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Fixation strength of four headless compression screws

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ABSTRACT

To promote a quicker return to function, an increasing number of patients are treated with headless screws for acute displaced and even non-displaced scaphoid fractures. Therefore, it is imperative to understand and optimize the biomechanical characteristics of different implants to support the demands of early mobilization. The objective of this study was to evaluate the biomechanical *fixation strength* of 4 headless compression screws under distracting and bending forces. The Acutrak Standard, Acutrak Mini, Synthes 3.0, and Herbert-Whipple screws were tested using a polyurethane foam scaphoid fracture model. Implants were inserted into the foam blocks across a linear osteotomy. Custom fixtures applied pull-apart and four-point bending forces until implant failure. Pull-apart testing was performed in three different foam densities in order to simulate osteoporotic, osteopenic, and normal bone. The peak pull-apart forces varied significantly between implants and were achieved by (from greatest to least): the Acutrak Standard, Synthes 3.0, Acutrak Mini, and Herbert-Whipple screws. The fully threaded screws (Acutrak) failed at their proximal threads while the shanked screw (Synthes and Herbert Whipple) failed at their distal threads. Similarly, the screws most resistant to bending were (from greatest to least): the Acutrak Standard, Acutrak Mini, Herbert-Whipple, and Synthes. Although the amount of force required for pull-apart failure increased with each increasing simulated bone density (a doubling in density required triple the amount of pull apart force), the mode and sequence of failure was the same. Overall, the fully threaded, conical design of the Acutrak screws demonstrated superior fixation against pull-apart and bending forces than the shanked designs of the Synthes and Herbert-Whipple. We also found a strong relationship between simulated bone density and pull-apart force.

1. Introduction

Traditionally, nondisplaced and minimally displaced scaphoid fractures have been considered stable and were treated conservatively with cast immobilization. Although this approach achieves healing rates ranging from 90% to 100% [1,2], there is a trend in orthopaedic practice towards early internal fixation of these injuries in order to avoid prolonged immobilization and expedite return to work [3] and sport [4]. This is especially true for the young and active patient in whom these injuries are most prevalent [5]. Prospective randomized trials [6,7] have compared cast immobilization to percutaneous fixation with a headless compression screw (HCS); demonstrating a significantly quicker time to union and return to work in the surgical group notwithstanding the occurrence of some surgical complications. Subsequent meta-analysis [8] confirmed improved standardized functional outcomes in patients treated with surgery in lieu of casting.

As more patients are offered surgical fixation of these injuries, and thus growing emphasis on early mobilization, the post-operative fixation of the implant to provide absolute stability [9,10] is of increasing importance. Numerous studies have examined the interfragmentary compression of HCSs [11–13]; however, little is known about the strength of current implants to withstand the deforming forces within a mobilizing carpus. Furthermore, the few studies that describe biomechanical testing through pull-apart [14–16], bending [17,18], and cyclical loading [19] mostly involve a comparison to the original Herbert screw rather than current, widely used implants.

The primary objective of this study was to evaluate the biomechanical *fixation strength* of 4 popular, commercially available HCSs under the forces the scaphoid is subjected to with early motion: distraction and bending [20]. These two modes of failure were tested in a polyurethane foam scaphoid model by measuring the pull-apart and four-point bending forces respectively. As a secondary objective, we tested the pull-apart force of each implant

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in 3 different foam densities – simulating osteoporotic, osteopenic, and normal bone. Our null hypothesis was that there would be no difference in fixation strength between implants and that the pull-apart force would increase proportionately with denser bone.

2. Materials and methods

2.1. Implants

Four commercially available HCSs were tested (Fig. 1). All screws were chosen to have similar length (24–25 mm) in order to control for bone purchase. The *Acutrak Standard* (Acumed, Hillsboro, OR) is a highly polished titanium, conically shaped, self-tapping, fully threaded, cannulated screw with a variable thread pitch spanning the entire screw. It has a distal outer-diameter (DOD) of 3.3 mm, and proximal outer-diameter (POD) of 4.4 mm. The *Acutrak Mini* (Acumed, Hillsboro, OR) is a scaled-down version of the Acutrak-Standard with DOD and POD of 2.8 mm and 3.5 mm respectively. The *Synthes 3.0 mm HCS* (DePuy Synthes, West Chester, PA) is a cannulated 316 L stainless steel, self-drilling and self-tapping headless screw with DOD and POD of 3.0 mm and 3.5 mm respectively. A smooth shank that allows for pre-compression to be applied during screw insertion separates the distal and proximal threads. Finally, the *Herbert-Whipple HCS* (Zimmer, Warsaw, IN) is a modified version of the original Herbert screw with a slightly larger diameter (2.5 mm) to accommodate cannulation and has self-tapping leading threads. Made of Titanium (Ti-6AI-4V alloy), the DOD and POD are 3.0 mm and 3.85 mm respectfully, separated by a smooth 2.5 mm diameter shank between proximal and distal threads.

