Biomechanical Modelling of Knee Joint for Assisting High Tibial Osteotomy

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Summary

A biomechanical model of the lower limb with active three-dimensional (3D) muscles was developed in the open-source Artisynth platform (www.artisynth.org) to simulate knee movement. This model is going to be used in particular to broaden our knowledge about the biomechanical effects of high tibial osteotomy surgery and to assist the surgical planning procedure. The model geometry was reconstructed from MRI and CT data of a volunteer. The joint movement is acquired by activating various muscle groups. The joint kinematics as well as contact pressure distribution is monitored.

Introduction

High tibial osteotomy (HTO) is a common surgical procedure for treatment of patients with early-stage osteoarthritis that has damaged a single side of the knee joint. This surgical procedure can relieve pain and significantly improve the patients' joint function by reducing the pressure of the damaged side of the knee. However, the success rate seems to be strongly affected by the quality of the deformation correction, which is indeed related to surgical planning and the physical execution of the plans [1]. An accurate pre-planning in addition to a better understanding of the biomechanical effects of HTO is thus essential to ensure that the correct lower limb alignment is achieved postoperatively. A significant alternative to the experimental studies is the use of computer modelling techniques. As a result, many biomechanical models of the knee joint with different levels of complexity exist in the literature. However, the number of biomechanical studies concerning the HTO intervention is relatively small and the models studying this surgical intervention seem to suffer from lack of precision in modelling the connecting soft tissue structures and the muscles [2,3]. Thus, the objective of this study is to generate a patient-specific biomechanical model of the lower limb including 3D active muscles so as to acquire a practical tool to simulate a variety of knee movements and use it in particular for the simulation of high tibial osteotomy.

Methods

To better understand the mechanical and functional consequences of HTO, the knee kinematics as well as individual soft tissue contributions need to be monitored. The classical musculoskeletal (MSK) modelling technique based on 1D muscles models facilitates simulating joint kinematics but is not capable of monitoring the stress and strain distribution inside the 3D anatomical structures. In addition, the accuracy of such biomechanical models with 1D line-segment muscles is limited most importantly because the muscle insertion area, muscle fiber directions and the contacts/sliding between the muscles are not taken into account. This can be addressed by the use of Finite Element (FE) modelling technique that enables us to capture the individual soft tissue contributions and joint motion simultaneously in response to a given loading condition. Hence, the model in this study is generated in Artisynth which is an open-source 3D modelling platform supporting the combined simulation of multibody and finite element models.

The 3D geometry of the muscles and bones was reconstructed based on the medical images of a healthy volunteer. MRI and CT images were used to perform the manual segmentation in Amira software and to acquire the 3D surface of the bones and 40 soft tissue components including the muscles as well as joint connective tissues and articulation (Figure 1a). The bones were modeled as rigid bodies and the soft tissues as FE meshes. Muscle fiber directions are assigned along the length of the muscles and the flexor and extensor muscle groups are activated to simulate a variety of knee movements (Figure 1b).
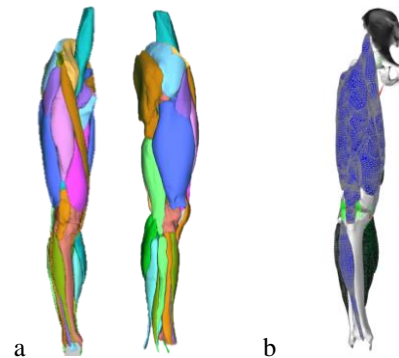

Figure 1: a. Reconstructed 3D surfaces of the lower limb muscles, b. The FE model generated in Artisynth

Results and Conclusion

The developed biomechanical model of the lower limb with 3D active muscles is capable of generating various knee movements by activating the muscle groups. The joint kinematics and contact pressure distribution on the articulation is monitored. This model is the first step in developing a patient specific model to study the mechanical and functional effects of HTO.

Acknowledgments

References

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