Muğla Sıtkı Koçman Üniversitesi Tıp Dergisi 2026;13(1):44-52
Medical Journal of Mugla Sitki Kocman University 2026;13(1):44-52
Doi: 10.47572/muskutd.1790656

Research Article

Comparison of K-Wire and Plate Applications in Multiple Metacarpal Fractures

Multipl Metakarp Kırıklarında K-Teli ve Plak Uygulamalarının Karşılaştırılması

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Received: 24.09.2025
Accepted: 05.01.2026

Abstract
The aim of this study was to compare the mid-term clinical and radiological outcomes of intramedullary K-wire and plate-screw fixation in multiple extra-articular metacarpal fractures, and to evaluate the impact of fracture localization on functional outcomes. This retrospective study included 46 patients with at least two metacarpal shaft fractures between January 2018 and December 2023. Twenty patients underwent plate-screw fixation, while twenty-six patients received intramedullary K-wire osteosynthesis. Grip strength was measured using a digital dynamometer. Pain intensity was assessed with the Visual Analog Scale (VAS), and functional status was evaluated using the Michigan Hand Outcomes Questionnaire (MHQ). All patients were followed for a minimum of 15 months. Clinical scores were compared according to surgical method and fracture localization. Grip strength was significantly higher in the K-wire group (p=0.013). No statistically significant difference was observed between the groups in MHQ or VAS scores. Analysis based on fracture localization revealed that grip strength was significantly lower in 2nd and 3rd metacarpal fractures (p=0.036), whereas higher grip strength and lower pain scores were recorded in 4th and 5th metacarpal fractures (p=0.044). K-wire fixation is less invasive and provides better mid-term grip strength outcomes. However, functional scores were comparable between both techniques. Regardless of the surgical method, fractures involving the 2nd and 3rd metacarpals were associated with poorer prognosis. Fracture patterns and localization should be considered in treatment planning. Level II – Single-center randomized controlled trial.
Keywords: Functional outcome, Grip strength, Intramedullary K-wire fixation, Multiple metacarpal fractures, Plate-screw Osteosynthesis.

Özet
Bu çalışmanın amacı, çoklu ekstraartiküler metakarp kırıklarında intramedüller K-teli ile plak–vida tespitinin orta dönem klinik ve radyolojik sonuçlarını karşılaştırmak ve kırık lokalizasyonunun fonksiyonel sonuçlar üzerindeki etkisini değerlendirmektir. Bu retrospektif çalışmaya Ocak 2018 ile Aralık 2023 arasında en az iki metakarp diafiz kırığı bulunan 46 hasta dâhil edilmiştir. Yirmi hastaya plak–vida tespiti uygulanırken, yirmi altı hastaya intramedüller K-teli osteosentezi yapılmıştır. Kavrama gücü dijital dinamometre ile ölçülmüştür. Ağrı şiddeti Görsel Analog Skala (VAS) ile, fonksiyonel durum ise Michigan El Sonuçları Anketi (MHQ) ile değerlendirilmiştir. Tüm hastalar en az 15 ay boyunca takip edilmiştir. Klinik skorlar cerrahi yönteme ve kırık lokalizasyonuna göre karşılaştırılmıştır. K-teli grubunda kavrama gücü anlamlı derecede daha yüksekti (p=0,013). MHQ veya VAS skorları açısından gruplar arasında istatistiksel olarak anlamlı bir fark gözlenmedi. Kırık lokalizasyonuna göre yapılan analizde, 2. ve 3. metakarp kırıklarında kavrama gücünün anlamlı derecede düşük olduğu (p=0,036), buna karşılık 4. ve 5. metakarp kırıklarında kavrama gücünün daha yüksek ve ağrı skorlarının daha düşük olduğu kaydedildi (p=0,044). K-teli tespiti daha az invazivdir ve orta dönemde daha iyi kavrama gücü sonuçları sağlar. Bununla birlikte, fonksiyonel skorlar her iki teknik arasında benzer bulunmuştur. Cerrahi yöntemden bağımsız olarak, 2. ve 3. metakarpı içeren kırıklar daha kötü prognozla ilişkilidir. Tedavi planlamasında kırık paterni ve lokalizasyonu dikkate alınmalıdır. Düzey II – Tek merkezli randomize kontrollü çalışma.
Anahtar Kelimeler: Fonksiyonel sonuç, Kavrama gücü, İntramedüller K-teli tespiti, Çoklu metakarp kırıkları, Plak–vida osteosentezi.

