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Comparison of low-profile locking plate fixation versus antegrade intramedullary nailing for unstable metacarpal shaft fractures––A prospective comparative study☆

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ABSTRACT

Background: The purpose of this study was to compare the effectiveness of mini-open antegrade intramedullary nailing (AIN) and open reduction and internal fixation (ORIF) using the low-profile locking plate for angulated metacarpal shaft fractures, through prospective comparative trial.
Methods: Group 1 (mini-open AIN; 40 patients) and the other consecutive patients in group 2 (locking plate; 35 patients) who met our inclusion/exclusion criteria were investigated between January 2010 and December 2016. We compared radiological findings (e.g., union and residual angulation or shortening); clinical conditions (e.g., pain, measured on a visual analog scale (VAS), and Disabilities of the Arm, Shoulder, and Hand (DASH) scores); active range of motion (ROM); and grip strength.
Results: Union was achieved in both groups without any major complications. The final angulation measurements were not significantly different ($p = 0.402$). The final VAS scores were not different ($p = 0.868$); however, the final DASH score was better in group 1 than in group 2 ($p = 0.034$). The plates were removed in 14 patients at 9.6 months postoperatively for various reasons. Mean ROM at the time of hardware removal in these 14 patients was significantly lower compared with the final ROM in groups 1 and 2 (non-removal patients). Final grip strengths recovered significantly more in group 1 than in group 2 ($p = 0.029$). Extension lag was found in four patients in group 2, and the mean amount was 15°; however, it was resolved by tenolysis during hardware removal.
Conclusions: Both mini-open AIN and low-profile plate fixation are excellent options for metacarpal shaft fractures without significant radiological or clinical problems; however, some clinical outcomes evaluated at least 2 years postoperatively, such as DASH scores and grip strength, were better in the AIN group than in the locking plate group. Plate removal was performed under anesthesia in some patients in the plate group for various reasons, and this may have caused the small differences in the final outcomes evaluated 2 years after surgery.

Introduction

Metacarpal fractures are common upper extremity injuries, accounting for 42% of hand fractures [1,2]. The majority of metacarpal fractures are treated nonoperatively; however, closed reduction and percutaneous pinning as well as open reduction and internal fixation (ORIF) are recognized options for the fixation of metacarpal fractures [3–5]. Of the several options, dorsal plate constructs have demonstrated fixation strength that is superior to that of other methods [2,6–8]. However, such implants can prohibit extensor tendon gliding, cause stress shielding of the bone beneath the plate, or, rarely, induce metallosis [3,9,10]. Subsequent surgery to remove the plates is frequently required and may be particularly difficult in some cases. Overcoming these lacks, the effectiveness of the low-profile plate has been reported, recently [11,12].

On the other hand, intramedullary pinning using K-wires for metacarpal fractures is also regarded as a safe and simple option. In particular, the antegrade intramedullary nailing (AIN) method is used commonly for neck fractures and has been named the "Bouquet technique". In AIN, all metal is embedded in the bony structures, and two or three K-wires (nails) are impacted into the medullary cavity; neck and even head fractures have been fixed without any violation of the metacarpophalangeal (MP) joint. Additionally, bending or rotation stability has been verified as sufficient in several biomechanical studies [9,13].

☆ Level of evidence: Therapeutic level II.

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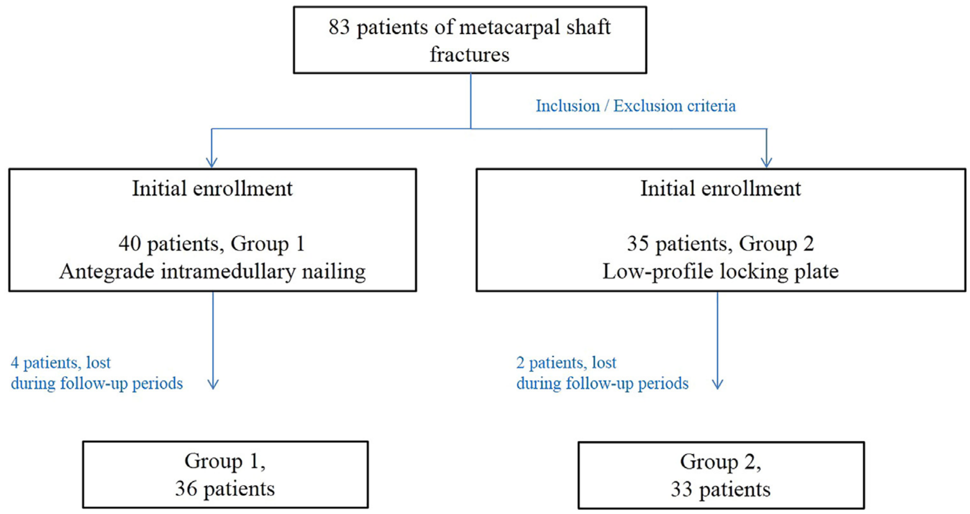

