Initial Stability of Cementless Femoral Stems: An In Vitro Technique to Measure Micromotion and Gap Around the Loaded Stem

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Introduction: Primary stability of femoral stems is essential for the long-term success of cementless total hip arthroplasty. Durable fixation of uncemented components depends on initial press-fit that provides the conditions allowing bone ingrowth to the porous surface of the metallic stem. Excessive early interfacial micromotion after implantation has been directly related to a poor initial stability of the stem and aseptic loosening of the implant [1]. Different techniques based on imaging or linear variable differential transducers (LVDT) sensors have been used to measure in vitro micromotion directly at the bone-implant interface [2]. While LVDT sensors allow for a good precision, they also include the bone deformation between the device fixation point and the measurement site. Moreover, the reported maximum number of simultaneous measurement points on bone with sensors was six [3]. Other measurements at the interface of transverse sections of bones implanted with cementless stems were completed using a high resolution imaging system with digital image correlation [4]. This system allowed to compute a micromotion distribution but was restricted to a few sections along the length of the stem. Recently, we proposed a new technique based on µ-CT imaging allowed up to 200 measurement points around the stem but was restricted to a region of 4 cm in length [5, 6]. In this study, we extended this µ-CT method to allow the measurement of interfacial micromotion and gap around the entire length of a cementless femoral stem during compression.

Methods: A cementless anatomical femoral stem (SPS, Symbios Orthopédie Sa, Switzerland) was implanted in a cadaveric femur (fixed in 10% formalin) of a 90 year old male, based on a CT based pre-operative planning. After broaching of the femoral medullary canal, about 1000 stainless steal markers (600 µm diameter) were press-fitted on the femoral endosteal surface. A custom-made loading device was developed to apply 1800 N axial compressive load on the stem, corresponding to conditions during a gait cycle [7]. This loading-device was designed to fit inside a µ-CT scanner (Skyscan 1076 in vivo µCT, Bruker, Belgium). Two scans were performed at a resolution of 36 μm: one during loading and one after loading. Pre-conditioning of the system was performed by mean of 3 successive loadings before the loaded scan. Images were reconstructed using the NRecon software (Skyscan NRecon, Bruker, Belgium). Bone, bone markers and implant were segmented with Amira (www.amira.com). The implant and bone surfaces were reconstructed and the center of mass of each bone marker was computed. The unloaded scan was used as a reference and the first scan was rigidly transformed so as to have the implant overlapping in the 2 scans. Correspondence between the markers in each scan was computed using an iterative closest point algorithm. We calculated the micromotion in 3 dimensions as the displacement of bone markers between the loaded and unloaded scan. The gap was defined as the closest distance
between the reconstructed stem surface and bone surface. The values of micromotion and gap for each marker were then interpolated and projected onto the implant surface.

**Results:** Over 600 measurements points were obtained around the entire stem. Micromotion amplitude varied from 7 µm to 338 µm with a median at 79 µm. The direction of implant micromotion was mainly observed along the loading axis, with a median at 59 µm in the cranio-caudal direction. The upper part of the posterior face was the region with the lowest micromotion amplitude while the tip of the implant was the region with the highest micromotion amplitude (Fig. 1). A circular area located on the upper lateral part of the posterior face presented higher micromotion than the surrounding regions. Overall, micromotion amplitude around the metaphyseal part of the implant was inferior to 100 µm. The gap between the bone and the implant extended from 0 to 5.3 mm with a median gap size of 1.4 mm. The largest gap was measured on the upper lateral part of the posterior face of the stem and on the posterior part of the stem tip.

**Discussion:** The large number of measurements points around the stem allowed for a comprehensive evaluation of the distribution of interfacial micromotion and gap. The observed range of micromotion was consistent with measurements obtained with LVDT sensors [3] or with digital image correlation techniques [4]. Lowest micromotion was observed around the metaphysis, which is consistent with the design rational of metaphyseal fixation. The two regions where the gap was the highest corresponded to regions with higher micromotion amplitude. This result is coherent with previous studies reporting a strong inverse relationship between the amount of bone-implant contact and micromotion [4]. This pilot study is limited to only one femur, perfused with formalin, which might affect the biomechanical properties of bone [8]. The applied load was restricted to pure compression. Other loading types such as pure torsion or a combination of axial compression, torsion and bending should be tested in the future to better mimic activities of daily living, such as stair climbing that are thought to have a more relevant impact on primary implant stability than pure axial compression [3].

**Significance:** We developed a method to compute the distribution of micromotion and gap around entire cementless femoral stems. This technique offers new insights into the analysis of cementless implants initial stability by providing the location of micromotion along the stem directly after implantation. This information may also be used to validate numerical models or to improve implant design and surgical techniques.
Figure 1. Micromotion around the stem surface

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