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Distal Fibula Fracture Fixation: Biomechanical Evaluation of One Third Tubular *vs*. Anatomical Contoured Locking Plate

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Abstract

Background: This investigation compares the biomechanical properties of one-third tubular and newer anatomically contoured locking plate-and-screw implants for fixation of Danis-Weber Type B (OTA 44B) distal fibula lateral malleolar fractures in Saw-Bones models.

Methods: This study utilized fibula Saw-Bones that were osteotomized to simulate a distal fracture and plated with one-third tubular or locking plates. Valgus bending and torsional tests were performed for each plated specimen.

Results: A statistically significantly higher (P=0.001) peak load to failure during valgus bending was observed in specimens with anatomical locking plates over one-third tubular plates. There was no significant difference between the stiffness of the two plate constructs during valgus bending. The anatomically contoured plate construct withstood a significantly higher (P<0.001) peak moment of torsion at failure compared to the one-third tubular plate construct during torsional testing. Additionally, the anatomically contoured plate construct displayed a significantly higher (P=0.002) stiffness compared to the one-third tubular plate construct during torsional testing.

Conclusion: When operatively managing Danis-Weber Type B distal fibular lateral malleolar fractures, the use of an anatomically contoured locking plate should be considered over a one-third tubular plate due to the former's biomechanical advantages over the latter, while considering cost.

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Introduction

Ankle fractures are very common fractures treated by many orthopedic surgeons, with up to 174 cases treated operatively or non-operatively per 100,000 adults per year [1]. With regard to Open Reduction and Internal Fixation (ORIF) of the lateral malleolus at the distal fibula, there are many methods and implants to achieve fibular fracture repair. Choosing a biomechanically advantageous and patient centered strategy based on factors such as bone quality, fracture type, cost of material, and risk of side effects is important to optimize bony fracture healing and minimize post-operative problems. While post-operative complications from ORIF of the fibula are rare, they can occur. Such difficulties include superficial or deep infection at an incidence of 2% and ankle arthrosis and/or arthritis at a rate of 10% over the intermediate to long term [2]. Other post-operative problems can be implant-related and include failure and/or pain at the implant(s) [3,4]. In addition, some patients may be slower to heal at their fracture, where they may develop fracture nonunion and/or malunion [5]. While ankle fractures can be categorized in accordance of fracture types and location, one of the most common methods used to describe the distal fibular fracture is the Danis-Weber classification system [6]. The fibular fracture is a Danis-Weber Type A, B, or C based on its location relative to the ankle's syndesmotic ligaments (Figure 1) [7,8].

Specifically, Danis-Weber B fractures occur at the level of the syndesmosis and may extend distally to the level of the talar dome [9]. Using the Orthopedic Trauma Association (OTA) classification system, Weber B fractures can also be described as OTA 44B fractures of the lateral malleolus [10]. Within the Danis-Weber B classification, there are three subgroups. Type B1 is an isolated distal fibular injury. Type B2 is a distal fibular fracture associated with a medial malleolar fracture or deltoid ligament injury. Lastly, type B3 is a distal fibular fracture with a medial malleolar fracture or deltoid ligament injury and fracture of the posterolateral malleolus of the distal tibia [7]. The most common mechanism of injury by which Weber type B fractures occur is from an external

Figure 1: Radiographs of Danis-Weber type fractures.

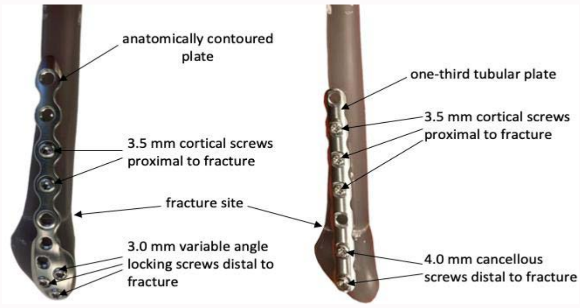

Figure 2: Anatomically contoured locking plate (left) and one-third tubular plate (right) applied to distal end of sawbones fibula.

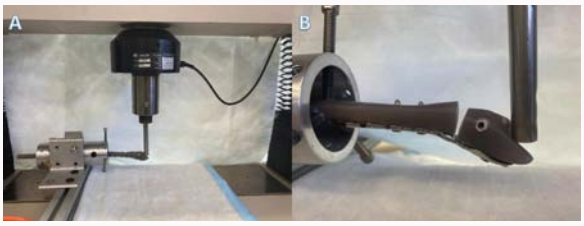

Figure 3a, 3b: Biaxial load frame applying load to sawbones specimen during bending test.

rotation force applied to the ankle while the ankle itself is supinated [7,11].

