Prediction Of The Primary Stem Stability For Total Hip Arthroplasty Using Numerical Modal Analysis Based On Preoperative Computerised Three-dimensional Planning

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Introduction: Cementless total hip arthroplasty involves a press-fit condition between the stem and the femur. The primary stem stability is crucial in order to achieve bone in-growth and good functional outcomes especially in the early post-operative period. The stem stability is usually assessed intuitively by the surgeon at the time of the surgical procedure with an inherent risk of size error. An underestimation may lead to pain, lower limb shortening or dislocation, whereas an overestimation may generate bone fractures and limb lengthening. A common approach to objectively determine the initial stem stability at the time of surgery is to measure the frequency response of the stem. Some studies showed that the most sensitive parameter was the shift in the resonance frequency of the stem-bone system [1]. However, these techniques are not available at the time of the pre-operative planning and thus cannot be used in order to choose the stem size that would best restore the hip anatomy. Furthermore, these techniques generate an increase in the operative time and the cost. Our hypothesis was that the stem stability may be anticipated before surgery using a three-dimensional pre-operative planning and a numerical modal analysis of the stem. The aim of this study was to determine the feasibility of a numerical analysis based on the modal behavior of the stem which may predict the primary stability during a pre-operative computerized three-dimensional planning with HIP-PLAN software [2]. To our best knowledge this technique of numerical modal analysis based on 3D planning has never been reported in the literature.

Methods: The numerical simulation we carried out, combined a computerized three-dimensional planning and a finite element method. On one hand, a three-dimensional planning was performed with the HIP-PLAN software using a low-dose hip CT-scan. Once the stem implantation has been simulated, a cartography of the Hounsfield densities of the bone in contact with the stem on a distance of 1.8 mm was plotted on the stem (Figure 1).

On the other hand, a FE model of the stem was developed. The contact between the femur and the stem was modeled using the boundary conditions. In this purpose, local rigidities were applied on the nodes of the stem. The values of those rigidities were based on the values of the Hounsfield densities measured with the three-dimensional planning. Finally, the modal analysis of
The surgeon selected four patients. All of them were operated with the same stem size (SPS modular stem, Symbios, Yverdon-les-bains, Switzerland). Two of them had an immediate stable stem and a good osteointegration (group A). The others had an unstable stem (group B). The choice was made using clinical arguments as pain or limping. Their cartographies were determined using their post-operative CT-scan. The objective was to visualize the final position of the stem after the operation in the pre-operative CT-scan of the femur. The purpose was to compare the vibrational behaviour of the stem between the two groups using a modal analysis.

**Results:** First of all, the values of the rigidities which were applied on the stem were equivalent from one patient to another (4 $10^7$ N/m). The mode shapes showed for the stable cases that the displacement was mainly located on the caudal part of the stem for all the first five Eigen modes (Figure 2-A). The most important difference between the stable and the unstable cases was found for the Eigen mode 3. Indeed, the two unstable patients showed a flexion mode which appeared for a relatively low frequency (7.6 kHz). This mode shape allowed a displacement of the proximal part of the stem (Figure 2-B).

**Discussion:** A numerical method has been set up to calculate the vibrational behavior of the stem using the Hounsfield densities mapmaking extracted from a 3D pre-operative THA planning. The appearance of a stem flexion mode seems to be the signature of a bad primary stem stability. These results are coherent with the clinical experience. Indeed, surgeons avoid as far as possible micromotion of the proximal part of the stem in order to insure a primary stability. However, only four patients were analyzed. More patients have to be included. To our knowledge, this is the first time that such a simulation based on a Hounsfield densities cartography was used to predict the stability of the stem before total hip arthroplasty, allowing, thus, an optimal selection for the stem size and position.

**Significance:** The presented technique is innovative with a high clinical relevance as it helps to enhance the accuracy and the safety of total hip arthroplasty especially in young and active patients with high clinical expectations. This technique can be integrated in a THA 3D planning software and used routinely. To our knowledge, it is the first time that a simulation based on a Hounsfield densities cartography was used to predict the stability of the stem before total hip arthroplasty, allowing thus an optimal selection for the stem size and position.

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