2.2. Scaphoid bone model

Biomechanical stability was studied using a rigid polyurethane foam scaphoid fracture model (1522-1-3, Pacific Research Laboratories, Vashon, WA). In addition to providing consistent inter-specimen size, shape, density, and screw purchase, these foams have been specifically validated by the American Society for Testing and Materials as a cancellous bone testing medium for orthopaedic implants [21]. Polyurethane foam has therefore been used extensively for biomechanical evaluation of scaphoid screws [13,15,22–27]. The biomechanical properties of the foam are well controlled, compress and crush like cancellous bone, and were selected to best approximate scaphoid cancellous bone of a young adult [28,29] – comprising a density of 0.32 g/cc (20 pcf). Pull-apart testing was repeated in 0.24 g/cc (15 pcf) and 0.16 g/cc (10 pcf) to simulate osteopenic and osteoporotic bone respectively [30].

The foam was machined by computer numerical control into 10 mm by 30 mm by 70 mm blocks and a diamond saw created a linear osteotomy at the midpoint. The model simulates a scaphoid waist fracture perpendicular to the long axis of the bone and therefore a best-case scenario for fixation (equal screw purchase on either side of the fracture, no comminution, and fixation perpendicular to the fracture). Each implant under test was inserted into a new fracture specimen (specimens were never re-used) according to the manufacturer guidelines. A drill press was used in lieu of a freehand drill to ensure accurate placement of the implant in the center and perpendicular to the fracture specimen. The implants were buried into the foam block by 2 mm from the surface (as recommended by the implant manufacturers and practiced clinically by the authors), achieving compression between the two fracture fragments. Approximately two screw turns of pre-compression was applied to the Synthes screw using the compression sleeve provided by the manufacturer. A stopper was used to ensure the screws were placed equidistant across the fracture plane.

2.3. Pull-apart

A custom fixture (Fig. 2A) separated the two halves of the foam block at a constant speed of 0.05 mm/s while continuously recording the applied force and displacement of the fracture until one end of the implant entirely dislodged from the foam. The displacement was produced by a motorized torque meter (Imada, Northbrook, IL). The mode of failure was recorded for each implant. The experiments were performed using 0.16, 0.24, and 0.32 g/cc foam and repeated 6 times per implant type for a total of 72 tests.

2.4. Four-point bending

A custom apparatus (Fig. 2B) applied bending stresses on either side of the simulated fracture plane through a four-point configuration at a rate of 0.01 mm/s while a chronometric camera

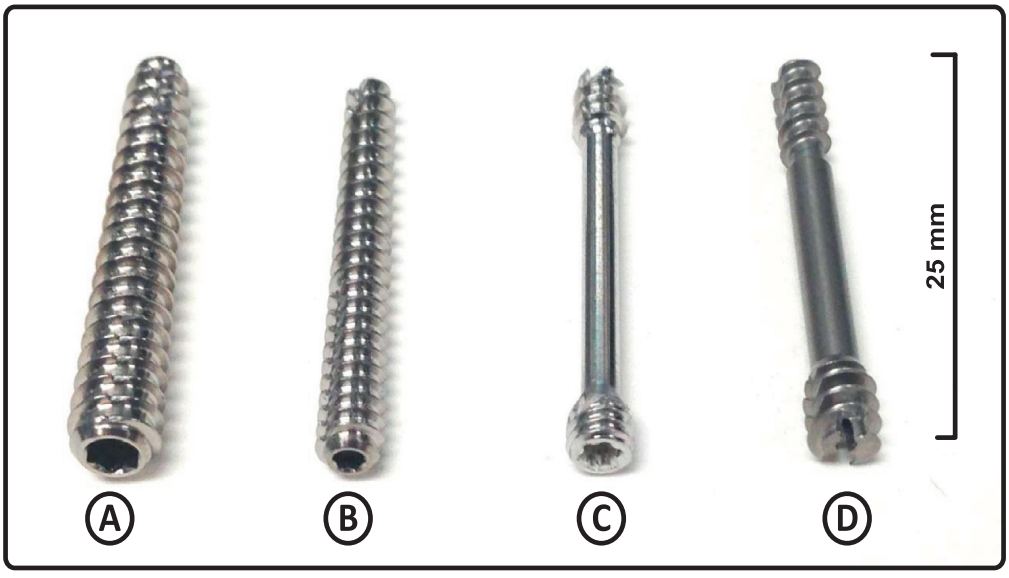

Fig. 1. Four HCSs tested: (a) Acutrak Standard, (b) Acutrak Mini, (c) Synthes 3.0, (d) Herbert-Whipple.

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