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QUANTIFICATION OF THE ROLE OF MECHANICAL PARAMETERS ON THE BONE RESPONSE AROUND LOADED TITANIUM IMPLANTS.

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INTRODUCTION: Bone has the ability to alter its mass and structure with changing mechanical usage. It is well established that strain magnitude [1], rate and frequency [2-3] are variables that affect bone. However, questions remain with respect to the actual nature of the mechanical stimulus and the mathematical model that best describes and predicts bone adaptive phenomena. An important factor that hampers the interpretation of animal experimental results is the fact that the bone adaptive response seems to be *site-specific* and *species-specific.* This makes the validation of mathematical theories of bone adaptation an even greater challenge. The influence of several loading parameters on the peri-implant bone adaptive response will be investigated. The aim of this study is to describe the experiments guided by poro-elastic finite element modeling.

METHODS: Highly controlled loading experiments are designed for a c.p. titanium cylindrical implant that is osseointegrated within a bone chamber (Figure 1) installed into the proximal tibia of adult New Zealand white rabbits. The bone chamber model allows to investigate the effect of well controlled loading parameters and protects the tissues inside the chamber from external (uncontrolled) mechanical loading conditions. Data derived from pilot studies on the bone chamber model within our group [4] has shown its validity. The outer bone chamber (∅ 10 mm) (a) is in close contact with the inner bone chamber (b) and both are perforated (c). After osseointegration, the test implant (d) is subjected to specific loading conditions (applied at point 'e') in a displacement-controlled manner by means of an external loading device. During loading, the test implant slides in a Teflon bearing (f). All components are held together by means of screws (g). For every considered loading mode (compression, tension, shear) the bone response will be investigated for 3 different strain rates. For every strain rate two different combinations of amplitude and frequency will be investigated. By combining different load parameters in the animal experiment, the relative importance of strain magnitude, frequency, and rate can be investigated.

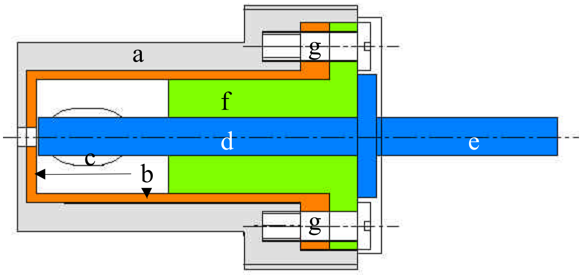

Figure 1: Scheme of bone chamber with test implant.

Before the actual animal experiment starts, a poro-elastic finite element analysis was performed to define the implant displacement that induces the required strains in the tissue surrounding the loaded implant. Frost's mechanostat (Frost 1987) was used as a guideline for the different loading conditions to be applied, resulting in strain levels corresponding to different bone modeling and remodeling activities at the bone-implant interface.

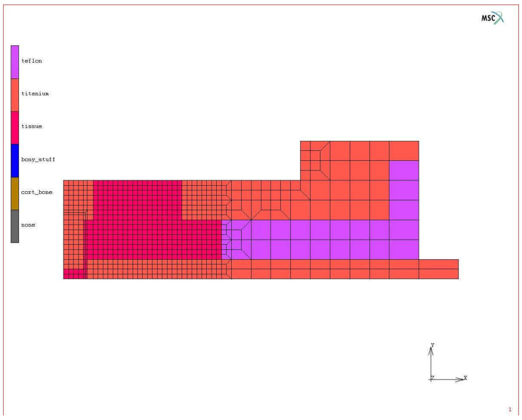

Figure 2: 2D (axisymmetric) model of the bone chamber. The following materials are present: teflon (purple), titanium (orange), tissue (pink).

An axisymmetric finite element model of the chamber and the tissue inside the chamber was created (Figure 2). Poro-elastic material properties were assigned to the tissue inside the chamber and corresponded to immature (trabecular) bone (Table 1). In order to determine the displacements that have to be applied in the animal experiments a cylindrical volume of interest was defined around the implant, which considered the tissue within a distance of 0.5 mm from the implant surface. The average (equivalent Von Mises) strain within this volume was used as a criterion to determine the displacement to be applied.

Table 1. Material properties used in the simulations.

Young's modulus [MPa]	Poisson's ratio	Permeability $[m^4(Ns)^{-1}]$
500	0.32	10^{-13}

The bone response to the mechanical stimuli will be investigated by use of microfocus computer tomography and will be analysed histologically and histomorphometrically on undecalcified sections after harvesting the test implant and the inner bone chamber containing the tissue inside the chamber.

RESULTS: Results of the poro-elastic finite element analysis defining the implant displacement which induces the required strains in immature bone tissue surrounding the loaded implant are shown in Table 2.

Table 2. Results of the poro-elastic finite element analysis (loading frequency 1 Hz). Average (equivalent Von Mises) strains (+ standard deviation) within the volume of interest are presented.

Required strain	± 100 με	1800 με	4000 με
Displacement	1 µm	7 µm	14 µm
Real strain	297 ± 130 με	2082 ± 913 με	4161 ± 1826 με
Reaction force	10 N	71 N	141 N

Figure 3 shows the equivalent Von Mises strain distribution for the '4000 με' loading regime.

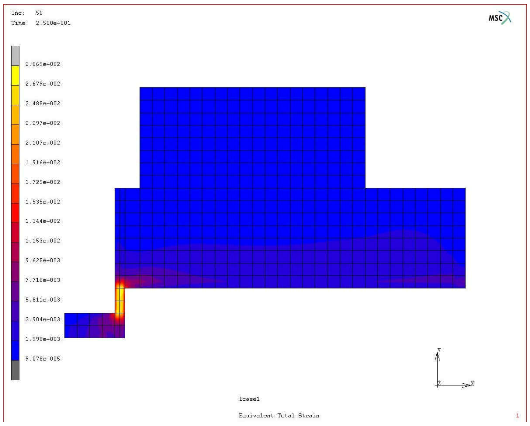

Fig. 3: 2D-analysis for the loading regime of 1 Hz-4000 µe, requiring a displacement of 14 µm. The equivalent Von Mises strain distribution is shown here.

DISCUSSION: The originally created finite element analysis served as input for defining the loading conditions of the animal experimental part. The results of these experiments will in return be used as input for the optimalisation of the finite element analysis. The study of different loading parameters within the same site of the same animal by means of a repeated sampling bone chamber eliminates variability due to site-specific and species-specific influences. At this moment the animal experimental part is in progress. Due to the assumptions made for the composition of the computer model and its boundary conditions, the results from the finite element analysis are inherently limited and will be evaluated and optimized when the results of the experimental part are available.

The gained knowledge will be relevant for the biomechanical optimization of skeletal implant fixation and for the application of biomechanical principles within the field of skeletal tissue regeneration.

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