouce ont été traitées en utilisant le cadre os-broches-ciment. L'âge moyen des patients était de 34 ans. L'histoire racontée par les patients décrivait une chute sur la main dans 7 cas, un traumatisme direct dans 31 cas, et un polytraumatisme avec un mécanisme peu clair de la lésion dans 3 cas. Au recul final, les forces de poigne et de pince ont été mesurées à l'aide d'un dynamomètre. Toutes les mesures ont été comparées avec celles de la main opposée. Les patients ont été évalués sur le plan fonctionnel grâce au score de Smith et Cooney. Toutes les broches de Kirschner ont été laissées en place jusqu'à la consolidation osseuse. Celle-ci a été obtenue dans tous les pouces en 5,2 semaines en moyenne. Le recul moyen était de 27 mois. Les forces moyennes de poigne et de pince étaient respectivement de  $8,7 \text{ kg} \pm 2,4 \text{ kg}$  et de  $38,4 \text{ kg} \pm 5,9 \text{ kg}$ , pour des chiffres moyens du côté opposé respectivement de  $9,2 \text{ kg} \pm 2,5 \text{ kg}$  et de  $40,2 \text{ kg} \pm 6,6 \text{ kg}$ . Sur la base du score de Smith et Cooney, nous avons obtenu un score moyen de  $87 \pm 9,3$ , correspondant à 25 excellents, 9 bons et 2 moyens résultats. Le cadre os-broches-ciment est un fixateur externe intelligent et peut être une alternative pour le traitement des fractures articulaires comminutives de la base du premier métacarpien. Le système est bon marché, facile à appliquer et offre une fixation rigide, permettant une bonne récupération fonctionnelle.

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\* Corresponding author.

E-mail address: [gongyongc@sina.com](mailto:gongyongc@sina.com) (Z. Zhang).

## 1. Introduction

Thumb metacarpal fractures make up almost 25% of all metacarpal fractures [1]. Approximately 80% of thumb fractures involve the metacarpal base and 20% of thumb basal fractures are intra-articular [2]. Comminuted fractures are usually treated surgically because it is difficult to maintain reduction with a cast [3]. The best treatment is still debated. Owing to the advantages of minimally invasive procedures, closed and percutaneous reduction and fixation may be a worthy strategy.

Fractures at the base of the thumb metacarpal are classified into four types: Bennett fracture, Rolando fracture, comminuted fracture, and extra-articular fracture [4]. The Rolando fracture was first described in 1910 by Silvio Rolando [5]. It consists of three distinct fragments and is typically Y-shaped. This term now includes essentially all comminuted fractures of the base of thumb metacarpal [6]. Therefore, we combined Rolando fractures and comminuted fractures into one group in our study.

For the treatment of comminuted fractures, there are various surgical procedures, including open reduction and internal fixation (ORIF) with K-wires [7], ORIF with Herbert screws, external fixation, closed reduction with percutaneous K-wire fixation [8,9], oblique traction with a K-wire and splinting [10,11]. Although ORIF can achieve good reduction, the major drawbacks are tendon adhesions, wound infection, and decreased vascularity.

A mini plate-and-screw system can achieve more rigid fixation, which allows almost full joint motion soon after surgery. However, the extensive dissection required carries a high risk of nonunion, infection, tendon excursion limitation and stiffness, as well as higher treatment costs and the need for secondary implant removal [12]. Longitudinal pinning is typically unable to maintain satisfactory reduction [13]. An external fixator can be used to achieve rigid fixation with the advantages of restoring the length of the metacarpal and controlling rotation [14]. However, owing to the inherent weakness in the design of small devices, mini-fixators are difficult to assemble, especially for a small thumb base and small bone fragments [15]. Usually, a maximum of four pins can be inserted. External fixators are expensive. To get around these drawbacks, we used K-wires and bone cement to create a clever external frame. Ebelin et al. [16] were the first to use bone cement and K-wires to build an external fixator. Ebelin's study encompassed thumb to little finger injuries, and their surgical procedures included fixation of various fractures and joint fusion, as well as compression and traction of phalanges. Their study did not specifically focus on thumb basal fractures.

The purpose of this retrospective study was to report on closed reduction and percutaneous fixation for the treatment of comminuted thumb basal fractures. We also introduce our fixation technique using a cemented bone-K-wire frame.

