Comparison of Fixation Methods for Scaphoid Nonunions
A Biomechanical Model


Abstract
The purpose of this study was to analyze the relative biomechanical stability of three types of internal fixation with cancellous bone graft in a cadaveric, scaphoid nonunion model. A scaphoid nonunion model was created by removing a volar wedge of bone from the waist of the scaphoid in 18 fresh frozen human cadavers. Cancellous sawbone graft was inserted into the osteotomy site and three groups of six cadavers each were then internally fixed with a pair of parallel 0.045-inch K-wires, Mini-Acutrak® screws, or Standard Acutrak® screws, respectively for each group. The potted specimens were tested using an Instron® tensile testing machine by applying force to the distal pole of the scaphoid. The load and stiffness were calculated at 2 mm and 4 mm of displacement. Results showed that both the Mini-Acutrak® screw and the Standard Acutrak® screw were statistically stronger and stiffer at 2 mm displacement than the pair of parallel 0.045-inch K-wires. No statistically significant difference between the Standard and Mini-Acutrak® screws was noted at 2 mm displacement. At higher loads (4 mm displacement), the Standard Acutrak® became statistically stronger and stiffer than the Mini-Acutrak® screw. It was concluded that the Standard Acutrak® screw followed by the Mini-Acutrak® screw may be a better option than a pair of parallel 0.045-inch K-wires when treating scaphoid nonunions. The screws have increased strength of fixation and stiffness when compared to K-wires. Also, unlike the K-wires, the Acutrak® screws enhance fracture healing by achieving interfragmentary compression. Even in a cancellous bone graft model, interfragmentary compression was achieved and our concern that the bone graft would “spit out” was allayed.

Scaphoid fractures constitute 60% to 70% of all carpal bone fractures.1 These fractures have a well-documented tendency to progress to nonunion.2-5 There are an estimated 35,000 scaphoid nonunions per year.1 The etiology of scaphoid nonunions includes a tenuous blood supply, delay in treatment, fracture displacement, fracture comminution, and inadequate immobilization.1,6-11 Most symptomatic scaphoid nonunions eventually develop a collapse, or “humpback” deformity, followed by the onset of wrist arthrosis.12,13 If left untreated, scaphoid nonunions are predisposed to premature carpal arthrosis and long-term disability.14,15

Collapsed scaphoid nonunions can be addressed surgically by curettage of necrotic bone, impaction bone grafting, and internal fixation. Stable fixation of an established scaphoid nonunion can prevent progressive degenerative changes.16 There are a number of different surgical approaches available to achieve the desired stability, including bone grafting, internal fixation, or a combination of both.

Commonly used internal fixation devices include parallel Kirschner (K) wires and variable pitch compression screws.1,17-19 K-wires are easy to insert and remove and provide satisfactory, although not rigid, stability. However,
K-wires are unable to provide compression at the fracture site, and there is a need for extended postoperative immobilization, which may lead to wrist stiffness. There are many different compression screws available to help achieve stable fixation when treating scaphoid nonunions. The Acutrak® screw (Acumed® LLC, Acutrack Screw System, Hillsboro, Oregon) is a cannulated, headless screw with differential pitch throughout its length. The cannulated aspect allows for easy insertion and, as the screw is headless, it may be buried under the articular surface. The differential pitch allows for interfragmentary compression. Previous studies have documented that fixation of scaphoid fractures is optimized by the central placement of a cannulated compression screw.20

Previous studies have documented the improved efficacy of the Acutrak® screw in relation to other variable pitch compression screws.21,22 However, no studies comparing K-wire fixation with bone grafting to the Acutrak® screw with bone grafting have been reported. We sought to further define the characteristics of the Acutrak® screw by analyzing the relative biomechanical stability using a cadaveric, scaphoid nonunion model of three types of internal fixation devices: a pair of parallel 0.045-inch K-wires, Mini-Acutrak® screws (1.5 mm), and Standard Acutrak® screws (2.0 mm) (Fig. 1).

Materials and Methods

Eighteen human fresh-frozen cadaveric scaphoids were collected and cleaned of all soft tissue. The average age of the cadavers was 78 years. Radiographs of all scaphoids were made to rule out intraosseous abnormalities. The proximal aspect of each specimen was potted in a holder with use of polymethylmethacrylate and two crossed K-wires passed through the proximal end of the scaphoid to augment the fixation to the cement. The scaphoids were oriented in a neutral position in the lateral plane and 45° to the horizontal in the AP plane to mimic the scaphoid’s natural position in a wrist held at neutral, as described by McCallister and colleagues.20 The scaphoids were marked circumferentially at the narrowest aspect of the scaphoid waist. Using a small hand-held power saw, a volar wedge of bone was removed from the waist of each scaphoid to recreate the “humpback” deformity. The dorsal cortex was left intact temporarily until the osteotomy was internally fixed to recreate the dorsal hinge seen clinically.