Fig. 1. Flow chart of the study.

However, AIN for traditional closed reduction of metacarpal shaft fractures is difficult. Unstable shaft fractures tend to dorsally angulate, and the periosteum or tendons are interposed at the fracture surface, interfering with precise reduction without a fracture gap. We have performed AIN with mini-open incisions only for fractured areas for a decade, and outcomes have been excellent. Our modification was to “check for a complete reduction and insert a nail through the fractured area”. Thus, the purpose of this study was to compare the effectiveness of mini-open anterograde intramedullary nailing (AIN) and open reduction and internal fixation (ORIF) using the recently developed, low-profile locking plate for angulated metacarpal shaft fractures, through prospective comparative trial.

Patients and methods

Patient selection

Eighty-three patients suffering from metacarpal shaft fractures were admitted to our institute between January 2010 and December 2016. Among them, 75 patients who met the inclusion/exclusion criteria were designated as group 1 (mini-open AIN group; 40 patients), and the other consecutive patients were designated as group 2 (locking plate group; 35 patients). The inclusion criterion for this study was an apex angulation > 30° (5th), 20° (4th), and 10° (2nd and 3rd metacarpal bone) on initial presentation before manual reduction on a lateral view three-dimensional computed tomography (3D-CT) scan. We enrolled only those with the transverse and oblique types of fracture in the current study. Patients with the following characteristics were excluded: (1) metacarpal fractures of the thumb; (2) spiral or longitudinal fractures; (3) open fractures with/without segmental bone defects; (4) comminuted fractures; (5) concurrent fourth or fifth metacarpal injuries, including carpometacarpal dislocation; (6) injuries that occurred more than 6 weeks previously; (7) fractures in the open physis; (8) fractures involving more than two metacarpals, regardless of the neck or shaft/base; and (9) any concomitant fracture in the ipsilateral hand or wrist. Two patients in each group were lost to follow up (Fig. 1). The demographic characteristics of the patients in both groups are described in Table 1.

Surgical treatment

All manipulations and procedures were performed by a single surgeon. In group 1, a 1–1.5-cm incision in the fractured area was made under an image intensifier. After the muscle fascia and periosteum were split, the hematoma or interposed tissue was debrided, and a precise reduction was performed. Manually extending the distal fragment usually produced a precise reduction. Two 1.4-mm K-wires were used in all patients for fixation. First, a 1.6-mm K-wire was inserted at the dorsal metaphysis from the articular cartilage facing the hamate at a sharp angle of 20–30° under guidance of an image intensifier [14]. Similar to a trocar, the 1.6-mm K-wire was passed through the insertion area, and the first 1.4-mm K-wire with a blunt tip was then inserted in an antegrade fashion just before the fracture by tapping with a locking plier while holding the K-wire. The slightly bent second wire was inserted at the opposite dorsal cortex into the metacarpal base via the same method. Just before passing the fracture area, we checked the exact reduction of the fracture, extended the distal fragment, and passed the two wires through the fracture area (Fig. 2). The two wires were bent and left protruding from the skin about 1.5 cm. In group 2, the fractures were exposed by a direct incision made on the radial border of the second metacarpal

Table 1
Basic demographic factors and preoperative status.