Introduction

Hand and upper extremity injuries are among the most commonly treated conditions in emergency departments. Phalangeal and metacarpal fractures account for approximately 10% of all fractures (1). While half of all hand injuries involve metacarpal fractures, phalangeal and metacarpal fractures together comprise at least 41% of all upper extremity fractures (2). Among these, non-thumb metacarpals constitute 88% of all hand fractures, with fractures of the fifth metacarpal being the most frequent (3). These fractures are most commonly caused by falls or direct blunt trauma (4).

Shaft fractures of the metacarpals may result in potential deformities such as shortening, dorsal angulation, and malrotation. Multiple metacarpal fractures are rare, accounting for approximately 0.6% of all upper extremity fractures (5). While isolated metacarpal fractures are often treated conservatively, the risk of deformity is significantly higher in multiple metacarpal fractures (2), due to loss of stability between adjacent intact metacarpals and the associated risk of stiffness caused by soft tissue injury (5,6). Inadequate reduction can lead to metacarpal shortening and subsequent grip strength loss. Furthermore, even when closed reduction of multiple metacarpal fractures is successful, maintaining the reduction remains challenging (7–9).

Traditionally, percutaneous K-wire fixation has been widely used in unstable metacarpal fractures due to its technical simplicity. However, there has been a growing tendency toward the use of plate-screw fixation, which enables direct fracture reduction and early mobilization. Low-profile plates allow periosteal healing and may reduce adhesion formation compared to earlier plate designs. Nevertheless, despite these innovations, plate fixation techniques have not been definitively shown to yield better functional outcomes or faster recovery (10).

A review of current literature reveals that data on grip strength outcomes in multiple metacarpal fractures remain limited (11). To the best of our knowledge, this is the first study to compare K-wire and plate-screw fixation techniques in patients with multiple metacarpal fractures. Our hypotheses were: 1 K-wire fixation would provide superior mid-term grip strength; and 2 fractures involving the 2nd and 3rd metacarpals would be associated with worse functional outcomes. Accordingly, this study aimed to evaluate the impact of surgical technique on functional outcomes in multiple metacarpal fractures treated with K-wires or plates, and to compare these findings with existing literature.

Material and Method

Study Design and Ethical Approval

This study is a retrospective cohort study conducted at a tertiary training and research hospital between January 2018 and December 2023. The study was planned in accordance with the principles of the Declaration of Helsinki, and approval was obtained from the local ethics committee (Ethics Committee Decision No: 2025/01-07).

Patient Selection

Patients who presented to the emergency department with hand trauma and were diagnosed radiographically with at least two closed extra-articular metacarpal shaft fractures treated surgically were included in the study. Depending on fracture type, patients were treated using either intramedullary K-wire or plate-screw fixation. The minimum follow-up period was set at 15 months, and patients with shorter follow-up were excluded.

Inclusion Criteria:

- At least two closed extra-articular metacarpal shaft fractures
- Surgical treatment with either K-wire or plate-screw fixation
- Age ≥ 18 years
- Completion of at least 15 months of clinical and radiological follow-up

Exclusion Criteria:

- Open fractures
- Associated phalangeal fractures
- Patients treated conservatively
- First metacarpal fractures (due to biomechanical differences)
- Bilateral hand trauma
- Presence of neurological deficit or neuromuscular disorders

A total of 62 patients with multiple metacarpal fractures were initially evaluated; 16 patients were excluded due to not meeting the inclusion criteria or loss to follow-up. Thus, 46 patients were included in the study: 20 underwent plate-screw fixation, and 26 received K-wire fixation. Both groups were comparable in terms of age, sex, fracture pattern, and affected hand. Surgical technique selection was based on fracture type, existing literature, and biomechanical considerations. Transverse and short oblique fractures, which require relatively low stability, were treated with intramedullary K-wires due to their minimally invasive nature. In contrast, oblique and spiral fractures with a higher tendency for rotation and displacement were treated using plate-screw fixation to provide rigid stabilization and anatomical reduction. These approaches are consistent with fixation strategies recommended in previous studies (12,13).