## 2. Patients and methods

Between March 2010 and January 2016, 49 consecutive patients with comminuted fractures were treated in our unit. The ethics committee of our hospital approved the study. The eligibility criteria were as follows:

- patient age between 18 and 65 years;
- acute fracture within 14 days;
- a normal opposite hand for comparison.

Patients with any of the following criteria were excluded:

- fractures that could not be reduced by closed means;
- older than 65 years of age (due to possible osteoporosis);

- skeletal immaturity ( $n = 1$ );
- combined tendon or neurovascular injury ( $n = 2$ );
- extra-articular fracture ( $n = 5$ );
- old fractures exceeding 14 days;
- diabetes, gout, ganglion, or bone tumors;
- declined to participate in the study.

Thus, a total of 41 patients (41 thumbs) were analyzed for this study (Table 1).

Preoperative radiographs and CT images were obtained in all patients (Fig. 1A–E). All procedures were performed by the same senior hand surgeon using the same surgical technique.

### 2.1. Surgical technique

The procedure was performed under brachial plexus block without tourniquet control. First, the intra-articular fracture of thumb base was reduced with axial traction in most cases (Fig. 2A). Otherwise, adequate reduction could be achieved with the aid of percutaneous leveraging, hooking and joystick techniques (Fig. 2B, C). Intra-articular reduction was verified under fluoroscopy as needed. Second, we inserted an axial 1.0 mm K-wire into the metacarpal, from the head to the base, to maintain the reduction temporarily (Fig. 2D). Third, two or three K-wires (1.0–1.5 mm) were inserted into the basal fragments to maintain the intra-articular reduction (Fig. 3A). Fourth, we inserted two K-wires (1.0–1.25 mm) into the distal fragment in a transverse manner. We inserted another two K-wires into the trapezium in a transverse manner (Fig. 3B, C). During insertion, care was taken to avoid injuring the tendon and neurovascular structures (Fig. 4A). Acceptable K-wire positioning was confirmed under fluoroscopy on Kapandji's six views [17]. The K-wires were bent about 1.5 cm distal to the skin, toward the fracture site. The monomer (liquid) and polymer (powder) components of bone cement (Palacos<sup>®</sup>, Hanau, Germany) were mixed. The bone cement's viscosity changed over time from a runny liquid into dough-like state that was applied to the K-wire ends, and then finally hardened into solid material (Fig. 4B, C). The distance between the cement glob and skin was about 1 cm. The axial K-wire for temporary fixation was removed. Acceptable fracture reduction and alignment was confirmed on radiographs. If the articular surface was still displaced, complete reduction was achieved with the aid of percutaneous techniques using a K-wire and arthroscope.

**Table 1**  
Demographic data for the patients.

Age (years)	34 (18–63)
Sex (M vs. F)	38 vs. 3
Injury mechanism	
Fall on hand	7
Direct trauma	41
Polytrauma	3
Dominant vs. non-dominant	28 vs. 13
Injured side (R vs. L)	26 vs. 15
Time from injury to surgery (days)	3 (0–13)
Fracture type	
Rolando	11
Comminuted	30
Accuracy of reduction	
Anatomic	35 (85%)
Good	5 (12%)
Fair	1 (2%)
Pin tract infection ( $n$ )	0
Bone healing (weeks)	6.2 (4–8)
Cost (US\$)	2735 ± 462
Follow-up (months)	27 (25–30)

F: female; L: left; M: male;  $n$ : number; R: right.



**Fig. 1.** A 42-year-old male patient with a Rolando fracture. Lateral view (A). Posteroanterior (PA) view (B). CT images in sagittal (C), coronal (D) and transverse (E) planes.