Variable	Group 1 (Antegrade intramedullary nailing, $N = 36$)	Group 2 (Low-profile locking plate, $N = 33$)	*P* value
Age* *(yr)*	37 ± 12	40 ± 11	0.941
Sex (M:F) *(no. [%])*	31:5 (86:14)	25:8 (76:24)	0.364
Injury on dominant side (yes:no) *(no. [%])*	27:9 (75:25)	24:9 (73:27)	0.992
Time to surgery* *(days)*	3 ± 1	3 ± 1	0.584
Lesion (2nd:3rd:4th:5th) *(no. [%])*	4:8:12:12 (11:22:33:33)	5:7:6:15 (15:21:18:46)	0.498
Preop. angulation* *(°)*	29 ± 8	29 ± 9	0.831
Preop. shortening* *(mm)*	3 ± 1	4 ± 2	0.787

* The values are given as the mean and standard deviation.

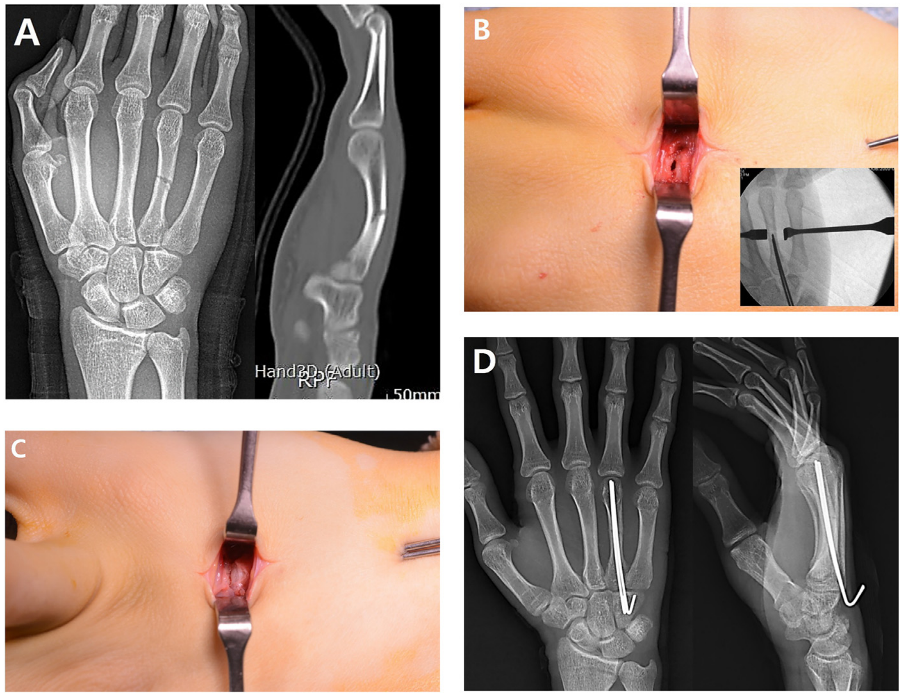

Fig. 2. A 22-year-old male. (A) Transverse fracture at the fourth metacarpal bone with angulation of 27°. (B) We made a 1-cm skin incision on the dorsum of the fourth metacarpal bone. After dividing the muscle fascia/periosteum and debriding the hematoma or interposed soft tissue, the surgeon inserted two K-wires and advanced distally, just before the fracture lesion. (C, D) Then, precise fracture reduction was performed, and the two K-wires were gently passed to the subchondral bone of the metacarpal bone head.

and the ulnar border of the fifth metacarpal. The third and fourth metacarpals were exposed with a longitudinal incision between these two bones. After complete debridement of the fracture, a low-profile locking plate (1.0 mm in thickness; Jeil Medical, Seoul, Korea) was applied on the dorsal aspect of the metacarpal. Use of the proper contour according to the location of the lesion allowed each fragment to be fixed with at least six cortical screws (Fig. 3). Smooth gliding of the flexor tendon was checked against the protruding screw tip at the volar surface of the bone during the passive range of motion (ROM) of the finger. All screws were locking screws except the first one. All extensors were split longitudinally, even the junctunae tendinum during plating. All fascia of the intrinsic muscle was sutured to cover the plate.

Postoperative management

A short-arm splint (2nd/3rd finger fracture) or an ulnar gutter short-arm splint (4th/5th finger) was applied immediately after surgery in both groups. The splint was positioned with the wrist extended 20°, the MP joint at 60° degrees of flexion, and the interphalangeal (IP) joint at full extension in both groups. The splint was removed after 2 weeks, and a wearable wrist brace was applied. The patients performed passive ROM exercises of the MP joint using their contralateral hand while the brace was worn. Increasing the intensity of the passive flexion exercises of the MP joint was encouraged until 8 weeks postoperatively. The two extruding wires were removed at 8 weeks after surgery in group 1 without the need for a skin incision or local anesthetic (Fig. 4).