Danis-Weber B fractures are the most common type of distal fibular lateral malleolar fracture, accounting for approximately 40% of all ankle fractures [12]. When the fractured ends of the malleolus are displaced by more than 2 mm, such injuries are best treated with a operative Open Repair and Internal Fixation (ORIF) of the bone. Restoring bony alignment and continuity at the fracture provides anatomic reduction, which allows for improved bony healing than without ORIF [2,13]. The traditional implant used for fibular fixation is a one-third tubular plate, which is flat and not anatomically contoured to the lateral aspect of the distal fibula [4,14,15]. Alternate fibular materials used include fixation with inter-fragmentary lag-screws alone, bioabsorbable plate & screws, and anatomically contoured lateral malleolar locking plates with locking screws [14,16-18].

The purpose of our study is to compare the biomechanical strength of traditional one-third tubular and anatomically contoured locking plate-and-screw implants for fixation of Danis-Weber Type B distal fibula lateral malleolar fractures. This biomechanical study will add to existing literature in the area of distal fibular fixation by arming clinicians with additional engineering data to support the use of these plates. It has been described in literature that for stainless steel plates, failure occurs when the plate deforms plastically as a result of an applied stress greater than the yield strength of the material [19]. The constructs also fail due to screw loosening as a result of insufficient holding power in weak bone. We hypothesized that fixation with an anatomically contoured locking plate would allow for constructs to withstand higher peak loads to failure and also demonstrate higher stiffness as compared to the constructs fixed with a one-third tubular plate. Whether these biomechanical qualities lend to clinical advantages will be discussed.

Materials and Methods

Composite sawbones closely resembling the human distal fibula were used for all mechanical tests. Such sawbones are made of Short Fiber Filled Epoxy and can be used as an alternative testing material to human or cadaveric bones, as they closely mimic cortical bone density, fracture toughness, strength, modulus, and hardness of cadaveric bone [20]. Sawbones are ideal for biomechanical testing because of their uniformity [21]. Thus, biomechanical results are based on the properties of the plates and screws rather than the potentially variable quality of cadaveric bone.

Two types of biomechanical tests were performed: Valgus bending and torsional bending. These tests, which will generate load versus displacement data, can be used to draw conclusions about plate construct stability. Similar tests have been used in previous studies to evaluate the biomechanical properties of ankle fracture implants [13,15,16]. For both the valgus bending test group and the torsional bending group, Danis-Weber Type B fractures were generated in 12 composite sawbones using a power saw (24 in total including both groups). An experienced and board-certified orthopedic surgeon (JA) familiar with ORIF of lateral malleolar fractures applied 6 anatomically contoured locking plates (Arthrex, Naples, FL) to 6 composite sawbones fibulas per test and 6 one-third tubular plates (Arthrex, Naples, FL) to 6 sawbones fibulas per test (Figure 2). For the anatomically contoured plate, three 3.0 mm variable angle locking screws were inserted distal and two 3.5 mm cortical screws were inserted proximal to the distal fibular fracture. This arrangement of screws was determined at the discretion of the orthopedic surgeon (JA) and based on prior literature [22]. With the one-third tubular plate, two 4.0 mm cancellous screws were inserted distal and three 3.5 mm cortical screws were inserted proximal to the fibular fracture. This arrangement of screws was also determined at the discretion of the orthopedic surgeon (JA) and based on prior literature [23,24]. Distally, the amount of screws used was determined by the amount of space on the distal bone. Proximally, the amount of screws used was sufficient to provide biomechanical stability while considering cost of materials.

To conduct the valgus bending test, a cylindrical clamp was used to hold the specimen in place (Figure 3a). For the distal fibula to be left free for testing purposes, the clamping screws were fixed to the proximal region of the specimen. To prevent levering of the specimen with stress testing, metal screws were placed horizontally over the top of the clamp cylinder. The bending test was designed to recreate a laterally directed force from the talofibular joint and further simulate talar abutment against the distal talofibular joint space. Using a uniaxial load frame, MTS 858 Bionix test system (Minneapolis, MN), loading was applied gradually at a rate of 5 mm/min, starting at 1N and increasing incrementally until a gap of 1.5 mm was observed between the distal end of the bone and the proximal end, at which

Figure 4: Biaxial load frame applying load to sawbones specimen during torsion test.