## 2.2. Post-operative management

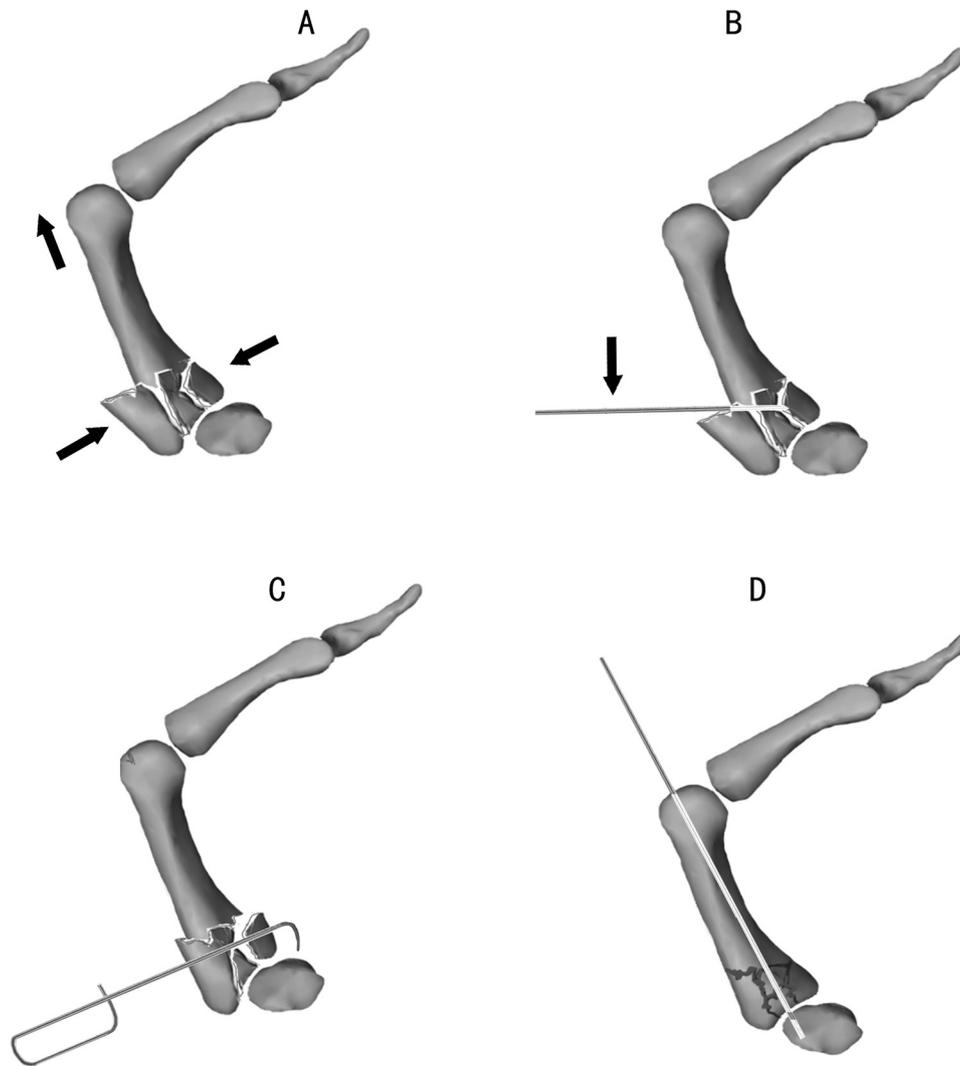
To avoid secondary retraction of the first web space, a palmar splint was used postoperatively to maintain the thumb in maximal abduction for 4 weeks. Active motion of the metacarpophalangeal and interphalangeal joints of the thumb started on the second post-operative day as tolerated (Fig. 5A–C). Pin care was done every 2 to 4 days as needed. Once bone healing was observed on radiographs (Fig. 6A, B), the K-wires and bone cement were removed. Active motion of the carpometacarpal (CMC) joint was initiated thereafter.

## 2.3. Outcomes

Outcome assessments were performed by the same senior hand surgeon. Pin tract infection was assessed from the third

post-operative day to the time of wire removal. The accuracy of reduction of the articular fragments was assessed according to criteria described by Ovadia et al. [18]. Reduction was judged as anatomic (0–8 points), good (9–11 points), fair (12–15 points), or poor (more than 15 points). Patient costs were calculated from admission to bone healing. The patients agreed to radiographs every 2 post-operative weeks. Bone healing was defined as a callus bridging the fragments and marginal sclerosis at the fracture site on radiographs [19]. Non-union was labeled as no evidence of bone healing after 3 months.

At the final follow-up, joint stability was tested in all directions. We measured active movements of the hand with a goniometer. The Kapandji Score [20] was used to assess thumb opposition based on the position that could be reached by the tip of the thumb. We measured the hand's pinch and grip strengths using a dynamometer [21]. All measurements were compared with those



**Fig. 2.** First set of maneuvers by axial traction along the first metacarpal and compression on the basal fragments to reduce the fracture (A). Leverage technique (B). Hooking technique (C). Use of an axial K-wire to maintain the reduction temporarily (D).

of the opposite hand. To prevent any discrepancy between dominant and non-dominant hand strength, we based the Scores for analysis on the premise that the grip strength was 6% higher on the dominant side than the non-dominant side [21].

