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Original Research

Outcomes Following Fully Threaded Intramedullary Nailing of Metacarpal Fractures

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Purpose: Intramedullary screw fixation has emerged as a popular approach for the treatment of displaced metacarpal fractures. The purpose of this study was to investigate the functional and radiographic outcomes of a newly designed, headless noncompressive fully threaded intramedullary nail (TIMN) for the treatment of metacarpal fractures.
Methods: A retrospective chart review was performed on patients who were treated with the INnate TIMN (ExsoMed) at a single academic institution with a minimum of 1-year follow-up. Patient-reported functional outcomes included Quick Disabilities for the Arm, Shoulder, and Hand (*Quick*DASH) questionnaires, return to work and physical activity time, and overall satisfaction. Radiographs were retrospectively reviewed to determine radiographic union, change in angulation, and metacarpal shortening.
Results: A total of 49 patients (58 fractures) with a mean age of 36 years (range: 17–75 years) were included. The mean follow-up time was 2.7 years (range: 1.4–4.3 years). Overall, the mean patient satisfaction rating was 4.9 of 5 (range: 3–5). The mean return to work time was 7.2 weeks (range: 0.14–28 weeks), and the mean return to sport or activity was 8.3 weeks (range: 1–28 weeks). Average *Quick*DASH scores across all patients were 4 (range: 0–56.9). The median radiographic healing time was 6.1 weeks (range: 4.7–15.4 weeks). Mean postoperative shortening in the fifth metacarpal fracture was 3 mm (range: −4.2 to 8 mm) at the initial postoperative visit and 3.6 mm (range: −3.3 to 7.9 mm) at the final radiographic follow-up. Subgroup analysis showed that postoperative shortening was similar, regardless of the fracture pattern. The following four complications were reported: one case of persistent pain and stiffness, one case of carpal tunnel syndrome, one nonunion, and one fractured intramedullary nail.
Conclusions: Our findings suggest that the TIMN allows for a reliable return to work and physical activity, high patient satisfaction, low complication rate, and minimal shortening at the final radiographic follow-up.
Type of study/level of evidence: Therapeutic IV.

Metacarpal fractures make up approximately 33% of all hand fractures in the United States.[1,2] Although multiple surgical fixation methods have been described,[3–5] a lack of consensus still exists on an optimal technique.[6,7] Over the past decade, headless intramedullary screw (HIMS) fixation has emerged as a safe and effective approach for displaced metacarpal fractures.[3,8–12] Proposed advantages of HIMS fixation are buried hardware, early postoperative mobilization, less soft-tissue morbidity, and faster return to work.[10,12,13] However, due to the usual compressive design of the HIMS and the resultant risk of intraoperative displacement and shortening, comminuted, spiral, and long-oblique fractures have been described as relative contraindications for this implant and technique.[14–16]

Current evidence for the utilization of intramedullary screws has primarily been limited to the study of a compressive HIMS design.[8,10,12,13,17] Recently, a new headless noncompressive fully threaded intramedullary nail (TIMN) has been introduced as an alternative fixation implant (INnate by ExsoMed). This new TIMN purports to eliminate shortening in long-oblique, spiral, and comminuted fractures while providing outcomes comparable with

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Figure 1. Two metacarpal fractures repaired with headless noncompressive fully threaded intramedullary nails.

the existing HIMS techniques (Fig. 1). However, outcomes of this newly designed TIMN have yet to be described in the literature.

The purpose of this study was to investigate midterm functional and radiographic outcomes of metacarpal fractures treated with the INnate TIMN at a single institution. We hypothesize that when compared with the existing HIMS literature, metacarpal fractures surgically treated with the TIMN will provide comparable patient satisfaction, return to work and physical activity times, and complication rates, with additional benefits of minimal fracture shortening.

Methods

After obtaining institutional review board approval, a retrospective chart review was performed on all patients treated with the INnate TIMN by three fellowship-trained board-certified orthopedic hand surgeons from October 2018 to September 2021 at a single academic institution. Patients with concomitant injuries or other surgeries performed at the time of their index metacarpal fracture repair surgery were excluded. Patient demographics including age, date of surgery, injured metacarpal, fracture pattern (transverse, short-oblique, long-oblique, spiral, and comminuted), fracture location (base, neck, and shaft), open versus closed fracture, mechanism of injury, primary indications for surgery, and time to surgery were collected. Implant details including nail length and diameter were also collected. All intraoperative and postoperative complications were recorded.