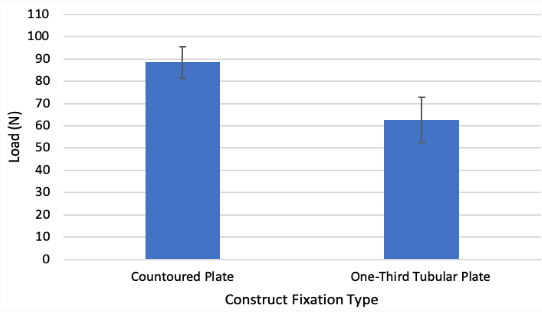

Figure 5: Valgus bending test - Peak load to failure of one-third tubular and contoured lateral malleolar fracture plate constructs.

point the test stopped and the "load to failure" was determined (Figure 3b). This test was repeated six times for each of the two plate types (once per specimen).

To conduct the torsional bending test, in which a torsional force was applied to each specimen to construct failure, a cylindrical clamp was used to hold the specimen in place (Figure 4). A screw was fixed to the distal end of the specimen so that a torsion force (external moment) could be applied 1.8 cm from the center. Using a uniaxial load frame, loading was applied gradually to the screw, rotating the specimen. The applied torsion force increased incrementally until the distal and proximal portions of the specimen became separated with complete failure of the plate as observed by a drop in load on the MTS load-displacement curve or pullout of screws by more than 2 mm. This test was repeated six times for each of the two plate types (once per specimen).

During testing, data for applied load and extension of the load cell were collected at a sampling rate of 10 samples/sec. For the torsional bending test, in order to calculate a moment of torsion, the length of the moment arm (the screw) was multiplied by the applied force. In addition to examining the peak load on the construct at failure, the stiffness of the construct was also noted. The values for construct valgus bending stiffness were calculated by plotting the applied load *vs.* extension of the load cell and taking the slope of the curve. The values for construct torsional bending stiffness were calculated by plotting the moment of torsion versus the angular displacement of the moment arm and taking the slope of the curve.

Statistical analysis was performed using Microsoft Excel with Analysis ToolPak Add-in. The significance of differences in peak load at failure, peak moment of torsion at failure, bending stiffness, and torsional stiffness between the two plate construct types was analyzed using a two sample t-test assuming unequal variances. Significance was set at $p<0.05$.

Results

Bending test

The valgus bending tests revealed a biomechanical advantage to using a contoured plate as opposed to a traditional one-third tubular plate (Figure 5, Table 1). The mean peak load to failure for the one-third tubular plate was 62.72 N with a standard deviation of 10.22 N (62.72 ± 10.22 N), in comparison to the anatomically contoured plate which withstood a mean peak load to failure of 88.54 ± 7.06 N. These findings proved statistically significant (p=0.001).

For the bending test, the construct fixed with a one-third tubular plate had a higher mean stiffness (8.78 ± 1.49 N/mm) than the construct fixed with the contoured plate (7.28 ± 0.96 N/mm) (Figure 6, Table 1). This difference was not statistically significant (p=0.069).

Torsion test

The torsion test demonstrated a biomechanical advantage to using the anatomically contoured plate as opposed to a traditional one-third tubular plate (Figure 7, Table 1). The mean peak moment of torsion at failure for the contoured plate was 2539.65 ± 215.55 Nmm, while the mean peak moment of torsion at failure for the one-third tubular plate was 1547.69 ± 124.35 Nmm. These findings proved statistically significant (p<0.001). The contoured plate construct proved to have a higher stiffness (2919.48 ± 388.78 Nmm/rad) than the one-third tubular plate construct (2084.93 ± 300.39 Nmm/rad) (Figure 8, Table 1). This difference proved statistically significant (p=0.002).

