Impact of Screw Length on Proximal Scaphoid Fracture Biomechanics

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Abstract

Background Proximal scaphoid fractures display high nonunion rates and increased revision cases. Waist fracture fixation involves maximizing screw length within the cortex; however, the optimal screw length for proximal scaphoid fractures remains unknown.

Purpose The main purpose of this article is to compare stiffness and ultimate load for proximal scaphoid fracture fixation of various headless compression screw lengths.

Methods Eighteen scaphoids underwent an osteotomy simulating a 7 mm oblique proximal fracture. Screws of three lengths (10, 18, and 24 mm) were randomly assigned for fixation. Each specimen underwent cyclic loading with stiffness calculated during the last loading cycle. Specimens that withstood cyclic loading were loaded to failure.

Results No significant difference in stiffness between screw lengths was found. Ultimate load was significantly impacted by the screw length. A significant difference in ultimate load between a 10 and 24 mm screw was found; however, no significant difference occurred in ultimate load between an 18 and 24 mm screw.

Conclusions No significant difference in stiffness between all groups could be due to similarities in purchase in the proximal aspect. The 10 mm screw withstanding less ultimate load compared to the 24 mm screw could be due to the 10 mm screw gaining less purchase on either side of the fracture site compared to the 24 mm screw. Lack of significant difference in ultimate load between the 18 and 24 mm screw could be occurring because the fracture site is closer to the 18 mm screw midpoint, as distal threads are engaged closer to the fracture.

Clinical Relevance Maximizing screw length may not provide superior fixation biomechanically compared with fixation utilizing a 6 mm shorter screw for proximal scaphoid fractures.

Keywords
- screw length
- fixation
- proximal scaphoid
- biomechanics

The scaphoid is the most commonly fractured carpal bone, accounting for approximately 50% of all carpal bone fractures and up to 15% of acute wrist injuries.[1,2] Acute proximal pole fractures and proximal pole nonunions of the scaphoid present a clinical problem since patients display few symptoms shortly after injury and as a result, a delay in treatment can lead to an increase in revision cases and failure.[3,4] Approximately 33% of proximal pole scaphoid fractures result in nonunion.[5,6] The use of internal fixation for proximal pole scaphoid fractures has resulted in improved

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outcomes.[7–10] Headless compression screws have evolved to promote fracture healing.[6,11–13]

Previous studies analyzing scaphoid fracture fixation biomechanics have tested various headless compression screws through cyclic loading and load to failure testing. Scaphoid fractures fixed with 3 mm diameter headless compression screws were found to be able to withstand greater ultimate load compared with scaphoid fractures fixed with two 1.5 mm diameter headless compression screws.[14] Additional mechanical studies have attempted to determine whether an eccentrically or centrally fixed screw across scaphoid waist fractures would withstand less displacement during cyclic loading and greater ultimate load during load to failure testing.[12,15,16]

A current recommendation for stabilizing scaphoid waist fractures involves placing a headless compression screw of maximum length along the long axis of the scaphoid.[17] A previous study found that scaphoid fracture fixation with longer length headless compression screws decreased fracture fragment motion possibly due to the increase in purchase, or bone–screw interaction between the scaphoid and screw.[17] Stability of the fixed specimen through both cyclic loading and load to failure testing was not assessed, rather wrist stability was quantified from a fracture fragment motion perspective. Additionally, only waist fractures were examined and recommendations for fractures located at the distal and proximal poles cannot be made. In placing a headless compression screw across a scaphoid fracture, there is an inclination to select a shorter screw to avoid possible consequences associated with screw prominence onto the articular surface. Additionally, a biomechanical study has recommended aligning the fracture site created in this study with the midpoint of the screw.[3] A previous study has suggested that the fracture should be placed at the midpoint of the screw to optimize biomechanics compared with fractures placed at the screw head or screw tip.[3] For fractures that deviate from the scaphoid waist, the question of maximizing screw length or placing the fracture at the screw midpoint to optimize healing remains. The effect of screw length on stiffness and ultimate load of fixed proximal scaphoid fractures has not been examined.

