AGE-RELATED PERI-IMPLANT BONE YIELDING IN UNILATERAL EXTERNAL FIXATION OF TIBIAL MIDSHAFT FRACTURES

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INTRODUCTION
Loosening of half-pin tracts is a considerable source of failure in external fracture fixation [1-3]. Over-loading at the pin-bone interface can induce bone yielding and loss of pin stability. Bone density, stiffness and strength reduce significantly with ageing, leading to higher likelihood of bone yielding under patient loading. It remains unclear how fixator design and selection should be adapted for cases of reduced bone competence following ageing or disease such as osteoporosis. In this study the yielding of peri-implant bone in unilateral fixation of tibial midshaft fractures across a range of age-groups was investigated using finite element analysis. Results were used to assess the effect of ageing on peri-implant bone yielding and identify strategies to minimize the associated loosening risk.

METHODS
Unilateral external fixation of the tibial midshaft was modelled using finite element analyses. Configurations of two (Figure 1) and three half-pins were modelled under single-legged-stance loading of 700N. Bone competence was varied to approximate three groups: a) healthy/young bone; b) osteoporotic/middle-aged bone and c) osteoporotic/old bone. The tibial cross-sections were varied to match reported age-related variations [4]. Orthotropic elastic constants of bone were assigned, including the variation of elastic constants with age/porosity and periosteal-endosteal position based on a recent study by the authors [5]. Implant-bone interactions were modelled with contact analysis, enabling realistic separation in regions of tension and slippage in shear. Bone damage was simulated using a bone-specific, strain-based yield criterion. To the knowledge of the authors this is the first time that all these key features of bone-implant interaction and bone properties have been included in a computational model. Analyses were repeated with titanium half-pin properties to investigate the effect of this more biomechanically compatible material of peri-implant bone yielding.

RESULTS AND DISCUSSION
The pattern of yielded bone was compared between age-groups at the entrance cortex of the near-fracture half-pin. Close-up images are presented in Figure 2 for two-pin fixation. It was observed that extensive peri-implant yielding only occurred on the superior (loaded) side of the half-pins at the entrant cortex. Bone yielding initiated between the periosteal thread and the periosteum before progressing in the direction of the endosteum. In the case of the young and middle-aged groups yielding was confined to the periosteal half of the cortex. In the old group however, yielding propagated through the entire cortical thickness in both two and three-pin fixation.

Figure 1: Two-pin external fracture fixation model geometry and applied loading.

Figure 2: Regions of yielding bone (red) in the two-pin model for young (a), middle-aged (b) and old (c) groups. A similar pattern was observed in three-pin fixation.

The volume of yielded bone at pin entrance sites for two-pin fixation is shown in Figure 3. The volume of yielded bone increased with ageing, approximately three times greater in old-aged bone than in young bone. The volume of yielded bone increased with proximity to the fracture gap; the near pins in each case. The use of a third half-pin was found to reduce the volume of peri-implant yielded bone by 66-75%.
However, the full cortical thickness was yielded in the old age group in both two and three-pin fixation. The use of titanium pins (not shown) increased the volume of yielded bone around half-pins by approximately 1.7 times.

![Figure 3](image) Figure 3: The volume of peri-implant yielded bone at the two pin entrance sites in two-pin fixation for all age-groups.

CONCLUSIONS

The volume of yielded bone and implied risk of loosening were seen to increase considerably with bone degradation associated with ageing/osteoporosis. It was apparent that to achieve stable fixation of older patients is a greater challenge than with younger groups.

Pin location was found to affect the risk of loosening; pins nearer the fracture gap were at greater risk. Targeting these locations with extra pins could be an effective method to reduce loosening.

The use of titanium pins increased the observed risk of loosening compared to stainless steel. Titanium’s lower Young’s modulus induced greater sagging deformation of the pins and consequent ‘pinching’ of the bone at the entrance site.

ACKNOWLEDGEMENTS

The authors would like to thank the Carnegie Trust for the Universities of Scotland for supporting this study.

REFERENCES