The Effect of Scaphoid Fracture Site on Scaphoid Instability Patterns

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Abstract

Background Scaphoid fractures are common carpal fractures that are often misdiagnosed as wrist sprains and may go on to nonunion. The location of the fracture site may influence the stability of scaphoid nonunions.

Purpose To determine whether the stability of a scaphoid nonunion depends upon the fracture's location, we tested the hypothesis that a simulated fracture distal to the apex of the scaphoid dorsal ridge will have greater interfragmentary motion than proximal.

Methods Eleven cadaver wrists were moved through three wrist motions using a wrist simulator. In six wrists, a fracture was created distal to the scaphoid apex, and in five a fracture was created proximal to the apex. Sensors attached to the distal and proximal parts of each scaphoid measured the interfragmentary motion during wrist motion.

Results In those wrists in which the scaphoid was sectioned distal to the apex, the distal fragment became significantly more unstable relative to the proximal fragment. It flexed, ulnarly deviated, and pronated. These motion changes were less when the scaphoid was sectioned proximally.

Discussion Scaphoid fractures distal to the scaphoid apex will have greater interfragmentary motion. The mobility of the fragments at the fracture site is possibly a more important contributory factor of nonunion in scaphoid waist fractures than for proximal scaphoid fractures.

Clinical Relevance Understanding the effect that the location of a scaphoid fracture has on the potential for nonunion may influence the modalities of treatment and follow-up.

Keywords

- scaphoid fractures
- scaphoid instability
- carpal fractures

Scaphoid fractures are common carpal fractures that are sometimes misdiagnosed as wrist sprains and may go onto malunion or nonunion.¹ Treatment options vary from cast immobilization to percutaneous or open surgical techniques.¹ As reported by Vender et al,² scaphoid nonunion can lead to a high frequency of degenerative changes and thus warrants concern in those cases when a nonunion is more likely to occur. As suggested by Moritomo et al,³ the

location of the fracture site in the scaphoid may influence the stability of scaphoid nonunions. They observed that if the fracture line was distal to the apex of the scaphoid dorsal ridge, the fracture was unstable, whereas a fracture proximal to the apex was associated with a more stable fracture. They suggested that this is due to the dorsal scapholunate interosseous ligament (SLIL) inserting onto the apex since an intact SLIL would tend to minimize

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motion at the fracture site when the fracture line is proximal to it.

Smith et al⁴ examined in vitro kinematics of transverse scaphoid waist fractures. With wrist flexion, they observed an increase in flexion of the distal fragment. Leventhal et al⁵ reported on interfragmentary motion in six patients with scaphoid fractures but their sample size was too small to associate different fracture types with variations in motion.

The purpose of this study was to determine if different interfragmentary motions can be associated with the location of the fracture line. The hypothesis of this study is that a scaphoid fracture distal to the scaphoid apex will have greater interfragmentary motion.

Methods

Eighteen fresh-frozen cadaver wrists were tested in a wrist joint simulator.^{6,7} Each wrist was arthroscoped and only those with an intact SLIL were included in this study. As noted later, 7 wrists were rejected after testing, leaving 11 arms in the study. These 11 arms had an average age of 58 years (range 21–83). Eight were males and three were females. Each wrist was moved through repetitive flexion–extension, radioulnar deviation, and dart throw motions under computer control by applying physiological forces to five wrist flexors and extensors (extensor carpi ulnaris, extensor carpi radialis brevis, extensor carpi radialis longus, flexor carpi radialis, and flexor carpi ulnaris).^{8,9} The cyclic flexion–extension motion was from 30 degrees of extension to 50 degrees of flexion. The cyclic radioulnar deviation motion was from 20 degrees of ulnar deviation to 10 degrees

of radial deviation. The cyclic dart throw motion was from 30 degrees of extension and 10 degrees of radial deviation to 30 degrees of flexion and 10 degrees of ulnar deviation.

During each wrist motion, electromagnetic sensors measured the motion of the third metacarpal, the lunate, and the distal and proximal scaphoid. The sensors in the lunate and scaphoid were mounted on acrylic platforms attached to composite rods cemented into each bone (►Fig. 1). In the scaphoid, two composite rods were inserted into its volar surface, both under fluoroscopic imaging. One was inserted distal to where later a simulated fracture was created and another proximal (►Fig. 2). The skin surrounding the composite rods was released if it was felt to impinge on the posts and affect the measured motion. During each wrist motion, kinematic data were acquired while the scaphoid was intact and then afterward a simulated scaphoid fracture was created using a small oscillating saw under direct visual control. After the scaphoid fracture was created, each wrist was moved through 100 cycles of wrist flexion–extension, under computer control, to replicate continued use after wrist fracture.