Patient-reported functional outcomes were collected by a research fellow via telephone or email surveys at a minimum 1-year follow-up. Patient-reported functional outcomes included Quick Disabilities for the Arm, Shoulder, and Hand (*Quick*DASH) questionnaires, ability to return to work at the same level, return to work time, ability to return to sport or physical activity at the same level, return to sport or physical activity time, and overall satisfaction rating (extremely unhappy vs somewhat unhappy vs neutral vs somewhat happy vs extremely happy; 1–5 scale).

Radiographic outcomes were retrospectively measured by two independent reviewers using digital imaging software (PACS and SECTRA). Radiographic measures included time to radiographic union, change in angulation, change in metacarpal length, and postoperative metacarpal shortening. Radial and ulnar angulation were measured using the MC-90 method as described by Sletten et al.[18] Metacarpal length and postoperative shortening were assessed using the shortening absolute value and shortening stipulated (SH-stip) methods, respectively, as described by Sletten et al.[18] For all fractures, shortening absolute measurements were used to determine the change in postoperative metacarpal length from the initial to the final radiographic follow-up. For the fifth metacarpal fractures, the SH-stip method was used to estimate the preinjury metacarpal length and determine postoperative shortening at the initial and final radiographic follow-up. Healing status was retrospectively measured using the Radiographic Union Score for Tibial Fractures (RUST) assessment tool.[19,20] However, RUST grades radiographic union by a scoring system that incorporates the presence or absence of callus and fracture line along each cortex.[19] A standard RUST score of 10 or greater has been previously shown to suggest radiographic union.[21] Therefore, we considered time to radiographic union to be the first postoperative image with a RUST score $\geq$10.

Descriptive statistics were used to report patient-reported functional outcomes and radiographic outcomes. Mann-Whitney U tests were used to conduct a subgroup analysis to compare radiographic shortening among spiral, long-oblique, and comminuted fractures to transverse and short-oblique fractures. Statistical significance was established at $P < .05$. A post hoc power analysis indicated that the study population identified was powered ($\beta = 0.20$) to identify an effect size of 0.75 at $\alpha = 0.05$.

Surgical technique

Reduction of metacarpal fractures was achieved under fluoroscopy with manual traction and rotation. Under fluoroscopic guidance, a guide wire was percutaneously advanced in a retrograde fashion through the dorsal third of the metacarpal head into the intramedullary canal until reaching the proximal metacarpal cortex. The TIMN diameter and length were determined using preoperative measurements and confirmed intraoperatively using the provided measuring guide and fluoroscopy. Nail diameters include

Table 1
Patient Demographics of All Patients and Survey Respondents

Variable	All Patients ($N = 49$)	Survey Respondents ($N = 25$)
Age, y (mean[range])	36 (17−75)	39 (21−67)
Gender, *n* (%)		
Male	41 (84)	18 (72)
Female	8 (16)	7 (28)
Injured metacarpal, *n* (%)		
First	0	0
Second	4 (7)	1 (4)
Third	3 (5)	1 (4)
Fourth	15 (26)	4 (16)
Fifth	36 (62)	19 (76)
Fracture pattern, *n* (%)		
Transverse	15 (26)	7 (28)
Short-oblique	9 (16)	5 (20)
Long-oblique	13 (22)	6 (24)
Spiral	5 (8)	2 (8)
Comminuted	16 (28)	5 (20)
Fracture location, *n* (%)		
Shaft	39 (68)	15 (60)
Neck	17 (29)	9 (36)
Base	2 (3)	1 (4)
Open fractures, *n* (%)	3 (5)	1 (4)
Multiple metacarpal fractures, *n* (%)	7 (14)	3 (12)
Time to surgery, d (mean[range])	9.3 (2−24)	10.5 (3−24)

3.6 mm and 4.5 mm, whereas nail lengths range from 25 mm to 75 mm. Typically, a 4.5 mm implant was used in the first, second, third, and fifth metacarpals, whereas the 3.6 mm implant was used in the fourth metacarpal due to its narrower isthmus. Cannulated drilling through the intramedullary canal was performed percutaneously. The TIMN was advanced retrograde also percutaneously until adequately below the subchondral bone in the metacarpal head. Reduction, alignment, and rotation were verified clinically and fluoroscopically. The percutaneous opening was sealed with Dermabond® and Steri-strips®, and the patient was placed in an ulnar or radial gutter splint in the intrinsic (+) position. Early motion was encouraged immediately postoperatively. An initial postoperative evaluation was performed in the office within 2 weeks of the surgery, where patients were placed in a hand-based splint and instructed to remove it when performing active and passive range-of-motion exercises. Routine imaging was performed at each postoperative visit. Patients were allowed to weight bear and progress to activities as tolerated, based on individual symptoms. Once patients demonstrate clinical and radiographic healing, patients are asked to discontinue the use of the splint and gradually return to the previous level of activity. Occasional adjustments to the postoperative protocol, including initiating formal therapy and further orthoplast splinting, were made based on patient factors and individual healing/recovery processes.

