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NUMERICAL MODELING OF HIP IMPLANT VIBRATIONAL BEHAVIOR FOR THE ANALYSIS OF STABILITY

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Background and objective Total Hip Replacement (THR) is known to be one of the most common orthopedic surgical interventions nowadays. This type of surgery needs to be performed when the femur/iliac-crest joint is permanently damaged, being replaced by a hip prosthesis. Appropriate long-term integration (stability) depends to a great extent on the osteointegration process, which refers to the regeneration of the bone around the implant, and which is only possible when the micro-movements between the two are kept under a range of 30-150 µm [1].

On the one hand, the vibrational response of the bone-implant system depends on the nature of the bone-implant contact. Several authors have performed vibrational analysis to monitor stability [2]. On the other hand, some orthopedic surgeons use a pre-operative three-dimensional (3D) quantitative computed tomography (QCT) X-ray scans to plan surgery [3]. They use the images of Hounsfield values but they do not directly assess the expected mechanical stability.

The objective of this study is to determine the feasibility of incorporating the bone X-ray data in the numerical simulation of the vibrational response of the implant and to test relevance of the procedure to enhance the pre-surgical positioning planning of a cementless hip prosthesis for a THR. For this purpose, we use post-operative QCT scans of patients with stable and unstable hip prosthesis and compute the modal response of a finite element model (FEM) of the implant with boundary conditions calculated from QCT data. The modal response is analyzed to find a criterion which distinguishes patients with stable and unstable implant.

Materials and Methods A 3D planning tool allows the reading of the Hounsfield values of the bone in contact with the implant in the pre-operative QCT scan of each patient. The boundary conditions on the implant surface are obtained with the following reasoning. Zones corresponding to three different Hounsfield density ranges (red, green, and blue zones in Figure 1, left) are defined on the surface of the implant, which correspond to locations of more or less strong contact between the bone and the implant. Local values of stiffness for each zone are calculated from Hounsfield values. The proposed contact model consists of attaching one spring to each one of the nodes of the three identified zones representing the local stiffness (Figure 1, right). Prospective FE modal analysis of the prosthesis was performed for a group of two patients with an unstable implant and a group of four patients with a stable implant. Stability was defined based on the level of osteointegration observed by the surgeon after the surgery. The modal analysis was performed in the frequency range of [0:20] kHz, using the FEA software Code-Aster [4].

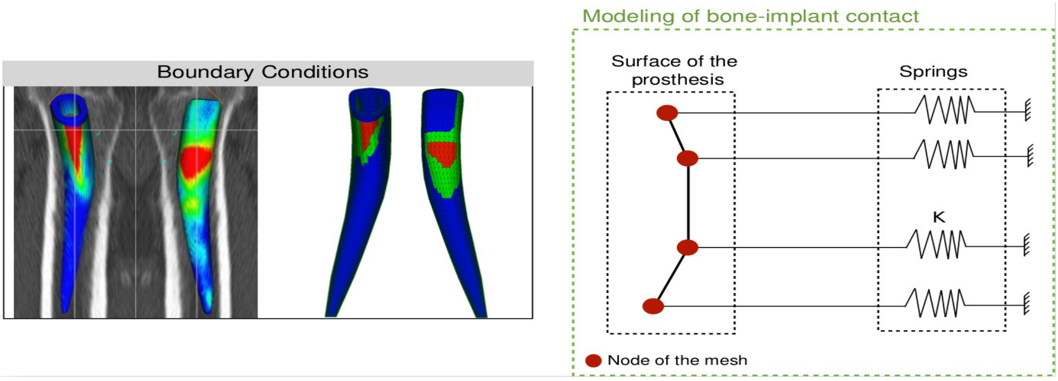


Figure 1: Figure 1. Left: Contact zones defined of the prosthesis with a 3D planning. Right: Bone-implant contact modeling principle.

Results The eigenfrequencies and modal shapes obtained for stable and unstable cases were compared (Figure 2). It was observed that the values of modal frequencies were very close for the two first modes despite the different stability status. The modal shapes of the mode 3 of the unstable cases had a characteristic pattern with high values of displacements in the upper part of the stem. If the occurrence of this pattern can be confirmed on a larger number of cases, it could be of significant interest for surgeons to optimize the choice and positioning of the stem in the pre-operative planning.

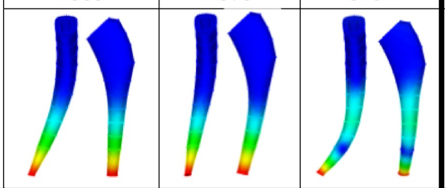
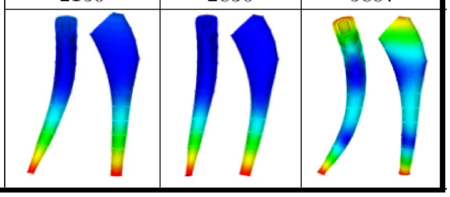
Modes	1	2	3
8	2338	2878	8254
			
9	2150	2830	5887
			

Figure 2: Modal shapes and eigenfrequencies of the three first modes of a stable case (top) and an unstable case (bottom). The numbers in the first column are the number of modes in the frequency range [0:20] kHz.

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