Influence of Surface Roughness in uncemented Hip Implants on Press-Fit Conditions and Bone Morphology during the Implantation Process: Assessment via high Resolution µCT

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Introduction

Cemented implants are a standard option in total hip replacements (THR) since they provide immediate primary stability after the operation. Nevertheless these implants depend on a reproducible and precise operation procedure. If these requirements are lacking excessive cement mantle thickness could cause non optimal implant positioning and high curing temperatures (Ohnsorge, 1969). Regarding the femoral surface replacement this is associated with early post operative femoral neck fractures (Morlock, 2006). Since more and more younger patients require an artificial joint uncemented versions are gaining an increasing interest. They allow a simplified operation procedure and due to a better bone quality of younger patients are supposed to provide sufficient primary stability. This study is focusing on the implantation procedure which is an important precondition for implant stability. The purpose is to analyze the influence of surface roughness on the press-fit condition and bone morphology during the implantation.

Methods

Experimental:

8 cube sized bone samples (a =10 mm) were extracted from the subchondral region of each femoral head from a pair of human femora (female, 86 years) using a band saw (EXAKT 311, Germany). These are the contact regions for standard femoral resurfacings (Fig.1).

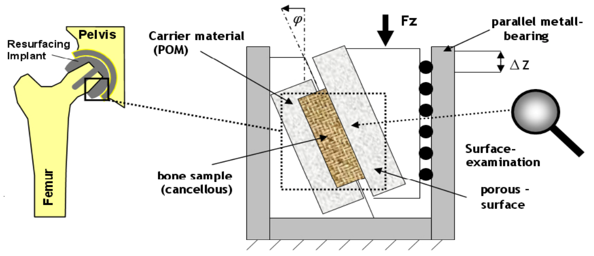

Fig.: 1 left: Location of bone extraction right: Test set-up for simulating the implantation process with different surface coatings.

Each specimen was equipped with 4 Tantalum markers for a precise superposition of CT data sets pre- and post-operativly. The left femur samples were scanned with a µCT (SCANCO 40, SCANCO Medical AG, Germany, resolution = 35 µm) before and after the implantation procedure in order to detect normal and shear bone deformation as well as volume fraction. A coated stamp with either polished or PoroCoat surface finishing was displaced tangential to the bone sample (V = 0.05 mm/sec = 0.5 %/sec, Wang, 2007) under an angle of 3.5° (Fig. 1) producing an interference between bone and stamp. This was varied from 25 to 100 µm for the left femur and from 100 to 400 µm for the right femur side. During testing the shear and normal forces were recorded for the right femur side using a 3d load cell (AMTI, Massachusetts, USA, Resolution: 0.2N). Bone volume fraction was determined using Archimedis principle (Sharp, 1990) in order detect an optimal labeling threshold for CT data analysis.

Analysis

For post processing the bone volume was labeled and pre and post implantation data super positioned with a surface fit algorithm using the labeled Tantalum markers (AMIRA 3.0, Mercury Systems Berlin, Germany). Mean surface deformation of the bone after the implantation has been calculated with a surface distance module which is accounting for the local shape. Additionally the volume fraction (BV/TV) was assessed in 10 slices of 0.5 mm thickness parallel to the contact surface. Regarding the force measurements the maximum force in normal and shear direction was calculated. For statistical analysis of the different coatings a paired t-Test (SPSS 15.0.1, Illinois, USA, $\alpha<0.05$) was used.

Results

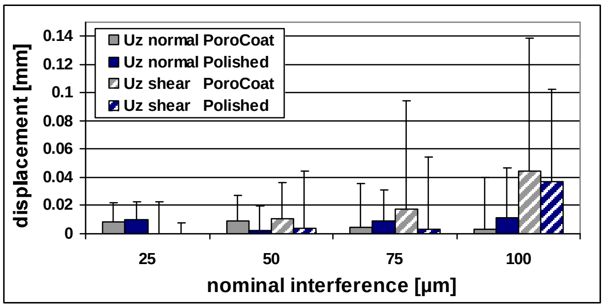

Fig.: 2 Mean normal and shear plastic bone deformation after removal of the implant stamp.

A large amount of plastic deformation occurs along the shear direction during the implantation process (Figure 2) which was significantly higher for the PoroCoat surface (p=0.0336). The mean normal to shear force ratio was 5.6 for the polished and 1.1 for the PoroCoat surface resulting in a contact pressure which is 5 times higher for polished surfaces. The volume fraction was not significantly different before and after the implantation (p = 0.2191). Results indicate that the press-fit is compromised by large shear forces and related deformations. For the clinical practice this means that surgical planning of uncemented press-fit implants requires considering a loss of effective interference due to high shear forces.

References

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