Interfragmentary Compression Forces Vary Based on Scaphoid Bone Screw Type and Fracture Location

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Abstract

Background: The objective of this study was to determine the interfragmentary compression forces generated in a foam model as a function of headless compression screw type (fully threaded and central threadless) and fracture location. **Methods:** Eighty-eight polyurethane foam models were fixed across a simulated transverse fracture with either a fully threaded screw or a central threadless screw. The location of the transverse fracture varied along the length of the foam model in 2 mm increments for 11 fracture locations. The force generated at the fracture site upon fixation was utilized to determine the interfragmentary compression. Interfragmentary compression was compared using a paired *t* test and 2-way analysis of variance, with significance set at $P < .05$. **Results:** Interfragmentary compression was found to vary based on fracture location and screw type. The fully threaded screw generated significantly greater compression for fracture locations at 12 mm and 18 mm from the top edge of the foam model, while the central threadless screw generated significantly greater compression for fractures located 2 mm from the top edge of the foam model. **Conclusions:** The central threadless screw and the fully threaded screw had different fracture locations where maximum compression force occurred. The fully threaded screw generated greater compression force toward the screw center due to greater thread purchase. However, the central threadless screw generated greater compression at the most proximal fracture location due to its greater thread pitch toward the screw head. Maximizing interfragmentary compression may aid in reducing nonunion rates associated with the internal fixation of proximal scaphoid fractures.

Keywords: compression force, fixation, scaphoid fracture

Introduction

Scaphoid fractures are the most common carpal fracture, accounting for up to 15% of acute wrist injuries.⁹ Proximal scaphoid fractures carry a greater risk of nonunion depending on fracture location due to a tenuous blood supply.^{11,12,19} With 33% of proximal pole scaphoid fractures resulting in nonunion, surgical techniques utilizing headless compression screws (HCS) have evolved to promote healing through compression across the fracture site.^{5,10,24} Surgical advancements and implant technology have resulted in improved outcomes with internal fixation for proximal pole scaphoid fractures.^{20,21,27}

Recent HCS designs have evolved from the original Herbert design and claim to improve load to failure, stiffness, and interfragmentary compression at the fixed fracture site.^{2,3,14} Interfragmentary compression is important when achieving fracture stability and optimizing clinical results for union.¹⁷ Although the optimum magnitude of compression required

to obtain scaphoid union in vivo remains unknown, interfragmentary compression decreases fracture gapping and allows for early mobilization by accelerating cancellous bone healing.⁴

Central threadless screws generate compression through pitch differences between the trailing and leading threads, while fully threaded screws utilize a variable thread pitch over a fully threaded screw length (Figure 1). Although both screw geometries are routinely used for scaphoid fracture fixation, a screw is selected based on surgeon preference. A greater understanding of compressive forces generated

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based on screw design and fracture location may aid in determining the optimal fixation technique.

Inherent differences in geometrical design between HCS have been recently shown to alter the amount of interfragmentary compression.² Fully threaded, variable pitch HCS exert greater compressive forces across a scaphoid waist fracture compared with central threadless screws.^{3,8,15,16} These biomechanical studies were almost exclusively performed with simulated fractures at the central portion of the scaphoid, and limited data exist on HCS compression forces generated along varying fracture locations along the screw. Recently, compressive forces were examined at different locations with a fully threaded screw in a simulated foam model and demonstrated differences in interfragmentary compression generated depending on fracture location.²³

Previous HCS biomechanical studies have not assessed the influence of screw type on interfragmentary compression generated at varying fracture positions.^{2,3,13,15,23} As proximal pole scaphoid fractures present the greatest clinical risk for nonunion, determining the screw geometry that provides the greatest interfragmentary compression may help improve clinical outcomes. The objective of this study was to determine the interfragmentary compression forces generated in a simulated foam model based on two HCS designs and fracture locations. We hypothesized that the fully threaded screw would generate greater interfragmentary compression for fixation at all fracture locations due to its variable pitch along the entire screw length.

Materials and Methods

Simulated foam models of 28 mm length and 10 × 10-mm rectangular cross sections were constructed from .24 g/cc density foam with 210 MPa compressive modulus and 33 MPa shear modulus.²⁶ The density and mechanical properties of the polyurethane foam are similar to those of cancellous bone.^{18,25} Polyurethane foam (Sawbone, Vashon Island, Washington) is often used as a bone analogue to minimize variability between specimens and meets standards defined by the American Society for Testing and Materials (F-1839-08).²⁵ The unique cortical-cancellous ratio of the scaphoid is ignored because clinically, the HCS is not in contact with the cortical cortex upon fixation.

