Micromotion around a cementless hip stem measured with µCT imaging

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INTRODUCTION:
It has been established that primary stability of femoral stems is a determinant of the clinical success of cementless total hip arthroplasty[1]. Excessive interface micromotion may lead to a peri-implant fibrous tissue formation resulting in aseptic loosening of the implant [2]. The effect of micromotion on the tissue outcome remains still unclear. However, it is becoming increasingly clear that interstitial fluid flow is the primary mechanism by which bone cells perceive changes in their mechanical environment [3]. Therefore, to estimate the interstitial peri-implant fluid flow, tangential and perpendicular micromotion measurements are required along the peri-implant surface. The objective of this study is to assess the feasibility of micromotion measurement on human cadaveric femurs using spherical Tantalum beads as markers and micro computed tomography (µCT).

METHODS:
A sps-standard hip stem (Symbios Orthopédie, Yverdon, Switzerland) was implanted in a fresh human cadaveric femur by a senior surgeon following standard clinical practice. The neck of the stem was cut to apply the load in the center of the femoral head (Fig. 1). Five tantalum (Ta) spherical beads of a diameter of 800µm were superglued in drilled holes on the stem surface (Fig. 1). Prior to implantation, 8 Ta beads were also placed manually in the inner reamed cavity of the bone.

The distal part of the femur was removed and cemented within an Aluminum cylindrical support (Fig. 2.c) that was fixed to an Aluminum gage. The whole system was specifically designed to operate inside a Skyscan 1076 µCT scanner with the loading device (Fig. 2.a). The load was applied by a piston and measured with a strain gage. The whole system was specifically designed to operate inside a Skyscan 1076 µCT scanner with the loading device (Fig. 2.a). The load was applied increasingly in 7 steps: 0, 300, 600, 900, 1200, 1400 and 0 N. A µCT measure was performed at each loading step. The region of interest was 20mm along the loading axes (Fig. 1). The µCT measure was performed at 100 kV and 100 µA and provided 360 images at a resolution of 36 µm, with a rotational step of 1°. CT images were reconstructed using Skyscan software (www.skyscan.be). The center of gravity of all Ta markers was calculated with a custom algorithm developed in Mathematica (www.wolfram.com).

The micromotion was defined as the displacement of the bone markers relative to the initial unloaded case, within a coordinate system based on the stem markers. A least square fit of rigid body transformation was used to obtain the moving coordinate system [4]. The error was calculated by measuring the mapping error and value shown as 95% confidence interval. Tangential micromotion is calculated along the loading axis, and perpendicular micromotion is calculated within a plane perpendicular to it.

RESULTS:
Tangential and perpendicular micromotions are shown in Fig. 3 (top and center respectively). The error of the mapping of the stem markers for all directions (Fig. 3, bottom) resulted in an error of ±10µm on the tangential and perpendicular micromotions.

DISCUSSION:
This study shows that using 800µm diameter beads is sufficient to measure tangential micromotion starting at low loading values (~100% body), but perpendicular micromotion could not be resolved. The latter were indeed of the order the measurement error. Nevertheless it is believed that the reason for this error is due to the high density and mass of the Ta beads, which introduced artifacts during the image reconstruction. We are currently experimenting other beads of lower mass and density to improve the resolution.

Although this error is of an order of magnitude larger than standard micromotion measurement systems [5], it is capable of measuring many more micromotion points (depending only on the quantity of beads added) than standard systems. The strength of this method is to provide a directed measure of the micromotion between the implant and the surrounding bone. Current measurement systems indeed measure micromotion between the stem and some periosteum anchoring sites [5], including thus all the bone deformations between the endosteum and periosteum. With the proposed technique, a more direct correlation between micromotion and fibrous tissue formation could be obtained.

REFERENCES:

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Fig. 1: Left and center: posterior and anterior views of the sps-standard stem before implantation, showing Ta beads and region of interest which was later scanned. Right: stem implanted in a cadaveric femur.

Fig. 2: a) µCT scanner with the loading device. b) Femur distally cemented within the loading support. c) Loading device with the femur (cylindrical container semi-transparent). The loading piston is show in red.

Fig. 3: Tangential (top) and perpendicular (center) micromotions at different loading amplitude. The bottom plot reflects the error of the measurement.

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