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THE CONTRIBUTION OF ACTIVITY, LOADING AND TOTAL JOINT REPLACEMENT TO REMODELLING IN THE PROXIMAL FEMUR

A. S. Dickinson[1]

[1] Bioengineering Science Research Group, University of Southampton,
Highfield, Southampton, SO17 1BJ, United Kingdom, alex.dickinson@soton.ac.uk.

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INTRODUCTION

Bone remodelling is frequently observed around orthopaedic implants after surgery. Adverse remodelling, in particular stress shielding, results in a loss of bone mineral density (BMD) which increases the stress sustained by the implant and implant-bone interface. Periprosthetic resorption also reduces the bone stock at revision surgery giving an increased risk of complications. Predicting the remodelling around a joint replacement implant is an important step in its performance evaluation, for which computational tools have been developed.

Existing remodelling simulation methods at the continuum level applied to total hip replacement (THR) agree with the main BMD changes observed clinically by radiography, including proximal resorption and distal hypertrophy [1]. However, these methods do not reproduce all clinically observed BMD trends, including BMD loss-recovery temporal trends around the implant stem tip. Prior research [2] demonstrated that this was due in part to a common simplification, that patient activity and joint loading applied to the model are identical in the pre- and postoperative cases. Non-uniform load and activity profiles over time were proposed, appropriate for a range of patient recovery levels. This study evaluated the influence of the proposed activity and loading changes upon predicted postoperative remodelling, in comparison to the influence of implantation with a common THR implant.

METHODOLOGY

A finite element (FE) model of a femur implanted with a Charnley stem was used to predict 60 months of periprosthetic remodelling, building upon the established strain-adaptive approach [3,4]. A control simulation assumed identical pre- and postoperative loading and activity, and was compared to two simulations, using implanted and intact bone models, with a varying activity and load profile. Pre- to postoperative joint force changes due to the use of walking aids, and activity changes during rehabilitation representing a strong recovery, were included implicitly by scaling the calculated remodelling stimulus [2]. Predicted temporal BMD change trends were analysed using virtual x-rays and DXA scans, and absolute BMD changes and the time to homeostasis were compared to clinical data [1] in seven Gruen zones.

RESULTS AND DISCUSSION

The predicted periprosthetic BMD changes obtained using the modified activity and loading profiles (‘Implanted–Recovery’) demonstrated closer agreement with clinical measurements (‘Clinical’) than the Implanted–Control (Figure 1), in particular in the Gruen zones where resorption was dominant (GZs 2, 6 and 7). Agreement was closer both for absolute BMD change magnitudes and the time taken to reach homeostasis. However, in the three distal GZs (3, 4 and 5) where bone densification is the dominant clinically observed change, both models underestimated the bone resorption observed in the first 3 postoperative months.

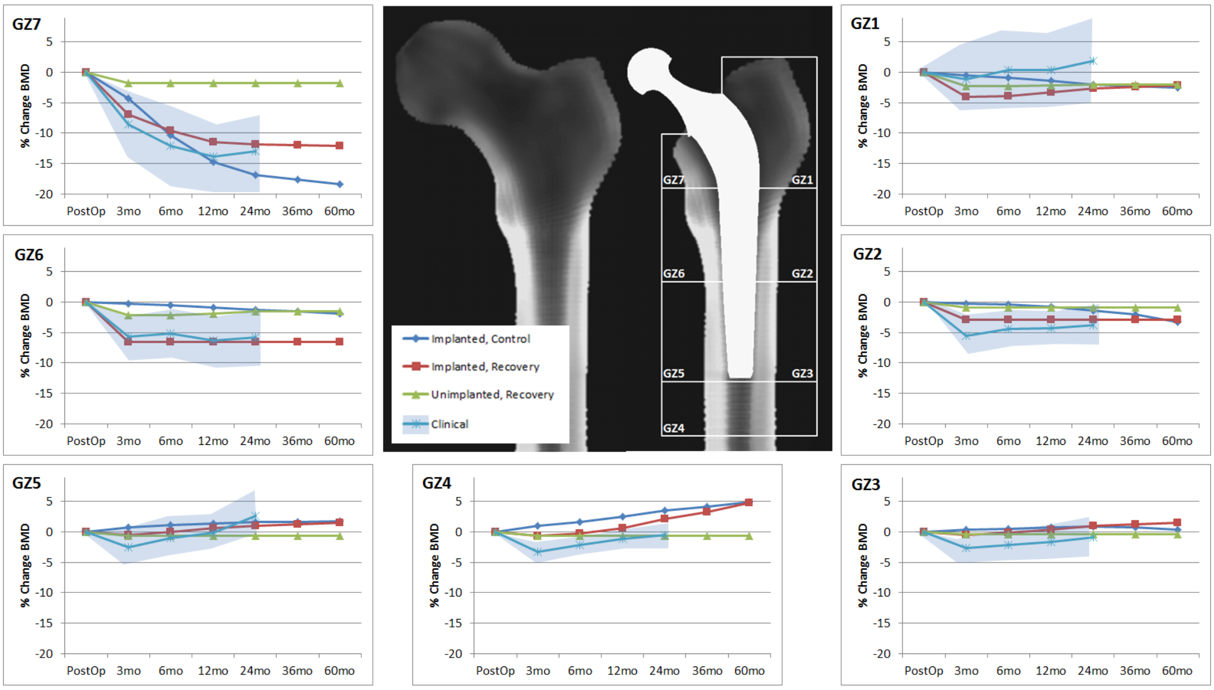

Figure 1: Predicted BMD changes resulting from implantation and pre- to postoperative trends in activity and loading ('Recovery') from virtual DXA scans, compared to clinical data [1].

The activity and loading changes alone (Unimplanted–Recovery) were predicted to stimulate a BMD loss in all proximal zones, of 1.50% in GZ6, 1.75% in GZ7 and 2.01% in GZ1. They were predicted to reduce BMD by less than 1.00% in all the other, more distal zones. Comparing the Implanted–Control and Unimplanted–Recovery cases indicated that BMD changes were considerably more sensitive to implantation than to activity and loading effects. The exception was GZ1 where the BMD change at homeostasis was predicted to be similar in all modelled cases, and not successfully predictive of clinically observed BMD hypertrophy.

The under-estimated distal BMD loss during the first 3 postoperative months supports the conclusion that micro-scale mechanobiological processes have additional influence to strain adaption. These include the repair of micro-fractures created during implantation, thermal damage from bone cement polymerisation, and vascular interruption. Furthermore, the results justify development of bone repair and remodelling algorithms, in order to capture the pre-osteoblastic bone destruction by osteoclasts inherent in bone repair and remodelling.

CONCLUSIONS

This study demonstrates the importance of accounting for pre- to postoperative changes in joint loading and patient activity when predicting periprosthetic bone remodelling, but indicates that strain changes caused by implantation with a commonly used THR implant are dominant. The results indicated that the simulation of stress-shielding resorption is more reliable than hypertropic densification, using current strain adaptive techniques.

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