Eklem Hastalıkları ve Cerrahisi
Joint Diseases and Related Surgery

Original Article / *Çalışma - Araştırma*

Joint Dis Rel Surg
2007;18(2):66-71

Comparison of fixation methods for scaphoid nonunions: a biomechanical model

Skafoid kaynamamalarında tespit yöntemlerinin karşılaştırılması: Biyomekanik çalışma

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Objectives: 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.

Materials and methods: 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 were randomized for internal fixation with a pair of parallel, 0.045-inch K-wires, a Mini Acutrak screw, or a Standard Acutrak screw, respectively. 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 displacements.

Results: Both the Mini and Standard Acutrak screws were statistically stronger and stiffer at 2-mm displacement than the pair of parallel K-wires. No statistically significant difference was noted between the Standard and Mini screws at 2-mm displacement. At higher loads (4-mm displacement), the Standard Acutrak screw exhibited significantly greater strength and stiffness than the Mini Acutrak screw.

Conclusion: Due to increased strength of fixation and stiffness, and with an additional advantage of interfragmentary compression, the Standard Acutrak screw followed by the Mini Acutrak screw may be a better option than a pair of parallel K-wires in the treatment of scaphoid nonunions.

Key words: Biomechanics; bone screws; cadaver; fracture fixation, internal/methods; scaphoid bone/injuries; stress, mechanical.

Amaç: Bu kadavra çalışmasında, skafoid kaynamamalarında kansellöz kemik grefti ile birlikte uygulanan üç tip internal fiksasyonun biyomekanik stabilitesi değerlendirildi.

Gereç ve yöntemler: On sekiz adet taze donmuş insan kadavrasında, skafoidin bel kısmında volar yüzde üçgen şeklinde bir kemik parçası çıkarılarak kaynamama modeli oluşturuldu. Osteotomi alanına kansellöz kemik grefti yerleştirildi ve altışarlık üç gruba ayrılan kadavralara üç tespit yönteminden biri uygulandı: 0.045 inçlik iki paralel K-teli, Mini Acutrak vidası veya Standart Acutrak vidası. Örnekler gerilme testi için Instron makinasına yerleştirilerek, skafoidin distal kutbuna güç uygulandı. Örneklerin 2 mm ve 4 mm deplasmanlarında yetersizlik kuvveti ve sağlamlığı ölçüldü.

Bulgular: İki milimetre deplasmanda, hem Mini hem de Standart Acutrak vidaları paralel K-teli çiftine göre anlamlı derecede güç ve sağlamlılık gösterdi. İki vida arasında 2 mm deplasmanda güç ve sağlamlık açısından anlamlı farklılık görülmedi. Daha yüksek kuvvetlerde (4 mm deplasman), Standart Acutrak vidası Mini vidaya göre anlamlı derecede fazla güçlülük ve sağlamlık ortaya koydu.

Sonuç: Tespitin daha güçlü ve sağlam olması ve, ek olarak, interfragmanter kompresyon sağlama avantajı nedeniyle, Standart Acutrak vidası ve ikinci sırada olmak üzere Mini Acutrak vidası, skafoid kaynamamalarının tedavisinde bir çift paralel K-telinden daha iyi bir seçenek olabilir.

Anahtar sözcükler: Biyomekanik; kemik vidası; kadavra; kırık tespiti, internal/yöntem; skafoid kemik/yaralanma; stres, mekanik.

- *Received: October 19, 2006 Accepted: May 9, 2007*

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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] It is estimated that there are about 35,000 scaphoid nonunions per year.[1] The etiology of scaphoid nonunions include tenuous blood supply, delay in treatment, fracture displacement, fracture comminution, and/or inadequate immobilization.[1,6-11] Most symptomatic scaphoid nonunions eventually develop a collapse, or "humpback" deformity, followed by 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 dealt with 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. These include 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 do not provide compression at the fracture site and there is a need for extended postoperative immobilization which may lead to wrist stiffness. There are many types of compression screws to help achieve stable fixation when treating scaphoid nonunions. The Acutrak® screw (Acumed, Hillsboro, OR, USA) 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. It has been documented that fixation of scaphoid fractures is optimized by the central placement of a cannulated compression screw.[20]

Several studies demonstrated an improved efficacy of the Acutrak screw in comparison with other variable pitch compression screws.[21,22] However, no studies have been reported that compared the results of fixation using K-wires and the Acutrak screw with bone grafting.