Surgical Technique

Plate-Screw Fixation

A dorsal longitudinal incision was made to expose the fracture site. The extensor tendons were retracted laterally to visualize the fracture ends. Reduction was achieved using the "Jahss technique" with the metacarpophalangeal and proximal interphalangeal joints in flexion. Following stable reduction, fixation was performed using low-profile dorsolateral plates. The periosteum was sutured over the plate to minimize tendon contact. Postoperatively, the hand was immobilized in a splint for 7 days, after which active and passive finger motion exercises were initiated (Figure 1).

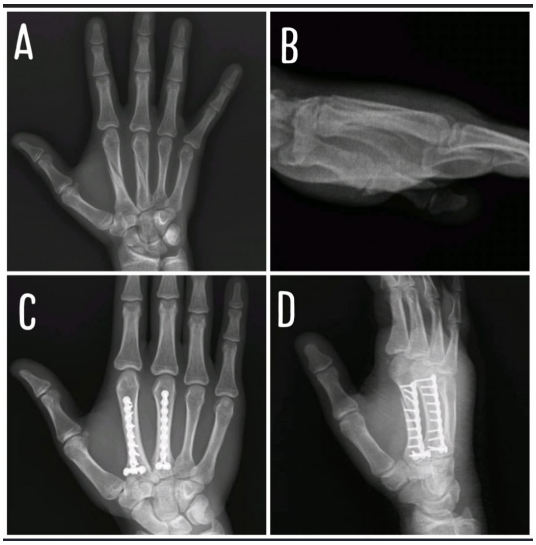

Figure 1. A and B: Preoperative anteroposterior and lateral radiographs of long spiral fractures of the 2nd and 3rd metacarpals, respectively. C and D: Postoperative images of the same fractures following fixation with plate and screws.

K-Wire Fixation:

After closed reduction, one or two K-wires were inserted from distal to proximal through the metacarpal shaft. The wire tips were left exposed outside the skin. The hand was immobilized in a volar splint for 4 weeks with the wrist in 20°–30° extension and the metacarpophalangeal joints in 70° flexion. Interphalangeal joint movement was allowed during this period. At the end of the fourth week, the wires and splint were removed, and full hand mobilization was initiated (Figure 2).

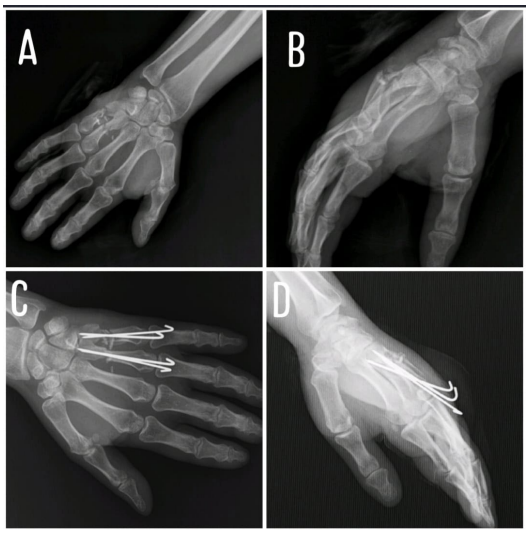

Figure 2. A and B: Preoperative radiographs showing transverse fractures of the 4th and 5th metacarpals. C and D: Postoperative radiographs of the same fractures fixed with K-wires.

