The Research and Scholarship Symposium
The 2015 Symposium

Apr 1st, 11:00 AM - 2:00 PM

Design of TKR Tibial Insert for Bowlegged Gait

Michael R. Gardner
Cedarville University, michaelgardner@cedarville.edu

Nathan A. Hanbury
Cedarville University, nhanbury@cedarville.edu

Joel D. Hutchison
Cedarville University, jdhutchison@cedarville.edu

Dana C. Madsen
Cedarville University, dmadsen@cedarville.edu

Joel D. Slabach
Cedarville University, joelslabach@cedarville.edu

See next page for additional authors

Presenters
Michael R. Gardner, Nathan A. Hanbury, Joel D. Hutchison, Dana C. Madsen, Joel D. Slabach, Kyle M. Bradley, Timothy L. Norman, and J. D. Blaha

Design of TKR Tibial Insert for Bowlegged Gait

M. Gardner, N. Hanbury, J. Hutchison, D. Madsen, J. Slabach, K Bradley, T.L.Norman, and J. D. Blaha[1]
School of Engineering and Computer Science
Cedarville University, Cedarville Ohio
[1]Department of Orthopeadics
University of Michigan, Ann Arbor, MI

INTRODUCTION

Wear on the medial side of the knee can be caused by many things. One such cause can be due to a person's gait being bowlegged. The bowlegged gait then causes an increase in adduction moment which adds contact stresses on the medial compartment of the knee. This is due to a varus deformity in gait. It was hypothesized (JDB) that another type of bowlegged gait, having a reduced ability to internally rotate the hip, results in an increased adduction moment. Thus, this type of abnormal gait would increase the medial compartment stresses as well.

OBJECTIVES

The objective of our project was to investigate the hypothesis that the failure to internally rotate the femur increases medial compartment stresses in the knee. Should this hypothesis prove to be true, our next objective was to design, test, and provide design recommendations on how to account for the increased medial compartment stresses caused by the abnormal gait.

DEFINITIONS

- **Normal Gait:** The walking pattern of a person who goes through the gait cycle without any known pathological variations of gait.
- **Abnormal Gait:** The walking pattern of a person who has at least one pathological variation of gait.
- **Bowlegged Gait:** The specific pathological variation of gait where the knees are positioned more laterally. This causes the person to have an outward bend in his or her legs.
- **Tibial Plastic:** The part of a total knee replacement attached to the tibial tray and forms the shape of the tibial plateau (see Figure 2).
- **Varus:** A type of bowlegged gait in which the outward bend of the leg is caused by an angle in the frontal plane of the body.
- **External Rotation of the Femur:** A type of bowlegged gait caused by the rotation of the femur in the outward direction which causes the leg to move laterally in the forward positions of gait.

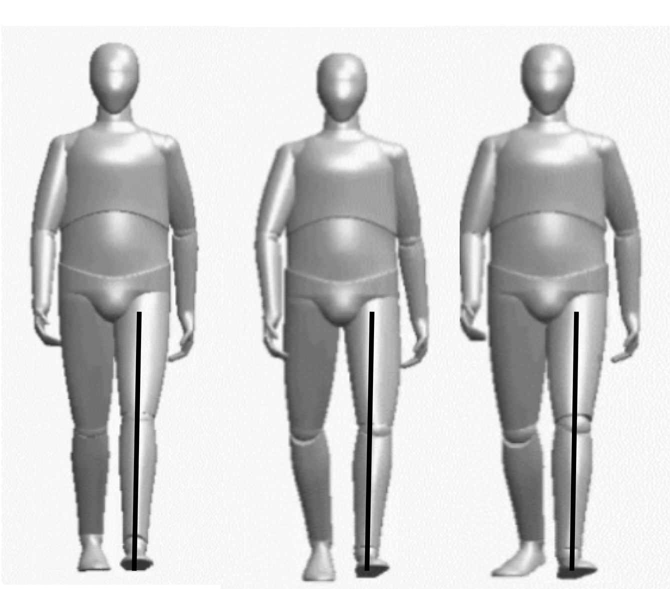

Figure 1: *Three figures with a normal gait, varus, and external rotation of the femur respectively. The black line represents the relation of the hip, knee and ankle for a normal gait.*

