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Biomechanical evaluation of medial malleolus fractures treated with headless compression screws

Robert M. Corey[a], Lisa K. Cannada[a,*], Gary Bledsoe[b], Heidi Israel[a]

[a] Department of Orthopaedics, Saint Louis University, United States
[b] Parks College of Engineering, Saint Louis University, United States

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ABSTRACT

Purpose: The gold standard for fixation of medial malleolus fractures has yet to be determined. Most agree the best results of displaced unstable ankle fractures are with open reduction and internal fixation. Hardware irritation necessitating screw removal is a known complication. An alternative fixation method of medial malleolar fractures has been described using headless compression screws. There are currently no biomechanical studies that assess the stability of this method. The purpose of the study is to complete a biomechanical evaluation of partially threaded cancellous screws (PT) and headless compression screws (HC) in an external rotation ankle fracture model.

Methods: Composite polyurethane sawbone models of tibia were obtained. A custom jig was created to ensure identical osteotomies. The models were fixed with either two partially threaded cancellous screws or two headless compression screws. The models were fitted into the Material Test System (MTS) machine and the force transducer was programed to apply axial offset. The two constructs were loaded until 5 mm of displacement occurred, our defined point of failure. The amount of force (Newtons) necessary to create fracture line displacement was recorded for each model.

Results: The axial rotational force to create facture displacement between 1 mm and 3 mm, between 1 mm and 5 mm, and between 3 mm and 5 mm were statistically significant ($p < 0.05$) for both models. The mean axial rotational force measured in Newtons at 1 mm, 3 mm, and 5 mm of displacement for the PT was 149.32, 244.19 and 477.76 respectively. The mean axial rotational force measured in Newtons at 1 mm, 3 mm, and 5 mm of displacement for the HC was 152.05, 224.07, and 498.31 respectively.

Conclusion: No statistically significant difference was found between the biomechanical properties of partially threaded cancellous screws and headless compression screws used in the fixation of medial malleolus fractures. These results support HC screws as a viable alternative in a biomechanical model of medial malleolus fractures.

1. Introduction

The gold standard for fixation of medial malleolus fractures has yet to be determined. Prior to the mid 1970's, fixation of medial malleolar fractures was often ignored. Beginning in the mid 1970's, the literature documented the need for adequate fixation of medial malleolar fractures that occurred with ankle fractures. The fixation producing superior results has often been in question over the years. Traditionally, Kirschner wire fixation with a tension band construct, partially threaded K wire fixation, and partially threaded cancellous screws (A/O malleolar screw) have been used.[1,2] Fixation of the medial malleolus is also commonly performed with bicortical partially threaded cancellous lag screws,[2,3] which has been shown to biomechanically stronger than unicortical cancellous lag screws.[4]

In general, surgical outcomes are considered to be good for fixing medial malleolar fractures. Most agree the best results of displaced unstable ankle fractures are with open reduction and internal fixation to restore anatomic parameters.[4–11] Nevertheless, it is noteworthy that many patients state post-operative dissatisfaction due to pain. Hardware-related pain can be due to multiple factors including subcutaneous positioning, impingement of bone, or irritation of deeper soft-tissue structures. The posterior tibial tendon is intimately apposed to the medial malleolus, passing directly posterior and inferior to it, and it is therefore a structure likely to be affected by the placement of medial malleolar hardware.[3]

* Corresponding author at: Department of Orthopaedic Surgery, Saint Louis University School of Medicine, 3635 Vista Avenue, 7th Floor Desloge Towers, St. Louis, MO, 63110, United States.
E-mail address: lisa.cannada@health.slu.edu (L.K. Cannada).

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Rotational injuries of the ankle lead to predictable fracture patterns.[12] During external rotation injures of the ankle, the fractures are classified as supination-external rotation (SER) and pronation-external rotation (PER) forces. The medial malleolus fracture type is typically a horizontal oblique fracture in both the SER and PER mechanisms of injury. Ebraham at el. reported that SER and PER are observed in approximately 83% of medial malleolus fractures.[13] The horizontal oblique fracture of the medial malleolus is the focus of this investigation.