Rehabilitation Protocol

All patients were enrolled in a standardized physical therapy and rehabilitation program starting from the 4th postoperative week. The program began with active and passive finger range of motion exercises following the removal of immobilization. The rehabilitation protocol included:

- Active/passive range of motion (ROM) exercises
- Intrinsic hand muscle mobilization
- Isometric and isotonic grip strength exercises
- Functional tasks and return-to-activity exercises

The rehabilitation was supervised by the same physiotherapist for all patients, and the average rehabilitation duration was 6 weeks.

Clinical Evaluation

Patients who had completed a minimum of 15 months postoperative follow-up were evaluated clinically by a single orthopedic and trauma specialist.

Grip Strength Measurement:

Grip strength was measured using a digital hand dynamometer (capacity: 120 kg) with patients seated, shoulder adducted, elbow at 90° flexion, forearm in neutral, and wrist positioned in 0–30° extension. Three measurements were taken for each hand, and the average value was recorded. This protocol was applied in accordance with the American Society of Hand Therapists (ASHT) guidelines.

Pain Assessment (VAS) (14):

Pain levels were assessed using the Visual Analog Scale (VAS), scored from 0 (no pain) to 10 (worst imaginable pain). Patients were asked to report the most severe pain they experienced during the past week.

Functional Assessment (MHQ) (15):

Functional outcomes were assessed using the Michigan Hand Outcomes Questionnaire (MHQ), which had been validated and adapted into Turkish. The MHQ consists of six subscales: overall hand function, activities of daily living, work performance, pain, aesthetics, and patient satisfaction. It was administered separately for each hand, and scores ranged from 0 to 100, with higher scores indicating better function.

Radiological Follow-Up

All patients underwent a structured radiographic follow-up protocol. X-rays were obtained postoperatively at weeks 4, 8, and 12, and at least once during the final follow-up (minimum 15 months). Standard anteroposterior, oblique, and lateral views were evaluated. The following parameters were assessed:

- Union time: Defined as the point when cortical continuity was restored, callus formation was visible, and the fracture line was obscured.
- Malunion: Defined as >10° dorsal/volar angulation, >2 mm shortening, or any rotational deformity.
- Implant failure: Assessed by the presence of wire migration, screw loosening, plate fracture, or hardware displacement.
- Nonunion: Defined as persistent fracture line and clinical tenderness after 6 months without visible callus formation.

K-wire patients were closely monitored for subcutaneous wire irritation and migration. In the plate-screw group, periosteal reactions, screw loosening, and plate malposition were specifically evaluated. Radiographs were independently reviewed by one orthopedic surgeon and one radiologist. Interobserver agreement was analyzed using Cohen's kappa coefficient and showed good consistency ($\kappa = 0.82$).

Statistical Analysis

Statistical analyses were performed using SPSS v24 (IBM Corp., Armonk, NY, USA). The distribution of continuous variables was assessed visually (histograms, probability plots) and analytically (Kolmogorov-Smirnov test). Categorical variables were presented as counts and percentages. Normally distributed continuous variables were expressed as mean ± standard deviation, while non-normal data were reported as median [interquartile range].

Categorical variables were compared using Chi-square or Fisher's exact test.

Continuous variables were compared using Student's t-test or the Mann-Whitney U test, as appropriate. Linear regression analyses were used to evaluate predictors of clinical outcomes, with three separate models analyzing VAS scores, grip strength differences, and grip strength change percentages as dependent variables. All models were adjusted for age, sex, treatment method, and fracture localization. Results were presented as beta coefficients and 95% confidence intervals. A p-value of <0.05 was considered statistically significant.

Results

A total of 46 patients were included in the study. The mean age was 30.8 ± 14.1 years (range, 18–69 years), and 91.3% of the patients were male. The average follow-up duration was 31.6 ± 15.5 months (range, 16–56 months). Twenty patients (43.5%) were treated with plate-screw fixation, and twenty-six patients (56.5%) were treated with intramedullary K-wires. There were no statistically significant differences between the groups in terms of age (p=0.96) or sex distribution (p=0.18). All patients were right-hand dominant, and the distribution of fractures in the dominant hand was similar between groups (p=0.71). Fracture localization was also comparable across both treatment groups (p=0.067) (Table 1).

