Comparison of Joint Compression and Pull-Out Strength of 6.5-mm Self-Drilling Screws With Headed and Headless in Subtalar Arthrodesis: A Pilot Study

Christian Douthit, MD[*]; Matthew Blue, MD[*]; Adam N. Wooldridge, MD, MPH[*]; Micah Lierly-Chick, DPT[†]; Kerry Gilbert, ScD[†]; Jerry Grimes, MD[*]

[*]Department of Orthopaedic Surgery and Rehabilitation, Texas Tech University Health and Science Center, Lubbock, Texas

[†]Department of Physical Therapy, Texas Tech University Health and Science Center, Lubbock, Texas

Corresponding Author Jerry Grimes, MD. 3601 4th Street STOP 9436, Department of Orthopaedics, Lubbock, TX 79410 (email: speight@grimesmd.com).

Funding Research support provided by Synthes as a grant for cost of specimens and implants for testing. Additional funds provided by the Texas Tech University Health and Science Center (TTUHSC) Department of Orthopaedic Surgery and Rehabilitation. Research also supported by the TTUHSC Department of Physical Therapy.

Conflict of Interest Jerry Grimes, MD receives research grant funding for an unrelated multicenter trial sponsored by Ferring Pharmaceuticals. The other authors report no conflicts of interest.

ABSTRACT

Background: In patients with degenerative osteoarthritis of the subtalar joint, surgical treatment can include subtalar arthrodesis. Notably, mechanical factors such as compression and pull-out strength contribute to successful union, which can be achieved through use of headed or headless cannulate screws. The purpose of this study was to compare the resultant joint compressive force and pull-out strength between use of a headless 6.5-mm self-drilling cannulated compression screw and a more traditional headed 6.5-mm self-drilling cannulated compression screw.

Methods: This study used the calcaneus and talus from six paired fresh frozen specimens. The soft tissues were stripped and the joint was separated. Fujifilm Prescale Compression Paper (Minato, Tokyo, Japan) was placed in the subtalar joint, and both the talus and calcaneus were fixed with either traditional headed or a headless cannulated screw. Pull-out strength was measured by fixing the fused subtalar joints to a servohydraulic activator and measuring peak load at failure in distraction. Imaging analysis of the compression paper determined peak compression across the joint.

Results: The resultant joint compressive force and pull-out strength were not statistically different between use of headed and headless cannulated compression screws (P = 0.30 and P = 0.67, respectively).

Conclusions: In a small sample, use of headless cannulated compression screws offered equivalent joint compression as that of a headed screw in subtalar arthrodesis and showed equivalent resistance to pull-out force.

Keywords: Subtalar Joint, Arthrodesis, Subtalar Fusion, Headless Compression Screw, Pull-Out Strength

INTRODUCTION

Degenerative osteoarthritis of the subtalar joint is a common chief concern. A few pathologies that can ultimately result in end-stage osteoarthritis of the subtalar joint are posttraumatic and inflammatory arthritis, Charcot arthropathy, pes planus due to posterior tibial tendon insufficiency, and talocalcaneal coalition.[1] After exhausting nonoperative measures, treatment can include a subtalar arthrodesis, an accepted technique for obtaining a successful fusion that utilizes compression screws across the subtalar joint.[2]

Various methods for screw type, orientation, and quantity have been studied and reported.[2,3] Compression and pull-out strength are two important mechanical factors that contribute to successful union of the arthrodesis. These studies have led to the use of large cancellous screws inserted in one of two orientations: dorsal to plantar or plantar to dorsal.[4] Regardless of the approach, the heads of these large screws have the potential to impinge on surrounding soft tissues. This can cause symptoms related to hardware and the potential need for a revision procedure.[5] Rates of hardware removal are reported to range from 7% to as high as 12%.[6]

In contrast, the original headless compression screws were designed to be used with small bones (eg, those in the carpus and forefoot) in which k-wire fixation was too unstable.[7] Because of enhancements in the design, indications for use of headless cannulated compression screws have expanded. The headless nature of the

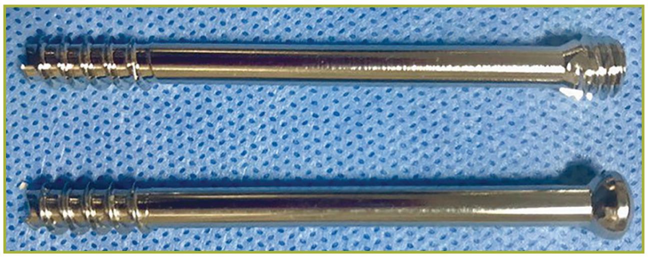

Figure 1. *(Top) headless and (bottom) headed 6.5-mm cannulated screws.*

screw allows it to be completely buried beneath the surface of the bone without use of counter sink, thus avoiding the problem of impingement to surrounding soft tissues. To our knowledge, no study has directly compared joint compression and pull-out strength between use of the 6.5-mm headless cannulated compression screw to the standard 6.5 mm headed cannulated compression screw across the subtalar joint (Figure 1).