Results

A total of 49 patients (58 fractures) with a mean age of 36 years (range: 17−75 years) were identified and included in the analysis. Patient demographics are described in Table 1. Most fractures involved the metacarpal shaft (68%) and most fractures were located on the fifth metacarpal (62%). Long-oblique, spiral, and comminuted patterns made up 22%, 8%, and 28% of all fractures, respectively. Seven patients were treated for multiple metacarpal fractures in the same procedure. The average time to surgery was 9.3 days (range: 2−24 days).

A 51% response rate was achieved for patient-reported outcomes ($N = 25$; Table 1). The mean follow-up time was 2.7 years (range: 1.4−4.3 years). Overall, mean patient satisfaction rating was 4.9 of 5 (range: 3−5) at a minimum 1-year follow-up. Twenty-four of the 25 respondents described being either somewhat ($N = 2$) or extremely happy ($N = 22$) with their procedure, whereas the remaining one patient felt neutral about their procedure. Most patients (92%) reported being able to return to work at the same level and were so by a mean of 7.2 ± 6.7 weeks (range: 0.14−28 weeks) postoperatively. Among those who participated in physical activity or sport, 100% returned to their activity at the same level by a mean of 8.3 ± 6.6 weeks (range: 1−28 weeks). Average *Quick*DASH scores across all patients were 4 ± 11.3 (range: 0−56.9) at a minimum 1-year follow-up. The one patient with a *Quick*DASH score of 56.9 had persistent stiffness and pain up to 1 year postoperatively. After removing this single outlier, mean and median *Quick*DASH scores were 1.8 ± 3.4 and 0 (range: 0−11.4), respectively.

The median radiographic healing time was 6.1 weeks (range: 4.7−15.4 weeks). Changes in metacarpal length and metacarpal shortening for all fractures are described in Table 2. Mean change in postoperative length from the initial to the final radiographic follow-up was 1.3mm (range: −3.1 to 9.8 mm) among all fracture patterns (Table 2). Postoperative shortening (compared with estimated anatomic length), determined for fifth metacarpal fractures, was 3 mm (range: −4.2 to 8 mm) at the initial postoperative visit and 3.6 mm (range: −3.3 to 7.9 mm) at the final clinical follow-up (Table 2). Subgroup analysis showed that postoperative shortening at the initial and final clinical follow-ups was similar for all fractures ($P > .05$; Table 3). Mean preoperative, initial postoperative, and final angulation measurements (radial-ulnar/dorsal-volar) were 12.8°/30.2°, 5.1°/7.4°, and 5.8°/7.3°, respectively.

The following three postoperative complications were reported: one case of persistent pain and stiffness at 1-year follow-up, one case of carpal tunnel syndrome, and one nonunion. No patients required revision surgery.

One intraoperative complication of a broken TIMN occurred (Fig. 2). During the final turn of nail insertion, approximately 10 mm of the nail head sheared off. The distal fragment of the broken nail fragment was easily removed with a screwdriver through the incision. The decision was made to leave the proximal part of the broken nail in place as it was in an acceptable position across the fracture site and removal of the proximal hardware would require a large incision and cause additional morbidity. To provide additional fixation in this situation, the fractured fourth and fifth metacarpals were transfixed to the third metacarpal by two 1.2 mm k-wires. The percutaneous k-wires were removed 1 month postoperatively. The operating surgeon attributed the broken nail to strong bone purchase and significant friction experienced during the final tightening of the implant.