The objective of this study was to determine the biomechanical stability through cyclic loading and ultimate load testing during cantilever loading of cadaveric scaphoids with proximal fractures internally fixed with a short, long, or medium length central threadless screw. We hypothesized that a long screw would allow for greater biomechanical stability since it will gain greater purchase distal to the fracture site even though the distal threads are engaged further from the fracture site. The results of this data will help in determining an optimal central threadless screw length from a biomechanical perspective for the fixation of proximal scaphoid fractures.

Materials and Methods

Eighteen fresh-frozen cadaver scaphoids (age: 56.7 years, standard deviation: 9.2 years, 13 males and 5 females) were harvested with all soft tissue attachments dissected from the scaphoid. Upon dissection, none of the scaphoid specimens showed evidence of pre-existing fracture. Specimen long axis length was determined utilizing digital calipers and a laser micrometer. Each scaphoid was randomly assigned for fixation to one of three possible screw lengths ($n = 6$ for each screw length) of a 2.5 mm diameter centrally threadless headless compression screw (Stryker, Kalamazoo, MI): 10 (short screw), 18, and 24 mm (long screw) length.

The long axis was marked along the scaphoid from the most proximal articular surface to the most distal articular surface of the distal pole.[18] The start point of the oblique osteotomy was marked 7 mm distal to the proximal pole of the scaphoid; using a protractor, the oblique osteotomy was marked perpendicular to the long axis for consistency. A 0.52 mm oscillating blade saw (Dremel, Racine, WI) was used to perform the osteotomy.

After creating the osteotomy, a single Kirschner wire was drilled through each specimen along the long axis of the scaphoid. Long axis screw placement central to the scaphoid was confirmed with X-ray fluoroscopy (►**Fig. 1**). Fixation of the simulated fracture was performed by a fellowship trained hand surgeon using the respective central threadless headless compression screw with the screw head inserted below the subchondral cortex (►**Fig. 2**). The headless compression screw was inserted from the volar aspect of the proximal pole toward the distal pole to simulate clinical fixation. The fixed scaphoids were stored in a freezer at –20°C and thawed for ~2 hours before testing.

The distal pole of the scaphoid was potted in epoxy putty (Bondo, St. Paul, MN) with the scaphoid long axis perpendicular to the horizontal plane; this allowed for biomechanical

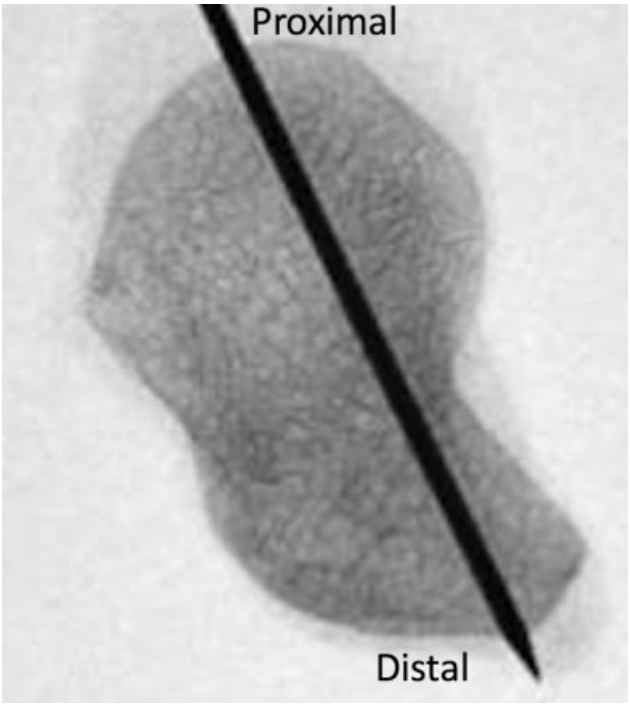

Fig. 1 Scaphoid specimen with a Kirschner wire inserted along the scaphoid long axis. The osteotomy location is perpendicular to the long axis and 7 mm distal to the proximal aspect of the scaphoid.