Patients rated trapeziometacarpal joint pain on the dorsum of the joint using a visual analog Scale (VAS) (0 = no pain, 10 = worst pain) [22]. Using a self-administered questionnaire, patients also rated numbness on the dorsum of the joint using a VAS (0 = no numbness, 10 = worst numbness). All patients were assessed functionally according to the Smith and Cooney score [23]. The 11-item version of the Disabilities of the Arm, Shoulder and Hand (QuickDASH) questionnaire was used to assess the subjective disability of arm and shoulder function [24].

#### 2.4. Statistical analysis

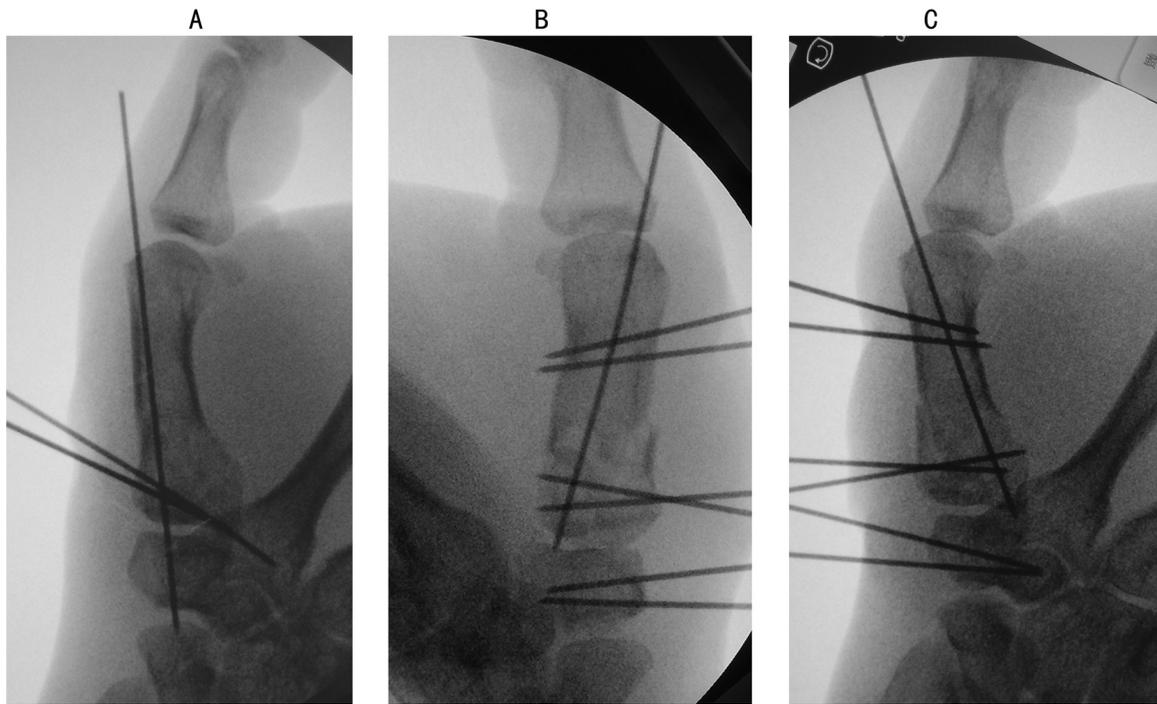
Quantitative variables were described as mean and standard deviation when normally distributed or median and interquartile range when not. We used the one-way analysis of variance to determine whether there were any significant differences between groups. Differences were considered statistically significant at  $P < 0.05$ . The collected data were analyzed with the Statistical Package for Social Sciences 13.0 (SPSS, Inc., Chicago, IL, USA) and Product Application and Support Software 14 (PASS, NCSS LLC).

