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Scaphoid interfragmentary motions due to simulated transverse fracture and volar wedge osteotomy

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ABSTRACT

Background: Our goal was to determine 3-dimensional interfragmentary motions due to simulated transverse fracture and volar wedge osteotomy of the scaphoid during physiologic flexion–extension of a cadaveric wrist model.

Methods: The model consisted of a cadaveric wrist ($n = 8$) from the metacarpals through the distal radius and ulna with load applied through the major flexor–extensor tendons. Flexibility tests in flexion–extension were performed in the following 3 test conditions: intact and following transverse fracture and wedge osteotomy of the scaphoid. Scaphoid interfragmentary motions were measured using optoelectronic motion tracking markers. Average peak scaphoid interfragmentary motions due to transverse fracture and wedge osteotomy were statistically compared ($P < 0.05$) to intact.

Findings: The accuracy of our computed interfragmentary motions was ± 0.24 mm for translation and $\pm 0.54°$ for rotation. Average peak interfragmentary motions due to fracture ranged between 0.9 mm to 1.9 mm for translation and 5.3° to 10.8° for rotation. Significant increases in interfragmentary motions were observed in volar/dorsal translations and flexion/extension due to transverse fracture and in separation and rotations in all 3 motion planes due to wedge osteotomy.

Interpretation: Comparison of our results with data from previous *in vitro* and *in vivo* biomechanical studies indicates a wide range of peak interfragmentary rotations due to scaphoid fracture, from 4.6° up to 30°, with peak interfragmentary translations on the order of several millimeters. Significant interfragmentary motions, indicating clinical instability, likely occur due to physiologic flexion–extension of the wrist in those with transverse scaphoid fracture with or without volar bone loss.

1. Introduction

Scaphoid fractures occur most often due to a fall on an outstretched hand, motor vehicle collision, sports or blunt impact, or assault (Leslie and Dickson, 1981). Epidemiological studies indicate that young males and individuals between 10 and 19 years of age are at the highest risk of injury (Duckworth et al., 2012; Van Tassel et al., 2010). A meta-analysis of studies that investigated the management of displaced scaphoid fractures found that the risk of nonunion was 17 times higher when treated with a plaster cast as compared to surgery (Singh et al., 2012). Nonunion of the scaphoid fragments can lead to altered loading and motion patterns of the wrist which may accelerate degenerative arthritis (Slade and Dodds, 2006). Clinically, the relation between scaphoid interfragmentary displacement and nonunion is not precisely known, however motion greater than 1 mm has been used as a threshold for instability indicating the need for internal fixation (Cooney, 2003; Cooney et al., 1980).

Previous biomechanical studies have determined scaphoid interfragmentary displacements in patients with actual fractures or cadaveric wrists with simulated fractures using computed tomography, radiography, or direct measurements (Falkenberg, 1985; Kaneshiro et al., 1999; Leventhal et al., 2008; Smith et al., 1989). In a study of the effects of simulated scaphoid osteotomy on wrist kinematics in a cadaveric model, Smith et al. (1989) used biplanar radiography to track the positions of markers that were rigidly fixed to the scaphoid fragments. They observed large scaphoid interfragmentary rotation, up to 30°, due to wrist flexion–extension and radial and ulnar rotation. Kaneshiro et al. (1999) studied the effects of a short-arm thumb cast on scaphoid interfragmentary motions in a cadaveric model during forearm supination and pronation. They observed peak scaphoid interfragmentary translation up to 3.8 mm and rotation up to 4.6°. A novel *in vivo* investigation by Leventhal et al. (2008) used computed tomography and a markerless registration technique to determine wrist kinematics in patients with unilateral scaphoid nonunion during active wrist flexion and extension. They observed large variation in the scaphoid interfragmentary displacements with peak translation up to 1.4 mm. Interfragmentary rotation

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was generally small, under 5°, for wrist flexion–extension within ±20° but increased to approximately one third of overall wrist motion at extreme ranges of motion. Continued *in vitro* and *in vivo* biomechanical research is needed to further understand scaphoid interfragmentary motions due to physiologic wrist movements and to quantify the motions as functions of fracture type. These data are also valuable clinically for diagnosis and management of those sustaining actual scaphoid fractures.

The goal of this study was to determine interfragmentary motions due to simulated transverse fracture and volar wedge osteotomy of the scaphoid during physiologic flexion and extension of a cadaveric wrist model.

2. Methods

2.1. Specimen preparation

The fresh-frozen upper extremities from 4 donors of unknown age and gender were prepared, resulting in 8 total wrist specimens (Fig. 1a). The specimens were dissected of soft tissues from 20 cm proximal to the radial styloid to the distal end of the metacarpals, leaving intact only the major wrist tendons (flexor carpi radialis, flexor carpi ulnaris, extensor carpi radialis brevis, extensor carpi ulnaris), ligamentous and capsular attachments of the wrist, the pronator quadratus, and the interosseous membrane (Dodds et al., 2006). Fluoroscopy was used to confirm that the specimens did not have irregularities secondary to wrist surgery, trauma, arthritis, or irregular scaphoid shape. The specimens were mounted proximally at the radius and ulna in resin in neutral forearm rotation and neutral ulnar variance, confirmed using fluoroscopy. For subsequent load application, the primary wrist flexor and extensor tendons were harnessed with sutures (no. 1 Ethibond suture; Ethicon, Inc., Somerville, NJ) using a modified Kessler stitch. The tendons and their harnesses passed proximally along low friction linear bushings which ensured physiologic lines of tendon action.