Discussion

To date, there is limited biomechanical literature comparing different means of distal fibular fracture fixation. White et al conducted a biomechanical cadaver study comparing locked versus non-locked lateral fibular bridge plating of comminuted Weber C fractures and found no difference in biomechanical properties between the two plating techniques [25]. The conclusions of clinical literature in this area are varied Yeo et al. [17] conducted a prospective and non-comparative study regarding clinical outcomes for patients with lateral malleolar fractures treated with an anatomically contoured locking plate and screw system. At 1 year after surgery, the authors achieved high rates of fibular fracture healing without implant-related complications such as stress-shielding and screw migration that have been reported with the use of one-third tubular plates [17]. However, this study lacked biomechanical data and a comparison between fibular plates. Huang et al. compared the utility of one-third tubular

Table 1:

	Bending Test				Torsion Test			
Device	Peak Load (N)	SD	Stiffness (N/mm)	SD	Peak Moment of Torsion (Nmm)	SD	Stiffness (Nmm/rad)	SD
One-Third Tubular	62.72	10.22	8.78	1.49	1547.69	124.35	2084.93	300.39
Contoured	88.54	7.06	7.28	0.96	2539.65	215.55	2919.48	388.78

SD: Standard Deviation

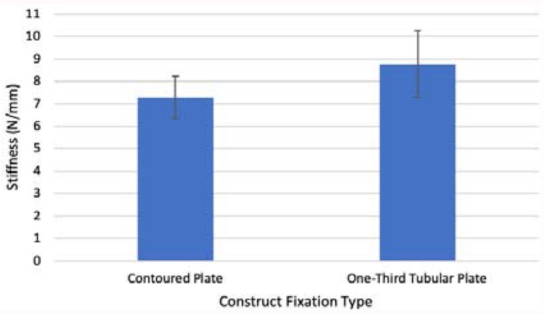

Figure 6: Valgus bending test - Bending stiffness of one-third tubular and contoured lateral malleolar fracture plate constructs.

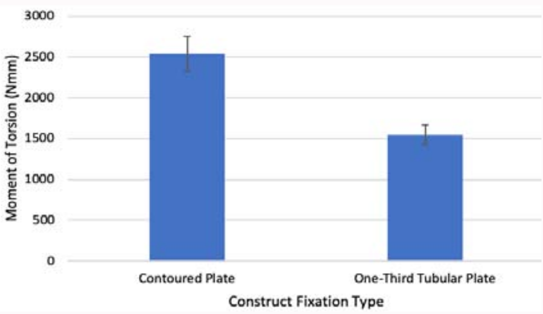

Figure 7: Torsional test - peak moment of torsion at failure of one-third tubular and contoured lateral malleolar fracture plate constructs.

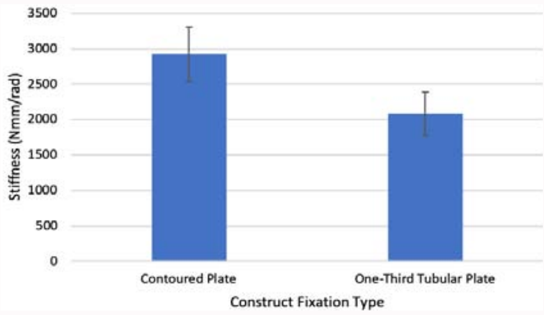

Figure 8: Torsional test - torsional stiffness of one-third tubular and contoured lateral malleolar fracture plate constructs.

plates, locking compression metaphyseal plates, and anatomically contoured locking compression distal fibula plates for lateral malleolar fixation in a clinical retrospective cohort study [5]. They found that those patients with either the metaphyseal or anatomic locking plates had higher return to function with higher Olerud & Molandar Scores (OMS) and the American Orthopedic Foot & Ankle Society (AOFAS) scores than those with one-third tubular plates. However, this study also lacked supplemental biomechanical data. A retrospective analysis by El Fatayri et al. [23] concluded that treatment with constructs using non-locking plates and locking plates did not exhibit significant differences in wound complication rate, hardware removal rate, and bone union rate of distal fibula. However, they acknowledged that a future randomized control trial was needed to verify their findings. A comparative study by Herrera-Pérez et al. [26] found that in 62 patients over age 64, locking and conventional non-locking plates allowed for similar treatment outcomes. Although, they suggested that locking plates may have benefits in cases that must consider immobilization time and concomitant soft-tissue damage.

