

# 3D FINITE ELEMENT SIMULATION OF BONE REMODELLING UNDER THE TIBIAL COMPONENT OF AN OXFORD KNEE REPLACEMENT

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## INTRODUCTION

Two distinct types of radiolucency can be observed at the bone-implant or bone-cement interface. The first type is usually thicker than 2mm, has no definite boundary, and is usually an indication that the implant is loose [1]. The second type has a distinct boundary and is usually less than 2mm thick. This type is commonly seen under the Oxford Unicompartmental Knee Replacement (OUKR) (Biomet, Swindon, UK) tibial component and is not an indication that the implant is loose [2]. Confusion about the two types of radiolucency has led to unnecessary revisions of OUKRs [3].

Histological studies of retrieved implants have shown that soft tissues such as fibrocartilage and fibrous tissue are formed at the bone-implant interface. There is evidence that radiolucency is a result of this tissue, but the reasons for this tissue formation are not entirely understood. Similar tissue formation takes place in the callus during fracture healing.

The aim of the current study was to investigate whether tissue remodeling rules proposed for fracture healing can explain formation of radiolucencies under OUKRs.

## METHODS

A 3D finite element (FE) model of the medial half of the proximal 75mm of a tibia implanted with a cemented OUKR was

created and run over 365 iterations linked with a simple remodelling rule. The model consisted of 110,555 ten-node tetrahedral elements and was based on a previously experimentally validated FE model of a complete human cadaveric tibia with an OUKR tibial component [4]. The model was initially run under a load of 1157N perpendicular to the implant, the peak load seen by the medial plateau of the tibia of an 82kg (mass of cadaveric tibia donor) person during normal gait [5]. The model was also run under 578N (half load) and 2314N (double load).

After each iteration, new material properties were calculated for elements in a 2mm thick remodelling area which was adjoining the bone cement. An element's new material property was a function of the stress-strain condition [6] at its centre of gravity, its current material property, and a rate of change. The rate of change was set so that an iteration represented roughly a day of in vivo remodelling. It was assumed that these elements represented granulation tissue before the first iteration with Young's modulus and Poisson's ratio assumed to be 0.2MPa and 0.47 respectively.

The material properties of the elements which represented bone were changed based on a set of established remodelling rules [7]. The initial properties of these elements were calculated from radiographic density (RD) values from CT scans [8].

The variation of material properties of each element was plotted against the iteration number in order to visualise the evolution of material properties with time (iterations).

Next “synthetic AP radiographs” were generated by reverse calculating RDs from material properties for the model after 365 iterations. Comparisons were made between these plots and patient AP radiographs.

## RESULTS AND DISCUSSION

The material properties of the remodelling zone stabilised after about 365 iterations, which is consistent with stabilisation of radiolucent lines which occurs about a year after surgery [3].

Application of smaller loads resulted in more of the elements in the 2mm remodelling zone turning to bone than did the application of larger loads, suggesting that radiolucency is related to patient weight or activity level (Figure 1). An investigation is now being carried out using patient follow-up radiographs to find out if this in fact is the case.

In the trabecular bone adjacent to the 2mm remodeling zone an increase in RD was observed. A similar observation was made on some of the radiographs where a sclerotic

line was observed just below the radiolucent line (Figure 1).

Although based on a simple remodelling rule, the model was able to simulate the formation of soft tissue in a realistic manner, providing synthetic radiographs which compared well with patient radiographs.

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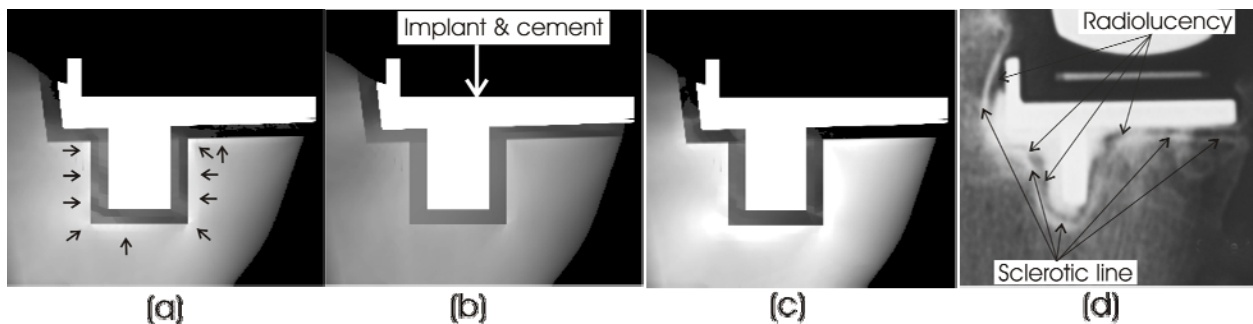


Figure 1: “Synthetic radiographs” (a, b, and c) and patient radiograph (d). (a) 1157N load (b) half load and (c) double load applied on implant. Radiolucency (the dark area under the implant) in increasing order – (b) < (a) < (c). Arrows in (a) point to stiffened bone.