# Investigating the Difference between FEA on Tibial 3D Models and 2D Cross-Sections Patricia Butler<sup>1</sup>, Mara Thompson<sup>1</sup>, Ali Vahdati<sup>1</sup>, PhD, Stacey Meardon<sup>2</sup>, PhD, Stephanie George<sup>1</sup>, PhD

## Abstract

Running is an activity that has gained popularity for its physical and mental benefits. While running, the tibia is subjected to repetitive forces which can result in bone stress injuries (BSI) [1]. Runners commonly experience BSIs in the tibia, which is the predominate site for BSIs [1]. The severity of the injury dictates how long the recovery time is, however, it is suggested that the patient waits 2-6 weeks before resuming normal exercise activities. Surgery may be required if the patient continues to experience pain or if the BSI increases in magnitude [2]. Computational methods such as finite element analysis (FEA) are used to better understand mechanisms for BSIs, and thus propose interventions. The objective of this study is to perform FEA on two-dimensional (2D) models and compare the results to three-dimensional (3D) models produced from the same subjects. FEA is a tool that is used for finding the stress caused from applied loads, how those stresses alter the mechanical properties of the bone and how the bone distributes stress [3]. FEA can be performed on a 2D cross-section of the tibia by using the program VA-BATTS within MATLAB, however, FEA is typically performed on 3D models. While 3D models are used more frequently, there are drawbacks, due to the method being time consuming and potentially computationally expensive. The focus of this study is to produce and compare the stress values collected from FEA on 3D models and 2D cross-sections and determine if the difference between the results are statistically significant. If the difference is not significant, then it is beneficial to perform tibial FEA studies on 2D cross-sections instead of on 3D models. It is expected that this study, comparing methods of FEA, will contribute to the study of tibial stress.

## **Clinical Significance**

Stress injuries are a common, painful musculoskeletal injury that make up anywhere between 6-20% of runner injuries [1]. The tibia is the most prevalent location for stress injuries to occur, accounting for 19-54% of all stress injuries [1]. An example of a stress injury can be seen in Figure 1.

The severity of the stress injury dictates the length of recovery; however, it is suggested that the patient waits 2-6 weeks before resuming their regular exercise routines [2]. Surgery may be required if pain remains or if the severity of injury increases [2].

## **Data Collection**



Figure 1: Tibial Stress Injury. Arrows are indicating that the periosteal edema is extended more than the cortex [4].

The Internal Review Board (IRB) at East Carolina University (UMCIRB) 14-000009) previously authorized the data collection for the study performed at Vidant Medical Center in the Human Movement Analysis Lab (Greenville, North Carolina) [5]. The study included in this poster will be performed on de-identified data that was previously collected.

## **Data Collection:**

The aforementioned study had 40 volunteers, 21 of which will be included in this study [5]. Participants were aged 18-35, healthy, noninjured, and were runners who often ran more than 16 kilometers a week [5]. All participants gave their informed written accept before being accepted by the IRB [5]. MRI images were collected of the frontal, coronal, and sagittal plane of each participant's tibias with the use of a 1.5-T scanner (Figure 2) [5], these images will be used to create 3D models and 2D cross-sections.



Figure 2: The Model of MRI scanner used to Collect Tibial Images. Image from [9]

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## Objectives

- Create Subject-specific 3D Models and 2D Cross-sections of 12 Males and 9 Females
- 2. Perform FEA on each Model/Cross-section
- 3. Compare the Stress Found from each Model via a Paired t-test 4. Determine Stress Differences Between the Methods (3D full model or 2D cross-section)

# **3D Models**

FEA is typically performed on full 3D models. There are three major steps that will be performed to analyze the 3D models. Before these steps, the MRI DICOM images were imported and converted into MIMICS files.

## **Segmenting the Models:**

To segment the tibia (Figure 4), the mask will be adjusted to only select the aspects that we want to model. After the desired parts of the tibia have been masked, the model will be imported into 3-matic.

## **Creating a Mesh:**

Within 3-matic, a volume mesh (Figure 3) will be produced and imported into ANSYS Mechanical [5].