Discussion

Since it was first described, HIMS fixation of metacarpal fractures has grown in utilization due to reported benefits of less postoperative immobilization, early initiation of range of motion and rehabilitation, reduced complication rates, and reduced operation times compared with other surgical fixation methods.[22] Notwithstanding, current indications for compressive HIMS are limited to transverse and short-oblique fractures due to concerns for compressive shortening.[14−16] The TIMN evaluated in our study is a noncompressive intramedullary nail that has been suggested to be advantageous over HIMS in preventing metacarpal shortening.[23,24] Nevertheless, no clinical studies have described the outcomes of TIMN for metacarpal fractures. The present study found that patients treated with the TIMN quickly returned to work and activities, were highly satisfied with their hand at minimum

Table 2
Radiographic Metacarpal Length and Shortening Outcomes[*]

Variable		Follow-up Time (d)	All Fractures
Metacarpal length (mm)	Preoperative ($N = 34$)		54.9
	Initial postoperative ($N = 57$)	12 (5–39)	58.1
	Final postoperative ($N = 44$)	93 (17–648)	56.6
	Change in postoperative length[†]		1.3 (−3.1 to 9.8)
Fifth metacarpal shortening (mm)[‡]	Preoperative ($N = 22$)		4.6 (−1.4 to 11)
	Initial postoperative ($N = 36$)	14 (6–39)	3 (−4.2 to 8)
	Final postoperative ($N = 26$)	105 (73–648)	3.6 (−3.3 to 7.9)

[*] Data are presented as mean (range) unless otherwise noted.

[†] Change in postoperative length is measured as the mean difference between final and initial postoperative length measurements for all fractures. Positive values represent shortening while negative values represent lengthening.

[‡] Metacarpal shortening measured using the SH-stip method for fifth metacarpal fractures within our case series. Positive values represent shortening while negative values represent lengthening.

Table 3
Radiographic Shortening Outcomes for 5th Metacarpal Fractures Using SH-Stip Method

Variable	Transverse and Short Oblique ($N = 17$)	Spiral, Long Oblique and Comminuted ($N = 19$)	P-Value
Preoperative (mm)	4.6 (−1.4 to 9.5)	4.5 (0 to 11)	.867
Initial Postoperative (mm)	3.1 (−2 to 6.7)	3 (−4.2 to 8)	.824
Final Postoperative (mm)	3.3 (−1.8 to 6.6)	3.8 (−3.3 to 7.9)	.739

1-year follow-up, and had acceptable healing rates, angulation, and shortening.

When compared with existing literature on HIMS fixation, findings from this study suggest that TIMN produces comparable patient-reported function and return to work time. Doarn et al[25] studied short-term outcomes in 10 patients treated with retrograde HIMS for displaced fifth metacarpal neck and shaft fractures. In their series, patients returned to work by 6 weeks (range: 4–10 weeks) postoperatively and achieved a mean DASH score of 0.7 at an average 36-week follow-up.[25] In a larger comparative study, Esteban-Feliu et al[26] found that patients treated with retrograde HIMS returned to work by 7.7 weeks and obtained a mean DASH score of 4 (range: 0–25) at the 5-month follow-up time. In a case series of 48 metacarpal fractures treated with HIMS, del Piñal et al[27] observed a similar mean return to work time of 10.9 weeks (range: 3–15 weeks).[27] The present study reports a comparable mean return to work time of 7.2 weeks (range: 0.14–28 weeks) and a mean *Quick*DASH score of 4 (range: 0–56.9) at an average 2.7-year follow-up.

Few studies have explored the return to sport or physical activity after HIMS fixation.[27,28] A case series presented at the 2018 American Association for Hand Surgery annual meeting studied clinical outcomes and return to sport time in 16 consecutive elite athletes treated with HIMS.[28] Their results showed that HIMS provides athletes the ability for early mobilization and a mean return to play time of 5 weeks.[28] Our results suggest a similar outcome for TIMN as our institution experienced a return to sport or physical activity of 8.3 weeks (range: 1–28 weeks) in a nonelite athlete cohort. Most of the existing literature on metacarpal fracture return to sport time involves the use of internal fixation with plates and screws.[29] A recent systematic review noted a mean return to play time of 4.07 weeks (range: 2.3–5.8 weeks) across five studies using plate and screw fixation.[29] Moreover, two retrospective studies investigating the return to play time in football players found a <2-week return to play time with plate and screw fixation.[30,31] These results are promising as they relate to HIMS and TIMN fixation as recent biomechanical studies have provided evidence that HIMS fixation offers similar durability and biomechanical stability as plate fixation.[13] Nevertheless, additional high-quality clinical studies in athlete populations are needed to confirm this benefit.