Medial malleolar fixation can be fraught with complications. Hardware irritation necessitating screw removal is a known complication, along with a nonunion rate ranging from 3% to 20%.[4] This pain may arise from soft-tissue irritation resulting from hardware placement. In some circumstances, a patient's pain might be severe enough to require hardware removal.[4,14]

Barnes et al recently reported an alternative fixation method of medial malleolar fracture using headless compression screws. These screws have the benefit of the screw being flush with the bone surface, potentially minimizing complaints of prominent hardware. In their study, radiographic evidence of fracture union was noted in all patients, and none of the patients requested or required hardware removal from screw prominence.[15] To our knowledge, there are currently no biomechanical studies that assess the stability of this method.

The purpose of the study is to biomechanically evaluate partially threaded cancellous screws (PT) and headless compression screws (HC) in an external rotation ankle fracture model. We hypothesize that the headless compression screws construct will provide similar fixation to the partially threaded headless compression screw construct in regards to stiffness, rotational stability, and failure.

2. Materials and methods

Twenty fourth generation composite polyurethane sawbone models (Sawbones, Vashon, WA, Model 3401) of the left tibia were obtained. The left tibia was randomly chosen over the right tibia. A custom jig was created to ensure identical osteotomies in each model. Identical oblique osteotomies at 35 degrees from horizontal were created in the medial malleolus of the tibia models with a table saw. (Fig. 1) After completion of the osteotomies, two separate customized jigs produced identical drill holes, drill length, and screw placement for each screw model for testing.

The 4.0 mm partially threaded cancellous screw (DePuy Synthes Trauma®, West Chester, PA) was selected as the control group for this study, while the 4.5 mm headless compression screw (DePuy Synthes Trauma®, West Chester, PA) was selected as the experimental group. The 4.5 mm diameter screw was selected from a limited supply of manufactured headless compression screw diameters (1.5 mm, 2.4 mm, 3.0 mm, 4.5 mm, 6.0 mm) in order to assure the closest size diameter screw for comparison to the partially threaded cancellous screw.

Drill holes were made in both the anterior and posterior colliculus at distance of 14 mm apart. (Fig. 2) The midpoint between the colliculli was 7 mm. The holes were drilled to the site of the fracture using a drill clamp to ensure uniform penetration in all models.

Once the drill holes were created, the models were fixed with either two 4.0 mm partially threaded cancellous screws (10 total models per group) or two 4.5 mm headless compression screws (10 total models per group). The screws were placed perpendicular to the fracture line. The screw length was uniform in both models (30 mm). The 30 mm length was chosen following the article by Parker et al, who demonstrated that the use of a 30 mm partially threaded screw engaged the physeal scar more efficiently than longer partially threaded screws.[16] All screws in each model were then tightened to 10 inch pounds of torque using a torque driver.

Fig. 1. Creation of identical oblique osteotomies using a custom jig.

Fig. 2. Creation of identical drill holes for screw insertion.

After the screws were placed, each model was then marked using a permanent marker with two lines. One line was carefully marked at the posterior border of the plafond and one line was marked 5 mm proximal to this line using a digital ruler. The models were fitted into the MTS machine using a three dimensional clamp. The MTS machine force transducer was programed to apply axial offset loading to the posterior aspect of the medial malleolus fracture fragment. (Fig. 3) The purpose of this is to simulate weight bearing and test the axial rotational stability of the construct in each group. The two constructs were loaded at a constant rate of 1 mm per sec until 5 mm of displacement occurred, defined as the point of failure for this study. The MTS machine was immediately stopped once the 5 mm line of displacement was reached. (Fig. 4) The amount of force in Newtons was recorded for each model at 1 mm, 3 mm, and 5 mm of fracture line displacement.

3. Statistics

The data was analyzed via SPSS 23.0 (IBM, NewYork) for descriptives, Mann-Whitney test, and Wilcoxin Repeated Measures.

