Integration of external knee joint loads in the pre-surgical planning of high tibial osteotomy: a proof-of-concept study

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Summary

High tibial osteotomy (HTO) is a surgical procedure used to correct leg malalignment and redistribute load across the knee to slow down or prevent the onset of osteoarthritis. In this study, two musculoskeletal (MSK) models, created using three-dimensional (3D) medical images, were used to calculate the knee adduction moments (KAM) during walking and stair climbing before and after virtual HTO surgery. These simulations demonstrated the effectiveness of HTO in reducing the KAM by up to 32% at its peak value, while a sensitivity study suggested that including dynamic loads at the pre-operative planning stage could optimize the long term outcome of HTO. These results will be used to inform a planned clinical trial.

Introduction

High tibial osteotomy (HTO) is a surgical intervention to correct the malalignment of lower limbs in young and active individuals at risk of developing mono-compartmental osteoarthritis of the knee. Pre-operative HTO planning aims to realign the mechanical axes of femur and tibia using two-dimensional radiographs, or 3D bone models derived from computed tomography (CT) scans [1]. Currently this pre-operative planning relies on geometrical considerations, but it is well known that dynamic knee loads, often quantified using the KAM, influence the long-term outcome of HTO, with better long term outcomes observed in patients with KAM peaks smaller than 6% body weight*height (%BW*Ht) during walking [2]. This work is a proof-of-concept demonstration of how dynamic knee joint loads could be integrated into existing surgical planning workflows using patient-specific MSK models.

Methods

3D bone geometries obtained from CT scans of the lower limbs of two cadavers (P1: female, mass: 64 kg, Ht: 171 cm; P2: male, mass: 45 kg, Ht: 166 cm) were used to plan a virtual HTO cut with a biplanar opening wedge technique, as per the workflow used commercially by Embody (London) [1]. The surgical plan, for each dataset, provided 1) the post-operative bone geometries, including the bone cuts, 2) the axis of the HTO hinge around which the correction is applied and 3) the planned angular correction (P1: 8°, resulting in 3.4° valgus alignment, P2: 7°, resulting in 3.5° valgus alignment).

Two "pre-operative" personalised MSK models were created in OpenSim [3] from the anatomical datasets using NMSBuilder [4] and subsequently modified according to the HTO surgical plan. Motion capture data from two anthropometry-matched healthy volunteers were then selected from a large dataset of daily living activities collected in the Human Performance Laboratory of Charing Cross Hospital, equipped with an instrumented walkway and staircase. Tracking simulations of walking (Figure 1, A) and stair climbing were used as input for pre-operative and post-operative conditions, assuming complete functional postoperative recovery. Finally, a sensitivity study was performed by correcting the knee joint alignment from the nominal alignment to 15° of valgus correction in both models and computing the associated KAM.

Results and Discussion

The pre-operative KAM peaks for walking (P1:7.5%BW*Ht, P2: 9.3%BW*Ht) were reduced by 32% and 24% by the HTO, with a similar effect observed for stair climbing (P1: 30%, P2: 26% reductions). Post-operatively, P1 was categorised in the low KAM group (<6 %BW*Ht) [2] while P2 would have required an additional 3° of valgus correction to be similarly categorised [2].

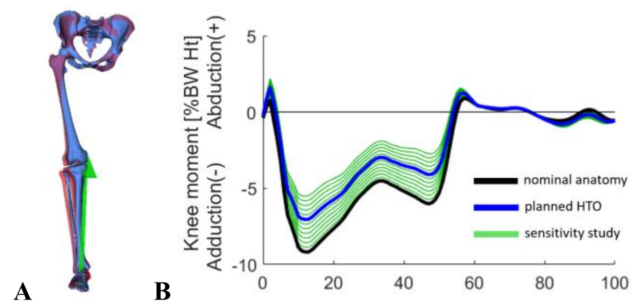

Figure 1: Walking simulation for P2 (red: nominal 'pre-operative' anatomy, blue: post-HTO) (A) and resulting KAM for the nominal anatomy, the post-HTO model and varying knee joint alignments (sensitivity study) ranging from nominal to 15° valgus correction (B).

This workflow is currently being extended to include estimations of muscle and joint contact forces and predictive simulations of post-operative walking.

Conclusions

This proof-of-concept study demonstrates the feasibility of combining modelling techniques and HTO pre-surgical planning to optimize the intervention outcome.

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References

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