A 2D finite element model of bone adaptation in the proximal femur of osteoarthritic patients

An assignment by the Research Laboratory of the Department of Orthopaedics of the Erasmus University

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Introduction

Osteoarthritis (OA) is a disorder which involves cartilage breakdown, irregular bone formation and eventual joint failure. It is a common disease in the elderly, causing pain and decreased mobility. OA usually occurs long before it can be detected with current diagnostic methods, so permanent and irreversible damage of the joint has often occurred by that time. By this study more insight can be gained in the disease and the factors that cause it. The health of the cartilage depends on the mechanical properties of its bony bed. In this study a two-dimensional (2D) finite element (FE) computer model of the proximal femur (see Fig. 1) was constructed, where the bony changes of OA were modelled as a local change of stiffness of the bone bed. It was investigated if this model could predict the altered density distribution of a femur with severe OA as can be observed on x-rays of patients (see Fig. 3).

Methods

A linear 2D FE model of the proximal femur was constructed of 133x190 cubes (voxels) (Fig. 2). Bone density data were taken from a scan of a slice of a real human femur. The cup of the joint (the acetabulum) and the cartilage were modelled based on pictures of the human anatomy. The main force had a magnitude of 800N based on the weight of the average human body and was applied in the direction of the trabecular architecture. The force exerted on the femur that keeps it in its place, was represented by distributed point loads of respectively 60N, 120N, 180N and 240N. Boundary conditions were chosen to prevent the model from rotating and bending.

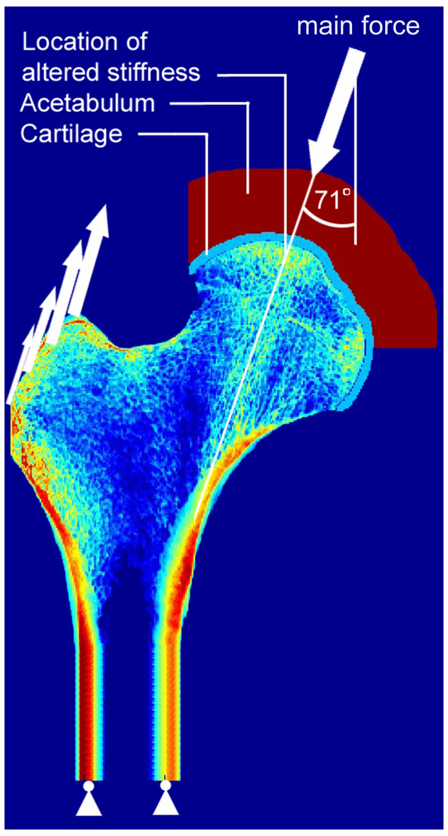


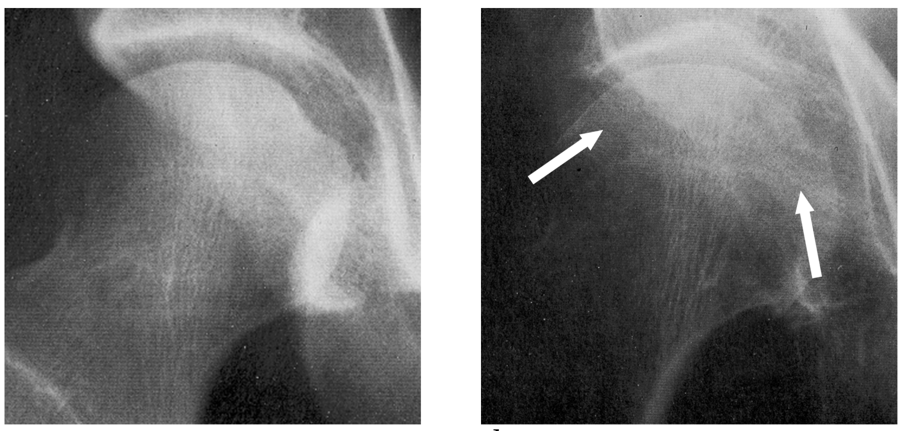
Fig. 2. 2D FE model of a femur, with boundary and loading conditions.

To establish the reliability of the model a sensitivity analysis was performed. Then, OA conditions were implemented by a local reduction respectively increase of the stiffness (see Fig. 2).

After running the model, in each voxel the bone remodelling signal (RS) was defined. Contour plots of the RS were compared with x-rays of patients with OA.

