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RESEARCH

Biomechanical study of the tibia in knee replacement revision☆

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Abstract The best management of severe bone defects following total knee replacement is still controversial. Metal augments, tantalum cones and porous tibial sleeves could help the surgeon to manage any type of bone loss, providing a stable and durable knee joint reconstruction. Five different types of prostheses have been analysed: one prosthesis with straight stem; two prostheses with offset stem, with and without supplement, and two prostheses with sleeves, with and without stem. The purpose of this study is to report a finite element study of revision knee tibial implants. The main objective was to analyse the tibial bone density changes and Von Misses tension changes following different tibial implant designs. In all cases, the bone density decreases in the proximal epiphysis and medullary channels, with a bone density increase also being predicted in the diaphysis and at the bone around the stems tips. The highest value of Von Misses stress has been obtained for the straight tibial stem, and the lowest for the stemless metaphyseal sleeves prosthesis.

PALABRAS CLAVE
Elementos finitos;
Vainas metafisarias;
Vástagos;
Reabsorción ósea;

Estudio biomecánico de la tibia en el recambio de una artroplastia de rodilla

Resumen No hay consenso en el tratamiento de elección de los recambios protésicos de rodilla con defectos óseos severos. Las opciones son variadas, cada una con sus ventajas e inconvenientes. Los trabajos clínicos publicados tienen sus limitaciones en cuanto al número de pacientes y el poco seguimiento clínico. Se presenta un trabajo biomecánico con elementos

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Recambio de prótesis de rodilla

finitos comparativo de 5 diseños de implantes tibiales: vástago recto, con offset con/sin suplemento y vainas con/sin vástago, para poder analizar el comportamiento tanto del hueso tibial como del material a lo largo del tiempo. Dentro de las limitaciones que presenta un modelo matemático hemos podido ver que los implantes con vástago recto producen el mayor valour de reabsorción ósea alrededor del vástago, mientras que la menor reabsorción ósea tiene lugar en el hueso de la diáfisis proximal. Las vainas metafisarias tibiales sin vástago producen una menor reabsorción ósea que el resto en el canal medular.

Introduction

One of the key factors in prosthetic knee replacement is the bone defect. A preoperative evaluation can be carried out through radiographic and computed tomography (CT) studies, but the type of defect will be defined during the surgical procedure.[1-3] If the defect is not contained, that is, an Anderson type 2 or 3, it is possible to use trabecular metal cones or metaphyseal sleeves.[4-9] Both provide a mechanical support for the implant, favouring long-term biological fixation, decreasing the complexity of the reconstruction and avoiding possible load transmission problems related to grafts from an organ bank.[1,10]

The long-term effect of this type of prosthetic knee replacement on tibial bone resorption is not clearly known. There are several computational studies of bone remodelling based on the finite elements method for fixations in the femoral component,[11,12] as well as the tibial component, but only for primary implants.[13-15]

In the present work we conducted a biomechanical study based on the finite elements method to analyse the effect of incorporating a tibial implant after prosthetic knee replacement on the process of bone remodelling. The study compared 5 types of tibial implant designs: straight stem, sleeves with and without stem, offset stem with and without supplement.

The working hypotheses were the following: (a) that metaphyseal sleeves provide better load transmission with less tip effect; (b) that the tip effect is greater in the case of straight stem, since this stem is adjusted to the diaphyseal canal; (c) that the tibial implant with offset may be indicated in selected cases of tibial deformity. The general objectives were: (a) to improve the knowledge of the biomechanical behaviour the tibial implants according to their prosthetic design; (b) to improve the indication of the type of implant for each type of tibia to be treated with prosthetic replacement. The specific objectives were: (a) to analyse the tension supported by each prosthetic design with physiological loads in order to predict the evolution of bone density in the long term and (b) to compare the biomechanical behaviour of the sleeves, combining a short stem and no stem.

Material and methods

Finite elements models

Fig. 1 shows all the steps followed for a complete reconstruction of prosthesis modelling up to the final analysis of bone remodelling. The starting point were images provided by an axial computed tomography study of the left tibia of a 36-year-old male. The images were acquired through a Brilliance 64 device (Philips Healthcare, The Netherlands) using a current of 257 mA and a voltage of 120 kV. The spatial resolution was 0.65 mm × 0.65 mm, with a reconstruction matrix of 768 × 768. The distance between images was 2 mm. We analysed 5 different types of knee revision prosthesis models: straight stem, sleeves with stem and without stem (model PFC SIGMA TC3, Depuy, Johnson & Johnson, Warsaw, USA) and offset stem with and without supplement (model NextGen Legacy Constrained Condylar Knee-LCCK, Zimmer, Indiana, USA), (Fig. 1a–e). All 5 models were made of titanium and were uncemented stems, with cement at the surface.

We used the software package Mimics v.11 (Materialise, Louvain, Belgium) to segment and reconstruct the geometric models. The software was used to position the different tibial stems in the correct orientation. The finite elements meshes were generated automatically, with the Harpoon v.2 software package (Harpoon Sharc Ltd, Manchester, UK, 2006) (Fig. 1a–e). The elements comprising the models were tetrahedrons, in order to reproduce the complex geometry of the bone with sufficient precision.

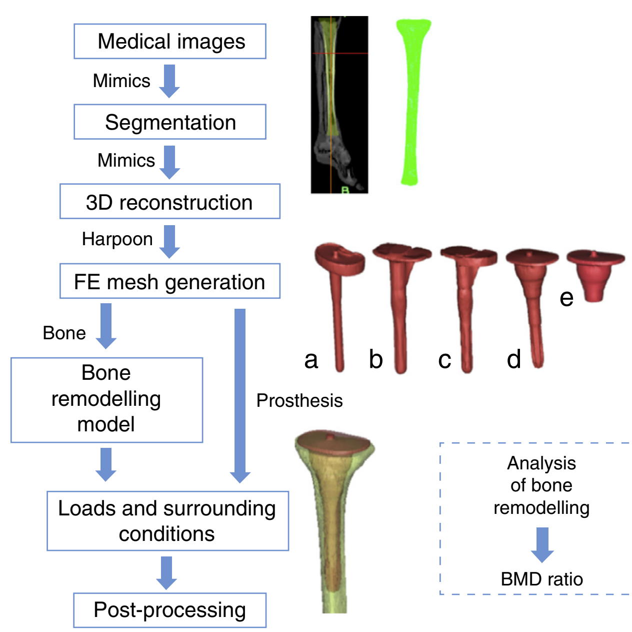

Figure 1 Process followed for the reconstruction and analysis using the method of finite elements based on medical images. (a) Straight stem. (b) Stem with offset without supplement. (c) Stem with offset with supplement. (d) Sleeves with stem. (e) Sleeves without stem.