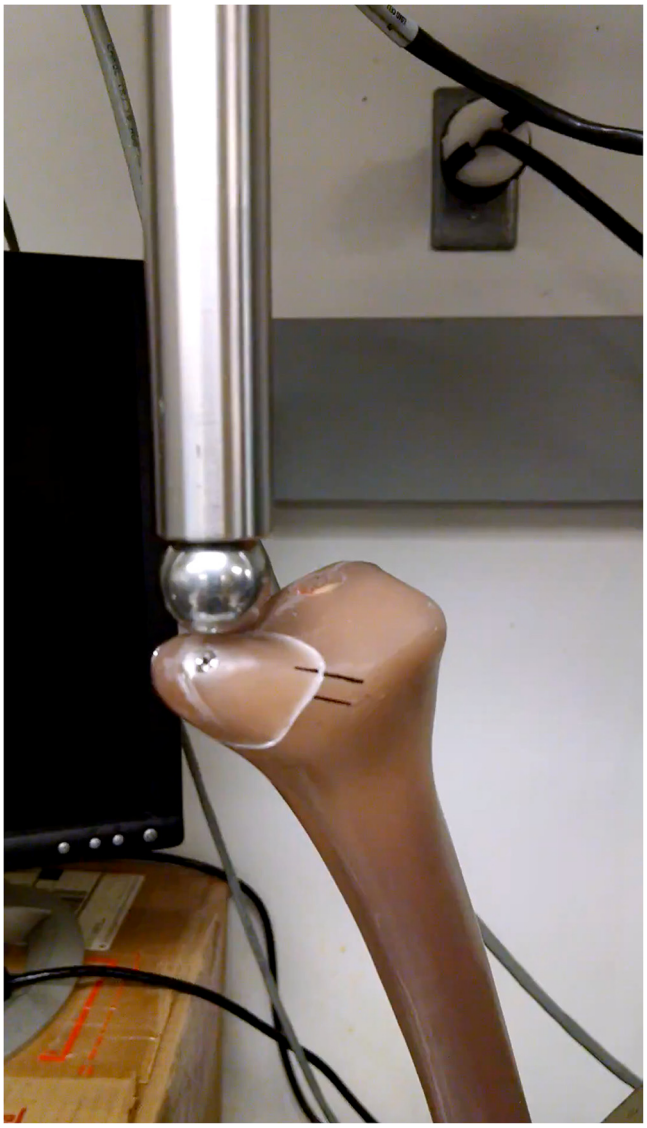

Fig. 3. MTS machine applying axial offset loading to the posterior aspect of the medial malleolus.

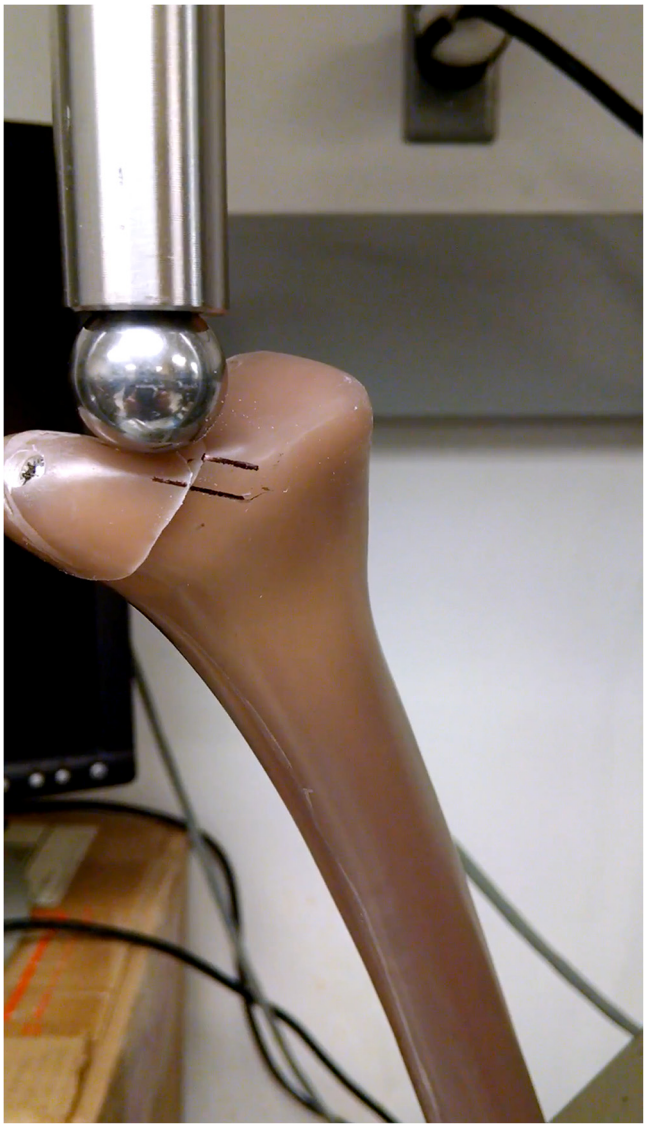

Fig. 4. 5 mm of displacement after application of axial offset loading using the MTS machine.