Radiological evaluation

Radiological assessments were performed monthly for 2 months after surgery and then every 6 months for 1 year. A final evaluation was conducted at least 2 years after surgery. All evaluations were made using a picture archiving and communication system. Proper union was defined as more than three regions of bone bridging among the radial, ulnar, dorsal, and volar cortical aspects of the distal part of the metacarpus as seen on anteroposterior, lateral, and both oblique projections. The presence of delayed union or nonunion of the lesion was evaluated. We evaluated any dorsal angulation at the fractured lesion using 3D-CT scans taken at the final follow up. Among the images reconstructed from the 2-mm sliced coronal, sagittal, and transverse sections, the most precise lateral view was chosen to measure the final angulation. The degree of shortening was measured using a simple anteroposterior radiograph by comparing the contralateral uninjured metacarpal length at the final follow up. All radiological measurements were evaluated by two orthopedic surgeons other than the authors, and each radiograph was reevaluated 1 day later by both surgeons. Bland–Altman [15] plots and repeatability coefficients were used as measurements of interobserver and intraobserver repeatability for all measurements. The 95% limits of agreement represented a visual judgment of how well the measurements of the two reviewers agreed. By definition, the measurement error was smaller than the repeatability coefficient for 95% of the observations.

Clinical evaluation

Clinical outcomes were assessed at least 2 years after surgery. Data were collected by an independent observer (an orthopedic surgeon) who was not an author of this study. Clinical outcomes were compared between the groups using a visual analogue scale (VAS) for postoperative pain; Disabilities of the Arm, Shoulder, and Hand (DASH) scores [16]; active ROM; and grip strength. A VAS score of 0 indicated no pain, whereas a score of 10 indicated extremely severe pain. Active ROM was measured at the MP joint using a finger goniometer. Grip strength was measured with a Jamar hydraulic hand dynamometer (Sammons Preston/Ability One, Germantown, WI, USA). Impairment values are expressed as a ratio (percent) of the affected to the unaffected regions.