Two cannulated HCS were utilized for fixation. The fully threaded screw was a 24-mm Mini Acutrak 2 HCS (2.5 mm diameter; Acumed, Hillsboro, Oregon) that is made of titanium and has a conical shape that tapers toward the distal end. The fully threaded screw has variable pitch, with greater pitch toward the distal end of the screw. The central threadless screw was a 24-mm Fixos Compression Screw (2.5 mm diameter; Stryker, Kalamazoo, Michigan) that has a threaded head and distal end with a threadless shaft (Figure 1). This central threadless screw has a constant differ-

Figure 1. Geometric differences between the fully threaded screw and the central threadless screw. The fully threaded screw has a variable pitch and a tapering diameter, while the central threadless screw has distinct variance in pitch between the 2 threaded screw portions.

ence in pitch between the head and distal tip of the screw. During fixation, the fully threaded screw is passed over a 1.14-mm guide wire, while the central threadless screw is passed over a 0.89-mm guide wire.

The experimental setup was similar to previously utilized reports²³ with transverse cuts along the 28 mm block simulating the fracture location. This cut divided the 28 mm length into a top block and bottom block, which was varied by increments of 2 mm from the top of the block for 11 fracture locations. For example, a 4-mm fracture would result in a 4-mm top block and a 24-mm bottom block. Four simulated foam models were tested for each fracture location and for each screw type, resulting in 88 simulated foam models for analysis.

Interfragmentary compression was measured as the top block applied compression onto the secured bottom block during fixation. A construct consisting of sensors, metal plates, and rubber was placed between the bottom and top blocks to allow measurement of the interfragmentary compression (Figures 2 and 3). The construct located at the fracture location had a thickness of 2.71 mm, similar to and smaller than previous literature.^{1,7,23}

FlexiForce Sensors (Tekscan Inc, Boston, Massachusetts) measured the interfragmentary compression that resulted from HCS insertion. The sensors had a thickness of .20 mm and can measure loads up to 111 N (11.32 kg) with 0.1 N accuracy and 2.0 N repeatability.

Figure 2. Fluoroscopic image of the central threadless screw fixed in a simulated 6-mm fracture. The construct (A) consists of sensors, metal, and rubber interposed as the simulated fracture site.

Figure 3. Experimental setup where fracture location was varied along the simulated foam model. The guide wire allows for screw placement and the base provides rotatory support to the system. (A) refers to the compression sensor apparatus.

Rubber was placed underneath the sensor and between the metal to allow for accurate sensor output readings. A guide wire allowed for accurate screw insertion and was placed through the center of the top block and the hole in the base (Figure 3). Kirschner wires (K-wires) were placed parallel to the guide wire through both blocks to provide rotatory stability. The base rigidly fixed the bottom block and contained holes that allowed for the guide wire and K-wires to be fed through; this ensured central and perpendicular placement of the wires through the fracture site.

The effect of different screw types on interfragmentary compression was assessed using the manufacturer's suggested protocol. The fully threaded screw was predrilled

before insertion, while the central threadless screw was not predrilled; predrilling has been shown to have no significant impact on compression force at the fracture site during fixation with similar screw designs.² Screws were inserted over the guide wire manually with a screw driver until the head was flush with the foam model (Figure 2). Interfragmentary compression forces were collected at a time point of 60 seconds after fixation to allow equilibrium to be reached.

An a priori power analysis was conducted with $\alpha = .05$ and $\beta = .20$ based on previous literature pertaining to interfragmentary compression at the screw center.^{20,22} A sample size of $n = 4$ was determined for each possible fracture location and screw type. A paired t test was utilized to determine differences in interfragmentary compression between fixation techniques for each fracture location, and a 2-way analysis of variance assessed differences in interfragmentary compression between fracture locations for both screws. A post hoc Bonferroni correction was applied and significance was set at $P < .05$.

Results

A significant effect of fracture location on interfragmentary compression ($P < .0001$) was found. For both screws, a fracture located at 22 mm generated 11.4% of the compression force generated by a fracture located at 6 mm (Figure 4). The fully threaded screw had maximum compression at fractures located 10 mm from the top edge of the top block. The fully threaded screw displayed a gradual increase and then decrease in interfragmentary compression from the maximum value with varying fracture locations. The central threadless screw generated maximum interfragmentary compression for fixation at a fracture location of 6 mm from the top edge. In contrast to the fully threaded screw, the central threadless screw had a skewed right distribution of interfragmentary compression forces, where maximum interfragmentary compression was located for fractures closer to the screw head.

A significant difference was found in the compression generated between the fully threaded screw and the central threadless screw depending on fracture location. For a fracture located 2 mm from the top edge of the top block, the central threadless screw generated significantly more interfragmentary compression ($P < .0001$) than the fully threaded screw (Figure 4). The fully threaded screw generated significantly greater interfragmentary compression than the central threadless screw for a 12-mm top block fixation ($P < .0001$) and an 18-mm top block fixation ($P < .001$). Other fracture locations demonstrated no significant difference in interfragmentary compression force (Figure 4).