In six wrists, the fracture site was distal to the scaphoid apex and therefore distal to the insertion site of the dorsal SLIL. In five wrists, the fracture site was proximal to the apex and therefore proximal to the insertion site of the dorsal SLIL. The fracture patterns were the same as previously described by Moritomo et al.³ In each wrist, the scaphoid apex was identified as the most dorsal and ulnar nonarticulating portion of the scaphoid. By using two sensors in the scaphoid, one proximal to the fracture site and one distal, the motion of the distal scaphoid fragment relative to the proximal was determined. After each wrist with the simulated fracture was moved for 100 cycles, the maximum changes in scaphoid interfragmentary flexion–extension, radioulnar deviation, and supination–pronation were computed during each wrist motion and an independent samples *t*-test, including Leven test for equality of variance, was used to compare changes in

Fig. 1 The two composite rods were inserted volarly into the scaphoid, while the rod for the lunate was inserted dorsally. The motion sensors were then attached onto an acrylic platform that was glued onto the end of each rod.

Fig. 2 This three-dimensional radial view of a reconstruction of the distal radius and scaphoid in one wrist shows the composite rods inserted in the distal and proximal portions of the scaphoid. After creating a simulated scaphoid fracture using a sagittal saw, the distal fragment is shown in red and the proximal fragment is shown in green.

Table 1 Average maximal motion between distal and proximal fragments

Wrist motion	Fracture site	Flexion–extension, degrees (SD)	Radioulnar deviation, degrees (SD)	Supination–pronation, degrees (SD)
Flexion–extension wrist motion	Distal	16.0 (7.2) ^a	7.4 (4.9)	12.9 (3.9) ^a
	Proximal	4.2 (2.0) ^a	2.2 (0.6)	2.9 (2.1) ^a
Radioulnar deviation wrist motion	Distal	13.6 (4.0) ^a	6.5 (4.6)	8.3 (2.7) ^a
	Proximal	2.3 (1.7) ^a	3.1 (1.9)	2.5 (1.6) ^a
Dart throw wrist motion	Distal	10.5 (7.1) ^a	6.3 (5.4)	9.1 (4.5) ^a
	Proximal	2.1 (0.6) ^a	3.0 (1.7)	2.0 (2.0) ^a

^aDuring all three wrist motions, the flexion–extension interfragmentary motion and the supination–pronation interfragmentary motion between the distal and proximal fragments were significantly greater ($p < 0.034$) with a distal fracture, compared with a proximal fracture. The radioulnar deviation interfragmentary motion was not significantly different ($p > 0.079$) between the two fracture sites. Flexion, ulnar deviation, and pronation are positive. Distal refers to when the fracture site was distal to the scaphoid apex. Proximal refers to when the fracture site was proximal to the scaphoid apex.

fragment motion between the two fracture location groups. A separate repeated measures analysis of variance test was performed to determine whether the changes in scaphoid interfragmentary flexion–extension motion differed among the three wrist motions (flexion–extension, radioulnar deviation, and dart throw).

At the conclusion of each experiment, each wrist, along with the attached motion sensors, was scanned with computed tomography (CT). Three-dimensional animated models were created of the lunate and the distal and proximal aspects of the scaphoid, using a previously described methodology.¹⁰ Finally, each wrist was dissected to verify that the simulated scaphoid fracture was located correctly and the distal and proximal composite rods were in the correct locations.

Results

When the scaphoid was sectioned distal to the SLIL attachment (scaphoid apex), the distal fragment became significantly

cantly more unstable relative to the proximal fragment (►Table 1; ►Fig. 3) compared with when the scaphoid was sectioned proximal to the SLIL (►Fig. 4). During the wrist flexion–extension motion, with the scaphoid sectioned distally, the distal fragment flexed significantly more relative to the proximal fragment ($p = 0.02$), had a trend to ulnarly deviate more ($p = 0.079$), and pronated significantly more ($p = 0.002$) as compared with the amount of motion when the scaphoid was sectioned proximally. During the wrist radioulnar deviation motion, with the scaphoid sectioned distally, the distal fragment flexed significantly more relative to the proximal fragment ($p = 0.001$), had a trend to ulnarly deviate more ($p = 0.141$), and pronated significantly more ($p = 0.002$) as compared with the amount of motion when the scaphoid was sectioned proximally. During the wrist dart throw motion, with the scaphoid sectioned distally, the distal fragment flexed significantly more relative to the proximal fragment ($p = 0.034$) and pronated significantly more ($p = 0.01$) as compared with the amount of motion when

Fig. 3 Flexion–extension motion of the third metacarpal, lunate, and the distal and proximal parts of the scaphoid following a simulated fracture distal to the scaphoid apex, during a wrist flexion–extension motion in one wrist. After 100 cycles of motion following creation of the simulated fracture, the distal scaphoid fragment moved with the third metacarpal, while the proximal scaphoid fragment did not.

Fig. 4 Flexion–extension motion of the third metacarpal, lunate, and the distal and proximal parts of the scaphoid following a simulated fracture proximal to the scaphoid apex, during a wrist flexion–extension motion in one wrist. After 100 cycles of motion following creation of the simulated fracture, the distal scaphoid fragment moved with the proximal scaphoid fragment and flexed far less than the third metacarpal did.

