OPTIMISATION OF MUSCLE FORCES TO MINIMISE TENSILE LOADING OF THE FEMUR

Alexander Brown[1], Neil Curtis[1], Ulrich Witzel[2], Michael Fagan[1]

[1] *University of Hull, United Kingdom;* [2] *Ruhr-Universität Bochum, Germany*

Introduction

Bone is well known to adapt to its mechanical environment, allowing the bone to support the loads to which it is routinely exposed. A lightweight structure with minimal bone is most efficient. The optimal loading to minimise material is compression. It has been postulated that muscles may activate not only to provide the necessary skeletal motion and/or posture, but also to place the bone in compression whenever possible [Pauwels, 1980; Sverdlova and Witzel, 2010]. The aim of this research is to investigate the implications of this idea in a musculoskeletal model of the lower limb during gait. In particular, we are examining the effect on the loading of the femur if this preference for compression is enforced, and the implications for the joint reactions. In the future, the effects of disruption or modification to the control mechanism and/or its feedback system will be examined.

Method

A simplified musculoskeletal model of the right leg has been developed in ADAMS (MSC Software) multibody dynamics software, including 24 key muscles that cross the hip and knee joints (Figure 1), where the maximum force each muscle can apply is based on its physiological cross-sectional area. Solution of the model involves non-linear optimisation of the muscle forces to satisfy a variety of selectable constraints and optimisation cost functions, including joint reaction forces and a 3 axis multi-functional mid-shaft load sensor in the femur. Studies have been carried out to determine the sensitivity of the results to various model parameters, for example the transverse position of the load sensor, and the overall impact of requiring compression-only in the bone through the gait cycle.

Results

Moving the location of the load sensor from the femur's neutral axis introduces significant variations in the muscle forces and a consequent reduction of hip and knee forces. For example, repositioning by 2mm in the medial-posterior direction reduces the knee reaction force by up to 0.45×BW at 15% of the gait cycle. Overall, when compared to muscle force optimisation without the requirement for the femoral shaft to remain in compression, the new model predicts (for example) a decrease in hip joint load of up to 0.48×BW at 35% of gait. However, large increases are observed in the knee joint load with a maximum variation of 3.96×BW at 50% of gait.

Figure 1: Frontal view of the model.

Discussion

The result of varying the position of the compression sensor shows that the model is finely balanced and sensitive to the position of the sensor. The large increases in knee contact forces for the compression-only solution are attributable to additional activity in the gastrocnemius and quadriceps, and further detailed investigation into their role is currently underway.

References

Pauwels F, Biomechanics of the Locomotor Apparatus. Springer-Verlag, 1980.

Sverdlova N, Witzel U, J Biomech, 43:387-396, 2010.

This work was supported by the charity OSPREY.