

Bone remodelling around dental implants based on functional loading

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Introduction

Bone remodelling in the field of total hip arthroplasty has been simulated in a large number of studies using numerical methods. However, bone remodelling around dental implants under different loading conditions, especially during the healing period, is still not fully understood. In this study, the behaviour of the cortical and spongy bone was studied under different loading conditions and different bone remodelling parameters with two-dimensional and three-dimensional finite element models.

Materials and Method

Clinically, it is assumed that bone apposition takes place when the driving mechanical stimulus is in a favourable range, while it is resorbed on either overloading or underloading [1] (see Fig. 1). Numerically this density change has been modelled by Li et al [2] as

$$\frac{d\rho}{dt} = B \left(\frac{U}{\rho} - k \right) - D \left(\frac{U}{\rho} - k \right)^2$$

where U is the strain energy density, ρ is the current bone density, and the remodelling parameters K , B and D are functions of critical stresses, strains, and maximum density. For the first step of finite element simulation; a two-dimensional model of a bone with an implant has been modelled. Loads of 100 N were applied on the implant with 20° and the muscle pressure of 2 MPa. For second step an idealised three dimensional finite element model of implant (Ø 3.7 mm, L 13 mm) in a bone segment was created. Bone segment consisted of 1.5 mm layer of cortical bone

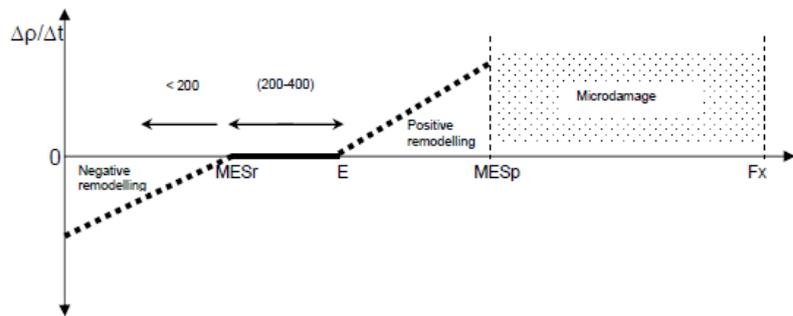


Figure 1: Bone density change as a function of the bone loading as represented by the strain energy density. Bone resorption occurs for underload as well as for excessive overload. For a mild overload, bone density is increased [1].

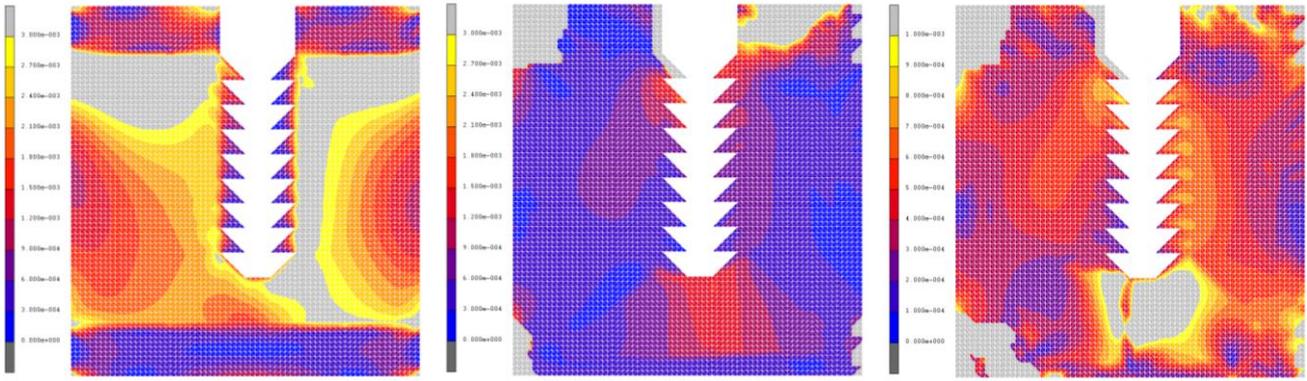
surrounding a core of cancellous bone. The given values for remodelling parameters were: $K = 0.0004 \text{ Jg}^{-1}$, $D = 19.48 (\text{gcm}^{-3})^3 \text{ MPa}^{-2}(\text{time unit})^{-1}$, $B = 1.0 (\text{gcm}^{-3})^2 \text{ MPa}^{-1}(\text{time unit})^{-1}$ and w was 20% of the threshold stimulus k where w is the dead zone [3]. The bone was considered to be an isotropic material with Young's modulus of 20 GPa and 300 MPa for cortical and cancellous bone, respectively. Two force magnitudes were applied on the implant at 20° from its long axis: 100 N and 300 N.