4. Results

The axial rotational force in order to create facture displacement between 1 mm and 3 mm, between 1 mm and 5 mm, and between 3 mm and 5 mm were statistically significant ($p < 0.05$) for both models. The mean axial rotational force measured in Newtons at 1 mm, 3 mm, and 5 mm of displacement for the PT was 149.32 (95% Confidence interval (CI) 115.92–182.72), 244.19 (95% CI 204.84–283.54) and 477.76 (95% CI 334.45–621.07) respectively. The mean axial rotational force measured in Newtons at 1 mm, 3 mm, and 5 mm of displacement for the HC was 152.05 (95% CI 114.40–189.71), 224.07 (95% CI 175.55–272.59), and 498.31 (95% CI 333.16–663.45) respectively. The descriptive data can be viewed in Table 1. Fig. 5 shows a graphical representation of this data.

The axial rotational force in order to create facture displacement between 1 mm and 3 mm, between 1 mm and 5 mm, and between 3 mm and 5 mm were statistically significant ($p < 0.05$) for both screw models. Additionally, the axial rotational force needed for fracture displacement increased from 1 mm to 3 mm to 5 mm for both models.

The Mann Whitney Test of Partially Threaded versus Headless Compression Screws at 1 mm, 3 mm, and 5 mm of displacement

Table 1
Descriptive Data of Partially Threaded (PT) and Headless Compression (HC) Screws at 1 mm, 3 mm, and 5 mm.

	Type of Screw	Mean axial rotational force (N)	Median axial rotational force (N)	Standard deviation	95% confidence interval	Range
1 mm						
	PT	149.32	148.06	46.69	115.92–182.72	151.32
	HC	152.05	164.60	52.63	114.40– 189.71	168.77
3 mm						
	PT	244.19	242.71	55.00	204.84–283.54	154.66
	HC	224.07	227.66	67.82	175.55– 272.59	256.58
5 mm						
	PT	477.76	422.10	200.32	334.45– 621.07	589.88
	HC	498.31	445.60	230.85	333.16– 663.45	691.27

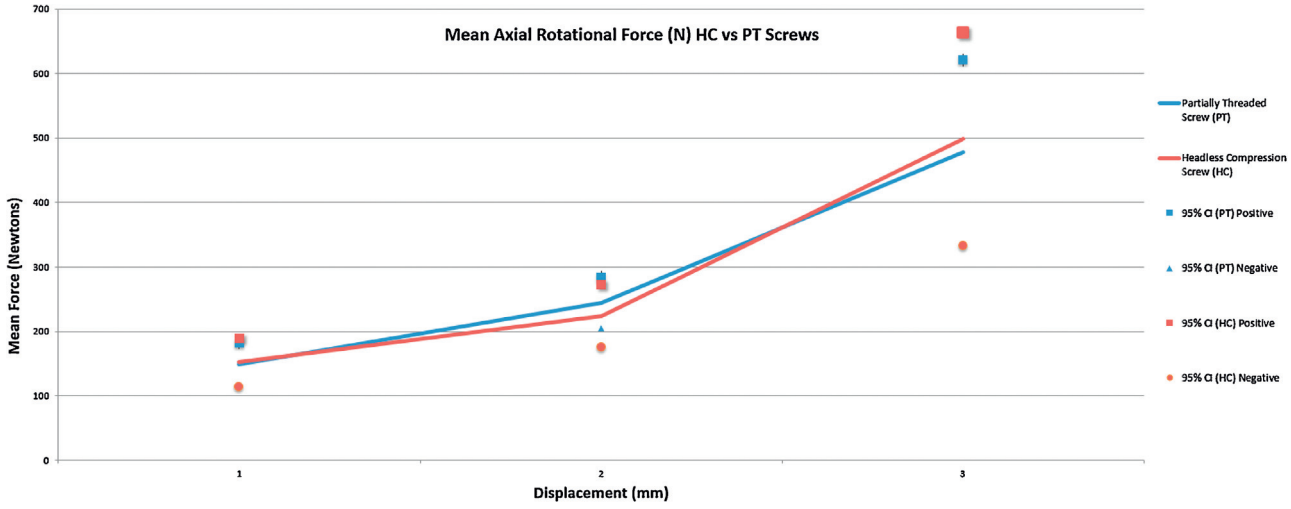

Fig. 5. Displacement versus Mean Axial Force (Newtons) of Partially Threaded and Headless Compression Screws.