Note: Values are presented as mean ± SD, median [IQR], or n (%). *p*-values were calculated using Chi-square, Fisher's exact, Student's *t*-test, or Mann–Whitney *U* test, as appropriate. Significance level set at *p* < 0.05.

Table 1. Baseline demographic and clinical characteristics of patients by treatment group

Parameter	Plate-Screw (n=20)	K-Wire (n=26)	p-value
Age (years)	31.0 ± 14.5	30.7 ± 14.3	0.96
Sex, Male [n (%)]	16 (80.0%)	26 (100.0%)	0.06
Dominant hand, right [n (%)]	20 (100.0%)	26 (100.0%)	–
Etiology			
– Blunt trauma [n (%)]	8 (40.0%)	10 (38.5%)	0.91
– Fall [n (%)]	4 (20.0%)	10 (38.5%)	0.18
– Crush injury [n (%)]	8 (40.0%)	6 (23.1%)	0.23
Injured hand, dominant [n (%)]	14 (70.0%)	20 (76.9%)	0.63
Fracture localization			
– 2nd and 3rd metacarpals	4 (20.0%)	4 (15.4%)	0.70
– 2nd, 3rd, and 4th metacarpals	4 (20.0%)	8 (30.8%)	0.40
– 3rd and 4th metacarpals	8 (40.0%)	–	–
– 4th and 5th metacarpals	4 (20.0%)	14 (53.8%)	0.02
No. of fractured metacarpals (mean ± SD)	2.2 ± 0.4	2.3 ± 0.5	0.38
No. of implants used (median [IQR])	2.0 [0.25]	2.0 [1.0]	0.44
Hospital stay (days)	2.9 ± 2.2	2.9 ± 2.2	0.99
Follow-up duration (months)	33.2 ± 17.8	30.3 ± 14.3	0.54

Values are presented as mean ± SD, median [IQR], or n (%). *p*-values were calculated using Chi-square, Fisher's exact, Student's *t*-test, or Mann–Whitney *U* test, as appropriate. Significance level set at *p* < 0.05.

Postoperative clinical outcomes for both treatment groups are summarized in Table 2. No significant differences were found between the plate-screw and K-wire groups in terms of postoperative pain scores (VAS) or Michigan Hand Outcomes Questionnaire (MHQ) scores. However, the grip strength measured in the affected hand was significantly higher in the K-wire group (mean 44.3 ± 5.1 kg) compared to the plate-screw group (38.3 ± 5.4 kg) (p=0.013). Other functional parameters showed no statistically significant differences between the groups.

Table 2. Postoperative clinical outcomes by treatment group

Parameter	Plate-Screw (n=20)	K-Wire (n=26)	p-value
VAS score (0–10)	2.2 ± 1.5	1.5 ± 1.8	0.11
Grip strength (affected hand) [kg]	38.3 ± 5.4	44.3 ± 5.1	0.013
Grip strength (unaffected hand) [kg]	42.4 ± 5.2	47.3 ± 4.8	0.07
MHQ score (0–100)	86.5 ± 5.8	81.9 ± 7.3	0.09
Grip strength difference [kg]	4.1 ± 3.8	3.1 ± 1.8	0.21
Grip strength loss (%)	11.4 ± 11.5	7.3 ± 4.4	0.10
>10% grip strength loss [n (%)]	6 (30.0%)	6 (23.1%)	0.61

Clinical outcomes according to fracture localization are shown in Table 3. Patients with 4th and 5th metacarpal fractures had significantly lower VAS scores than those with other fracture locations (p=0.044). Additionally, this group demonstrated the highest grip strength (mean 46.1 ± 4.2 kg), which was significantly greater than all other groups (p=0.022). The lowest MHQ scores were observed in patients with fractures involving the 2nd, 3rd, and 4th metacarpals (mean 79.2 ± 8.0), although the differences between groups were not statistically significant (p=0.17).

