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BONE HEALTH IN TRANSFEMORAL AMPUTEES

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INTRODUCTION

Osteoporosis of the pelvis and femur occur in a large proportion of military transfemoral (TF) amputees. Its prevalence in this, typically young, population has been reported at above 70% [1,2]. Osteoporotic bone carries an increased fracture risk, with many fractures occurring with minimal trauma [3]. Fracture has serious implications on mobility, physical dependency and morbidity [4]. For amputees this has a disproportionate effect on functionality as it can compromise future prosthetic use. To prevent or reverse the onset of this skeletal disease we must first understand the potential underpinning mechanisms.

METHODS

Through the development of biofidelic musculoskeletal (MSK) and adaptive finite element (FE) computational models, we aim to determine how the mechanical loading environment experienced during daily activities could contribute to the observed trend of deteriorating bone-mineral density (BMD) in the femur of a TF amputee subject.

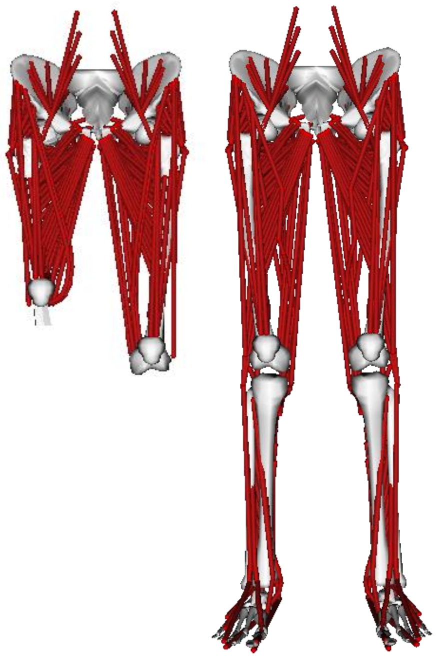

Fig 1: Patient-specific musculoskeletal models of a bilateral TF/TK amputee and a body-matched, able-bodied, volunteer.

The amputee MSK model is patient-specific (Figure 1). Muscle insertions and maximum isometric muscle forces have been derived from the MRI scans of a bilateral TF/through-knee (TK) amputee. Joint position and mechanics have been adjusted where necessary to match the degrees of freedom at the prosthetic socket [5], knee and ankle joints. The MSK model is used to estimate muscle and joint reaction forces during amputee gait. These can be compared and contrasted to those predicted for an able-bodied, body-matched, control.

The combined modelling approach with FE allows us to determine the subsequent effect of these forces on the residual femur of the amputee [6,7]. Predicted muscle and joint reaction forces from the MSK model make up the loading scenario used in an, MRI-derived, FE model of the amputee's right femur, residuum and prosthetic socket. We are, therefore, able to study the effect of specific muscle activations on the environment of stress and strain in the femur. By including the prosthetic socket in FE analysis, we aim to evaluate the direct effect of load-transmission through the socket on the residual femur by applying the knee joint reaction force into the knee joint of the prosthetic socket rather than directly into the femur.

The envelope of forces experienced by the residual femur of the amputee in comparison to that of the body-matched volunteer allows us to assess the risk of bone resorption.

RESULTS AND DISCUSSION

Altered muscle activation patterns, associated with TF amputee gait, affect loading of the femur at muscle insertions and origins. We see lowered activation in most muscles that functioned as knee-extensors or flexors prior to amputation. Lower strains along the intertrochanteric line could be attributed to the reduced contribution of the vastus muscles which no longer connect across the knee joint via the patella.

Our FE results confirm the hypothesis that weight-bearing through a prosthetic socket results in significant changes to the load-path through bone and tissues when compared to weight-bearing on a healthy limb. Forces during gait now transfer from the ground to the prosthesis, into the carbon fibre socket before being spread over large areas of the residuum soft tissue, with less load transferred axially through the shaft of the femur in comparison to in the able-bodied control. Consequently, large areas of the femoral shaft and neck experience significantly reduced levels of stimulation (Figure 2). This issue is believed to be accentuated by modern prosthetic socket design.

Based on the principles of Frost's Mechanostat [8], we believe that reduced strain from altered muscle activation patterns and stress-shielding of bone due to the prosthetic socket could be resulting in bone resorption within the femur of TF amputees.

With the addition of other activities to the current loading scenario, such as sitting and standing, we expect to see some improvement in bone stimulation as they will provide more varied muscle activation patterns and joint loading. However, we believe that weight-bearing through the socket and altered muscle activation could be key contributors to reduced BMD in the TF amputee population.

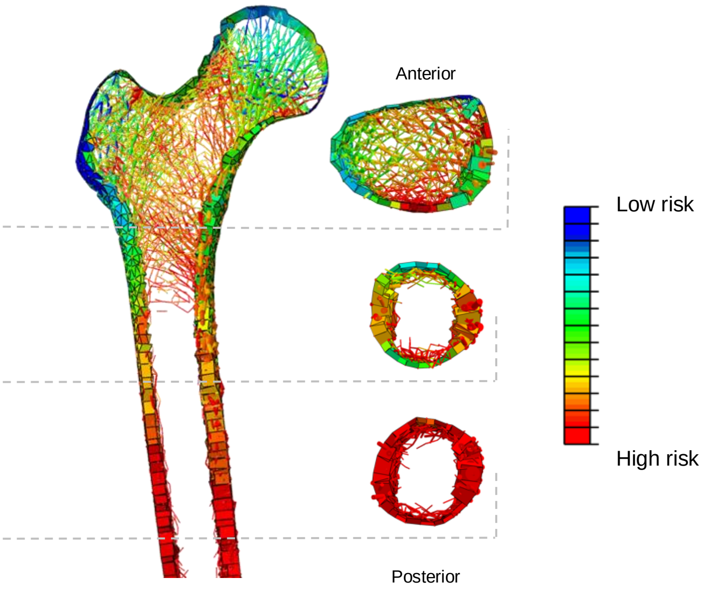

Fig 2: Frontal and transverse slices showing bone resorption risk in the femur of a TF amputee.

CONCLUSIONS

We believe the results show that the mechanical loading environment experienced by amputees while wearing a prosthesis should be considered a contributor to low BMD in the amputee population. Ultimately, we aim to determine a means for stimulating bone health, whether that is by identifying key regions for direct loading in physiotherapy, use of alternative prosthetic devices or by prescribing a daily routine of specific activities to stimulate key regions.

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