2024 BMES Annual Meeting - Undergraduate Abstract

A Biomechanically Informed Approach to Atypical Patellar Tendon Reconstruction

Sommer Allen, Matt Clontz, and Martin L. Tanaka

College of Engineering and Technology, Western Carolina University, Cullowhee, NC, USA

Introduction

There are various cancers that affect the knee, one of the main ones being osteosarcoma, a type of bone cancer that occurs around the knee joint. In this case, the osteosarcoma is assumed to be on the tibial tuberosity of the knee. To optimize surgery outcomes, a digital twin may be used for surgical preplanning. Digital twins are computerized models of a system that can be used to replicate or preplan a procedure. There are different types of digital twins such as component/part twins, asset twins, system/unit twins, and process twins. In this study, a system/unit twin would be the most appropriate option because this type of digital twin shows how small parts interact to allow a larger system to function. A system/unit twin also shows how changes in small parts may affect the system at large. The present work drew from previous studies to find the maximum ground reaction force in the knee, the cross-sectional area of the patellar tendon, and the maximum amount of stress the tendon can withstand in the knee. The purpose of the present work is to plan surgically for the reconstruction of the patellar tendon in the case where the original insertion point in the tibial tuberosity is no longer viable. This study aims to move the patellar tendon away from a "cancerous site" in the knee while maintaining as much of the original force balance on the knee as possible.

Materials and Methods

Estimated values for the width of the distal and proximal ends of the patellar tendon and length were drawn from previous studies. An analysis was performed using scaled drawings of a knee at 60 degrees of flexion (Watts et al, 2023). That angle was chosen based on results from (Edwards 2010) which stated that max patellar tendon loading occurs during a horizontal jump stop at a knee flexion angle of approximately 60 degrees. Once all dimensions were estimated using the scale established with data from (Yoo 2007), a cartesian direction vector was formed from the proximal end to the distal end of the tendon. Maximum patellar tendon force corresponding to the 60-degree flexion angle was found to be six times bodyweight (Edwards 2010). Assuming a bodyweight of 81.6 kg (180 lbs.), the peak magnitude of the force on the patellar tendon was estimated to be 4800 N. These ground reaction forces were then used to conduct a stress and factor of safety analysis on an unaltered patellar tendon. Subsequently, the same analysis was performed on a patellar tendon that had been "cut" into two sections with the distal end of one section being attached at a new location to the lateral side of the tibial tuberosity and the other to the medial side. Stress and factor of safety values of the new sections were then compared to that of the unaltered patellar tendon.

Results/Conclusions/Discussions

Based on the direction vectors assumed for the two parts of the split patellar tendon, the magnitudes were found to be 3407 N on the lateral section and 1839 N on the medial section. After the introduction of an x-component of force on the split portions of the tendon, the total force exceeded the original 4800 N. To split the stress evenly between the two portions, the magnitudes for each side were divided by the "new total" of 5246 N (note that this is not the actual magnitude of the force at the patella, but solely a value used to evenly distribute the stress). With the goal of maintaining equal stresses in the two tendon sections, the preceding results indicated that the tendon in this case should be split with 65% of the cross-sectional area going to the lateral section and 35% going to the medial section. Based on those percentages and a cross-sectional area of 104 mm^2 (Bennett 2021), the normal stresses in the original patellar tendon were found to be 46.2N/mm^2, and "new" sections were found to be 50.3994N/mm^2 for the lateral side and 50.522N/mm^2 for the medial side.

The preceding analysis is one of many possible solutions to splitting the tendon while maintaining appropriate balances of force and stress in each section. In this study, some assumptions were made, such as the location of attachment points at the proximal and distal ends of the tendon segments after the split. Furthermore, the introduction of additional patellar tendon force in the x-direction would reduce loading on several other tendons which warrants further investigation. Still, this approach of personalized care represents a significant advance over a basic approach of splitting the patellar tendon 50/50. Assuming the same attachment points are used, a 50/50 split of cross-sectional area would have resulted in a factor of safety of only 1.06 on the lateral side, compared to 1.38 with the personalized approach. By taking a biomechanically informed approach to the tendon reconstruction, 92% of the original factor of safety was retained, reducing the likelihood of a tear or catastrophic failure of the tendon.

References

Bennett, K. Vincent, T. Sakthi-Velavan, S. (2021). The Patellar Ligament: A Comprehensive Review. Wiley. 10.1002/ca.23791

Edwards,S., et al. (2010). Characterizing Patellar Tendon Loading During the Landing Phases of a Stop-Jump Task. Scandinavian Journal of Medicine and Science in Sports. 10.111/j.1600-0838.2010.01119.x

Yoo, J, H. Yi, S, R. Kim, J, H. (2007). The Geometry of Patella and Patellar Tendon Measured on Knee MRI. National Library of Medicine. 10.1007/s00276-007-0261-x

Watts, R. E., et al. (2023). Patellar tracking: An old problem with new insights. RSNA Publications Online, 43(6).