The difference in grip strength between the affected and unaffected hands was calculated as 12.0% in patients with 2nd and 3rd metacarpal fractures, and 15.3% in those with 2nd, 3rd, and 4th metacarpal fractures. These differences were significantly higher compared to the remaining two groups (p=0.036).

Table 3. Clinical outcomes based on fracture localization

Parameter	2nd & 3rd (n=8)	2nd, 3rd & 4th (n=12)	3rd & 4th (n=8)	4th & 5th (n=18)	p-value
VAS score (0–10)	2.5 ± 1.0	2.5 ± 2.1	2.5 ± 1.9	0.7 ± 1.5*	0.044
Grip strength (affected hand) [kg]	38.9 ± 3.7	39.3 ± 5.8	38.1 ± 6.8	46.1 ± 4.2*	0.022
Grip strength (unaffected hand) [kg]	43.6 ± 4.9	44.9 ± 5.2	40.7 ± 7.3	48.2 ± 4.0	–
MHQ score (0–100)	82.5 ± 5.0	79.2 ± 8.0	88.8 ± 4.8	85.6 ± 6.3	–
Grip strength difference [kg]	4.7 ± 2.0	5.6 ± 4.3	2.6 ± 1.4	2.1 ± 1.1	–
Grip strength loss (%)	12.0 ± 4.8*	15.3 ± 13.5*	6.9 ± 3.5	4.5 ± 2.6	0.036
>10% grip strength loss [n (%)]	6 (75.0%)	6 (50.0%)	–	–	–

Discussion

Closed multiple adjacent metacarpal fractures are rare, making them difficult to study in the literature. Current evidence is limited to a few small case series that combine isolated and multiple metacarpal fractures and typically advocate either surgical or conservative management. The outcomes of non-surgical treatment in multiple metacarpal fractures remain unclear (6,16). Percutaneous K-wire fixation offers several advantages, including minimal soft tissue damage, shorter operative time, and lower infection risk. However, due to its relatively lower fixation strength, it may lead to rotational deformities. Improper placement of K-wires near tendons can restrict tendon gliding and cause tendon adherence or even ankylosis (17).

In our study, grip strength in the K-wire group was statistically significantly higher than in the plate-screw group, supporting our first hypothesis. Nevertheless, no significant differences were found between groups in terms of pain (VAS scores) or Michigan Hand Outcomes Questionnaire (MHQ) scores. This could be explained by potential damage to the dorsal transverse arch during plate-screw fixation, which may impair the interosseous muscles and alter their anatomy, thus negatively affecting grip strength. The lack of difference in functional scores might indicate that overall hand function can be preserved through compensatory mechanisms in the kinetic chain, despite localized impairment due to metacarpal fractures.

Previous reports have suggested that rotational alignment problems are more

common in fractures treated with K-wires compared to plate fixation. Royle et al. (18) found that residual rotational deformity frequently occurs after K-wire fixation, noting that 1° of rotation at the metacarpal level may result in up to 5° of fingertip rotation. Tannenbaum et al. (19) showed in their study that fingertip rotation ranged from 0° to 6° in the K-wire group and 0° to 4° in the plate group. The authors attributed some of these deformities to the use of a single K-wire for fixation (20).

In our series, no clinically significant rotational deformities were observed in the plate group. However, in the K-wire group, rotational deformities averaging 6° were detected radiographically in 5 out of 26 patients (~19%). Two of these involved internal rotation, and three involved external rotation. Given the absence of scissoring in adjacent fingers and the fact that most rotational angles were below 10°, these deformities were not functionally significant. In fact, most patients were unaware of the deformity during clinical follow-up, and none required corrective osteotomy.

