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A central threadless shaft screw is better than a fully threaded variable pitch screw for unstable scaphoid nonunion: A biomechanical study

Il-Hyun Koh, Ho-Jung Kang, Ji-Sup Kim, Seong-Jin Park, Yun-Rak Choi *

Department of Orthopaedic Surgery, Severance Hospital, Yonsei University College of Medicine, Seoul, South Korea

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ABSTRACT

Introduction: An interpositional wedge bone graft is a procedure performed to restore carpal height and scaphoid length for displaced scaphoid nonunions with carpal instability. The purpose of this study was to investigate which headless screw design (threadless central shaft screw or fully threaded variable pitch compression screw) is biomechanically preferred when an interpositional bone graft is needed.
Methods: A total of 24 cadaveric scaphoid interpositional bone grafts were divided into three groups and fixed with HCS 3.0, Herbert–Whipple or Acutrak® mini-screws, and the relative biochemical stability of each was measured. The specimens were tested using an Instron® tensile testing machine to calculate stiffness and load to failure. To measure compression forces at different interfragmentary gaps, 30 interpositional polyurethane bone graft models were generated with three pieces of cancellous sawbone block, and two custom-made load-cells were inserted in each gap. The models were then divided into three groups and fixed with the above screw types. The compression forces at different interfragmentary gaps were measured immediately and 30 min after screw fixation.
Results: The average stiffness and load to failure were similar among the three groups ($p > 0.05$). The average compression force measured at each interfragmentary gap was highest in the HCS 3.0 fixation group, followed by the Herbert–Whipple and Acutrak® mini-screw fixation groups both immediately after screw fixation and after 30 min (at which time there were significant decreases in force). The compression forces measured at different interfragmentary gaps were almost identical in the HCS 3.0 and Herbert–Whipple screw fixation groups; however, the force measured at the leading side was significantly lower than that measured at the trailing side in the Acutrak® mini-screw fixation group.
Conclusion: The threadless central shaft screw design is biomechanically preferred over the fully threaded variable pitch screw design because it achieves higher and identical compression forces at different interfragmentary gaps with similar stiffness and load to failure.

Introduction

Scaphoid fractures are the most common carpal fracture, and 5–15% fail to heal [5,7,15]. Scaphoid nonunions can cause scaphoid nonunion advanced collapse, which can lead to symptomatic degenerative wrist arthritis [17,20,23]. The treatment goals for scaphoid nonunions are to achieve bone healing and to prevent wrist arthritis by correcting any carpal deformities [24]. An interpositional wedge bone graft is indicated in patients with scaphoid nonunion with carpal instability to restore carpal height and scaphoid length [8,10,19].

Headless compression screws can be divided into two types: threadless central shaft screws and fully threaded variable pitch screws [12]. The first category includes HCS 3.0 (Synthes®, Paoli, PA, USA) and Herbert–Whipple (Zimmer®, Warsaw, IN, USA) screws comprising a leading thread, a shaft, and a trailing thread. The compression forces in these screws are generated by pitch difference between the narrow trailing thread and the wide leading thread (Fig. 1). Fully threaded variable pitch compression screws include the Acutrak® screw (Acumed®, Hillsboro, OR, USA); these screws incorporate a patented taper, variable thread pitch, and fully threaded length (Fig. 1). Comparative studies of the compression forces of Acutrak®, HCS 3.0 and Herbert–Whipple

* Corresponding author at: Department of Orthopaedic Surgery, Yonsei University College of Medicine, 50 Yonseiro, Seodaemun-gu, Seoul, South Korea. Tel.: +82 2 2228 2183; fax: +82 2 363 1139.
E-mail address: yrchoi@yuhs.ac (Y.-R. Choi).

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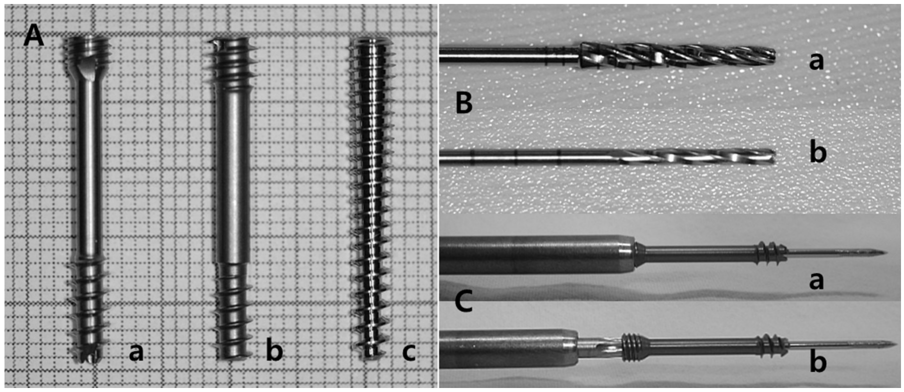