### 3. Results

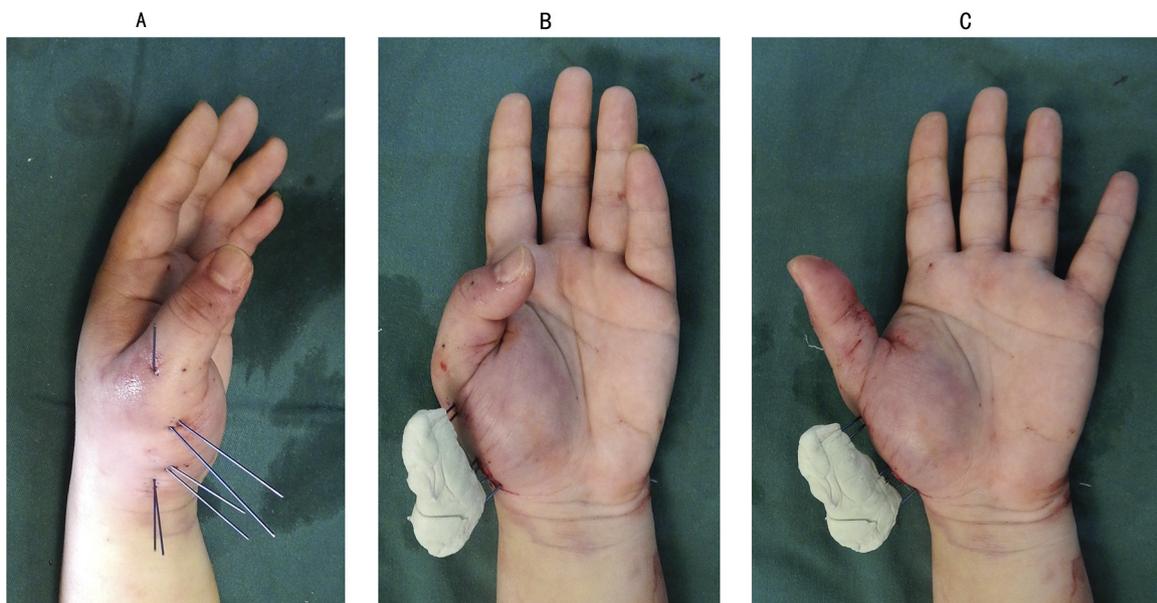
In our study, 37 of 41 (90%) fractures could be successfully reduced by closed means, and only 4 (10%) fractures were reduced percutaneously using a K-wire and arthroscope. The fractures were typical three-part Rolando fractures ( $n = 11$ ) and comminuted fractures ( $n = 30$ ). The accuracy of reduction was  $3.72 \pm 2.76$ , resulting in 35 (85%) anatomic, 5 (12%) good, and 1 (2%) fair reduction (Table 1).

Follow-up averaged 27 months (range, 25–30 months). The mean total palmar abduction of the thumb was  $59^\circ \pm 8^\circ$  and the radial abduction was  $64^\circ \pm 7^\circ$ . The mean flexion-extension arc the thumb was  $43^\circ \pm 5^\circ$ . The mean thumb opposition Score was  $9.3 \pm 0.7$ . The mean first web span was  $84^\circ \pm 9^\circ$ . The mean grip and pinch strength was  $38.4 \text{ kg} \pm 5.9 \text{ kg}$  and  $8.7 \text{ kg} \pm 2.4 \text{ kg}$ , respectively. Based on the Smith and Cooney score, we obtained a mean score of  $87 \pm 9.3$ , which corresponded to 37 (90%) excellent, 3 (7%) good, and 1 (2%) fair results. Two of the 41 (5%) thumbs developed mild radiographic osteoarthritis. The mean QuickDASH score was 5 (range, 0–11) (Table 2).

There were significant differences between both thumbs in the palmar abduction, radial abduction, flexion-extension arc, first web span, and grip and pinch strength ( $P < 0.01$ ). We found no significant difference in functional status ( $P = 0.07$ ).



**Fig. 3.** The fracture was reduced and fixed temporarily with an axial K-wire, and the fragments at the base were fixed with K-wires (A). Two K-wires were inserted into the shaft of the first metacarpal and the trapezium, respectively. PA view (B) and lateral view (C).



**Fig. 4.** Wire insertion is complete (A). The K-wires are bent to create a cemented frame. Thumb flexion (B) and extension (C).

#### 4. Discussion

Thumb function constitutes about 50% of the function of the entire hand. The metacarpal base of the thumb is a unique joint that has a wide range of motion [25]. Our study found that the cemented bone-K-wire frame is a clever external fixator for the treatment of comminuted intra-articular thumb basal fractures. It is easy to apply and can effectively maintain reduction, resulting in satisfactory functional recovery.

The price of bone cement, external fixators, and implants varies widely depending on the manufacturer, location, and country. The price of a cement package is typically about US\$ 110. The price of each K-wire ranges from US\$ 3 (stainless steel) to US\$ 45 (titanium alloy). When compared with the cost of a plate-and-screw system (about US\$ 2500) or an external fixator (about US\$ 2600), the price of a cemented bone-K-wire frame is less than US\$ 500 when eight K-wires are used. Thus, our system compares favorably with other systems as it costs five times less.