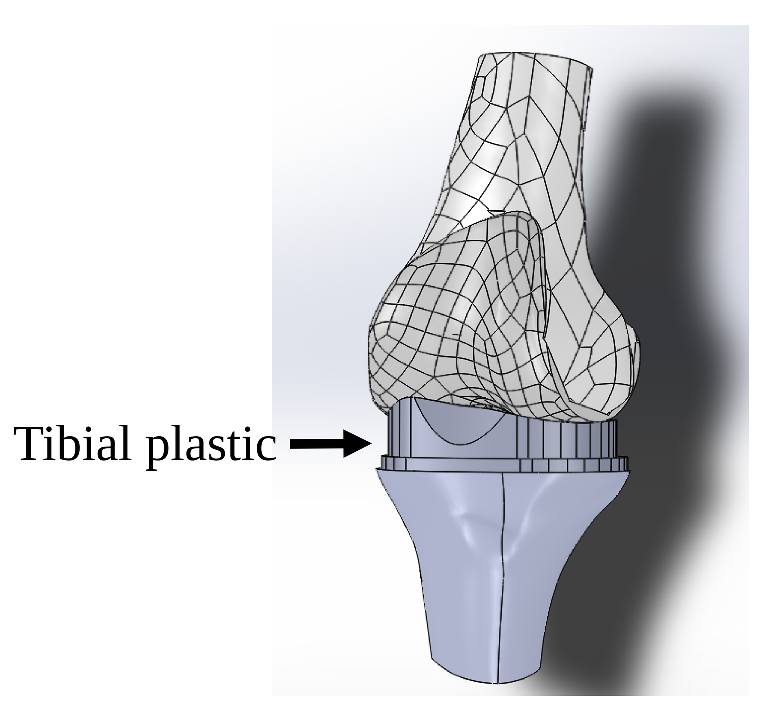

Figure 2: *A total knee replacement with the tibial plastic indicated.*

PROPOSED MODIFICATIONS

We considered several different design variables in our modifications, including thickening or angling the tibial plastic, thickening the anterior medial cusp of the plastic, or increasing the size of the tibial plateau while keeping the base of the component small. Each of these proposed modifications addressed either primarily varus or external rotation. The first of the three that were designed to counteract varus is the thickened plastic model (Figure 3). This operates on the experimentally confirmed principle that thickening the plastic of a TKR reduces the surface stresses in the plastic. The second varus option (Figure 4) angles the tray such that more of the femoral component will contact the tibial plateau, reducing stresses by increasing contact area.

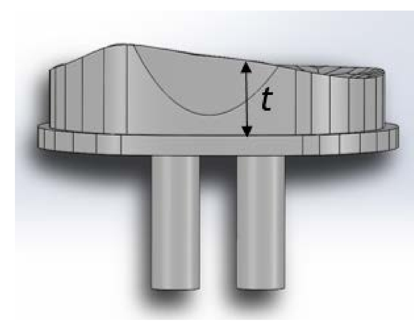

Figure 3: *Tibial plastic with an altered thickness.*

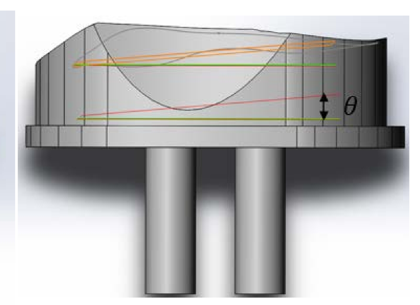

Figure 4: *Tibial plastic with an altered angle.*

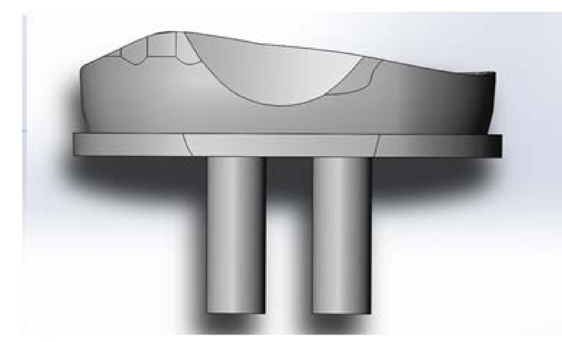

Figure 5: *A tibial component with a tibial plateau size increase and gradually reduced plastic profile.*