We sought to further define the characteristics of the Acutrak screw by analyzing the relative biomechanical stability of three types of internal fixation devices in a cadaveric, scaphoid nonunion model. The three types of internal fixation devices tested included the following: a pair of parallel, 0.045-inch K-wires, a Mini Acutrak screw (1.5 mm), and a Standard Acutrak screw (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. All scaphoids were radiographed to rule out intraosseous abnormalities. The proximal aspect of each specimen was potted in a holder with use of polymethylmethacrylate and two cross K-wires were passed through the proximal end of the scaphoid to augment the fixation to the cement (Fig. 2). The scaphoids were oriented in a neutral position in the lateral plane and 45° to the horizontal in the anteroposterior plane to mimic their natural position in the wrist held at neutral as described by McCallister et al.[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

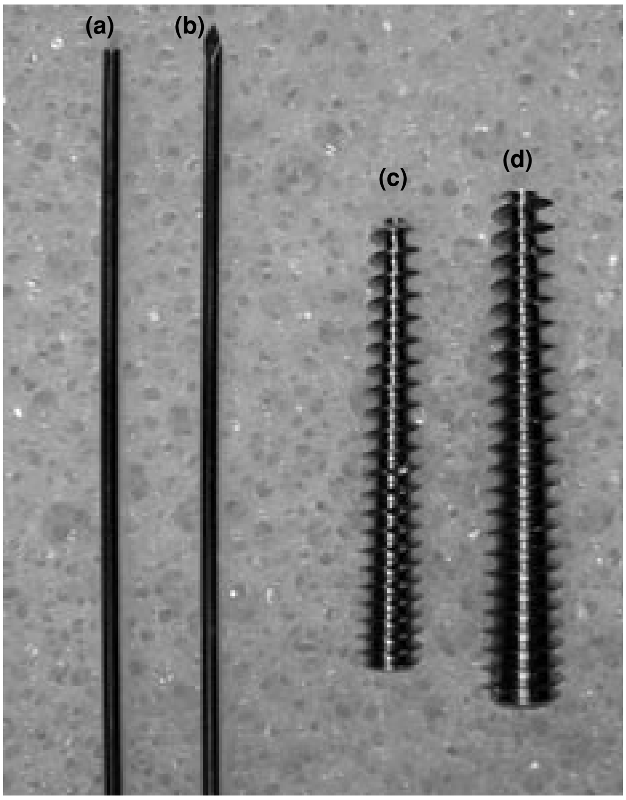

Fig. 1. (a) Flat and **(b)** sharp ends of the K-wire. **(c)** Mini-Acutrak screw, **(d)** standard Acutrak screw.

Fig. 2. Potted scaphoid model showing placement of parallel K-wires.

removed from the waist of each scaphoid to create the "humpback" deformity (Fig. 3) The dorsal cortex was left intact temporarily until the osteotomy was internally fixed to recreate the dorsal hinge.

The scaphoids were then randomly divided into three groups of six to be internally fixed with *(i)* a pair of parallel, 0.045-inch K-wires, *(ii) a* Mini

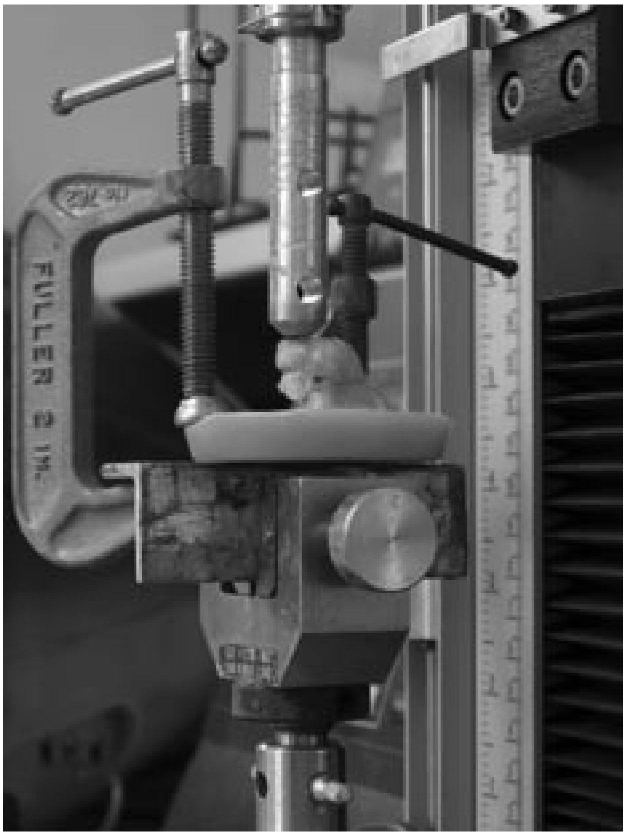

Fig. 4. Scaphoid model placed in Instron tensile testing machine to simulate compressive forces on the distal pole.

Fig. 3. Potted scaphoid specimen with volar cortex excised illustrating the humpback deformity commonly seen in scaphoid nonunions.

Acutrak screw, and *(iii)* a Standard Acutrak screw. Six specimens per group were enough to have 80% power and achieve statistical significance.

All screws were placed in accordance with the manufacturer's recommendations. The screws and K-wires were all placed 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 vice and attached to the Mini 44 Instron Tensile Testing Machine (Fig. 4). 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 (Fig. 5). 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 less than 0.05 considered significant.