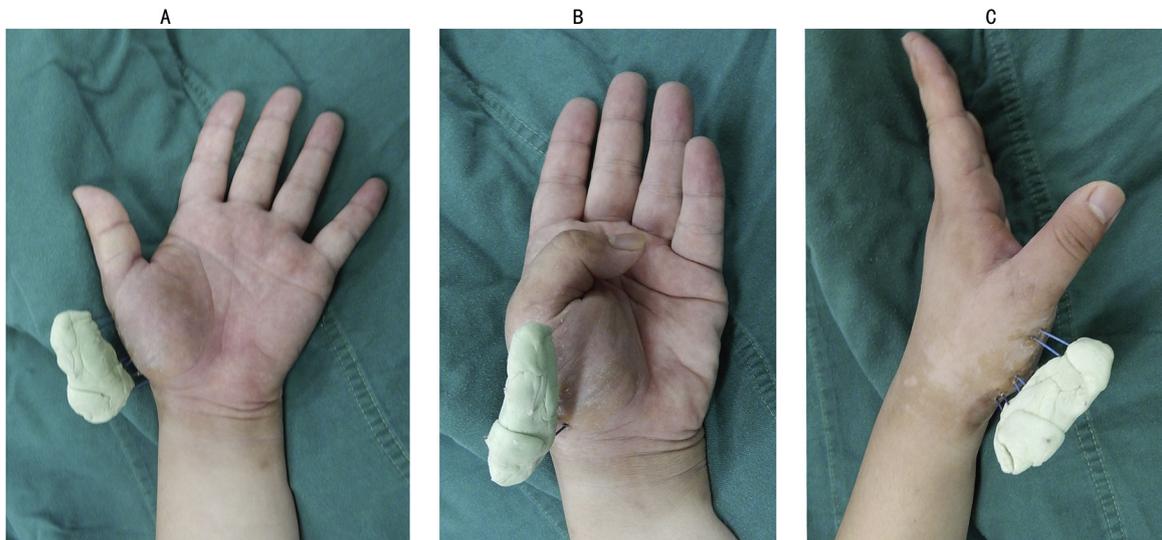


Fig. 5. Range of motion one month after surgery (joint motion was improved after 1 year). Extension (A), flexion (B) and adduction (C).

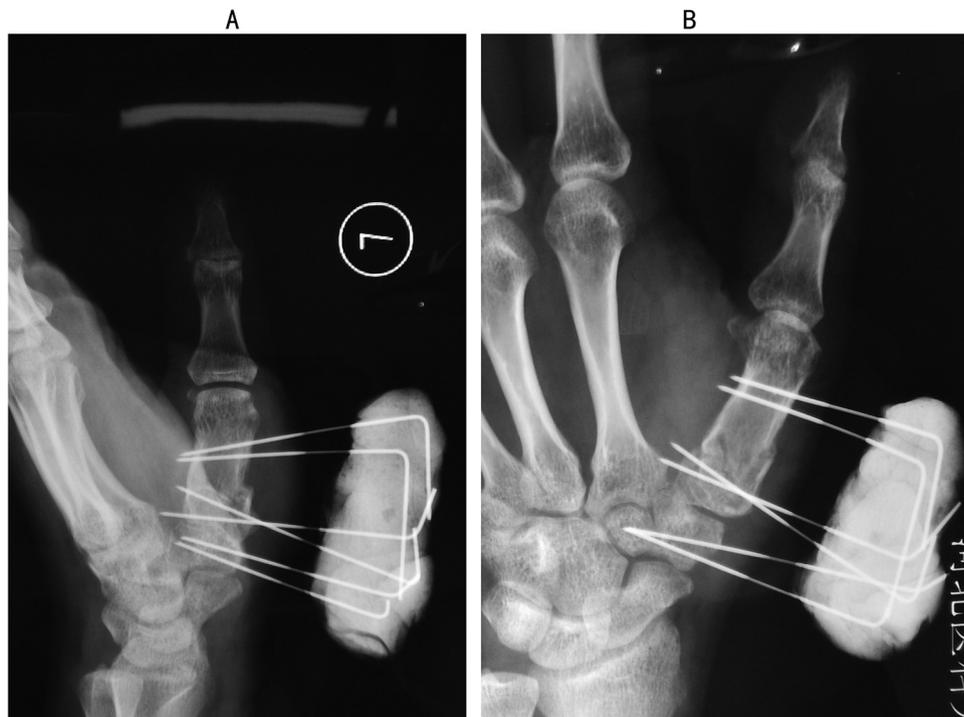


Fig. 6. One month after surgery. Lateral view (A) and PA view (B).

