Biomechanical Comparison of Fixation of Metacarpal Shaft Fractures with Intramedullary Threaded Nail & Dorsal Plate

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Disclosures: This work was supported by a research grant from ExsoMed (Aliso Viejo, CA). ExsoMed was not involved in any other aspect of this project including study design, execution, analysis, or manuscript preparation.

INTRODUCTION: K-wire or plate fixation are commonly used to stabilize transverse and oblique fractures of the metacarpal shaft. However, plate fixation requires an open surgical approach which can lead to joint stiffness or contracture, and tendon rupture or adhesions. K-wires carry a risk of skin irritation and infection due to exposed wires, precluding early rehab. In 2010, the use of Intramedullary Headless Compression Screws (IHCS) was described by Boulton [1] as a less invasive alternative to stabilize metacarpal fractures. This technique can reduce complications associated with plate fixation and allow early rehabilitation, which is not possible with K-wire fixation. However, there are concerns that IHCS might provide less stability than plates. Shaft fractures are rotationally unstable and intramedullary metacarpal fixation does not employ cross lock screws, to provide rotational stability, like other long bone intermedullary fixation devices. In addition, oblique shaft fractures are axially unstable and have the potential to shorten. Thus, we sought to evaluate the mechanical characteristics of shaft fractures, both transverse and oblique, stabilized with a 4.5 mm intramedullary threaded nail (ITN). The goal was to compare its performance to standard plate / screw fixation. We hypothesized that the ITN and plate construct strength would be similar in the transverse fracture model but diminished in the ITN with the oblique fracture pattern.

METHODOLOGY: Transverse and long oblique midshaft osteotomies were created in twenty-eight paired left and right metacarpal bones (all but the thumb) from four fresh frozen cadavers. The oblique osteotomies were made at 30 degrees to the long axis of the metacarpal. Eight metacarpal pairs were used for the oblique fracture and six pairs for the transverse fracture. For each pair, one bone received plate fixation and the other the ITN. The 2.0 mm straight stainless-steel plates (Synthes^{TM}) were secured on the dorsal aspect of the shaft with 6 bicortical screws. The 4.5 mm ITN (INnate^{TM}, ExsoMed) were placed using a customized 3D printed jig obtained by STL file of each bone obtained by an optical scanner. The jig ensured the bone to remain aligned. The ITN insertion starting point was at the dorsal one-third of the metacarpal head. A guidewire was placed to the proximal joint line and then reamed with the 3.4 mm cannulated drill. The length of the ITN was chosen to be between 5 -10 mm less than the measured overall bone length. Mechanical tests were performed on a tensile tester machine (Mark-10 ESM 1500) (figure 1). A Kevlar wire was secured to a wire grip on the actuator of the testing machine and then passed over the head of metacarpal producing an angle of 85° [2]. A progressive load was applied at a rate of 0.5 mm per second until failure. The statistical significance of the ultimate strength difference of the ITN and plate fixation was analyzed using a paired t-test for normally distributed variables and a Wilcox Rank sum test for non-normally distributed variables.

RESULTS: Overall, for both osteotomy types, failure occurred at an average of 153 ± 58 N for plate fixation and 189 ± 49 N for the ITN. For the oblique osteotomy, the nail has a statistically higher strength than the plate at 183±50 N versus 130±40 N ($p = 0.019$). The transverse osteotomy showed no statistical significance, with load to failure of the nail (215±33 N) similar to the plate (183±64 N). Plate failure modes included bone fracture around the osteotomy and yielding of the plate. Intramedullary nail failure modes included bone fracture with or without nail yielding (figure 2).

DISCUSSION: The 4.5 mm ITN were found to provide stronger fixation than a 2.0 mm plate/screw construct in oblique metacarpal shaft fractures. Comparable fixation strength was found in transverse fracture models. For maximum stability in these fracture patterns, we believe it is imperative to achieve endosteal fixation, which is possible with larger diameter screws/nails and IM canal reaming, and to secure the entire metacarpal length, from head to base, with the IM device. The weakest intramedullary construct failed at 107 N, where early post operative range of motion exercises require about 35 N of force. This suggests it is safe to start therapy immediately after surgery. Limitations of this study include the small number of specimens and the investigation of a single loading condition. Also, our study did not investigate strength in cyclic loading which is more representative of the physiologic loading of the metacarpal.

SIGNIFICANCE/CLINICAL RELEVANCE: Threaded intramedullary nail fixation of metacarpal shaft fractures may be an appropriate alternative to plate fixation in transverse and long oblique fracture patterns.

REFERENCES: 1. Boulton CL, Salzler M, Mudgal CS. Intramedullary cannulated headless screw fixation of a comminuted subcapital metacarpal fracture: case report. The Journal of hand surgery. 2010; 35(8):1260-3; 2. Jones CM, Mathew R, Anastasi N, Ilyas AM, Siegler S. Comparative Bending Strength of Metacarpal Neck Fractures Fixed with Two Types of Intramedullary Screws. The Archives of Bone and Joint Surgery. 2023; 11(7): 448-452.

ACKNOWLEGMENTS: Funding for this study, provided by ExsoMed is gratefully acknowledged.

IMAGES AND TABLE:

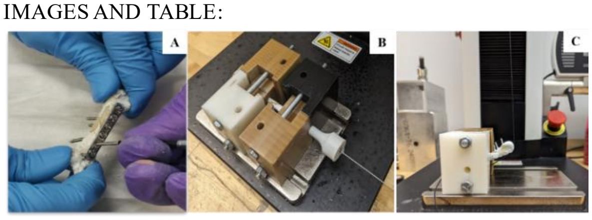

Figure 1 Workflow of the testing procedure. (A) fracture fixed using a plate. (B) fracture fixed in using the intramedullary nail, using the custom-made jig. (C) set up of the mechanical testing.

Figure 2 Failure types. (A) plate failure with yielding and bone fracture. (B) ITN failure with yielding (C) ITN failure without yielding.