Results and Discussion

Using the algorithm described above, the determined bone density changed depending on the current distribution of the strain energy density within the model and reached a steady state after 40 to 70 iterations. While the strain distribution in the initial models was inhomogeneous, the distribution got more homogeneous with each iteration. The bone remodelling algorithm could be successfully applied to the 2D model as well as to the 3D model. However, due to the limitations of the idealised model geometry in the 2D model, it was not possible to obtain an anatomically correct structure consisting of an outer cortical layer and an inner trabecular structure. For the 3D model, the resulting bone density distribution showed an outer layer of dense bone, corresponding to the cortical bone, and an inner, sponge-like structure corresponding to trabecular bone (see Fig. 3). The resulting equivalent of total strain shown after some iterations in 3D model (see Fig.4).

References

- [1] Frost H.M. Bone's Mechanostat: A 2003 update. *Anat. Record part A* 2003; 275:1081-1101.
- [2] Jianying Li, Haiyan Li, Li Shia, Alex S.L. Foka, Cemal Ucer, Hugh Devlin, Keith Horner, Nick Silikas. *Dent Mater*, 23:1073–1078, (2007).
- [3] Hasan Istabrak. *Computational Simulation of Trabecular Bone Distribution around Dental Implants and the Influence of Abutment Design on the Bone Reaction for Implant-Supported Fixed Prosthesis* (Doctoral dissertation 2011).

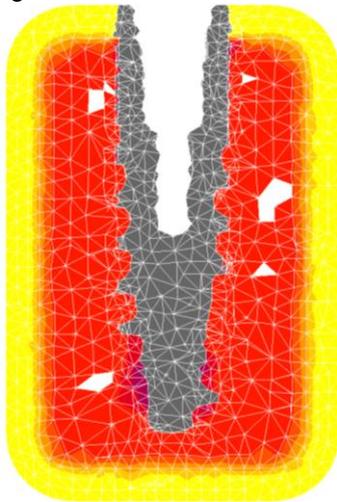


1st iteration

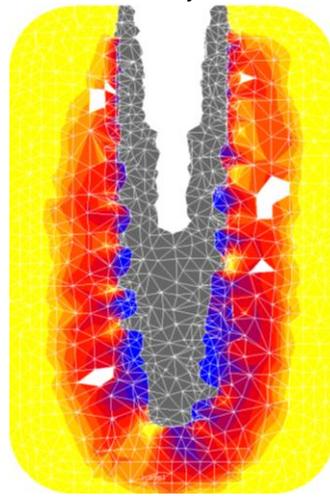
25th iterations

100th iterations

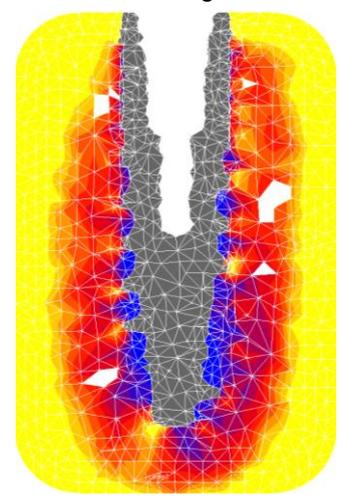
Fig. 2: Application of the bone remodelling algorithm in a simplified 2D model. The resulting strain distribution (Equivalent of total strain ($\mu\epsilon$)) after 1 (left), 25 (center) and 100 (right) iterations, respectively.



1st iteration

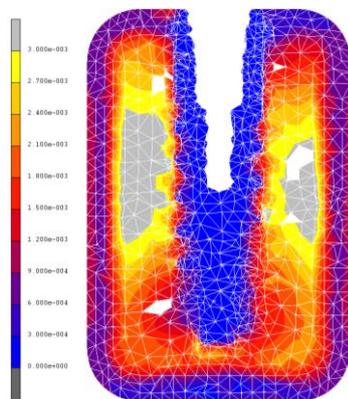


25th iterations

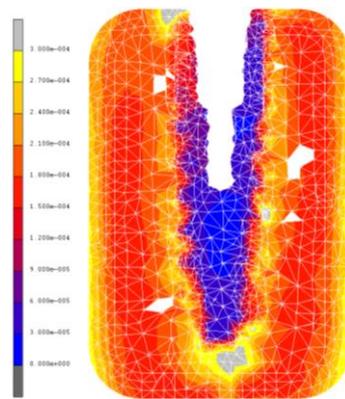


100th iterations

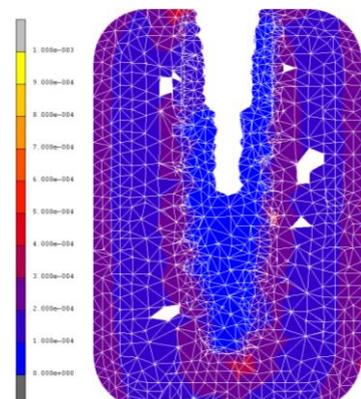
Fig. 3: Application of the bone remodelling algorithm in a simplified 3D model. Top row shows the bone density distribution, bottom row the resulting bone density distribution after 1 (left), 25 (center) and 100 (right) iterations, respectively.



1st iteration



25th iterations



100th iterations

Fig. 4: Application of the bone remodelling algorithm in a simplified 3D model. The resulting strain distribution (Equivalent of total strain ($\mu\epsilon$)) after 1 (left), 25 (center) and 100 (right) iterations, respectively.