## **Finite Element Analysis:**

FEA (Figure 5) will be performed in ANSYS Mechanical after identifying the boundary conditions and material properties.

## **Drawbacks:**

- Time consuming
- Computationally Expensive

## **2D Cross-sections**

## Creating the cross-sections:

A MATLAB code will be used to create the 2D cross-sections of the tibia. The cross-section will be taken at the distal third, because that is the most frequently fractured location of the tibia [7].

## **Analyzing cross-sections:**

Within MATLAB, the free program VA-BATTS (Figure 6) will be used to adjust the material properties and to identify the cross-sectional stress [8].

## **Data Analysis**

As each participant's MRI image was used to create both a 3D model and a 2D cross-section, a paired t-test will be performed to compare the identified stresses from the two models. The differences will be considered significant if the p-value is less than 0.05. If it is found to be significant, then the full 3D model should be used. If not, then the 2D cross-section method should be pursued. A depiction of the data analysis process can be seen in Figure 7.



Figure 7: Depiction of Planned Data Analysis.











Figure 3: Segmentation of a Tibia with Mimics

## Discussion

## **Alternative Methods:**

As the proposed methods have all been performed in previous research, there is unlikely to be any complications; however, alternative methods have been identified:

### Mesh Generation:

If generating meshes of the full 3D within MIMICS proves unsuccessful:

- Meshes will be produced within ANSYS
- In this scenario, FEA will still be performed in ANSYS Mechanical

### Finite Element Analysis:

If for any reason FEA does not work within ANSYS: • FEA will be performed within MIMICS.

## Limitations:

### Imaging Method:

MRI imaging is not the optimal method for imaging bone as trabecular bone is not visible. A better way of obtaining the images would be CT imaging

## Future

It is anticipated that the results of this study will shed light on differences in tibial cross-sectional stress between a 3D FEA method and a 2D method based on beam theory (VA-BATTS) If limited differences exist, then the more complicated 3D FE model may not be required. The results may also provide insight on tibial stress patterns during running and if there are gender differences.

## References

- Meardon, S. A., Willson, J. D., Gries, S. R., Kernozek, T. W., & Derrick, T. R. (2015). Bone stress in runners with tibial stress fracture. Clinical Biomechanics, 30(9), 895-902. doi:10.1016/j.clinbiomech.2015.07.012 2. M. Harrast and D. Colonno, "Stress Fractures in Runners", *Clinics in Sports Medicine*, vol. 29, no. 3, pp. 399-416, 2010. Available: 10.1016/j.csm.2010.03.001.
- Tarapoom, W., & Puttapitukporn, T. (2016). Stress Distribution in Human Tibia Bones using Finite Element Analysis. *Engineering Journal*, *20*(3), 155-167. doi: 10.4186/ej.2016.20.3.155 4. A. M. Gmachowska et al, "Tibial stress injuries - location, severity, and classification in magnetic resonance imaging
- examination," Polish Journal of Radiology, vol. 83, pp. e471-481, 2018. Thompson M. (2017). The Effect of Muscle Volume on Tibial Stresses Using FEM. Magesh, Varadaraju. (2018). FINITE ELEMENT ANALYSIS OF TIBIA BONE BY REVERSE ENGINEERING MODELLING APPROACH. International Journal of Pure and Applied Mathematics. 118.
- Mencio, G., Frick, S., & Green, N. *Green's skeletal trauma in children*. kopurtis Kourtis, L., Carter, D., Kesari, H., & Beaupre, G. (2008). A new software tool (VA-BATTS) to calculate bending, axial torsional and transverse shear stresses within bone cross sections having inhomogeneous material properties. Computer
- Methods In Biomechanics And Biomedical Engineering, 11(5), 463-476. doi: 10.1080/10255840801930728 Magnetic Resonance – 1.5 Tesla MRI Scanner | Vantage Titan 1.5T Zen Edition | Canon Medical Systems USA. (2019). Retrieved 7 December 2019, from https://us.medical.canon/products/magnetic-resonance/vantage-titan-15t/

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