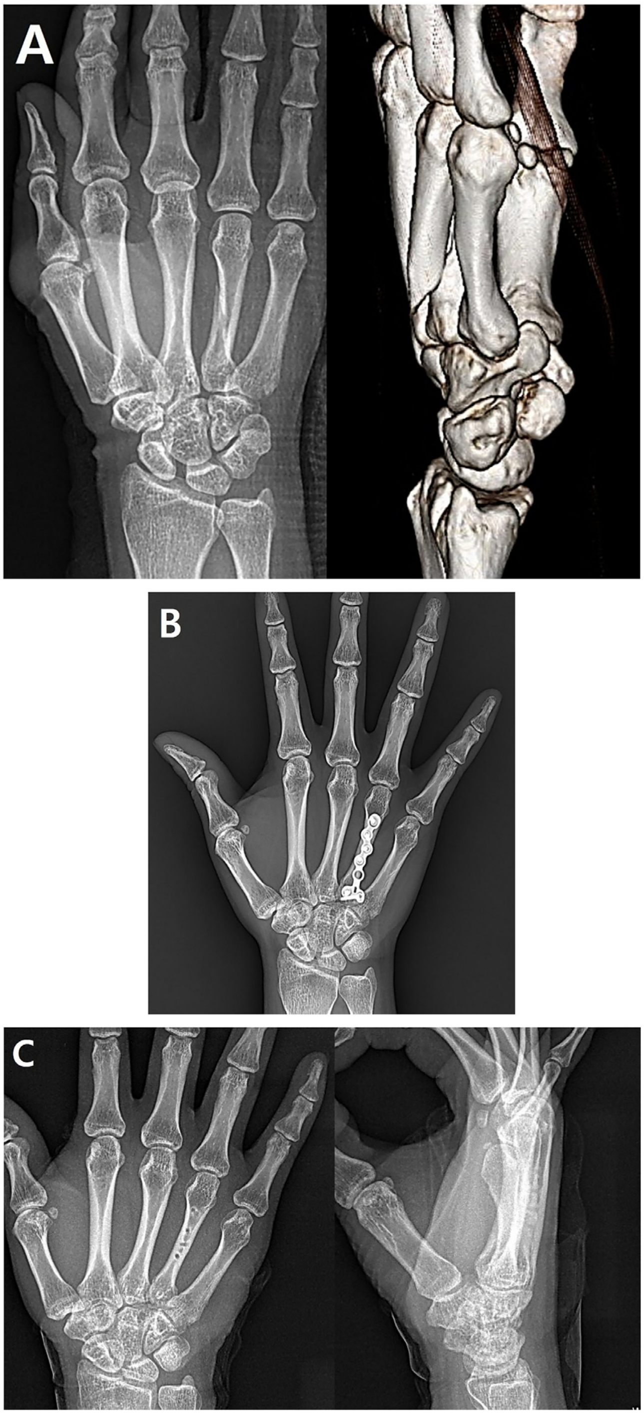

Fig. 3. A 54-year-old female. (A) An oblique fracture at the fourth metacarpal bone. Dorsal angulation was 28° on a three-dimensional computed tomography scan. (B) Open reduction and internal fixation (ORIF) using a low-profile plate was performed. (C) About a 10° extension lag was present 10 months postoperatively with discomfort when contacting the hand dorsum. Thus, the plate was removed under a brachial plexus block. The final visual analog scale and Disabilities of the Arm, Shoulder, and Hand scores were 0 and 6.8, respectively, without any discomfort 30 months postoperatively.

Criteria for complications

Surgery-related complications were defined as infection (superficial and osteomyelitis); tendon injury, including delayed rupture; and superficial nerve injury, including complex regional pain syndrome, according to the criteria of Doro et al. [17]. Nonunion or symptomatic malunion with a prominent palpable head on the palm, a definitive deformity due to rotation, or shortening was regarded as a "complication despite operative treatment". Plates were removed only in patients complaining of discomfort, including intermittent pain, cosmetic issues, or insufficient finger movement (extension lag).

Fig. 4. A 27-year-old male in group 1. Full range of finger motion without an extension insufficiency was seen at 10 weeks postoperatively. The wires were removed at 8 weeks postoperatively. Two small scars were the reason for the failed final clinical evaluation, including with regard to range of motion and grip strength.

Statistical analysis

We prospectively evaluated patients using a two-sided significance level of 0.05 and a power of 80%. The sample size was calculated by the outcome of the DASH score. A power analysis revealed that at least 23 patients were needed per treatment group to detect a minimum difference between the two groups of 15 points on the DASH scores, with 20% lost to follow up, a type-I error rate of 0.05, and a power of 0.8; these values are similar to those in the trial performed by Beaton et al. [16]. Continuous variables were analyzed by independent *t*-tests, and the Levene test was used to test for the heterogeneity of variances. Categorical variables, such as sex and hand dominance, were compared with Fisher's exact or the chi-square test.

Results

The two groups did not significantly differ with regard to basic demographic characteristics, such as age, gender, hand dominance on the injured side, and time to surgery ($p = 0.941$, 0.364, 0.992, and 0.584, respectively, Table 1). The preoperative dorsal angulation values were 29 ± 8° and 29 ± 9° in groups 1 and 2, respectively ($p = 0.831$). Union was achieved in both groups without any "complication despite operative treatment". In group 1, two K-wires were removed at 8.6 weeks postoperatively after radiological bony union. Only one patient developed a superficial pin site infection; thus, the K-wires were removed at 7 weeks postoperatively. The final angulation values measured on the 3D-CT scans were 0.8 ± 1° and 0.6 ± 1.0° in groups 1 and 2, respectively ($p = 0.402$). Preoperative/final shortening values evaluated by simple radiographs were 3 ± 1/0.3 ± 0.7 mm and 4 ± 2/0.1 ± 0.5 mm in groups 1 and 2, respectively ($p = 0.787$ and 0.282, respectively). The final VAS scores were not different ($p = 0.868$); however, the final DASH score was better in group 1 than in group 2 ($p = 0.034$). The plates were removed from 14 patients at 9.6 months postoperatively for various reasons (Table 2). The mean ROM of the respective MP joint (80 ± 4°) in these 14 patients at the time of hardware removal was significantly lower compared with 84 ± 4° and 84 ± 3° for the final ROM values in groups 1 and 2 (non-removal

Table 2
Final radiologic and clinical outcomes.