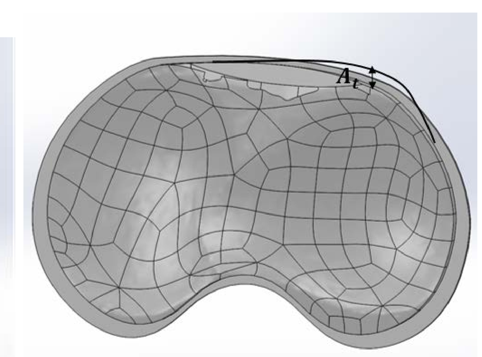

Figure 6: *Tibial plastic with an increased anterior medial thickness.*

The last varus option also increases contact area by increasing the size of the tibial plateau of the implant while keeping the base of the implant small to prevent impinging on the patellar tendon (Figure 5). This affords the benefits of increased contact area and decreased stress without risking damage to surrounding tissue by using a larger size of TKR. The model created to counteract the effects of external rotation has a reinforced anterior medial cusp to account for the increased stresses that external rotation places on that feature of the tibial component.

FINITE ELEMENT ANALYSIS ASSUMPTIONS

In order to run FEA on the knee implant, several assumptions needed to be made concerning the femoral condyle and tibial plastic interfacial properties (contact and overclosure) and the means with which to render the model stable and restrict relative motion. To Fix the overclosure we used a Boolean operation. This operation cuts away at one of the overcolsing surfaces to make the two surfaces congruent to each other. We cut away at the femoral surface because we were more concerned with stresses on the tibial surface.

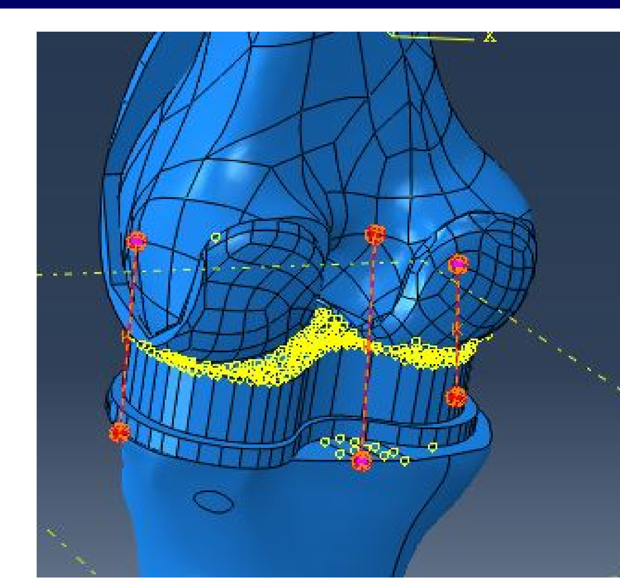

Figure 7: *A finite element model with ligaments and tendons.*

To constrain the relative motion we used a tie constraint between the cut femoral surface and the tibial surface. This type of constraint fixed the two contacting surfaces in all six degrees of freedom. However, this causes tension as well as compression on the tibial plateau. In order to alleviate the tensile stresses, we added springs to the implant to counteract the applied moment. Since these constraints are not representative of what is really going on in the knee, the results are not accurate. More work needs to be put into improving the accuracy of modeling the knee so the results can be refined.

RESULTS

We first conducted FEA on a non-modified implant for normal gait (see Figure 8). The maximum stress as well as the stress contour for this test was used as the control for our analysis. In other words, our subsequent experiments were compared with this control to determine which modifications decreased stress. Our control test had a maximum stress of 3.5 ksi and the stress was concentrated in regions 1, 2, 5, and 6 (see Table 1 and Figure 9).

Figure 8 also shows the FEA results for the normal implant under external rotation and varus, where for both cases the stress on the medial side is greater as compared to the control test. Therefore, Dr. Blaha's hypothesis was confirmed. The FEA results for the thickened anterior medial cusp for external rotation and the angled tray for varus are shown in Figures 10 and 11.

Table 1: FEA Results for location and magnitude of Max Stress.