RESULTS

At 2-mm displacement, the loads for the parallel K-wires, Mini Acutrak screw, and Standard Acutrak screw were 81.6±21.6 N, 147.4±52.8 N, and 194.6±46.5 N, respectively. Both the Mini and Standard Acutrak screws were statistically stronger than the pair of parallel K-wires.

Fig. 5. Scaphoid model illustrating active compression producing displacement on the dorsal cortex between the proximal and distal aspects of the model.

($p<0.001$) There was no statistically significant difference in strength between the two screws, although the trend was that the Standard type was stronger.

At 4-mm displacement, the loads for the parallel K-wires, Mini and Standard screws were 171.9±30.1 N, 263.8±83.7 N, and 395.0±73.4 N, respectively. This time, the Standard Acutrak screw was statistically stronger than the parallel K-wires and the Mini Acutrak screw ($p<0.05$). There was no significant difference in strength between the Mini Acutrak screw and the pair of parallel K-wires. Thus, at higher loads, the Standard Acutrak screw exhibited a significantly greater strength than the Mini Acutrak screw.

At 2-mm displacement, the stiffness for the parallel K-wires, Mini and Standard screws were 40.8±10.8, 73.7±26.4, and 97.3±23.2, respectively. The two screws showed a significantly greater stiffness than parallel K-wires ($p<0.05$). Again, although there was no significant difference in stiffness of the two screws, the Standard type had a greater stiffness.

At 4-mm displacement, the Standard screw showed the greatest stiffness which was significantly different from the other two (Standard screw 100.2±20.5, Mini screw 58.2±22.4, and K-wires 45.1±13.7; $p<0.05$). There was no significant difference in stiffness between the Mini screw and the pair of parallel K-wires. At higher loads, the Standard screw became statistically stiffer than the Mini screw.

DISCUSSION

Several biomechanical studies have been carried out on scaphoid fracture fixation.[16,19,21,23-26] There are no previously published biomechanical reports 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.[12,13,27] Additionally, associations between this type of deformity and the subsequent development of dorsal intercalated sequential instability have been documented and shown to result in earlier degenerative changes.[28,29]

The volar comminution and concomitant loss of bone in the palmar surface place high levels of stress on any fixation device.[30,31] Apart from this, the selection of a device for fixation of scaphoid nonunions involves numerous other factors, including 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 screw are that it is cannulated for ease of insertion and is headless and can therefore be buried under the articular surface. The screw is tapered on the outer profile, which minimizes fixation failure secondary to loss of screw purchase. Its 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 inter-segment gap but also to enhance the healing process.[32-34] Also, as this study showed, the Acutrak screw has increased strength and stiffness when compared to a pair of parallel, 0.045-inch K-wires. With the use of the Acutrak screw, rigid internal fixation can be achieved and rapid postoperative mobilization is possible. This can help avoid 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 screw was stiffer than the Mini Acutrak screw which was, in turn, stiffer than the pair of parallel, 0.045-inch K-wires.

Beadel et al.[21] in a biomechanical study, analyzed compression across a simulated scaphoid fracture and examined both the Standard and Mini Acutrak screws. They noted that the Standard screw achieved greater interfragmentary compression than did the Mini screw as well as the Bold® screw, a Hebert-like® screw with a central threadless shaft. However, the authors posited that the Standard Acutrak screw, due to its larger thread diameter, had the potential of affecting fracture healing as it would create a larger defect during insertion. Nevertheless, satisfactory clinical outcomes in several studies bear out the effectiveness of the Standard Acutrak screw and serve to belie the impact of the large thread diameter.[21]

Similar results have been reported favoring the merits of the Acutrak system. Wheeler and McLoughlin[22] compared the Acutrak screw with both the AO lag screw® and Herbert compression® screw in a cancellous bone model. They noted greater fracture fragment stability and compression as well as greater pull-out strength with the Acutrak screw. The Acutrak system also provided greater resistance to torque than did the AO 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 system compared to the AO and Herbert screws, we chose to evaluate the biomechanical properties of K-wire fixation in relation to the Acutrak 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 treatment of scaphoid nonunions. However, in a meta-analysis published in 2002, the treatment of scaphoid nonunions was examined and it was shown that, in treating unstable scaphoid nonunions, the union rate was 94% with screw fixation and grafting versus 77% with K-wires and wedge grafting.[35] High rates of union were also noted by Watson et al.,[36] who employed K-wire fixation with bone grafting via a dorsal approach.

In addition to these positive outcomes, our study demonstrated that the Acutrak system had increased efficacy at smaller loads and both the Standard and Mini screws were significantly stronger and stiffer than a pair of parallel, 0.045-inch K-wires. At higher loads, however, the Standard screw was significantly stronger and stiffer than both the Mini screw and the pair of parallel K-wires.

In conclusion, the Standard Acutrak screw followed by the Mini 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 compared to K-wires and the hardware can be buried under the articular surface. Moreover, the Acutrak screws can achieve interfragmentary compression which has been shown to enhance fracture healing - a property K-wire fixation does not possess.

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