METHODS

Cadaveric Specimens

We obtained six matched pairs of frozen cadaveric feet and stored them at -18° C. The sex and cause of death of each cadaveric specimen were unknown. At 24 hours before harvesting, we thawed the cadaveric specimen at room temperature (ie, 21° C). We then dissected and stripped the skin, muscle, tendons, and ligamentous attachments across 12 subtalar joints. Using an Excel randomization model, we randomly assigned the type of screw (ie, headed or headless) to the right versus left ankle of each cadaver. After assignment, we prepared each specimen for arthrodesis and the measurement of the experiments two major data points: compression and pull-out strength.

Measurement of Compression

With a starting point posterior to the origin of the plantar fascia, a 5.0-mm drill was used antegrade and perpendicularly across the subtalar joint. After completing the tunnel, a depth gauge was used to measure for the length of screw needed for arthrodesis. We sized the screws to ensure that the threads crossed the joint line yet did not engage the dorsal cortex. The screw lengths ranged from 75 mm (smallest) to 95 mm (largest).

Before final tightening of the screw across the joint, two pieces of compression paper (Fujifilm Ultra Super Low Pressure) were introduced between the talus and calcaneus on each side of the joint (Fujifilm, Minato, Tokyo, Japan). This was completed by ensuring that the joint compression pressure could be visually quantified and recorded for computer analysis. The compression paper was secured between clear and adhesive tegaderm. This was done to ensure that that the paper would remain dry and not affect the results.

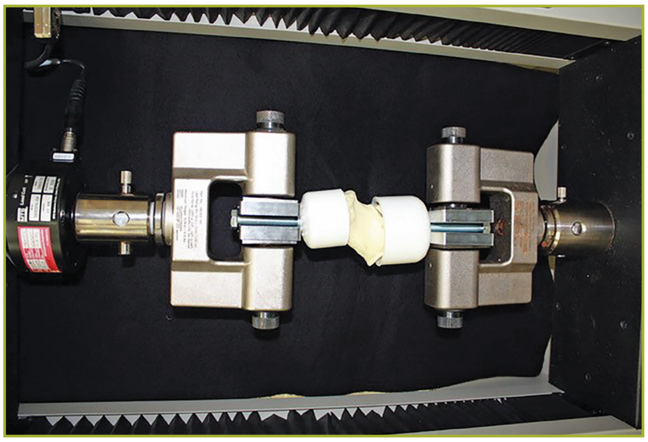

Figure 2. *Configuration of the servohydraulic loading device.*

The joint compression pressure between the surfaces of the posterior facet was recorded as pigmented areas on the film. We loosened the screw by one-half turn to withdraw the paper and retighten the screw. The compression paper was then scanned and uploaded into ImageJ software. We compared the peak saturation of the film's pigmented areas to the temperature-adjusted standards provided by the manufacturer.

Measurement of Pull-Out Strength

After obtaining final fixation across each joint, we placed two to three additional flathead screws in the talus and calcaneus making sure to avoid trajectory of the compression screw. This was done to improve adherence of polymethyl methacrylate (PMMA) bone cement to the surface of the calcaneus and talus. The specimens were potted in polyvinyl chloride (commonly known as PVC) plastic piping cups, with a single bolt and accompanying washer out the bottom to attach to our servohydraulic loading device, the Materials Testing System (MTS, Figure 2). Care was taken to ensure that PMMA did not cross the subtalar joint or cover the head of the compression screw.

The MTS was used to apply uniform tension to the subtalar joints fixed by compression screws (Insight 10 kN, MTS Systems Corporation, Eden Prairie, MN). The mounting screws were secured tightly between the MTS tension plates. The joints were loaded so that the talus was superior to the calcaneus and the distraction force would pull perpendicular to the subtalar joint line. Once mounted into the MTS, we zeroed both the forceplates and position monitors and then initiated the testing sequence into TestWorks 4 software. The subtalar joints were pulled at a constant rate of 1.0 until the MTS detected failure. No pretension was applied to the subtalar joints.