Fig. 2 Proximal 7 mm scaphoid fracture fixation construct fixed with (**A**) 10 mm headless compression screw (HCS), (**B**) 18 mm HCS, (**C**) 24 mm HCS.

testing of the proximal pole of the fracture. During potting, the guide wire was flushed with the distal most aspect of the scaphoid to ensure the epoxy putty would not settle into the guide wire hole within the scaphoid; the wire was removed prior to testing. The potted scaphoid was mounted on a wedge clamp at 45° to simulate clinical dorsal to volar bending load (►**Fig. 3**). A plunger was driven by a materials testing machine (Instron Model 5965, Norwood, MA) to the respective cantilever bending load upon the dorsal, proximal aspect of the scaphoid.

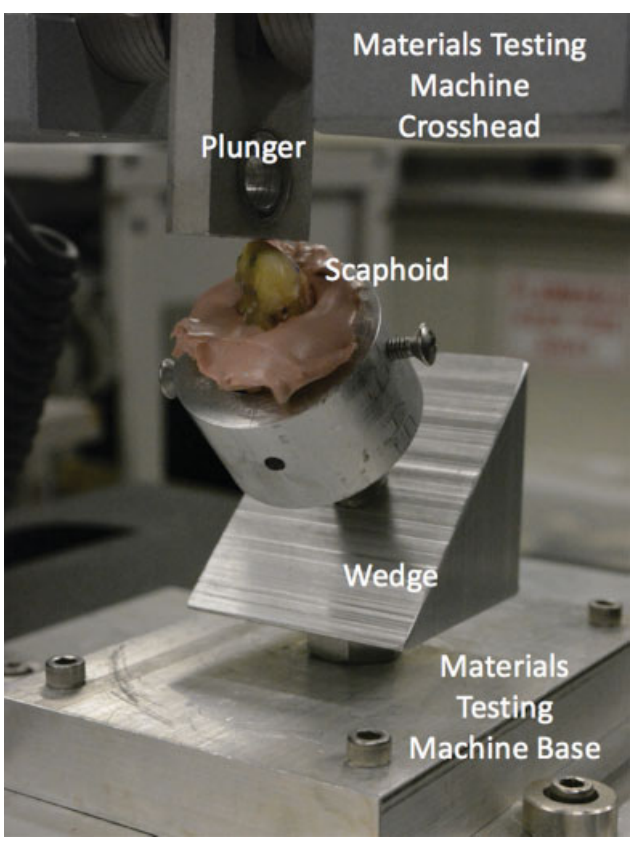

Fig. 3 Experimental setup with the distal scaphoid potted in the epoxy putty. Load was applied with a plunger attached to the materials testing machine crosshead. The scaphoid was potted upright for consistency and oriented at a 45° angle with the wedge attached to the materials testing machine base.