Results

The RS-plot of the situation with a reduction of stiffness shows that the bone will produce more bone material, especially in the softened spot (Fig. 4 a). Here, as a result of the OA process the production of bone-material will 'overshoot' the original environment, which causes the situation of a spot with a higher stiffness. Running the model with an increased stiffness of the spot results in the RS observed in Fig. 4 b.



a *b*

Fig. 3. x-rays of a human femur head (a) a healthy femur (b) femur with OA; the arrows show the areas of bone resorption.

This picture shows that there will disappear bone material in the more peripheral portions of the femur head. On the X-ray of the OA bone (Fig. 3 b), this resorption of bone can also be seen.

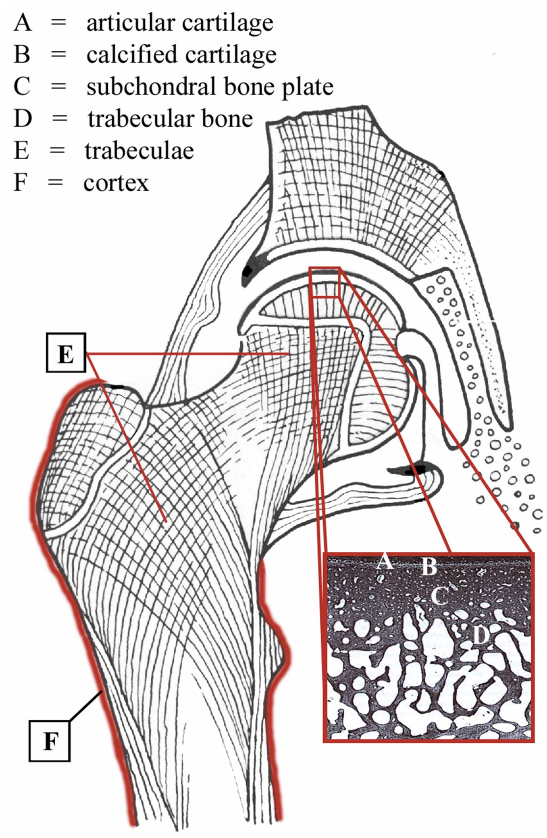
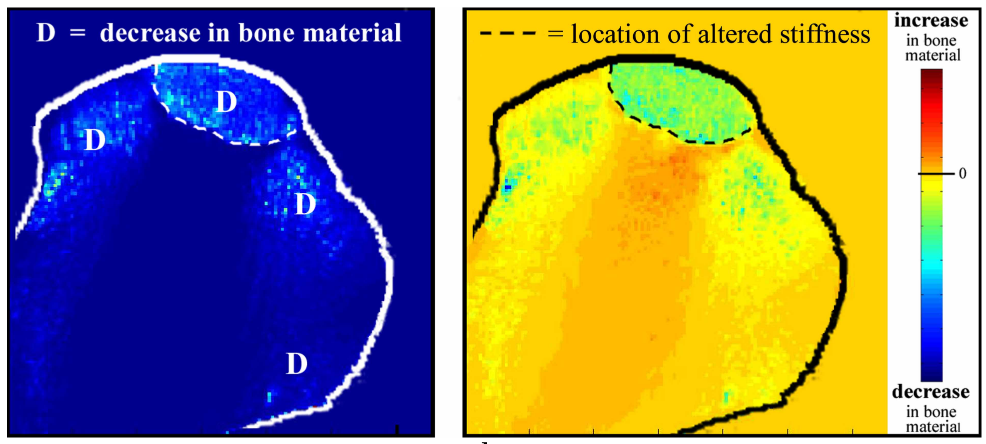


Fig. 1. Schematic figure of the composition of the tissues of the human hip joint and a histology of the osteochondral area.

Discussion

As a first study on this subject valuable information can be deducted from the model. Though, it should also be noticed that from our sensitivity analysis the conclusion can be drawn that our model is rather sensitive to variations of the chosen input parameters. A real femur is a 3D bone. Therefore, modelling it as a 2D object has already limitations in itself. Also the varying modelling assumptions were chosen rather roughly and will need further refinement. However, evaluating the results of the model has shown that there is a correlation between the signal predicted by the model and the altered density distribution, observed on X-rays of patients with OA. For future research this is a promising result.



a *b*

Fig. 4. remodelling signal plots of the femoral head (a) with a local reduction of the stiffness (b) with a local increase of the stiffness

Our recommendations to future models are:

- construct a 3D model, but take in mind the extra computation time;
- model cartilage and acetabulum more conform reality.
- conduct detailed studies on the exact location, direction and magnitude of the applied forces; the exact location and size of the spots with altered stiffness and the variations of stiffness of the spots.