are 0.85, 0.35, and 0.74, respectively. The Wilcoxin Repeated Measures for Median Axial Force Required to Displace Fracture Fragments using Partially Threaded Screws are < 0.001 (1–3 mm), <0.01 (1–5 mm), and < 0.01 (3–5 mm). The Wilcoxin Repeated Measures for Median Axial Force Required to Displace Fracture Fragments using Headless Compression Screws are < 0.001 (1–3 mm), <0.01 (1–5 mm), and < 0.001 (3–5 mm). Non parametrics using Mann-Whitney and Wilcoxon were reported because a post hoc power analysis showed that power was 9.8%

5. Discussion

Screw fixation has become the standard of care regarding the fixation of horizontal oblique medial malleolus fracture patterns. Most surgeons elect to fix this fracture pattern using two 4.0 mm partially threaded cancellous screws oriented perpendicular the fracture pattern. (*2–3*) In their 2014 article, Barnes at al stated advocated for the use of an alternative fixation strategy for medial malleolus fractures. They stated "Headless compression screws provide effective compression of medial malleolus fractures and result in good clinical outcomes. The headless compression screw is a beneficial alternative to the conventional methods of medial malleolus fixation." (*15*) This was concluded following a retrospective chart review of 44 patients that had previously undergone fixation of their medial malleolus fracture using headless compression screws. In their study, there were no screw removals due to painful hardware or non-union.

To our knowledge, this is the first study created in order to assess the biomechanical stability of medial malleolar fractures treated with headless compression screws. We found no difference in the force to failure between partially threaded cancellous screws and headless compression screws used in the treatment of a medial malleolus fracture model. This finding was statistically significant ($p < 0.05$) across all thee data points (1 mm, 3 mm, and 5 mm). The clinical utility of using headless compression screws may result in a decreased rate of painful orthopedic hardware, a decreased rate of re-operation for hardware removal, and improved patient satisfaction.

Limitations of this study include the use of Sawbones® models. Although these models are very similar in material properties to human bone, differences may inherently exist. Another limitation is the potential for minor variations in individual models themselves. Every step was taken to minimize any potential differences as all steps in this experiment were performed by the lead author. Another limitation is the difference in diameter between the screws (4.0 vs 4.5). We were limited to the available diameters available by the manufacturer. Finally, this is a biomechanical analysis and therefore is an approximation to forces applied in vivo and cannot fully simulate actual forces.

The strengths of this study include the total number of models tested in each group. Another major strength to the study is meticulous detail in each step to ensure near identical model construct and testing. To limit potential variation in models, great care was taken to minimize any differences in model construct and fixation by using uniform screws, creation of multiple custom jigs to ensure identical osteotomies and drilling/screw placement, and by using a torque wrench to ensure uniform screw tightness. Additionally each model was marked and positioned exactly the same way in the MTS machine during axial rotational loading. Finally, models were randomized in each phase of construct design and testing to limit the potential for error.

While this investigation serves as the first study to assess the biomechanical stability of medial malleolar fractures treated with

headless compression screws, we believe that further randomized controlled trials are necessary in order to determine the method of medial fixation that both optimizes the biomechanical properties of these screws, and attains improved clinical outcomes.

6. Conclusion

The biomechanical properties of partially threaded cancellous screws and headless compression screws used in the fixation of medial malleolus fractures are equivalent. There is no difference in the axial force in Newtons required to create fracture fragment displacement at 1 mm, 3 mm, and 5 mms. These results support HC screws as a viable alternative in a biomechanical model of medial malleolus fractures.

Ethical review board

Exempt from review by individual Institutional Review Boards.

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Conflict of interest

None of the authors have any conflicts of interest to report.

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