Peak load (N) was the dependent variable of primary interest. It represented the amount of load that each subtalar joint (which were fixed by an arthrodesis screw) was able to withstand during tension testing. For the purpose of this study, peak load was considered the pull-out strength of the construct. Additional

Table 1. *Comparison of measured variables between 6.5-mm headed screws and 6.5-mm headless screws used in six matched pairs of frozen cadaveric feet*

Variable	Headed screws mean (SD)	Headless screws mean (SD)	P value[a]
Length (mm)	85 (6.93)	83.3 (4.85)	0.74
Elongation at peak (mm)	6.91 (1.88)	10.01 (8.27)	0.83
Elongation at yield (mm)	1.73 (0.90)	3.23 (2.36)	0.39
Load at yield (N)	348.78 (237.46)	426.24 (142.4)	0.67
Peak load (N)	637.13 (362.84)	774.94 (188.64)	0.67
Strain at yield	0.03 (0.02)	0.06 (0.05)	0.39

SD, standard deviation.
[a]Values were obtained from the Mann-Whitney U test.

dependent variables included elongation at peak (mm), load at yield (N), elongation at yield (mm), and stiffness (N/mm). Stiffness was calculated as load at yield or elongation at yield.

Statistical Methods

For joint compression, statistical analysis was completed using Quickcalcs GraphPad software. Data were reported as averages with 95% confidence intervals. Paired *t* tests were used for parametric variables. Differences were considered to be significantly different when $P < 0.05$.

For pull-out strength, statistical analysis was performed using SPSS Statistics 22.0 (IBM, Armonk, NY). Data were reported as averages with 95% confidence intervals. Mann-Whitney U tests were used for nonparametric variables. Differences were considered to be significantly significant when $P < 0.05$.

RESULTS

The average peak compression for the headless screw specimens was 0.58 MPa (range, 0.55 - 0.60 MPa, SD 0.02), which was greater than the average peak compression obtained in the headed screw specimens with an average of 0.57 MPa (range 0.54 - 0.59 MPa, SD 0.03). This value, however, did not reach statistical significance with a *P* value of 0.31.

Comparison of Pull-Out Strength

We compared the specimen between headless and headed matched pairs in terms of their elongation at peak, elongation at yield, load at yield, peak load, and strain at yield. The average peak load for the headless group was 774.94 N, which was greater than the average peak load of 637.13 N for the headed screws (Table 1). With a *P* value of 0.67, there was no statistical difference between the groups.

With a *P* value of 0.74, there was no statistical difference in the length of headless (85 ± 6.93mm) versus headed (83.3 ± 4.85 mm) screws. Although the peak load was greater for headless screws (774.94 ± 188.64 N) as compared to headed screws (637.13 ± 362.84 N), there was no statistical difference ($P = 0.67$). The strain at yield was greater for compression screws (0.06 ± 0.05) as compared to cancellous screws (0.03 ± 0.02); however, there was no statistically significant difference ($P = 0.39$)

DISCUSSION

An established method for subtalar arthrodesis is fixation using cannulated screws that are large and headed. Several studies have compared compression across the subtalar joint with different screw positions, number of screws used, and compression staples.[8-10] In 2016, Matsumoto et al[11] compared compression across the subtalar joint using a two and a three headless compression screw construct. To our knowledge, no study has compared the compression and pull-out strengths of headed cannulated screws to that of headless cannulated compression screws. Our study, however, shows that headless compression screws may produce equivalent peak compression across the subtalar joint. It also shows that when compared to headed screws in a cadaveric model, headless compression screws may have equivalent pull-out forces.

Headed cannulated screws are common constructs used to treat subtalar arthrodesis; however, screws can create a prominence that irritate local tissues because the screw heads rest outside of the bone. By reducing prominence of hardware, the advent of cannulated headless compression screws can help reduce the incidence of symptomatic hardware.[12] Headless compression screws have equivalent compression and are therefore a reasonable option for fixation of a subtalar arthrodesis. Additionally, headless compression screws may potentially reduce the incidence of symptomatic hardware.

