INFLUENCE OF MATERIAL FORMULATION AND INTERFERENCE FIT WHEN SIMULATING PRESS FIT FIXATION IN FEMORAL RESURFACING ARTHROPLASTY

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INTRODUCTION:

The clinical outcome for the femoral component of metal-on-metal hip resurfacing systems with press fit fixation is poor due to biological and mechanical reasons [1]. Prerequisite for the long-term success of press fit fixation systems is primary stability [2]. The stability of the bone-implant-interface mainly depends on the bone quality, the reamed geometry and the interference fit. Numerical investigation using Finite Element (FE) analyses is an adequate method to estimate the influence of these factors on relative interface motion. Model validation is a decisive requirement to allow quantitative statements based on FE-analyses. The aim of this study was to assess the influence of Young's modulus function and interference fit on relative motion between implant and bone in press fit femoral resurfacing arthroplasty. In order to achieve this goal, a subject-specific FE-model was developed and a parametric study was performed.

MATERIALS AND METHODS:

Femur FE-models were set up based on CT-scans (voxel size 0.4x0.4x1.0mm) using a linear elastic solid element mesh (ABAQUS 6.4, C3D4 elements). Convergence of the calculation was confirmed. Apparent density was used for the allocation of distributed material properties based on the isotropic modulus function of Carter *et al*. and the two isotropic modulus functions (axial or transverse orientation of the main structural axis) of Wirtz *et al* [3][4]. The parametric study with the FE-model was based on two experiments conducted with the same human femur (male, 55 years) under different loading modes.

The stiffness of the femur was determined experimentally under dynamic axial loading (100,000 cycles) at four different load levels [5] (,*Figure 1a, Table 1*). The results were compared to the calculated stiffness with the respective modulus functions (Carter, Wirtz 'axial') in the FE-model (*Figure 1b*).

A torsion test was used to assess the relative motion between implant and bone. The femoral head was removed, embedded and reamed. An uncemented prototype resurfacing prosthesis (ASR®, DePuy, 170µm nominal radial interference) was implanted. Torsion loading was applied to the prosthesis under torque control at 0.5Nm/s until loosening of the implant. The experimental results were compared to the results obtained with a femoral head and neck FE-model (*Figure 2*). Calculations were performed for each of the 3 modulus functions and for 2 interface conditions: exact fit and the nominal press fit. Press fit was modelled by eliminating the initial overclosure. The contact problem was solved using coulomb friction at the interface (µ=0.4) [6]. The experimentally determined torsion stiffness during the 'sticking' phase was used to identify the most suitable modulus function and the 'relative motion' phase to identify the influence of interference fit.

RESULTS:

The femoral stiffness in the axial testing varied only slightly between load levels and number of cycles. The FE-model based on the 'axial' Wirtz *et al* modulus function matched the experimental data better than the one by Carter *et al* (*Table 1*).

Table 1: *Experimental femoral stiffness and deviation of calculated values from experimental results for the four load levels [%].*

	Load level I 50-800N	Load level II 50-1200N	Load level III 50-1600N	Load level IV 50-2100N
Stiffness [N/mm]	1773±54.8	1807±11.8	1785±35.4	1691±52.4
Stiffness deviation for Carter formulation [%]	-21	-17	-17	-21
Stiffness deviation for Wirtz 'axial' formulation [%]	1	5	6	3

In the torsion test the deviation of the calculated from the measured stiffness was -143%, -125% and -26% for the models based on Carter *et al*, Wirtz *et al* 'axial' and 'transverse' formulation, respectively. Experimental relative motion occurred at much lower torques than calculated for 170µm interference (*Figure 3*). In the model, sliding of the entire prosthesis occurred at about 12 and 88Nm torsion for interferences of 0 and 170µm at angles of about 0.9° and 5.5°, respectively.

DISCUSSION:

The slight variation of the axial stiffness with load amplitude indicates that a linear elastic model is appropriate for the modelling of the femur in a situation as investigated in this study. The 'axial' Wirtz *et al* modulus function matches the axial experimental results better than that of Carter *et al*. The torsion test yielded a good agreement of the initial stiffness ('sticking') with the softer 'transverse' rather than the stiffer 'axial' modulus function of Wirtz *et al*. Interference magnitude had a major influence on press fit strength in the FE-models. Therefore, the 'achieved' interference has to be modelled accurately. The higher system stiffness after the onset of relative motion in the 170µm press fit model in comparison to the experimental test (nominal 170µm) indicates that less bone becomes debonded in the model than in the experiment. This could be due to excessive interference fit, excessive bone stiffness, or a high friction coefficient in the model. Since the calculated bone stiffness in the "sticking" phase mimics the experimental results closely and since the friction coefficient used is supported by experimental data, it is most likely that the experimentally achieved interference fit was over-estimated. Abrasion of the bone by the roughened implant surface during implantation could be the reason for this discrepancy.

Since the femur model with the 'axial' Wirtz *et al* modulus function most closely matched the axial loading experiment, and the torsion model with the transverse formulation most closely matched the torsion experiment, it can be concluded that one isotropic modulus function is not sufficient for modelling bone under physiological multi-axial loading. This detail has been rarely addressed in the literature and has to be taken into account when modelling press fit of hip resurfacing prostheses for the investigation of relative motion.

REFERENCES:

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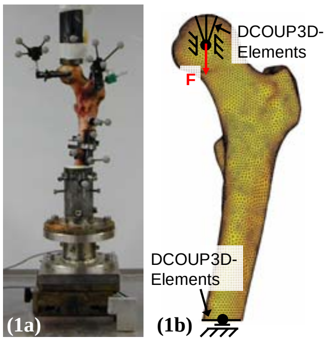

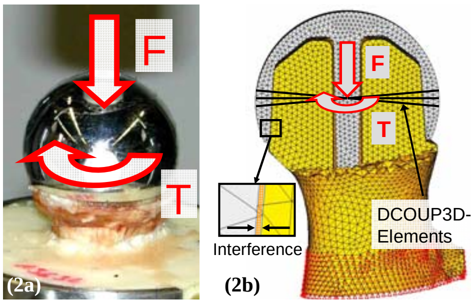

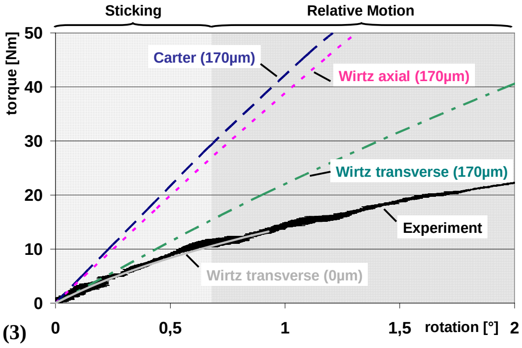

Figure 1*: (a) 'Axial' test setup, (b) FE-model: boundary conditions and load applied via DCOUP3D-elements;* ***Figure 2****: (a) Torsion test setup, (b) FE-model: interference, boundary conditions and load;* ***Figure 3****: Experimental and modeled torque vs. rotation (the two phases are indicated for the experimental data).*