Discussion

Proximal scaphoid fractures present a clinical challenge due to biological and biomechanical factors. Internal fixation

Figure 4. Compression of the central threadless screw versus the fully threaded screw for varying fracture locations. Statistically significant differences in compression for varying fixation types indicated by *.

with HCS has been associated with improved clinical results, but little is known regarding the amount of compression created by HCS for proximal scaphoid fractures.^{6,22}

Our results demonstrated that a significant difference in interfragmentary compression can be generated depending on the HCS design and fracture location. The fully threaded screw had greater compression for fractures located at the model waist (12 mm through 18 mm). For fractures located at the foam model waist, the screw design (fully threaded) that incorporates more threads on each side of the fracture was able to achieve greater compression than the design (central threadless) whose threads are located at the leading and trailing ends leaving a long central portion without purchase into bone.

The central threadless screw generated more compression at proximal locations and had a significantly greater amount of compression generated for the most proximal fracture (2 mm) model that was toward the threads closest to the screw head. While the etiology for the difference in proximal fracture compressive forces is unknown, a possible explanation may relate to the pitch of the threads that are engaged in the proximal fragment. The central threadless screw has a larger pitch and deeper thread depth compared with the fully threaded screw. This difference may be more biomechanically favorable when attempting to generate compressive forces in a smaller proximal fragment. The central threadless screw does not gain purchase into bone in its central region that is devoid of threads, for that reason perhaps, it is well suited for proximal fractures because it is only gaining purchase into the proximal segment regardless of fracture location. Thus, the fully threaded screw is not able to generate as much compression, given that it has threads along its entire length and is designed to create compression at its own geometric center. This geometric

center, however, is not at the fracture location when proximal fractures are being studied and yet the screw length is held constant.

The question remains how a screw design that incorporates variable pitch threads covering its entire length would fare if the screw was itself centered on the more proximal fracture. Given that a screw with continuous variable pitched threads can be surmised to generate maximal interfragmentary compression in its own geometric center, it remains to be seen how much interfragmentary compression a fully threaded screw would generate when placed in a manner where equal screw lengths exist on both sides of the fracture. In the future, the function of screws that are centered with respect to proximal fractures will be examined.

Compression generated with a fully threaded screw at various fracture sites of a 30-mm scaphoid foam model was previously examined.⁸ They found that different fracture locations generated a greater interfragmentary compressive force as maximum interfragmentary compression was found with a 12- to 16-mm top block.²³ This study supports earlier data in that a greater interfragmentary compressive force was created at the waist of the foam model and toward the center of the fully threaded, variable pitch screw.^{3,23}

This study does have several limitations. The biomechanical model utilized in this experiment was constructed from polyurethane foam and did not use human cancellous bone. However, this model removed bone quality as a confounding variable; the density and mechanical properties of the polyurethane foam model used in this study are comparable with those of scaphoid cancellous bone. Another limitation was the fracture thickness that was simulated with the experimental setup. The 2.71-mm gap interposed between both blocks simulating the fracture does not completely model clinical fracture thickness. This gap allowed for the

placement of sensors and allowed for appropriate force measurements within the construct. A similar fracture gap was utilized previously, while others have utilized fracture gaps greater in size.²³

This study was not performed in vivo, and conclusions regarding clinical outcomes cannot be determined from these data. Previous literature has not been able to determine the optimal interfragmentary compression force for bone union in a fracture; however, an increase in interfragmentary compression decreases bone gapping and promotes healing through increased fracture stability.⁴ In addition, previous retroactive studies have been unable to conclude that greater interfragmentary compression does not result in improved fracture healing.¹³ Results from this study can be used to retroactively determine if compression leads to fracture healing for various fracture locations.

The lack of interfragmentary compression with the antegrade fixation technique at the proximal fracture location could be a reason for the high nonunion rates during proximal fixation. The tenuous blood supply in the proximal pole may be difficult to overcome during healing even with significantly greater interfragmentary compression. However, surgeons are able to influence the interfragmentary compression more than the blood supply, and it seems intuitive to increase compression if possible.

Differences between interfragmentary compression forces generated by the HCS design and the location of the scaphoid fracture are important when selecting the appropriate HCS. This study demonstrated that HCS selection may play an important role when generating the greatest compressive force across a proximal scaphoid fracture. Based on the results of this study, while greater interfragmentary compression of proximal fractures were generated with a central threadless double threaded HCS, fully threaded variable pitch HCS achieved greater compression for central waist fractures.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

This study does not contain any live human or animal subjects.

Statement of Informed Consent

No identifying data were utilized pertaining to informed consent due to the anonymous nature of the report.

Declaration of Conflicting Interests

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