Computational Analysis of Quadriceps Tendon Force Following Total Knee Replacement Surgery Leads to Improved Patient Knee Flexure

Overview

Anterior knee pain is a significant complication following total knee arthroplasty (TKA) surgery. The inability to freely extend/flex the knee has a crucial influence on patients daily activities including walking, lifting and rising from a chair. This knee movement inability is one of the most common indications of needed TKA procedure revisions. Poor sizing during surgery of the patellar knee component – a "button-like" element that increases the mechanical advantage of the extension force. The research biomechanics group in the Department of Bioengineering at Clemson University has evaluated the effect of the patella-button thickness on the variation of the magnitude of the quadriceps tendon force by applying HyperWorks-based finite element analysis.

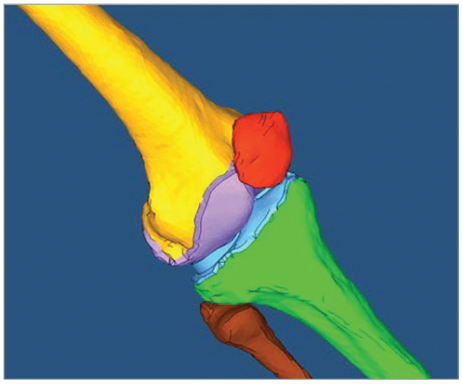
Anterior Knee Pain Following Total Knee Arthroplasty (TKA) Surgery

Business Profile

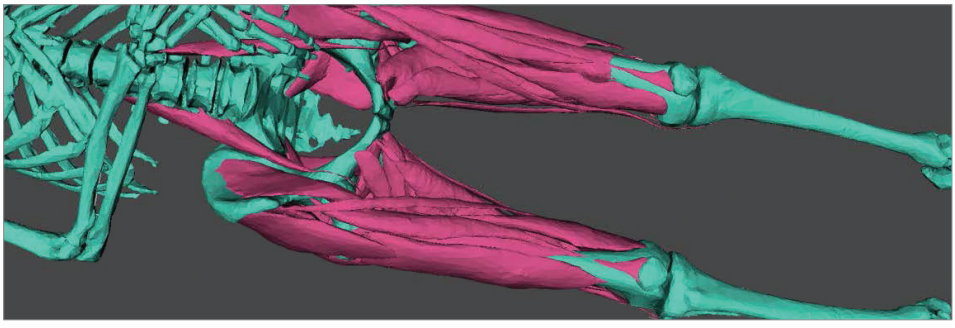
The Department of Bioengineering at Clemson University has for over 50 years provided students, faculty, and research staff with exceptional opportunities for intellectual, professional, and personal growth. Guided by a faculty committed to undergraduate and graduate research experience, bioengineering students apply engineering principles to understand and treat disease. Collaboration with physicians and entrepreneurs ensure that research focuses on high-priority health care challenges. Under the direction of Department Chair, Dr. Martine LaBerge, this collaboration has been enhanced through the addition of a Clemson University-Medical of South Carolina Bioengineering Program in Charleston, SC.

Challenge

The challenge of this study was to quantitatively evaluate the effect of the patellar button thickness on the variation of the quadriceps tendon force during knee joint flexion/extension using computational analysis. A reduction in the force variation is directly related to the mitigation of anterior knee pain following total knee arthroplasty (TKA) surgery.



Natural Knee Joint Modeled in HyperMesh



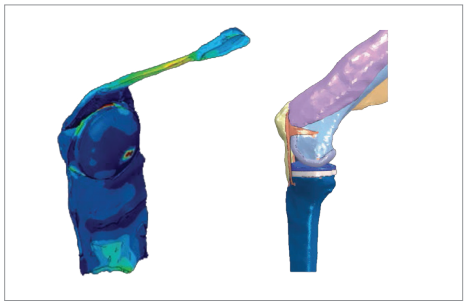
Reconstructed Human Skeleton System with Thigh Muscle Groups

"Altair provided Xin Xie, our PhD student and Altair Fellow, with a tremendous amount of support during his research studies on the effects of rotational TKA prosthetic misalignment on quadriceps tendon force."

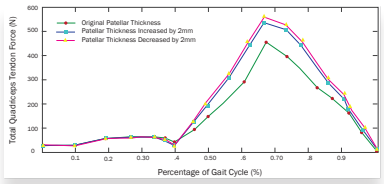
Dr. Martine LaBerge,
Chair, Department of Bioengineering
Clemson University

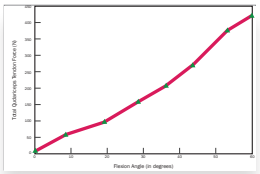
Solution

Three-dimensional (3D) explicit finite element analyses were completed by Xin Xie, an Altair Fellow and doctoral student, to assess the effect of the patellar button thickness on the quadriceps force magnitude and variation. Altair HyperMesh was applied to build a detailed, 3D model of the articular knee joint. A basic 3D model was developed through MRI reconstruction of an average-sized cadaver lower extremity to represent the realistic components of the human knee joint. The cadaver tibia, femur, and patella button were resected using the specific surgical procedures specified by suppliers of total knee joint replacements. The geometry of a specific TKA device was inserted into the natural knee model and aligned using HyperMesh. Muscular and ligamentous knee connectors were modeled as isotropic, hyper elastic materials quantified by experimental testing data. A motion tracking system was employed to define the displacement boundary conditions for the tibia and femur during knee flexing and extension. Finally, using the geometrical morphing capability of HyperMesh, two additional patellar buttons with varied thickness (+-2 mm) were created, thus generating three finite element models in total. Using output from quasi-static finite element analyses of these three models, the tendon force magnitudes for each thickness case were computed.

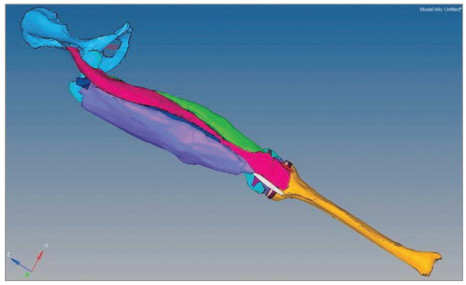


Deformation of Quadriceps Tendon at 60° of Femoral Flexion





Total Quadriceps Tendon Force Variation during 0 to 60° of Femoral Flexion



Total Geometrical Model for Finite Element Simulation

Results/Benefits

Von Mises stress distributions were computed throughout the volume of the quadriceps tendon during knee flexure/extension at full walking gait. For all three thickness cases, the peak stress occurred when the femur reached a maximum flexure angle (60°). All three cases showed similar results for the TF variation during the gait cycle. However, compared with a peak TF value obtained from the baseline patella button thickness, the thinner patella case revealed the highest TF force among the three cases. In summary, this study has shown that patellar component thickness has a significant effect on the quadriceps tendon force within the swing phase of a walking gait cycle.

More specifically:

- A thicker patella after TKA surgery may tighten the quadriceps tendon
- A thinner patella may lead to dysfunction of the knee extensor mechanism due to ineffective moment arm, thereby causing abnormal TF magnitudes

With further computational studies, the effect of a wider range of patellar button thicknesses on the knee joint reaction forces should be considered for achieving optimum thickness values.

Total Knee Replacement

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