During the cyclic loading aspect of testing, an 800 N/mm bending moment was applied for 1000 cycles at a crosshead speed of 10 mm/min; the crosshead speed is analogous to the rate of loading and was chosen based on the material tested, in this case bone. Previous studies have utilized a similar bending moment as a 800 N/mm moment is thought to be a clinically relevant load.[19,20] The bending moment was applied with a cantilever load on the proximal aspect where the cantilever load applied to the scaphoid depended on the moment arm which was measured as the horizontal distance between the midpoint of the fracture site and the location where cantilever load was applied. The cantilever load was calculated by dividing the bending moment of 800 N/mm by the moment arm. Thus, based on specimen geometry and length, the moment arms measured ranged from 12 to 20 mm and therefore, the maximum cantilever load during cyclic loading ranged from 40.0 to 66.7 N for various scaphoid specimens. Testing was performed until 1000 cycles were completed or failure occurred with 2.5 mm of fracture displacement. During each cycle, the load varied from 5 N to the maximum cantilever load determined for that scaphoid specimen based on the moment arm length. Fracture displacement was quantified by a displacement of the materials testing machine crosshead and has been previously utilized as failure criterion in biomechanical studies assessing mechanical properties of fixed scaphoids.[12,14,17] During cyclic loading, stiffness was calculated at the 1000th cycle or was calculated at the last cycle if the specimen failed prior to completion of the 1000th cycle. Stiffness was quantified by the slope from the linear region of the load-displacement curve. Upon completion of the 1000th cycle of cyclic loading, each specimen was then loaded to failure in the same position after cyclic loading. Failure was defined as a 40% decrease in the load-displacement curve. Mode of failure for each specimen was recorded.

An a priori power analysis was conducted with $\alpha = 0.05$ and $\beta = 0.20$ based on previous literature pertaining to stiffness and ultimate load of fixed scaphoid fractures[12,14,17]. A sample size of $n = 6$ was determined for each possible screw length. A one-way analysis of variance test was performed to evaluate differences in specimen age, long axis length, stiffness, and ultimate load. A post-hoc Bonferroni correction was applied and significance was set at $p < 0.05$.

Table 1 Scaphoid specimen factors based on screw length

Screw length (mm; $n = 6$)	Age (y)	Specimen long axis length (mm)
10	54.1 ± 11.5	26.4 ± 2.9
18	58.3 ± 7.1	25.8 ± 1.5
24	57.8 ± 9.8	27.8 ± 0.5

Results

There was no statistically significant difference between age in the three randomized groups that were tested (►**Table 1**). Additionally, we found no significant difference between the long axis lengths of the scaphoids in the three randomized groups tested (►**Table 1**). The lack of significant difference in long axis length justified the use of an osteotomy 7 mm distal to the proximal pole instead of a percentage length of the long axis where the osteotomy location with respect to the proximal aspect would vary in specimens of different length.

One scaphoid fixed with a 10 mm screw failed during cyclic loading after 121 cycles at a 44.4 N cantilever bending load. All other 10, 18, and 24 mm fixed scaphoids were able to withstand 1000 cycles of cyclic loading. No significant difference in stiffness was found at the last cycle of cyclic loading between different screw lengths (►**Fig. 4**). Even though there was no significant difference in stiffness, the 24 mm fixed scaphoids (236.7 ± 37.4 N/mm) withstood the greatest stiffness, while the 10 mm fixed scaphoids (209.2 ± 40.2 N/mm) withstood the least stiffness. Stiffness of the 10 mm fixed scaphoid that failed during cyclic load was accounted for with analysis of stiffness at the last intact cycle prior to failure.

The 24 mm fixed scaphoids (437.2 ± 68.5 N) withstood significantly greater ultimate load than the 10 mm fixed scaphoids (180.5 ± 83.2 N). There was no significant difference ($p = 0.606$) in ultimate load between the scaphoid specimens fixed with 18 (319.0 ± 95.4 N) and 24 mm screws. Additionally, there was no significant difference ($p = 0.503$) in ultimate load between the scaphoid specimens fixed with 10 and 18 mm screws. The 10 mm fixed scaphoid that failed during cyclic loading was not included in the ultimate load analysis.

The most common failure mode was loss of fracture reduction (►**Fig. 5**). This occurred in 9 of 18 tested scaphoids. The remaining eight failed by a proximal pole fracture; the proximal pole was the site at which the cantilever bending load was applied. One scaphoid failed during cyclic loading as there was greater than 2.5 mm of fracture displacement.

Discussion

Our study compared the biomechanical effect of screw length (10, 18, and 24 mm) on the stiffness and ultimate load of fixed proximal scaphoid fractures in response to cyclic loading and load to failure testing.

