A finite element model assessing micromotions of a bimodular hip prosthesis

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Introduction

Modular necks enable intraoperative adaptation of hip prostheses to the individual anatomical situation by varying neck length, femoral anteversion or femoral offset. Bimodular systems exhibit an additional interface between stem and neck adapter with the risk of micromotions between the components. In appropriate biological fluid environment, these micromotions may cause corrosion and wear debris. Cracks could be generated at the metals' surface and their propagation can ultimately lead to implant fracture. Presently, neck adapter fractures of various bimodular hip prostheses are observed. The precise failure mechanism is not yet known, but micromotions between stem and neck adapter play an important role in the fatigue mechanism. By minimization of micromotions, e.g. with new taper designs, the risk of neck adapter fractures can be reduced.

The objective of this study was to establish a finite element model to investigate the influence of design changes on the micromotion in the stem-neck interface. The seating behavior of the neck adapter during assembly was used in order to associate experimental and numerical set-up.

Materials and Methods

Experimental set-up:

Six bimodular hip prostheses (Metha, Aesculap AG, Germany) were used to determine the penetration depth of the neck adapter (140°, Ti6Al4V or CoCr29Mo, n=3 each). During assembly, the distal plane and the proximal plane of the neck adapters were kept parallel in order to prevent the generation of moments in the interface and ultimately tipping of the neck and ball head, respectively. Three spherical markers were affixed on each neck adapter. By means of a coordinate measuring machine (BHN 305, Mitutoyo, Germany) the distance along the taper axis (L_1) between the center of the spherical markers and the distal plane of the neck was measured (Fig. 1). Ti stems, embedded in PMMA, with proximal plane of the stem orientated horizontally, were consecutively assembled with neck adapters and implant heads (size L, CoCr29Mo). Consecutive, force controlled assembling with three different maximal loads was done (Z010, Zwick Roell, Germany, F_1=2kN, F_2=6kN, F_3=2kN, F_4=8kN, F_5=2kN; v=0.5kN/s). After assembly, the distance between the distal plane of the neck and spherical markers was measured with the coordinate measuring machine (L_2). The mean penetration depth (L_3) of the neck, depending on material coupling and assembly force, was calculated by subtracting the distance L_2 from L_1 for each case (Fig. 1).

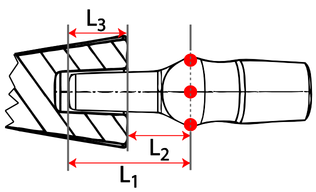

Fig. 1: Schematic diagram of a stem, neck adapter and the affixed spherical markers. The measured distances (L1, L2) for calculating the penetration depth of the neck (L_3) are given.

FE simulation:

Based on CAD data of the bimodular hip prosthesis, the components - stem, neck adapter and implant head - were meshed (tetrahedral elements, C3D4, Hypermesh, HyperWorks 9.0, Altair Engineering, USA). A convergence analysis showed that an element size below 1mm (106,229 elements, respectively) did not further influence the results. Alike the experimental set-up, a singular force (along the taper axis) was applied at the top of the ball head (F_1=2kN, F_2=6kN, F_3=8kN). Linear, homogenous and isotropic material properties with a Young's Modulus of 115GPa (Ti) and 225GPa (CoCr) respectively and a Poisson ratio of 0.34 or 0.3 were implemented. The embedding of the stem with an embedding height of 52mm, representing the experimental set-up was provided (external nodes, Boundary Condition). A tie junction at the neck adapter – implant head interface allowed no relative movements between the components. Interaction settings (surface nodes) in the stem-neck interface allowed a small sliding of the neck adapter into the stem. For Ti-Ti material couplings the friction coefficient was set to 0.3 [1, 2] and for Ti-CoCr couplings to a value of 0.2 [2]. To determine the influence and accuracy of this decisive property, the friction coefficient was varied between 0.2 and 1.0 for both material couplings. For solving the differential equations the finite element software Abaqus/ Standard FEA (Simulia, USA) was used.

Results

Consecutive testing of prosthesis components did not influence the penetration depth of the neck adapters (p=0.453). Rising assembly forces lead to an increase of the penetration depth - independent of the material coupling ($p<0.001$, Fig. 2). CoCr neck adapters showed significant higher penetration depths compared to Ti neck adapters (17.85µm ± 0.13µm vs. 17.74µm ± 0.15µm, p=0.006, Fig. 2).

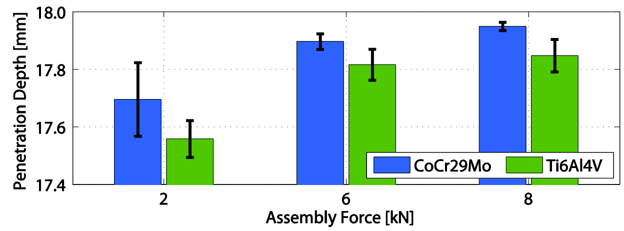

Fig. 2: Experimental results; penetration depth for different material couplings and assembly forces.

FE simulation showed similar trends. Higher coefficients of friction caused a reduced sliding of the neck adapter into the stem (Ti: 17.90µm vs. 17.67µm, CoCr: 17.88µm vs. 17.66µm, Fig. 3). For Ti-Ti material couplings, a coefficient of friction in the stem-neck interface of 0.3 and in case of CoCr neck adapters a value close to 0.2 resulted in similar seating magnitudes (Fig. 3, CoCr data not shown).

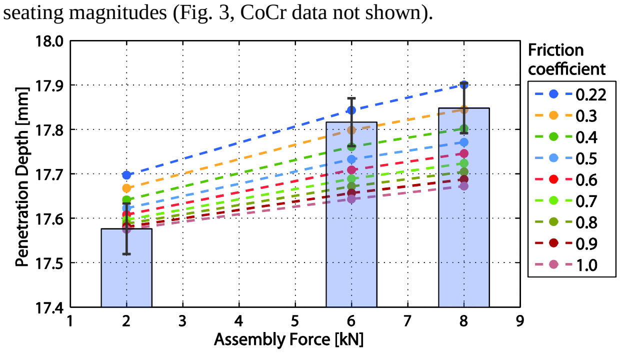

Fig. 3: Penetration depth of Ti neck adapters for different assembly forces and coefficients of friction; FEM vs. experimental data (Mean ± SD).

Discussion and Conclusion

CoCr neck adapters slid further into the stem than Ti neck adapters. This could be due to the different elastic and plastic behavior of the materials. In case of the CoCr adapters, the taper of the Ti stems seem to deform to a major extent.

The FE model to assess relative movements between stem and neck adapter was successfully developed using the seating behavior of the neck. Higher assembly forces seem to be more appropriate for the validation process since the influence of other factors such as the angular mismatch in the interface (not considered in the FE model) on the penetration depth is reduced. The next step will be the comparison of experimentally determined micromotion during dynamic loading with the model predictions.

References

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