The 18 scaphoids were then randomly divided into three groups of six. The first group of six scaphoids were internally fixed with a pair of parallel 0.045-inch K-wires. The second group of six scaphoids were internally fixed with Mini-Acutrak® screws, and the last six scaphoids were internally fixed with Standard Acutrak® screws. The three groups of six specimens per group were sufficient to achieve 80% power and achieve statistical significance.

All screws were placed in accordance with the manufacturer’s recommendations. The screws and K-wires were positioned under direct visualization. After the scaphoids were internally fixed, the dorsal cortex was transected with a small hand-held saw. Cancellous sawbone graft was then placed into the osteotomy site.

The potted specimens were then inserted into a vise and attached to the Mini 44 Instron® tensile testing machine. A force was applied to the distal pole of each scaphoid to reproduce the primary physiologic load encountered by the scaphoid. The load was increased until 2-mm displacement and 4-mm displacement occurred. The load was recorded at both of these endpoints. Stiffness was then calculated with the use of the load and displacement measurements.20 All statistical calculations were performed using ANOVA, with an alpha value of significance of less than or equal to 0.05.

Results

At 2-mm displacement, the load for the parallel 0.045-inch K-wires was 81.6 N (± 21.6 N), the load for the Mini-Acutrak® screw was 147.4 N (± 52.8 N), and the load for the Standard Acutrak® screw was 194.6 N (± 46.5 N) (Fig. 2). Both the Mini-Acutrak® screw and the Standard Acutrak® screw were statistically stronger than the pair of parallel 0.045-inch K-wires (p < .001). There was no statistically significant difference in strength between the Standard and Mini-Acutrak® screws, although the trend was that the Standard Acutrak® screw was stronger.

At 4-mm displacement, the load for the parallel 0.045-inch K-wires was 171.9 N (± 30.1 N), the load for the Mini-
Acutrak® screw was 263.8 N (± 83.7 N), and the load for the Standard Acutrak® screw was 395.0 N (± 73.4 N) (Fig. 3). The Standard Acutrak® screw was statistically stronger than the parallel 0.045-inch K-wires and the Mini-Acutrak® screw (p < 0.05). There was no statistically significant difference in strength between the Mini-Acutrak® screw and the pair of parallel 0.045-inch K-wires. Thus, at higher loads, the Standard Acutrak® became statistically stronger than the Mini-Acutrak® screw.

At 2-mm displacement, the stiffness for the parallel 0.045-inch K-wires was 40.8 (± 10.8), the stiffness for the Mini-Acutrak® screw was 73.7 (± 26.4), and the stiffness for the Standard Acutrak® screw was 97.3 (± 23.2) (Fig. 4). At 2-mm displacement, both the Mini-Acutrak® screw and the Standard Acutrak® screw were statistically stiffer than the pair of parallel 0.045-inch K-wires (p < 0.05). There was no statistically significant difference in stiffness between the Standard and Mini-Acutrak® screws, although the trend was that the Standard Acutrak screw was stiffer.

At 4-mm displacement, the stiffness for the parallel 0.045-inch K-wires was 45.1 (± 13.7), the stiffness for the Mini-Acutrak® screw was 58.2 (± 22.4), and the stiffness for the Standard Acutrak® screw was 100.2 (± 20.5) (Fig. 5). At 4-mm displacement, the Standard Acutrak® screw was statistically stiffer than both the parallel 0.045-inch K-wires and the Mini-Acutrak® screw (p < 0.05). There was no statistically significant difference in stiffness between the Mini-Acutrak® screw and the pair of parallel 0.045-inch Kirschner wires. At higher loads, the Standard Acutrak® became statistically more stiff than the Mini-Acutrak® screw.

Discussion

Several biomechanical studies have been published evaluating scaphoid fracture fixation.16,19,21,23-26 There are no previously published biomechanical reports based solely on scaphoid nonunion fixation. Our volar wedge osteotomy helped to create a situation typically seen in scaphoid nonunions—the “humpback” deformity. This deformity, if allowed to progress, typically results in carpal collapse and
arthrosis.\textsuperscript{12,13,27} Additionally, associations between this type of deformity and the subsequent development of dorsal intercalated sequential instability (DISI) have been documented and are noted to result in earlier degenerative changes.\textsuperscript{7,8,29}

The volar comminution and concomitant loss of bone in the palmar surface place high levels of stress on any fixation device.\textsuperscript{30,31} Allowing for this, the selection of a device for the fixation of scaphoid nonunions involves numerous other factors and includes ease of insertion, prominence of hardware, degree of stability achieved, compression achieved at the fracture site, strength and stiffness of the fixation, and the ability to achieve early postoperative mobilization.