Another important measure is pull-out strength because it shows a construct's resistance to failure when subject to a load. Between the headless screw and headed screw, our experiment shows no difference in "load at yield" and "peak load" across the arthrodesis constructs. This suggests that headless screws, in addition to offering comparable compressive force, is equally as resistant to pull-out forces as the headed screw. When comparing the torsional resistance of a two and a three headless construct, Riedl et al[13] found no statistical significance. Our study validates the findings of Riedl et al[13]. Additionally, our study even compares the pull-out strength to the headed cannulated screw, which showed equal resistance to pull-out.

One limitation of this study is that a cadaveric model cannot fully simulate the in vivo environment. The mechanical characteristics of the fixation is only one factor in the success of an arthrodesis procedure, and the equivalence of mechanical characteristics does not directly imply clinical performance. The typical forces at the subtalar joint are not distractions as measured by our study. More physiologic loads would improve the real world comparison, but are difficult to simulate in a mechanical testing laboratory. We used a simplified model intended to find marked difference in fixation. That process might in-turn indicate concerns for using the headless design in the hindfoot setting.

In our study, the use of cadaveric specimens introduces variability. We attempted to minimize this variation by using matched pairs. A bone density scan would further improve the external validity of our study. Additionally, the limited number of specimens increases the risk for type II error; however, the small differences noted between the two comparison groups would require a large number of specimens to detect a statistical difference. This is unlikely to be clinically relevant.

After analyzing the data, we have concluded that headless cannulated compression screws provide a viable alternative to headed screws for subtalar arthrodesis, showing equivalent compression and pull-out strength.

REFERENCES

1. Dahm DL, Kitaoka HB. Subtalar arthrodesis with internal compression for post-traumatic arthritis. J Bone Joint Surg Br. 1998;80(1):134-138.
2. Frey C, Halikus NM, Vu-Rose T, Ebramzadeh E. A review of ankle arthrodesis: predisposing factors to nonunion. Foot Ankle Int. 1994;15(11):581-584.
3. Levine SE, Myerson MS, Lucas P, Schon LC. Salvage of pseudoarthrosis after tibiotalar arthrodesis. Foot Ankle Int. 1997;18(9):580-585.
4. McGlamry MC, Robitaille MF. Analysis of screw pullout strength: a function of screw orientation in subtalar joint arthrodesis. J Foot Ankle Surg. 2004;43(5):277-284.
5. Vilá-Rico J, Mellado-Romero MA, Bravo-Giménez B, Jiménez-Díaz V, Ojeda-Thies C. Subtalar arthroscopic arthrodesis: technique and outcomes. Foot Ankle Surg. 2017;23(1):9-15. doi:10.1016/j.fas.2015.11.007.
6. Peterson HA. Dowel bone graft technique for triple arthrodesis intalocalcaneal coalition--report of a case with 12-year follow-up. Foot Ankle. 1989;9(4):201-203.
7. Soroush A, Kurosh D, Asif M. Biomechanical analysis of second-generation headless compression screws. Injury. 2012;43(7):1159-1165.
8. Lee JY, Lee YS. Optimal double screw configuration for subtalar arthrodesis: a finite element analysis. Knee Surg Sports Traumatol Arthrosc. 2011;19(5):842-849. doi:10.1007/s00167-010-1383-y.
9. Chuckpaiwong B, Easley ME, Glisson RR. Screw placement in subtalar arthrodesis: a biomechanical study. Foot Ankle Int. 2009;30(2):133-141. doi:10.3113/FAI.2009.0133.
10. Herrera-Pérez M, Andarcia-Bañuelos C, Barg A, et al. Comparison of cannulated screws versus compression staples for subtalar arthrodesis fixation. Foot Ankle Int. 2015;36(2):203-210. doi:10.1177/1071100714552485.
11. Matsumoto T, Glisson RR, Reidl M, Easley ME. Compressive force with 2-screw and 3-screw subtalar joint arthrodesis with headless compression screws. Foot Ankle Int. 2016;37(12):1357-1363.
12. Kunzler D, Shazadeh Safavi P, Jupiter D, Panchbhavi VK. A comparison of removal rates of headless screws versus headed screws in calcaneal osteotomy. Foot Ankle Spec. 2018;11(5):420-424. doi:10.1177/1938640017744640.
13. Riedl M, Glisson RR, Matsumoto T, Hofstaetter SG, Easley ME. Torsional stiffness after subtalar arthrodesis using second generation headless compression screws: biomechanical comparison of 2-screw and 3-screw fixation. Clin Biomech (Bristol, Avon). 2017;45:32-37. doi:10.1016/j.clinbiomech.2017.04.004.