Fig. 5 Scaphoid motion after simulated distal fracture in one arm. In the left view (A), the wrist is flexed; in the right view (B), it is extended. In each view, the blue images correspond to the distal and proximal parts of the scaphoid when the scaphoid was intact. A gap between the blue images appears since the distal and proximal parts of the scaphoid were modeled after the simulated fracture was created. They were independently modeled but their positions reflect the intact scaphoid. The red images correspond to after the scaphoid was sectioned. In wrist flexion, the distal fragment flexed more than when the wrist was in extension.

the scaphoid was sectioned proximally. The greatest motion between the scaphoid fragments was typically during a flexion–extension axis of movement. In general, the interfragmentary motions were the largest with the wrist in maximum flexion (►Fig. 5) and to a lesser degree at maximum wrist extension.

Despite the appearance of a trend (►Table 1) that less flexion–extension motion occurred between the fragments with the scaphoid sectioned distally during the dart throw motion compared with the other two wrist motions, there was no significant difference ($p > 0.34$) in the interfragmentary flexion–extension among the three wrist motions.

Discussion

Scaphoid fractures distal to the scaphoid apex have greater interfragmentary motion. The reduced interfragmentary motion noted with a fracture location proximal to the apex can be explained by the stabilizing role of the intact dorsal SLIL attachment on the distal fragment. The mobility of the fragments at the fracture site is possibly a more important contributory factor of nonunion in scaphoid waist fractures than for proximal scaphoid fractures.

Limitations to this study include it being a biomechanical study in which interfragmentary motion was measured as if it was shortly after injury. Since the scaphoid fracture was simulated by the use of a small oscillating sagittal saw, there was a lack of any fracture impaction. During the course of creating the distal fracture of the scaphoid, a portion of the dorsal intercarpal ligament (DIC) was cut. However, inspection of the specimens revealed that only the portion of the ligament attached to the scaphoid in the area of the osteotomy was cut, leaving the majority of the ligament intact. As noted by Moritomo et al,¹¹ the location of the dorsal apex of the ridge of the scaphoid coincides with the location of the

attachment of the proximal part of the DIC ligament, which is just distal to the attachment of the dorsal component of the SLIL. They suggested that the DIC may provide some stability to the scaphoid. In a biomechanical study, Short et al⁹ found that sectioning the DIC ligament alone did not alter the motion of an intact scaphoid or lunate. However, this does not address the DIC's role in conjunction with a scaphoid fracture. Based on these two studies, if all of the DIC had been cut while creating the scaphoid fracture in the current study, perhaps slightly different results may have been found. Short et al⁹ also found that sectioning the dorsal radiocarpal ligament alone caused a slight increase in lunate radial deviation, but they did not find any changes in scaphoid or lunate flexion–extension. The small size of the scaphoid made it challenging to create the fracture and have the composite rods supporting the motion sensors properly located. At the conclusion of the experiment, each wrist was dissected to determine whether the composite posts had been correctly inserted into the scaphoid and lunate and whether the simulated fracture was correctly performed. Incorrect post positioning or incorrect fracture location caused us to reject data from 7 arms, leaving us with valid data from only 11 arms. Perhaps, greater differences would have been observed if the wrist had been moved into more flexion. However, the wrist flexion–extension motion was performed with the wrist in neutral radioulnar deviation, which, in some wrists, limited wrist flexion to 50 degrees. Another limitation is that the results from this study only apply to a wrist with an intact dorsal SLIL. Lastly, this study does not address any issues related to the proximity of the scaphoid blood supply to the fracture site and its effect on the potential for nonunion.

The relationship between the fracture location and the scaphoid's kinematic behavior in scaphoid nonunions has been discussed by Moritomo et al.³ In their review of 13 patients, they found that carpal instability following scaphoid

nonunion appeared to be related to where the fracture line passes relative to the scaphoid apex. The current biomechanical study was performed to verify this clinical observation. The importance of determining the fracture location has been emphasized by Oka et al.¹² They suggested that a larger bone graft be used for distal nonunions and that smaller bone grafts be used with proximal nonunions.

In Smith et al's⁴ biomechanical study of five cadaver wrists, they examined the effect of scaphoid waist fractures. Following osteotomy, they found the distal fragment flexed, pronated, and ulnarly deviated relative to the proximal fragment. Leventhal et al⁵ examined the three-dimensional motion of the distal and proximal scaphoid fragments in six patients using CT scans at multiple wrist positions. They found that motion between the fragments represented approximately one-third of overall wrist motion. They acknowledge that their patient population was too small to examine the relationship between fracture location and the alterations in kinematics.

These findings support the concept that the location of a scaphoid fracture can affect how much interfragmentary motion occurs. Direct visualization during our dissection of the tested specimens permitted us to corroborate the location of the fracture site relative to the dorsal SLIL. This allows us to more strongly support Moritomo et al's³ suggestion that reduced interfragmentary motion occurs with a fracture that is located proximal to the attachment of the dorsal SLIL. Understanding the effect that the location of a scaphoid fracture has on potential scaphoid nonunion may influence the modalities of treatment or the frequency of follow-up of scaphoid fractures.

Note

Work was performed at SUNY Upstate Medical University.

Conflict of Interest

None.

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