The index finger is the second most important digit after the thumb, due to its proximity to the thumb and its role in abduction–adduction and flexion–extension movements. Multiple studies have emphasized its contribution to precision pinch and grip function (12,21,22). Murray et al. (23) reported a ~20% reduction in fine motor skills, grip strength, and supination power following loss of the index finger. The middle finger, on the other hand, provides the greatest flexion force (24,25). In this context, the significantly lower grip strength observed in patients with 2nd and 3rd metacarpal fractures in our study (reflecting loss of index and middle finger contribution) supports our second hypothesis. Conversely, patients with 4th and 5th metacarpal fractures demonstrated significantly higher grip strength ($p=0.022$) and lower pain scores (VAS), suggesting a biomechanical advantage related to their location on the ulnar column, which bears less load during grip activity and may thus be more resilient during recovery.

To our knowledge, no prior studies have directly examined the effect of fracture location on grip strength. Thus, our investigation provides a valuable contribution to the literature as one of the first studies to explore the functional consequences of fracture localization in multiple metacarpal injuries.

Each fixation technique presents its own risk of complications. The literature reports complication rates as high as 36% after plate-screw osteosynthesis in metacarpal fractures (22). K-wire fixation may be associated with pin migration, pin-site infection, skin irritation, and joint stiffness (17). In our study, one case (5%) of minor screw loosening was observed in the plate group, which did not cause clinical symptoms. In the K-wire group, three patients (11.5%) experienced minor pin-site irritation and superficial infection, all of which resolved with conservative management. However, it should be noted that the limited sample size may have precluded the detection of rarer complications.

This study has several limitations. First, its retrospective design is a major constraint. The absence of randomization makes it difficult to control for potential confounding variables between groups. Consequently, the findings should be interpreted as correlational rather than causal. Second, heterogeneity in fracture patterns and rehabilitation protocols complicates interpretation of the results. The relatively small sample size (n=46) may also limit generalizability. Although subgroup sizes were sufficient for basic statistical analysis, the power to detect rarer complications or subtle differences was limited.

In conclusion, further large-scale, multicenter, prospective, randomized controlled trials are needed to validate and extend our findings. Such studies could better clarify the comparative efficacy of fixation methods and support the development of standardized treatment protocols.

Conclusion

While K-wire fixation offers advantages in terms of minimal invasiveness and mid-term grip strength, the comparable functional scores between the groups suggest that both techniques can be safely utilized when applied under appropriate indications. However, patients with fractures involving

the 2nd and 3rd metacarpals appear to carry a higher risk of poor prognosis, necessitating more careful treatment and rehabilitation planning. Ultimately, regardless of the surgical technique used, both the fracture pattern and its anatomical localization should be considered as critical factors in determining the treatment strategy.

Acknowledgements

The authors sincerely thank all the orthopedic trauma team members at Erzurum City Hospital and the collaborating tertiary trauma centers for their invaluable clinical support and contribution to patient care. We are also grateful to the nursing staff and data management personnel for their assistance in data collection and follow-up coordination. Finally, we appreciate the constructive feedback from our colleagues in the Department of Orthopedics and Traumatology, which helped improve the clarity and scientific quality of this work.

Conflict of interest statement

The authors declare that no specific funding was received for this study and that there are no conflicts of interest related to its content.

Ethics Committee Approval

This study was approved by the institutional ethics committee (Erzurum Medical Faculty Scientific Research Ethics Committee for Clinical Research) (08.01.2025-34923). Ethics Committee Approval Number: 2025/01-07.

Funding

None.