Variable	Group 1 (Antegrade intramedullary nailing, $N = 36$)	Group 2 (Low-profile locking plate, $N = 33$)	P value
Final angulation* (°)	0.8 ± 1.0	0.6 ± 1.0	0.402
Final shortening* (mm)	0.3 ± 0.7	0.1 ± 0.5	0.282
Final VAS pain score	0.3 ± 0.6	0.3 ± 0.6	0.868
Final DASH score	4 ± 3	6 ± 3	0.034
Final range of motion of metacarpophalangeal joint* (°)	84 ± 4	85 ± 3	0.219
Final grip strength* (% of unaffected side)	94 ± 5	91 ± 5	0.029

* The values are given as the mean and standard deviation.

Table 3
Comparisons of range of motions of the patients with hardware removal.

Variable	Group 1 (Antegrade intramedullary nailing, $N = 36$) At final follow-up	Group 2 (Low-profile locking plate, N = 14) Just before plate removal	Group 2 (Low-profile locking plate, $N = 19$) At final follow-up	P value	Post-hoc
Range of motion of MP joint* (°)	84 ± 4 (a)	80 ± 4 (b)	84 ± 3 (c)	< 0.001	a,c >b

* The values are given as the mean and standard deviation.

Table 4
Improvement of range of motion after hardware removal.

Just before hardware removal (°)	At final follow-up (°)	Remarks
80	90	Discomfort on contact
80	90	Pain during finger motion
75	85	Adhesion with skin
80	85	Pain during finger motion
85	90	Pain during finger motion
80	85	Extension lag (15°)
75	85	Adhesion with skin
80	85	Extension lag (15°)
80	85	Discomfort on contact
75	85	Discomfort on contact
80	90	Extension lag (10°)
90	90	Cosmetic issue
75	80	Extension lag (20°)
80	85	Pain during finger motion

patients), respectively ($p < 0.001$, Table 3). The final ROM after removal improved significantly, to 86 ± 3° ($p < 0.001$, Table 4). Final grip strength also significantly improved in group 1 compared to group 2 ($p = 0.029$). Extension lag (mean 15°) was detected in four patients in group 2; however, it was resolved by tenolysis during hardware removal.

The κ value [18] of the final follow-up angulations measured by 3D-CT and the amount of shortening measured by simple radiographs showed excellent results (0.84 and 0.85, respectively). On 3D-CT, the interobserver and intraobserver repeatability coefficients of the angulation measurements were 0.79 and 0.83, and those on simple radiographs were 0.81 and 0.85, respectively. On 3D-CT and simple radiographs, both interobserver and intraobserver repeatability coefficients indicated high reproducibility.

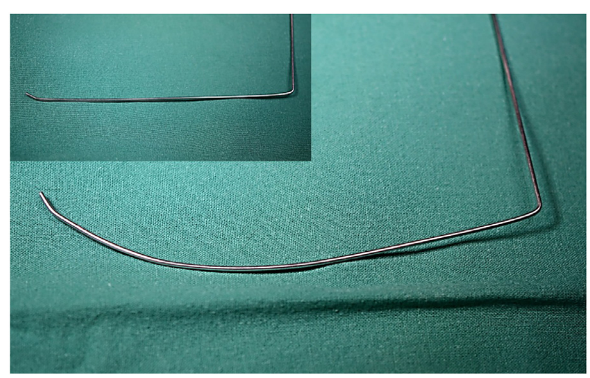

Fig. 5. Two types of prebent wires. Left upper image was initially inserted wire and large image was second wire.

Discussion

We found mini-open AIN revealed better DASH scores and improved grip strength than the low-profile plate fixation for metacarpal shaft fractures, and no significant radiological or clinical problems were reported. Our AIN method achieved primary bone healing without callus formation through absolute stability. All radiographs, including those taken during the follow up showed typical bony union by primary bone healing. This healing pattern occurred for two reasons. Complete gross fracture reduction and subsequent fixation was the first reason. The other reason was that interlocking intramedullary nailing was performed on large long bones (femur and tibia) and implemented similarly to the author's method [14]. The entry point was made using a 1.6-mm K-wire, not a drill. Thus, the 1.4-mm K-wire was precisely re-inserted and advanced while tapping with a locking plier holding the K-wire and a mallet against the metaphyseal cancellous bone. The prebent K-wires were adapted during passage through the narrow intramedullary space and then finally impacted on the subchondral bone of the metacarpal head (Fig. 5). The distal tip of the wire was ground smooth before the surgery; thus, proper gentle tapping with the locking plier distally produced firm and safe fixation under the image intensifier, without penetrating the articular surface.