Fig. 1. (A) Three types of 24-mm headless compression screws were used in this study (a: HCS 3.0; b: Herbert–Whipple screw; c: Acutrak® mini-screw). (B) The shapes of drill bits differed according to screw design (a: conically shaped Acutrak® mini-drill bit; b: cylindrical HCS drill bit). (C) The HCS 3.0 requires a compression sleeve system to control the compression force while inserting the screw.

screws on the scaphoid fracture model have been published [1–3,6,12,13]. However, a scaphoid nonunion model is different from a scaphoid fracture model because a scaphoid nonunion treated with an interpositional bone graft has two interfragmentary gaps. For these reason, the results from scaphoid fracture models are not applicable to patients with scaphoid nonunion.

The purpose of this study was to investigate which headless screw design is more biomechanically preferred when an interpositional bone graft is needed. We hypothesised that the various headless screw designs would achieve different biomechanical stabilities and compression forces in scaphoid nonunion models treated with interpositional bone grafts. We measured biomechanical stabilities and compression forces at proximal and distal interfragmentary gaps of scaphoid nonunion models following the insertion of three different headless screws (HCS 3.0, Herbert–Whipple screw and Acutrak® mini-screw).

Materials and methods

After obtaining institutional review board (IRB) approval, we harvested 24 fresh frozen scaphoids from 12 cadavers with an average age of 78.2 years (five males and seven females). The scaphoids were randomly divided into three groups. The average scaphoid length was 24.8 mm (range from 21.2 to 30 mm). After removing the soft tissue, each scaphoid was equally divided into three parts perpendicular to the long axis using a saw. Each type of screw, with a length 4 mm less than the measured scaphoid, was inserted from the proximal to distal side according to the manufacturer's guidelines. The proximal pole was fixed with bone cement and two K-wires tilted 45° from the horizontal plane (Fig. 2). The stiffness and load to failure were measured while applying a compression force to the distal pole with an Instron® tensile testing machine (Instron, Norwood, MA, USA).

Fig. 2. A cadaveric scaphoid nonunion model fixed with headless compression screws was tested with an Instron® tensile testing machine.

To measure compression forces at different interfragmentary gaps, 30 polyurethane foam scaphoid nonunion models were made with three pieces of cancellous sawbone block of grade 15 pcf (0.24 g/cm^3) sawbone, which has a density similar to that of scaphoid cancellous bone [21]. A 77-mm-diameter polyurethane foam disc of 6-mm thickness was inserted between the two 15-mm-diameter cylindrical polyurethane foam blocks of 8-mm thickness. Two custom-made load cells were inserted in two interfragmentary gaps. Each gap between the bone blocks was set to 1 mm (Fig. 3). These nonunion models were divided into three groups, and three types of 24-mm-long headless screws were inserted according to the manufacturers' guideline. The compression pressure in each gap was measured immediately and 30 min after screw insertion.

We performed a Wilcoxon signed-rank test to compare the pressure differences among the three groups. Nonparametric all-pair multiple comparisons based on pairwise rankings in the one-way design using the Steel–Dwass procedure were used for intergroup comparisons. The *p*-values <0.05 were considered statistically significant. All statistical analyses were performed using R version 3.0.1 (The R Foundation for Statistical Computing, Vienna, Austria).

Results

The average load to failure (N) and stiffness (N/mm) in the cadaveric scaphoid nonunion model was 123.95 ± 31.51 N and 64.09 ± 16.59 N/mm with HCS 3.0, 170.62 ± 26.89 N and 84.13 ± 12.29 N/mm with the Herbert–Whipple screw and 142.21 ± 19.65 N and 84.41 ± 11.74 N/mm with the Acutrak® mini-screw. There was no statistically significant difference between the three screws ($p > 0.05$) (Fig. 4).

Interfragmentary compression forces in the polyurethane foam scaphoid nonunion model immediately after screw insertion were highest to lowest as follows: HCS 3.0 (leading side: 44.4 ± 3.67 N, trailing side: 44.79 ± 3.26 N), Herbert–Whipple screw (leading side: 27.99 ± 0.76 N, trailing side: 28.11 ± 0.63 N), and Acutrak® mini-screw (leading side: 20.92 ± 1.47 N, trailing side: 26.7 ± 1.47 N)