References

1. Lambi AG, Rowland RJ, Brady NW, et al. Metacarpal fractures. J Hand Surg Eur Vol. 2023;48(2):42–50.
2. Bernstein ML, Chung KC. Hand fractures and their management: an international view. Injury. 2006;37(11):1043–1048.
3. Gould JS, Nicholson BG. Capsulectomy of the metacarpophalangeal and proximal interphalangeal joints. J Hand Surg. 1979;4(5):482–486.
4. Zhu X, Zhang H, Wu J, et al. Pin vs plate fixation for metacarpal fractures: a meta-analysis. J Orthop Surg Res. 2020;15(1):1–16.
5. Stern PJ. Fractures of the metacarpals and phalanges. In: Green DP, Hotchkiss RN, Pederson WC, eds. Green's Operative Hand Surgery. 4th ed. New York: Churchill Livingstone; 1998:711–726.
6. Jupiter JB, Hastings H 2nd, Capo JT. The treatment of complex fractures and fracture-dislocations of the hand. Instr Course Lect. 2010;59:333–341.
7. Low CK, Wong HC, Low YP, et al. A cadaver study of the effects of dorsal angulation and shortening of the metacarpal shaft on the extension and flexion force ratios of the index and little fingers. J Hand Surg [Br]. 1995;20(5):609–613.
8. Freeland AE, Orbay JL. Extraarticular hand fractures in adults: a review of new developments. Clin Orthop Relat Res. 2006;445:133–145.
9. Barton NJ. Fractures of the hand. J Bone Joint Surg Br. 1984;66(2):159–167.
10. Stanton JS, Dias JJ, Burke FD. Fractures of the tubular bones of the hand. J Hand Surg Eur Vol. 2007;32(6):626–636.
11. Kastanis GE, Siligardou MR, Chaniotakis C, et al. Acute Compartment Syndrome of the Hand Following Multiple Metacarpal Fractures: Current Concepts. Cureus. 2024;16(12):e75234.
12. Fusetti C, Meyer H, Borisch N, et al. Complications of plate fixation in metacarpal fractures. J Trauma. 2002;52(3):535–539.
13. Ushijima T, Ogawa H, Kojima T. Clinical outcomes of retrograde percutaneous pinning for shaft fracture of metacarpal bone: A case series. J Orthop Case Rep. 2025;15(4):239.
14. Delgado DA, Lambert BS, Boutris N, et al. Validation of digital visual analog scale pain scoring with a traditional paper-based visual analog scale in adults. JAAOS Glob Res Rev. 2018;2(3):e088.
15. Ergen Hİ, Yiğit S, Maden T, et al. The Turkish version of the brief Michigan hand outcomes questionnaire: cross-cultural adaptation, validity, and reliability testing. Acta Orthop Traumatol Turc. 2024;58(5):286-287.
16. Marjoua Y, Eberlin KR, Mudgal CS. Multiple displaced metacarpal fractures. J Hand Surg Am. 2015;40(9):1869–1870.
17. Kim BS, Cho D, et al. Operative treatment of metacarpal shaft fracture. J Korean Soc Fractures. 1999;12(3):720–726.

18. Royle SG. Rotational deformity following metacarpal fracture. J Hand Surg [Br]. 1990;15(1):124–125.
19. Tannenbaum EP, Burns GT, Oak NR, et al. Comparison of 2-dimensional and 3-dimensional metacarpal fracture plating constructs under cyclic loading. J Hand Surg Am. 2017;42(3):e159–e165.
20. Poolman RW, Goslings JC, Lee JB, et al. Conservative treatment for closed fifth (small finger) metacarpal neck fractures. Cochrane Database Syst Rev. 2005;(2):CD003210.
21. Melamed E, Joo L, Lin E, et al. Fixation versus percutaneous pinning for unstable metacarpal fractures: a meta-analysis. J Hand Surg Asian Pac Vol. 2017;22(1):29–34.
22. Page SM, Stern PJ. Complications and range of motion following plate fixation of metacarpal and phalangeal fractures. J Hand Surg Am. 1998;23(5):827–832.
23. Murray JF, Carman W, MacKenzie JK. Transmetacarpal amputation of the index finger: a clinical assessment of hand strength and complications. J Hand Surg Am. 1977;2(6):471–481.
24. Ejeskär A, Ortengren R. Isolated finger flexion force — a methodological study. Hand. 1981;13(3):223–230.
25. Hazelton FT, Smidt GL, Flatt AE, et al. The influence of wrist position on the force produced by the finger flexors. J Biomech. 1975;8(5):301–306.