Although we used a low-profile plate and provided sufficient information about the benefits of the implant before surgery, patients worried about the presence of metal devices; thus, active range of finger motion was limited, despite radiological bony union. On the other hand, group 1 patients performed the active finger exercises by themselves without the fear of metal. The strength of this study is that the recently developed low-profile locking plate was as effective for the proper bony union as the previously used 2.0- or 2.4-mm locking plates for transverse and oblique shaft fractures of metacarpal bones. Some patients in group 2 had excellent clinical status with the plate, despite it being just beneath the skin of the hand dorsum. However, AIN performed by precise reduction using a surgical modification of our method yielded more favorable outcomes due to the ease of removal and the cosmetic issues.

The high probability of angular and rotational deformities in cases of reduction and casting of unstable fractures is well known. If these deformities are not surgically corrected, serious aesthetic and functional problems, such as cross-fingering and superimposition, may occur [13]. Different approaches can be used by adapting the K-wire technique, type of plate used, internal and external fixation methods, fracture position, fracture condition, soft tissue condition, and, most importantly, preference of the surgeon. Among the various methods, plate fixation has the most promising results [19]. Additionally, a more comfortable low-profile was recently developed to minimize several problems, such as soft tissue injury due to a large incision [11,12,20,21], extension lag, tendon irritation, or tendon rupture [13,22-24].

Among the three fixation tools, the plate, intramedullary headless screws, and the K-wires, the plate was revealed to have the highest resistance to tensile stress in a recent cadaveric study [25]. However, that study was performed using one K-wire for the cadaveric model, and the authors did not explain the various modifications of the K-wire fixation method for metacarpal shaft fractures. Generally, fracture fixation using intramedullary nails means secondary healing under relative stability with acceptance of a gap forming in the fracture [26]. However,

Dreyfuss et al. [27] supported the usefulness of plates rather than K-wires; however, their study had somewhat heterogeneous patients among the two groups, and the number of wires inserted differed. Furthermore, multiple metacarpal fractures were mixed in the groups, and various confounding factors were present. Poor outcomes were seen in some patients in the K-wire group, and they developed finger-tip rotation deformities. We considered the possibility that the rotation resulted from inaccurate reduction and failure to maintain fixation. However, there was not any scissoring or overlap of the respective fingers associated with the metacarpal fractures in our study. In fact, rotation $< 5°$ was not perceived by the patients, and no patient in our study complained of a deformity. Dreyfuss et al. [27] performed both the antegrade and retrograde methods and reported some benefits to the antegrade method, especially during the early postoperative period [28].

One limitation of our study was that we did not include long spiral, comminuted, or multiple metacarpal fractures. Although the metacarpal bones are relatively small, additional stability through fragmental fixation or a bone graft are occasionally required. Additionally, a mangle injury of the metacarpal bone would be extended, such as tendons, neurovascular ruptures, or a soft tissue defect. In these injuries, it would be unrealistic to expect complete fracture reduction and achievement of stability by the AIN method; thus, AIN would be an inappropriate option compared to a plate. As clarified by the current study, AIN can be applied only for transverse/oblique fractures. Second, a randomized design was not employed due to the nature of the study; during the final evaluation of clinical outcomes, the differences in the scars between the groups were reflective of the procedures followed in each of the two groups.

In conclusion, both mini-open AIN and low-profile plate fixation were excellent options for metacarpal shaft fractures, with no significant radiological or clinical problems reported; however, several clinical outcomes, such as DASH scores and grip strength, were better in mini-open AIN patients at 2 years after surgery. Plate removal under anesthesia was performed in some patients in the low-profile plate group for various reasons, and this may have caused small differences in the final outcomes evaluated 2 years after surgery.

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Declaration of Competing Interest

Each author certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

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