Ebelin et al. used K-wires and bone cement to construct an external fixator, but the cement globs were used as connectors rather than bars [16]. In rare cases, they used the cement as bars because the distance between two K-wires was short. Unlike Ebelin's method, our bars consist of both K-wires and cement, and the distance between the cement and skin was approximately 1 cm, compared to 2.5 cm with Ebelin's method. Therefore, our frame is likely stronger than Ebelin's system.

A biomechanical study showed that significant incongruity in the joint surface might adversely affect hand function, including grip and pinch strength, and even contribute to the development of secondary arthritis [26]. To decrease the complications, restoring the joint surface is advocated for all fractures of the base of the

thumb. Medium and long-term studies on conservative treatment found varus angulation and thumb basal joint subluxation concomitant with movement restrictions [27]. A loss of grip strength is also common [28]. Currently, surgical treatments are the preferred approach.

A cadaver study demonstrated that comminuted fractures can be treated with two parallel K-wires between the shafts of the first and second metacarpals by the mean of closed reduction and percutaneous fixation [8]. In a series of seven comminuted fractures treated by positioning two K-wires between the first and the second metacarpal, two patients suffered decreased thumb motion due to limited first web space opening [7]. The major challenge of such pinning is maintaining the opening of the first web space [29].

**Table 2**  
Outcomes of the 41 treated cases.

	Injured side	Uninjured side	Injured/uninjured side (%)	P-value
Palmar abduction (°)	59 ± 8	64 ± 7	92	0.000
Radial abduction (°)	64 ± 7	69 ± 4	93	0.000
Flexion-Extension arc (°)	43 ± 5	48 ± 6	90	0.000
First web span (°)	84 ± 9	89 ± 8	94	0.000
Kapandji opposition Score	9.3 ± 0.7	9.7 ± 0.5	96	0.070
Grip strength (kg)	38.4 ± 5.9	40.2 ± 6.6	96	0.001
Key-pinch strength (kg)	8.7 ± 2.4	9.2 ± 2.5	95	0.000
Pain (100-mm VAS)	4 ± 3.5			
Numbness (100-mm VAS)	3 ± 1.2			
Smith and Cooney score	87 ± 9.3			
Excellent (n)	37			
Good (n)	3			
Fair (n)	1			
Mean QuickDASH (range)	5 (0–11)			

Data for motion and strength are expressed as mean ± SD.

Strength was assumed to be 6% higher on the dominant side than the non-dominant side.

VAS: visual analog scale.

DASH: disabilities arm shoulder and hand.

Dartée et al. [30] treated proximal thumb metacarpal fractures (7 extra-articular fractures, 2 Roland fractures, and 24 Bennett fractures) using the Iselin technique [28]. They drilled the first K-wire distally through the metacarpals from the index metacarpal to the thumb to maintain maximum distance between the two metacarpals. Then, a second K-wire was drilled proximally from the thumb to the index metacarpal to maintain reduction. The percutaneous K-wires were not parallel but converged. All operated hands had a stable CMC joint. However, those fracture patterns were relatively simple with large fragments. In more comminuted intra-articular fractures, the proximal K-wires cannot hold the small proximal fragments well enough to maintain the congruity of the joint surfaces [31]. Possible complications are secondary displacement and wire migration resulting in malunion and nonunion. In addition, there is a large span between the distal thumb metacarpal and distal index metacarpal. Fixation of the thumb metacarpal with a long K-wire is apparently unstable. Secondary displacements are also the major concern. In order to limit these problems, Adi et al. [29] bent the ends of two K-wires (1.8 mm in diameter) and stabilized them with a connector. However, high-quality reduction is sometimes difficult to obtain. In their study of 13 fractures (6 extra-articular and 7 Bennett fractures), malunion occurred in 3 (23%) cases. In the two studies above, the Iselin technique and its modification may be options for extra-articular and Bennett fractures. However, the techniques may not be a good choice for Roland fractures, because 2 (4%) Roland fractures out of 47 fractures do not reflect the characteristics of the entire series.

