OPTIMIZING ANTERIOR TIBIOTALAR (TT) AND LATERAL TIBIOTALOCALCANEAL (TTC) PLATE THICKNESS FOR AVOIDANCE OF STRESS SHIELDING AND IMPLANT BREAKAGE

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STATEMENT OF PURPOSE

The purpose of this research is to determine the optimal anterior TT and lateral TTC plate thickness using finite element analysis (FEA). The balance between plate thickness and screw diameter was investigated in order to evaluate Von Mises stresses of the plate and shear strength of the screws given their material properties. Additionally, pullout strength of the screws and micromotion at the joints were calculated. It is hypothesized that a relatively thinner plate may help prevent stress shielding and screw breakage that may occur with a thicker plate, given the force profile across these joints.

METHODOLOGY & HYPOTHESIS

Outcomes using locking plate fixation for TT and TTC arthrodesis have varied. Smith et al. studied the outcomes of TTC arthrodesis using a 4.5 mm thick TTC plate and reported a failure rate of 73%. The authors concluded that the high nonunion rate in the study was likely due to excessive stiffness of the construct rather than patient comorbidities, with the recommendation of using a less rigid (thinner) plate construct to allow micromotion necessary for union of the bone.[1]

Although the results of this study are inconsistent with published rates of TT and TTC arthrodesis, it does bring into question the role of plate thickness and screw diameter in stress shielding and the allowance for micromotion. The hypothesis of this study is that a relatively thinner plate (1.5 mm TT, 2.0 mm TTC) would result in allowance for micromotion, while maintaining the structural integrity of the plate and screw construct. The results of this study will be achieved using FEA.

PROCEDURES

A validated bone model was used to conduct this research. The model was created using quantitative computed tomography (QCT). The QCT scan was segmented using ScanIP (Synopsys®). Masking was performed to allow for cortical and cancellous bone to be represented in appropriate areas. Material properties assigned to the bone and implants are demonstrated in Table 1.

PROCEDURES (Continued)

Table 1: Material Properties of Implants and Bones[2, 3]

Material	Young's Modulus (MPa)	Poisson's Ratio
Cancellous Bone	500	0.3
Cortical Bone	17000	0.3
Titanium	113800	0.3
Joint (Healing Bone)	500	0.3

The plate and screw models were masked and inserted into the foot model. Contact pairs were created between the plate and cortical shell of each bone, such that the plate maximally contacted the bone without eroding present bone. Screw configurations are outlined in Figure 1 for the anterior TT and lateral TTC plate. The models were ran with and without the presence of crossing screw(s).

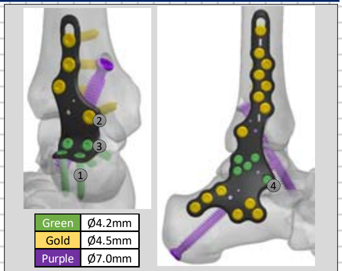

Figure 1: Screw Placement on Anterior TT (Left) and Lateral TTC (Right) Plates

Each model was imported into ABAQUS from ScanIP. The proximal tibia was pinned in place. A 979 N (220 lb) load was applied to each model at simulated heel strike, midstance and toe-off. Multiple nodes were placed proximal and distal to apply a force to simulate heel strike and toe-off, respectively (Figure 2). Stress in the plates was determined by placing elements in high stress areas. Von Mises stresses for each element in that area were extracted and averaged for each loading condition.

A coordinate system was created for each screw. The x-axis was positioned through the long axis of the screw, with pullout calculated along this axis (Figure 3). Resultant shear forces were recorded at the neck and combined as a vector to get the overall shear force of each screw (Figure 4).

To determine micromotion, pairs of nodes were placed at contact location between the tibia and talus for the anterior TT plate and between the tibia/talus and talus/calcaneus for the lateral TTC plate. To calculate micromotion, the distance between the pairs of nodes at each phase of gait were calculated and the maximum was reported.

Figure 2: Orange Nodes for Force Application in Heel Strike (Left) and Toe-Off (Right)

Figure 3: Pullout Force

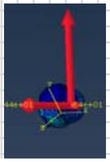

Figure 4: Shear Force

RESULTS

Table 2: Results of FEA Analysis

	Anterior TT Plate No Crossing Screw	Anterior TT Plate Crossing Screw	Lateral TTC Plate No Crossing Screw	Lateral TTC Plate Crossing Screw
Screw - Max. Pullout Force (N)	282.6 (TO, Screw 1)	164.1 (TO, Screw 3)	367.7 (TO, Screw 4)	304.6 (TO, Screw 4)
Screw - Max. Shear Force (N)	360.4 (TO, Screw 2)	203.6 (TO, Screw 1)	414.6 (TO, Screw 4)	179.2 (TO, Screw 4)
Plate - Max. Von Mises Stress (MPa)	566.6 (TO)	39.8 (TO)	485.0 (TO)	187.7 (TO)
Max Micromotion - Tibiotalar Joint (mm)	1.70 (TO)	.009 (TO)	.77 (TO)	.09 (TO)
Max Micromotion - Subtalar Joint (mm)			.09 (TO)	.07 (HS)

Key: TO=Toe-Off, HS=Heel Strike; Note: Screw numbers are labeled in Figure 1

A reduction in Von Mises Stress was observed for the both plates with the addition of a crossing screw (Figure 5). All pullout forces of the screws were below the maximum pullout calculated at the respective screw location, using Chapman's equation.[4] Micromotion was notably reduced with use of a crossing screw for the anterior TT plate. Maximum shear stress for all screws was below the material shear strength.[5]

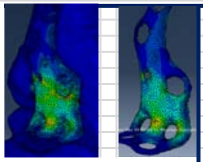

Figure 5: Von Mises stresses without crossing screw (Left) and with crossing screw (Right) for anterior TT plate

LITERATURE REVIEW

TTC arthrodesis is a solution for many pathologies including osteoarthritis, Charcot arthropathy, avascular necrosis of the talus, trauma, congenital deformities and rheumatoid arthritis. With complex deformity and the presence of the co-morbidities presented above, allowing for optimal healing conditions to achieve bony union is vital.[6] TTC Arthrodesis using locking plate fixation was first studied by Ahmad in 2007 with 17 of 18 arthrodesis progressing to union at 20.7 weeks post-operatively.[7] Although locked plating leads to a mechanically stiffer construct; clinically, failure to achieve union can be a result of implant breakage, lack of micromotion, or failure to compress while locking a gap in between two bones.[8]

Many factors influence the ability to fuse arthrodesis sites including compression of joint surfaces, rotational construct stiffness, bending stiffness, blood supply and bone apposition.[6] While not all of these factors can be studied with a single experiment, this study sought to evaluate construct bending and rotational stiffness, while evaluating the effect on the bone surface contact.

DISCUSSION

Using the FEA model to simulate static loading situation, neither plate nor screws failed as a result of the loading scenario used in this experiment. Micromotion was above the 0.2-1 mm desired for stimulation of callus formation[9] for an anterior TT plate without a crossing screw, yet fell below this number when a crossing screw was used. As expected, less change in micromotion was seen with the use of crossing screws in a lateral TTC plate, compared to a lateral TTC plate without crossing screws. With the absence of a soft tissue envelope in this model, as well as reported numbers being the maximum value at specific nodes, we believe that further study of micromotion should be explored. A thinner plate should withstand the large bending moment at the ankle, but a crossing screw may be beneficial to reduce levels of micromotion, especially for an anterior TT plate construct.

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Disclosure: This study was paid for by Paragon 28, Inc. Three authors as indicated above are employed by Paragon 28, Inc.