The advantages of the Acutrak\textsuperscript{®} screw are that it is cannulated for ease of insertion and it is headless; therefore, the screw is able to be buried under the articular surface. The screw is tapered on the outer profile, which minimizes fixation failure secondary to loss of screw purchase. The differential pitch throughout the length of the screw allows for compression through an intercalary fragment of cancellous bone and intact dorsal hinged cortex. Compression at the fracture site serves not only to maintain stability and reduce the intersegment gap but also to enhance the healing process.\textsuperscript{12,33,34} In addition, as this study showed, the Acutrak\textsuperscript{®} screw has increased strength and stiffness when compared to a pair of parallel 0.045-inch K-wires. With use of the Acutrak\textsuperscript{®} screw, rigid internal fixation can be achieved and rapid postoperative mobilization is possible. This can help to avoid the wrist stiffness seen with prolonged immobilization.

The ability of implants to resist bending is an important factor in the stability of fixation and subsequent healing of the nonunion. This study revealed that the Standard Acutrak\textsuperscript{®} screw was stiffer than the Mini-Acutrak\textsuperscript{®} screw that was, in turn, stiffer than the pair of parallel 0.045-inch K-wires.

Beadel and coworkers, in a biomechanical study analyzing compression across a simulated scaphoid fracture, examined both Standard Acutrak\textsuperscript{®} and Mini-Acutrak\textsuperscript{®} screws.\textsuperscript{24} They noted that the Standard Acutrak\textsuperscript{®} screw achieved greater interfragmentary compression than did the Mini-Acutrak\textsuperscript{®}, as well as the Bold\textsuperscript{®} screw (a Herbert-like\textsuperscript{®} screw with a central threadless shaft). However, the investigators posited that the Standard Acutrak\textsuperscript{®} screw, due to its larger thread diameter, has the potential of affecting fracture healing, as it creates a larger defect during insertion. Nevertheless, satisfactory clinical outcomes in several studies bear out the effectiveness of the Standard Acutrak\textsuperscript{®} screw and serve to belie the impact of the large thread diameter.\textsuperscript{21}

Similar results showing the merits of the Acutrak\textsuperscript{®} system have been reported. Wheeler and McLoughlin compared the Acutrak\textsuperscript{®} screw with both the AO lag screw\textsuperscript{®} and Herbert compression\textsuperscript{®} screw in a cancellous bone model.\textsuperscript{22} They noted greater fracture fragment stability and compression as well as greater pull-out strength with the Acutrak\textsuperscript{®} screw than with the AO\textsuperscript{®} and Herbert\textsuperscript{®} screws. The Acutrak\textsuperscript{®} system also provided greater resistance to torque than did the AO\textsuperscript{®} and Herbert screws, heralding its rotational stability and ability to maintain interfragment contact. Because of the results of these studies showing superior biomechanical performances of the Acutrak\textsuperscript{®} system compared to the AO\textsuperscript{®} and Herbert\textsuperscript{®} screws, we chose to evaluate the biomechanical properties of K-wire fixation in relation to the Acutrak\textsuperscript{®} screws. To our knowledge, this type of comparison has not been previously performed.

Likewise, there exists no clinical studies that directly compare screw fixation to K-wire fixation for the treatment of scaphoid nonunions. However, in a 2002 meta-analysis examining the treatment of scaphoid nonunions, it was shown that for the treatment of unstable scaphoid nonunions, the union rate was 94% with screw fixation and grafting versus 77% with K-wires and wedge grafting.\textsuperscript{35} High rates of union were also noted by Watson and associates, who employed K-wire fixation with bone grafting via a dorsal approach.\textsuperscript{16}

Despite these positive outcomes, the current study delineates the increased efficacy of the Acutrak\textsuperscript{®} system, as both the Standard Acutrak\textsuperscript{®} screw and the Mini-Acutrak\textsuperscript{®} screw are significantly stronger and stiffer than a pair of parallel 0.045-inch K-wires at lower loads. At higher loads, the Standard Acutrak\textsuperscript{®} screw is significantly stronger and stiffer than both the Mini-Acutrak\textsuperscript{®} screw and the pair of parallel 0.045-inch K-wires.

The Standard Acutrak\textsuperscript{®} screw followed by the Mini-Acutrak\textsuperscript{®} screw may be a better option than a pair of parallel 0.045-inch K-wires when treating scaphoid nonunions. The screws have increased strength of fixation and stiffness when compared to K-wires, and the hardware can be buried under the articular surface. Also, the Acutrak\textsuperscript{®} screws can achieve interfragmentary compression, which has been shown to enhance fracture healing, whereas the K-wires cannot.

**Disclosure Statement**

None of the authors have a financial or proprietary interest in the subject matter or materials discussed, including, but not limited to, employment, consultancies, stock ownership, honoraria, and paid expert testimony.

**References**