Implant Modification	Gait Style	Max von Mises	Location of Max Stress
		Stress (ksi)	Region
Normal Implant	Normal	3.5	1/2 & 5/6
	Ext. Rotation	4.0	1
	Varus	4.5	1
Thickened Plastic (2mm)	Normal	4.5	2
	Ext. Rotation	4.5	1
	Varus	5.5	1
Thicker Anterior Medial Cusp	Normal	3.0	1, 2, 5
	Ext. Rotation	3.5	1 & 6
	Varus	4.5	1
Angled Tray	Normal	N/A	N/A
	Ext. Rotation	N/A	N/A
	Varus	3.5	1
Graduated Tray	Normal	4.0	2 & 5/6
	Ext. Rotation	4.0	1 & 6
	Varus	6.0	1

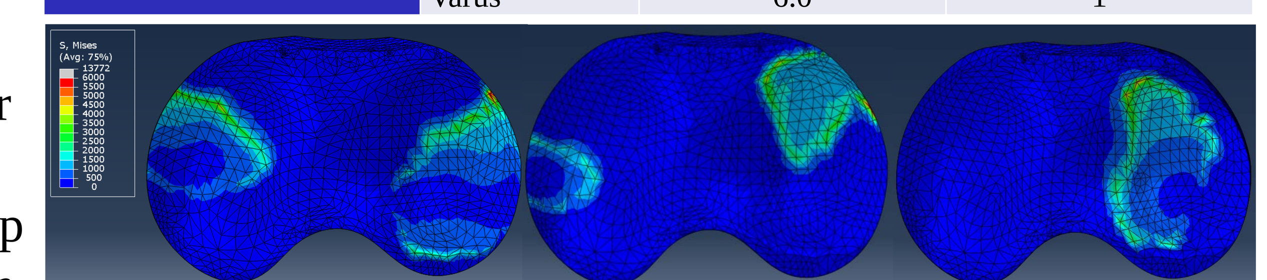

Figure 8: *Finite Element Analysis for the Normal Implant.*

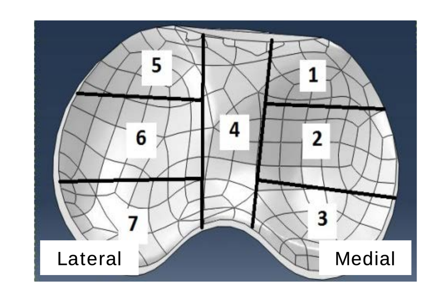

Figure 9: *Regions of Tibial Plataea*

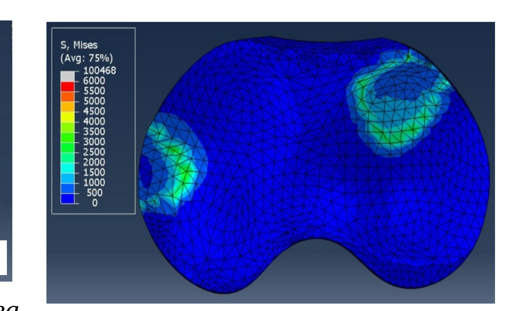

Figure 10: *Thickened Anterior Medial Cusp For External Rotation.*

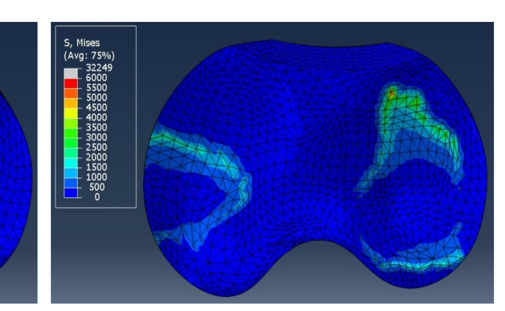

Figure 11: *Angled Tray for Varus.*

DISCUSSION

Based on the FEA results (see Figures 10 and 11), we recommend the thickened anterior medial cusp implant for users with abnormal gait because the maximum stress is reduced by 25%; however, this design could be further refined because the stress contour deviates from the control case where the concentration of stress resides on the medial side. For individuals with varus, we recommend the angled tray implant because the stress is reduced by 25%, and the stress contour conforms closely with the control result where there is a similar amount of stress on the lateral and medial sides.

ACKNOWLEDGEMENTS

Funding from School of Engineering and Computer Science, Cedarville U