The scaphoid was then prepared for internal screw fixation which was investigated in a parallel study. Briefly, a central axis guide wire was placed down the scaphoid axis from a proximal-dorsal to distal-volar direction and the scaphoid was reamed. For subsequent attachment of motion tracking flags, plastic supports were rigidly fitted onto the third metacarpal and radius/ulna mount and two threaded, laterally oriented Steinmann pins (1.1 mm diameter) were rigidly fixed into the distal and proximal scaphoid poles under fluoroscopic guidance (Fig. 1b). The lightweight flags, each with 3 noncollinear markers, were rigidly fixed to the plastic supports and Steinmann pins (Fig. 1a).

2.2. Simulated scaphoid fractures

To access the scaphoid midwaist, an 8-mm transverse incision was made in the wrist capsule just proximal to the dorsal intercarpal ligament. First, a transverse scaphoid midwaist fracture was simulated using a microsagittal saw with a 5 mm wide, thin blade. Subsequently, a 3 mm volarly based wedge osteotomy was simulated (Fig. 1c) and the bone wedge was removed *en bloc* with a hemostat. Prior to each flexibility test, the dorsal capsulotomy was repaired with a running 4-0 suture (Ethibond; Ethicon, Inc.).

2.3. Flexibility testing

Flexibility testing in flexion and extension was performed for each specimen while intact, following simulated transverse fracture of the scaphoid, and following volar wedge osteotomy of the scaphoid. The radius/ulna mount was rigidly fixed to the test table. Throughout all flexibility tests, a static preload of 10 N was applied to each of the 2 flexor tendons and each of the 2 extensor tendons to simulate physiologic muscle tension, resulting in 40 N compressive preload across the wrist (Carrigan et al., 2003; Dunning et al., 1999; Hara et al., 1992). Quasi-static flexion and extension loads of 20, 40, and 60 N were applied

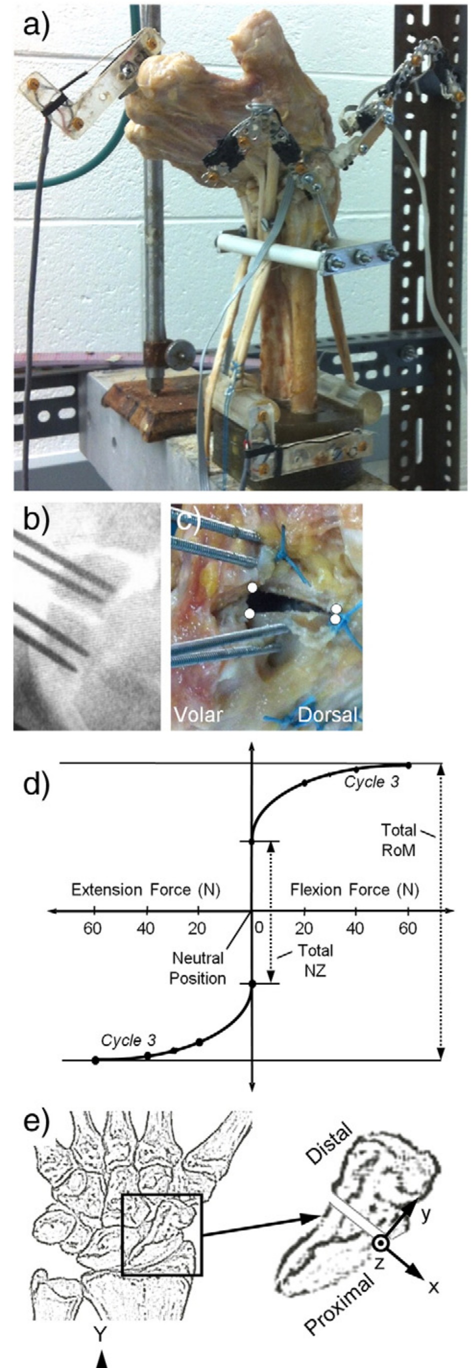

Fig. 1. The model and flexibility testing protocol. a) Photograph of the human cadaveric wrist model used to determine scaphoid interfragmentary motions. The model, shown for a left wrist, consisted of the metacarpals through to 20 cm proximal to the radial styloid. b) Dorsal and c) lateral view of a right wrist following simulated wedge osteotomy showing the positions of the Steinmann pins used to attach motion tracking flags. Frame c shows the points measured to define the scaphoid fracture corners. d) Displacement–force curve showing total range of motion (RoM) and total neutral zone (NZ). Forces up to 60 N were applied to the major wrist tendons to simulate physiologic flexion (positive) and extension (negative). e) Volar view of a right wrist indicating the global coordinate system, XYZ, and the scaphoid coordinate system, xyz, that was fixed to and moved with the proximal scaphoid fragment. The positive axes were oriented radially for x and X, distally for y and Y, and volarly for z and Z.

to the wrist through the tendons with the load evenly distributed among the 2 tendons for each load direction. Thus the peak load applied to the wrist in both load directions, including preload and