The three screw lengths had similar responses in terms of stiffness during the last cycle of cyclic loading. We hypothesized that a proximal scaphoid fracture fixed with a longer screw length would withstand greater stiffness in cyclic load due to its greater purchase in the distal fragment compared with the scaphoid fixed with shorter screw lengths. The similar stiffness between the three screw lengths could be due to the application of a consistent bending moment to each specimen in cyclic loading. Additionally, there is no significant difference in the distance to the neutral axis between the three groups and this may impact the stiffness of the fixation construct. It is possible that purchase in the proximal fragment may have a greater role on stiffness than the screw length utilized for fixation; all three screw lengths had similar purchase in the proximal fragment. All three screw lengths had different distances from the fracture site to the purchase site in the distal fragment. As such, this distance from the fracture site to the purchase site may not play a role in the stiffness of the fixed the scaphoid.

Previous studies have analyzed the effect of different fixation techniques on stiffness in scaphoid waist fractures. No significant difference in stiffness was found with increasing screw radius and constant screw length; however, synthetic scaphoid analogue was utilized and stiffness was not determined during cyclic loading.[14] This further suggests that an increase in purchase, with fixation of screw with

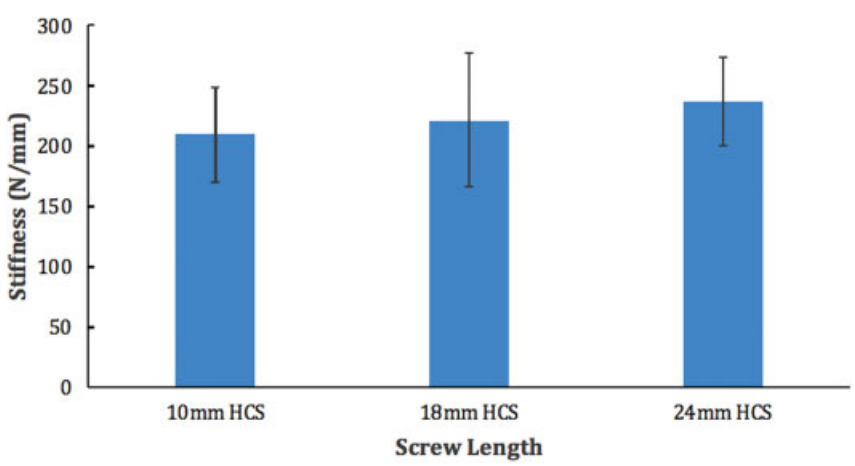

Fig. 4 Stiffness (mean ± standard deviation) based on the screw length utilized for scaphoid fracture fixation. HCS, headless compression screw.

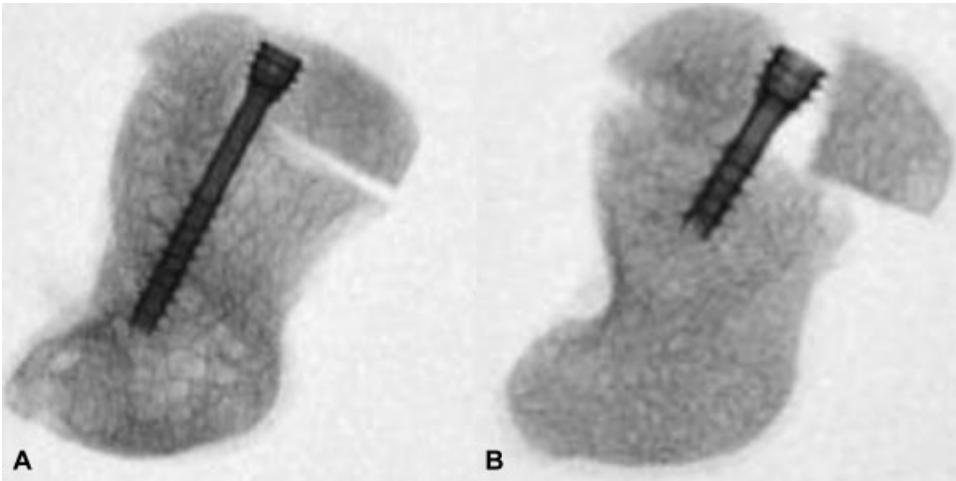

Fig. 5 Failure modes after testing with (**A**) failure by proximal pole fracture and (**B**) failure by loss of fracture reduction.