Postoperative metacarpal shortening after HIMS fixation has been an ongoing concern, particularly when treating long-oblique and comminuted fractures.[14] Originally described by Strauch et al,[32] an extensor lag of 7° occurs at the metacarpophalangeal joint for every 2 mm of metacarpal shortening.[32] Additionally, Meunier et al[33] determined that only 2 mm of shortening can result in an 8% decrease in interosseous muscle force capacity and that 10 mm of shortening may translate to an almost 45% decrease in power.[33] As a result, many have identified fracture patterns that are axially unstable and most susceptible to postoperative shortening (eg, long-oblique, spiral, and comminuted metacarpal fractures) as relative contraindications for compressive HIMS fixation.[14–16] Kwan et al[24] performed a cadaveric study analyzing metacarpal shortening across various intramedullary fixation designs, including HIMS and INnate TIMN. Their study found significantly less shortening across osteotomy sites with the INnate TIMN compared with both partially threaded (1 mm vs 2.1 mm) and fully threaded HIMS (1 mm vs 4.1 mm).[24] The results from the present study suggest comparable shortening among all fracture patterns treated with TIMN. These findings provide promising preliminary evidence for the safety of TIMN in axially unstable metacarpal fractures, thus expanding the surgical indications for intramedullary fixation.

Although intramedullary metacarpal fixation has shown to be safe and effective, postoperative complications are still pertinent. A recent systematic review by Anene et al[34] reports a complication rate of 4.6% among metacarpal fractures treated with IMS fixation, with 1.8% of cases requiring additional surgery. The most common postoperative functional complication was stiffness followed by less common complications of extension lag, loss of reduction, complex regional pain syndrome, and metacarpal shortening.[34] Screw-related complications were seldom reported but included bent screw, fractured screw, and symptomatic screw migration.[34] Similarly, the present study found a complication rate of 8% (4/49) with the TIMN including stiffness, persistent pain, malunion/nonunion, and an intraoperative broken nail. Considering HIMS and TIMN fixation are relatively novel techniques, long-term outcomes are not well reported. There is ongoing controversy that the disruption of articular cartilage by retrograde screw placement may predispose patients to early-onset osteoarthritis at the

Figure 2. A proximal fragment of the broken threaded intramedullary nail (TIMN) identified on intraoperative fluoroscopy.

metacarpophalangeal joint.[22] Additional studies exploring long-term complications of intramedullary screw fixation are warranted.

This study has several limitations. First, this was a retrospective chart review performed at a single institution. As a result, no comparative group exists, and the findings can only be assessed alongside the current literature. Furthermore, inherent limitations of retrospective chart review led to missing preoperative imaging in our cohort. Comparative, prospective trials comparing HIMS and TIMN are needed to provide a more robust analysis of radiographic and functional outcomes. Second, no collection of postoperative objective functional outcomes, such as grip strength and range of motion, compared with the contralateral hand exists. These data would help provide objective data in addition to the patient-reported outcomes, regarding postoperative function at the midterm follow-up. Moreover, postoperative pain scores were not assessed. Third, variability in clinical and radiographic follow-up is a limitation of the retrospective design of this study. Due to the retrospective review of radiographs, we did not have access to the contralateral hand. As a result, we used SH-stip methods as described by Sletten et al to estimate normal fifth metacarpal length. Although Sletten et al.[18] showed there to be strong inter- and intra-observer reliabilities for this method, the same study also found SH-stip to overestimate metacarpal shortening by approximately 1 mm.[18] Although a noncompressive fully threaded nail was used to avoid shortening and achieve optimal metacarpal length, we still experienced an average of 3–4 mm of shortening at the final radiographic follow-up. We believe this to be a shortcoming of our measuring estimations and the inability to truly compare the metacarpal length with the contralateral hand. Positive reports in subjective functional outcomes give us confidence that patients were not clinically shortened postoperatively. Finally, we had a relatively low response rate of 51% for the patient-reported outcome data, which poses a risk of selection bias. The use of patient-reported surveys at a minimum 1-year follow-up also poses a risk for recall bias.

Surgical fixation of fractures with TIMN offers similar advantages as HIMS including limited dissection, early mobilization, and fast return to activities. As a headless noncompressive intramedullary implant, TIMN can provide an added benefit of limited metacarpal shortening in long-oblique, spiral, and comminuted fracture patterns. As a result, TIMN has the potential to expand surgical indications for intramedullary fixation to include axially unstable metacarpal fractures. Further prospective studies are required that explore the utility of TIMN and investigate long-term functional and radiographic outcomes compared with alternative fixation methods.

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