Bone-implant Gap And Micromotion Around Cementless Femoral Stems: In Vitro Measurement During Compression And Torsion

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Introduction: Primary stability of implants is associated with long-term success of total hip arthroplasty. Excessive interfacial micromotion around the femoral component promotes aseptic loosening of the prosthesis and is related to a poor primary stability [4]. Physical activities such as stair climbing or raising from a chair induce high torsional loads that are thought to endanger more the implant primary stability than compressive loads [1, 7]. Different techniques based on imaging or linear variable differential transducers (LVDT) sensors have been used to measure experimentally micromotion at the bone-implant interface [3]. LVDT sensors allow a good precision but they also include the bone deformation between the device fixation point and the measurement site. Moreover, the simultaneous measure at multiple sites is an issue [7]. The aim of this study is to extend a technique using micro computed tomography (µCT) on cadaveric samples to measure simultaneously and at multiple sites the relative gap and micromotion around femoral stems, in compression and torsion [5-6].

Methods: Two lefts cadaveric femurs conserved in formalin from 2 different cadavers were used. The donors were 90 and 77 years old males. We used two cementless anatomical femoral stems (SPS, Symbios Orthopédie Sa, Switzerland). A senior orthopaedic surgeon performed pre-operative planning for each stem and implantation according to the recommendations of the manufacturer. A region of interest extending to 40 mm away from the osteotomy site was defined. Before implantation, six tantalum markers of 800 µm in diameter were stuck on the implants while 800 stainless steel markers of 600 mm in diameter were press-fitted on the endosteal bone surface of the femurs. A compressive load of 1800 N and a torsional load of 14Nm [2] were successively applied using custom loading devices. These loading devices were designed to fit inside a µCT scanner (SkyScan 1076 in vivo µCT, Bruker, Belgium). µCT scans were performed before, during and after loading for each loading case, at a resolution of 36 µm. Images were reconstructed using the NRecon software (Skyscan NRecon, Bruker, Belgium). µCT images were analysed with Amira (www.amira.com). Bone and implant markers were segmented through image processing techniques and the center of mass of each marker was computed. The final unloaded scan was used as a reference and the first two scans were rigidly transformed so as to have the implant markers overlapping. Gap was defined as the closest distance between the reconstructed stem surface and bone markers after unloading. Micromotion in 3 dimensions was obtained as the displacement of the bone markers between the loaded case and the reference position (3rd unloaded scan).

Results: Gap and micromotion in compression and torsion were simultaneously measured for over 200 measurement points spread around the region of interest. Gap extended to 4.9 mm for the first femur and to 5.6 mm for the second femur (Fig.1). Mean gap values were 1.3 mm and 1.6 mm for the first and second femur respectively. The 90th percentile value was 2.9 mm for the first femur and 3.2 mm for the second one. In compression, micromotion amplitude varied from 17.9 µm to 151.9 µm for the first femur and from 5.2 µm to 93.1 µm for the second femur (Fig. 2). The mean micromotion amplitude was 80.1 µm and 48.5 µm for the first and second femur respectively, while the 90th percentile value was 126.9 µm for the first femur and 75.8 µm for the second one. For the torsional loading case, micromotion amplitude varied from 8.9 µm to 100.7 µm for the first femur and from 39.0 µm to 373.2 µm for the second femur. Mean micromotion amplitude for was 49.3 µm and 204.2 µm for the first and second femur respectively. The 90th percentile value was 74.3 µm for the first femur and 336.6 µm for the second femur. For the torsion case, we observed higher micromotion in the upper half on the anterior face of the stem compared to the lower half (Fig. 2).

Discussion: The proposed µCT technique allowed simultaneous and multisite measure of bone-implant gap and micromotion. Its main advantage is to allow a local measurement. Conversely to the technique based on LVDT sensors, it does not include bone deformation between the device fixation point and the measurement site. Micromotion measured was in agreement with reported values in literature [7]. We observed a great variability between femurs and between each loading case. The main limitation of this study is the limited number of cadaveric samples used. Moreover the conservation of femurs in formalin might affect the mechanical properties of bone.

Significance: We developed a method to obtain a quasi-continuous distribution of gap and micromotion around cementless femoral stems. This technique can then be used to study implant design, surgical techniques or for the validation of numerical models.

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References:
Figure 1. Bone-implant gap.

Figure 2. Bone-implant micromotion

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