In our study, we compared the biomechanical properties of traditional one-third tubular plates and newer anatomically contoured locking plates with screws to treat Danis-Weber B distal fibular lateral malleolar fractures. We found that utilizing anatomically contoured locking plates resulted in statistically significant higher maximum load to fracture displacement in the setting of valgus bending and torsional stress than using one-third tubular plates. This lends support to previous research which has found that locking plate implants provide more homogenous load distribution across a fracture site, which allows for increased implant stability [27]. The valgus bending stiffness data showed no significant difference in mean stiffness in the one-third tubular plate construct compared to the contoured plate construct. As the contoured plate does withstand higher loads before failure, this may indicate that geometrical rigidity of the plate, while providing stiffness in response to valgus bending forces, does not ultimately allow for optimal construct stability at peak loads. The torsional stiffness data shows a statistically significant higher stiffness in the contoured locking plate construct compared to the one-third tubular plate construct. In practice, too much stiffness may be counterproductive to healing, as complications such as delayed or nonunion have been attributed to the increased rigidity of locking plates [13,28]. Our biomechanical data may have clinical implications for determining the best plate for distal fibular fracture fixation on a case by case basis. From the surgeon's perspective, the anatomically contoured locking plate offers ease of pre-contouring not afforded by a one-third tubular plate. In prior studies, locking plates and screws have provided superior bony fracture stability with lower incidences of screw loosening and pullout [13]. This may translate clinically to faster rates of fracture healing, which is especially important in patients with poor bone quality. This is an important consideration as the geriatric population rises and the incidence of ankle fractures in that population increases [29]. This may also provide an earlier return to clinical function and range of motion, which is important for an active patient population [30]. As one-third tubular plates and screw constructs are less resistant to bending and torsion, this may result in higher rates of bone healing problems such as delayed union or nonunion and implant related problems such as stress shielding [13]. However, these matters have yet to be determined and require further clinical study beyond our current biomechanical investigation.

While our biomechanical data favor anatomically contoured locking plates as the stronger implant for Danis-Weber type B distal fibular fracture fixation, other factors must be considered. With regard to financial cost, one-third tubular plates are less expensive than distal fibular locking plates. In 2018, Chang et al. [31] found that the average cost for a one-third tubular and locking plate was $90.86 and $746.97 respectively. This is not inconsequential when considering the already large spending on healthcare in the United States and worldwide. Another concern with distal fibular locking plates are their increased thickness compared to one-third tubular plates, which may be associated with increased rates of wound complications at the lateral distal fibula [28]. However, this matter requires further clinical study beyond our current biomechanical investigation. Despite these shortcomings, the benefits from using anatomically contoured locking plates for distal fibular fracture fixation should not be ignored.

We acknowledge the limitations of our study. One manufacturer (Arthrex, Naples, FL) provided our investigation's implants, and so our results may not be applied universally to other types of one-third tubular and distal fibular locking plates. It can be argued that our study may benefit from a recreation of the ankle joint complex or syndesmosis rather than simulating the distal fibula in isolation. Distal fibular fractures and implants are not always isolated but rather part of a joint complex which influences the ways in which the ankle responds to bending and torsional stress. It can be contended that our study would benefit from including cadaveric specimens. While the sawbones we utilized have properties that are very similar to human bone, the two may not be completely identical. Future studies in this field of research may include biomechanical evaluation of implants in both sawbones and cadaveric bone to explore possible differences between them. It was also considered to perform compression testing, as we believe there is clinical significance to this type of testing. However, due to the thin profile of the fibula and the irregular shape of the distal end of the bone, it was not practical to execute a compression test. Cyclic loading failure can be explored and may have clinical significance, as the implants must be able to withstand not only acute stressors but also repeated longitudinal stress leading to fatigue. Lastly, this study only investigated lateral plating. While posterior plating is another common method for fixation of distal fibular fractures, lateral plating was chosen in this study as it avoids soft tissue complications such as peroneal tendonitis and tears [13]. Additionally, the prone position required for posterior plating may be less tolerable for older patients from an anesthesia perspective.

This novel study demonstrated the biomechanical benefits of using an anatomically contoured locking plate versus a one-third tubular plate for Danis-Weber type B lateral malleolar fracture fixation. Specifically, the contoured plate withstood greater loads in valgus bending tests, as well as greater moments of torsion during torsion testing of both plates. These findings provide support for previous literature suggesting that use of anatomically contoured locking plates allows for superior fracture stability. Despite the biomechanical advantages of anatomically contoured locking plates presented in this study, a stronger construct cannot necessarily be equated with a better construct. Other factors, especially cost, must be considered. Due to their cost efficiency and relative low complication rate, one-third tubular plates may be the best option for uncomplicated Weber type B lateral malleolar fractures, while reserving anatomically contoured locking plates for cases of poor bone quality where additional implant stability is desirable.

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