Femoral Head Diameter, Neck And Taper Length Influence The Mechanical Load And Micromotion In The Taper Connection Of Total Hip Replacements

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Introduction: The higher revision rate of large stemmed metal-on-metal bearings in total hip arthroplasty compared to standard head sizes [1] requires research into risk factors connected to large diameter heads (LDH) which may contribute to implant failure. Since the revision rate of metal-on-metal hip resurfacings is lower than stemmed LDH, it is suspected that the modular connection between stem (neck taper) and head, respectively between stem, adapter sleeve and head contributes to the circumstance of failure. In a series of revisions of LDH hip replacements, it was reported that the modular connection was loose at reoperation [2]. However, the LDH devices with poor clinical performance entered the U.S. and / or European markets by regulatory approval. A common way to apply for medical device approval is practiced through the 510(k) process which involves evaluation of ‘substantial equivalence’ to previously cleared (predicate) devices [3]. Considering that, the present numerical study was conducted to investigate if there are significant differences in the mechanical load and stress of the taper connection with regard to head diameter, neck length and taper length. Therefore, a variety of designs was analysed by means of the finite element method.

Methods: For finite element analysis (FEA), the physical model was reduced to taper and neck of the stem, prosthetic head and
acetabular cup (Fig. 1). All components were modeled as arbitrary designs imitating commercial LDH devices using the software ABAQUS/ CAE V 6.11-2 (Simulia Dassault Systèmes, USA). A 32 mm metallic head was used to represent conventional head sizes, LDHs had diameters of 44 mm and 53 mm. Neck length was defined as the distance between the proximal surface of the taper to the centre of rotation of the prosthetic head. Small neck length was designed by moving the proximal taper surface into the head by 8 mm. Larger neck lengths were realized by a corresponding displacement of 4 mm, 0 mm and 8 mm into the opposite direction. The length of the taper was varied from 11 mm to 16 mm. The size of the acetabular cup was adapted to the head size of the THR. The cup was positioned at 45° inclination and 20° anteversion.

Cobalt chromium alloy material data (Young’s modulus of 220 GPa) was assigned to the components cup and head, titanium alloy was used for the material properties of the stem taper (114 GPa). Poisson’s ratio was 0.3 for all components. Discretization was conducted using hexahedral elements with a global size of 1.5 mm. The FE meshes were justified through a convergence study. A detailed parameter study, in which the pull-off force was determined as defined in ASTM F 2009, was conducted to ensure appropriate interlock conditions between the prosthetic head and the taper. The interaction was an isotropic contact with a friction coefficient of $\mu = 0.5$, similar to Shareef et al. [4].

Figure 1: left: components of the finite element model; right: cut view of the finite element mesh.
The interaction between prosthetic head and acetabular cup was defined as an isotropic surface-to-surface contact with a friction coefficient of $\mu = 0.1$. The definite simulation was conducted in five steps: 1) assembly of the taper connection by axial force; 2) calculation of mechanical equilibrium; 3) assembly of prosthetic head and the acetabular component; 4) joint loading and 5) abduction movement. The hip joint loading during normal gait ($Fx = -400.25$ N, $Fy = -1,844.28$ N and $Fz = -235.44$ N) was based on telemetric data [5].

The results of the FEA were evaluated with regard to stress distribution after step 2 and step 5, the magnitude of the relative micromotions after step 5 and the reaction torque around the centre of rotation during abduction. Micromotion was calculated as the amount of contact slip at the outer element surfaces of the stem taper.

**Results:** Reaction torque against abduction was 2.1 Nm using the 32 mm head, 2.9 Nm using the 44 mm head and 4.1 Nm using the 53 mm head. Hence, the reaction torque of the 53 mm head was nearly doubled compared to the conventional head size (32 mm).

Neck length had a significant influence on micromotions in the taper connection. With increasing distance between the rotation centre and the taper surface, micromotion also increased (Fig. 2). Exemplary for the large neck length in comparison to neutral neck length the micromotions were 8 to 29-fold higher in specific areas of the taper using a larger neck.

For THR designs with a taper length of 16 mm less micromotions were determined than with a taper length of 11 mm (Fig. 3), but the influence was less significant than neck
Figure 2: Influence of neck length on micromotion at the stem taper surface.
Discussion: The higher reaction torque of large heads needs to be transferred by the taper connection between stem and head. Thereby, large micromotions in the taper connection may lead to abrasion of the passivation layer with subsequent corrosion of the implant material substrate [6]. All risk factors for higher torques and increased micromotions may contribute to loosening of
the taper connection. The presented calculations show that ‘substantial equivalence’ between LDH total hip replacements and conventional THR may not apply under given circumstances.

**Significance:** Based on these results, the question arises if standard taper connections from total hip replacement can bear the higher loads of large diameter heads, especially in connection both with unfavourable larger neck lengths and shorter taper lengths of the stem.

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