In another series of nine comminuted fractures treated with ORIF using a mini T-plate and screws, there were three (30%) excellent, five (60%) fair, and one (10%) poor result, based on the measurements of palmar abduction, and the sum of total active flexion of the metacarpophalangeal and interphalangeal joints [32]. Compared with this open technique, our percutaneous fixation is a minimally invasive procedure that avoids opening the joint capsule and results in better functional recovery. Compared with the conventional external fixator, the K-wires are easily applied, without the need to consider bar assembly.

In severe comminution with very small fragments, the majority of fragments may be reduced by traction maneuvers [24]. In a series of 15 comminuted fractures, Galanakis et al. performed closed reduction and percutaneous fixation using a modified Suzuki frame followed by immediate mobilization [6]. The Kapandji Score was equal to that of the opposite thumb in eight

(53%) cases. Grip strength reached 78% and pinch strength was 78% of the opposite hand. In the series of 11 comminuted fractures treated using a mini-Hoffman external fixator, Kontakis et al. placed two pins in the distal portion of the first metacarpal and one pin in the trapezium [33]. Those studies and our study also showed that, in the majority of cases, the fracture was easily reduced by longitudinal traction. The external fixator was removed after 6 weeks. After a mean follow-up of 30 months, there were 7 excellent, 3 good, and 1 poor result. Soyer [34] used an external fixator with two 3-mm pins placed percutaneously in the dorsoradial aspect of the distal portion of the shaft of the first metacarpal and the trapezium, respectively. Two additional 1 mm K-wires were used to secure the fragments; the system was less reliable because the K-wires were not engaged on the bar of the fixator. Another option was to place two 3-mm pins in the dorsoradial aspect of the radius. The frame with pins was also placed in the second metacarpal to control the deforming forces and maintain reduction. ORIF using the same K-wires is also stable, but tendon adhesions, wound infection, and decreased vascularity are major complications [7].

Our study showed that the cemented bone-K-wire frame is a clever and effective option for treating comminuted fractures. Because all K-wires are cemented into one construct, wire loosening and migration can be avoided. This rigid fixation can control shortening, rotational, and angular deformities, as well as prevent post-operative shifting. Stability of the fixation depends not only on the fixation system, but also the bone's comminution. For the thumb base with comminution, fixation across the CMC joint to the trapezium provides a more rigid fixation, which decreases the risk of losing the reduction postoperatively. Assessing the range of motion of the CMC joint alone is usually difficult. Fracture and immobilization can cause joint stiffness, but our study showed this morbidity was minimal.

For preoperative assessments, Kapandji's six-view radiographs show the thumb CMC joint well [17]. However, radiologists may not have been trained on how to obtain those standard radiographs. Their inexperience and the patient's incorrect hand position due to pain are also influential factors. In comparison, a CT scan is a faster procedure for imaging and rarely affected by radiologist-related and patient-related factors. However, we used Kapandji's six views for intra-operative assessments.

We would like to share some surgical pearls and pitfalls:

- percutaneous leverage, hooking, and joystick techniques are helpful in difficult fractures;

- to reduce exposure to radiation, a lead apron is used to cover the patient's body; the surgeons can stay outside the operating room while X-ray irradiation is on-going;
- keep a 1-cm distance between skin and cement glob so the K-wires can be removed easily later on;
- the shape of cement is not unified, but wrapping the cement dough around all the K-wire ends can lead to a rigid system;
- when removing the frame, first remove the cement by cutting off the K-wire ends using diagonal cutting pliers, and then remove the K-wires one by one.

Indications for the cemented bone-K-wire frame are closed comminuted thumb basal fractures involving the articular surface of the metacarpal. Contraindications are non-displaced and stable fractures that can be treated by conservative means.

Advantages of the cemented bone-K-wire frame include a minimally invasive procedure, rigid fixation, and the possibility of controlling shortening and rotation. The disadvantages are that the frame is inconvenient for patients during their daily activities and the risk of pin track infection. Therefore, when compared with conventional cross pinning, cemented bone-K-wire fixation may be more appropriate for comminuted fractures.

Our retrospective study has limitations. The kinematics of external fixation needs further study. In addition, surgeon preference, experience, and ability may determine the effectiveness of the techniques.

## 5. Conclusion

The cemented bone-K-wire frame is a clever external fixator and is an alternative in the treatment of comminuted intra-articular fractures of the base of the thumb metacarpal. The system is cheap and easy to apply, and provides rigid fixation, resulting in good thumb function.

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### Disclosure of interest

The authors declare that they have no competing interest. The institutional review board of the participating hospital approved the study. Informed consent was obtained from each patient.

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