greater radius, may not significantly impact the stiffness of the construct. Additionally, a difference in stiffness during cyclic loading based on the screw orientation of fixation was previously found.[12] This study utilized a similar screw length for eccentric and centric placement; purchase was therefore similar between the groups. This shows that factors other than purchase may strongly affect stiffness.[12]

One 10 mm fixed scaphoid failed during cyclic loading and was not assessed for ultimate load during load to failure testing. Post-hoc power analysis was conducted to ensure an adequate number of samples for adequate power to assess differences in ultimate load. The sample size for each of the subject groups was deemed appropriate based on the results of this analysis.

The three screw lengths had differing responses when analyzing ultimate load. There was a significant difference between the specimens fixed with 10 and 24 mm screws. This indicates that a proximal scaphoid fracture fixed with a short screw where the fracture is at the midpoint of the screw is not as stable, from an ultimate load perspective, as a scaphoid fixed with a screw that is maximized from cortex to cortex. However, our study found that there was no significant difference in ultimate load between the scaphoids fixed with 18 and 24 mm screws. This indicates that an increase in purchase, beyond a certain screw length, may not necessarily provide additional stability through ultimate load. Additionally, this could be occurring because the 18 mm screw places the fracture closer to its midpoint compared with the 24 mm screw. As such, the distance between the fracture site and engagement of the threads in the distal fragment will be smaller in an 18 mm screw.

An increase in screw length was previously found to provide greater wrist stability for waist fractures.[17] This study by Dodds et al assessed scaphoid stability through fracture fragment motion of scaphoid waist fractures during applied loading in vitro. In contrast, our study found no difference in ultimate load between an 18 and 24 mm screw and during cyclic loading we found no significant difference in stiffness between all three tested screw lengths. The difference in results between this study and the study by Dodds et al could be due to fracture location; our study focused on proximal fractures. For proximal fractures, the fracture is placed closer to the screw head along the threadless shaft in comparison to waist fractures.

The question remains how screws of various length and radius would respond with proximal fractures from a biomechanical perspective. Given that an increase in radius is biomechanically optimal, as is an increase in length, to a certain degree, the interaction between these factors remains unknown for optimal fixation. Future studies will test proximal scaphoid fractures with the fixation of screws of various length and radius.

This study does have several limitations. One limitation of our study was that scaphoids of various lengths and geometries were utilized. Even though there was no significant difference in average long axis length between the three groups, differing scaphoid lengths could lead to variation in data. Another limitation was that cadaveric scaphoid specimens were utilized, and variances in bone mineral density could affect the purchase interaction between the bone and the screw. Previous studies have utilized the matched-pairs technique for testing.[12,15] Future studies could look at the effect of bone density on stiffness and ultimate load in the fixation of scaphoid fractures.

Differences in stiffness and ultimate load generated by the differences in headless compression screw length are important when selecting the appropriate headless compression screw for fixation. This study demonstrated that headless compression screw length selection plays an important role when optimizing stiffness and ultimate load across a proximal scaphoid fracture. The results of this study recommend fixation of proximal scaphoid fractures with the use of a long screw to withstand high ultimate loads; however, the screw length need not be maximized within the subchondral cortex to prevent screw prominence. Our study shows that proximal scaphoid fracture fixation with the use of a smaller screw length, 6 mm less than the longest possible screw length, will withstand similar ultimate loads and maintain a similar stiffness during cyclic loading, or repeated clinical loading.

Conflict of Interest

None declared.

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