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NUMERICAL SIMULATION OF STRESS-SHIELDING AT THE BONE-IMPLANT INTERFACE UNDER SHEAR LOADING

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Introduction

Inserting a titanium implant in bone tissue may modify its physiological loading and therefore cause bone resorption, a phenomenon known as stress-shielding [1]. While monitoring and preventing stress-shielding is necessary to ensure the surgical success, it remains difficult to experimentally retrieve information on the properties of the interfacial tissues at the scale of 1-100 μm from the implant surface, where this phenomenon is localized. Numerical modelling represents a complementary tool to better understand phenomena related to the coupled bone-implant system due to the difficulty of measuring the stress distribution *in vivo*. The aim of this study is to investigate numerically the influence of various geometrical and material parameters on the local stress field around a bone-implant interface (BII) subject to shear loading.

Methods

A 2D plane strain finite element model of a sinusoidal BII allowing to vary the bone-implant contact (BIC) and the implant roughness through its periodicity λ and its amplitude 2Δ , was derived from a previous study [2] (Fig.1b). A shear loading was applied at the top of two half-spaces corresponding to a rough implant and to cortical bone tissue respectively, separated from each other by an irregular interphase. The isostatic pressure and the maximum shear stress around the BII were simulated for different (i) implant roughness, (ii) implant materials, (iii) BIC ratios, and (iv) bone Young's moduli. The equivalent stiffness of the BII was also derived from the simulations.

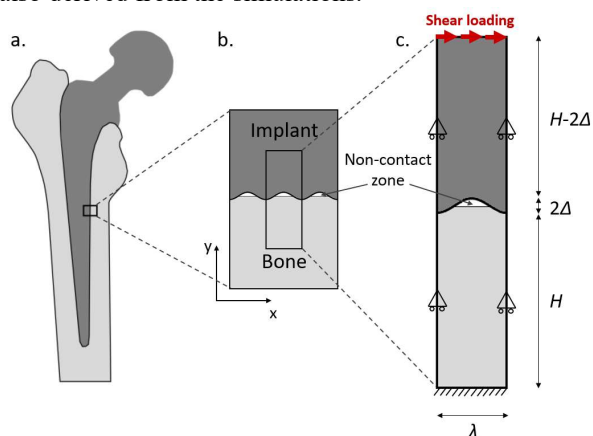


Figure 1: Schematic description of the model at the macroscopic level, with the example of a femoral stem (a). Geometrical description of the sinusoidal BII (b), with the numerical details in (c).

Results

A stress concentration is evidenced at the intersection between the implant, the void and the bone, in particular for lower roughness (Fig. 2). More generally, stress-shielding occurs at a distance lower than around 0.4λ from the BII, and increases (i) when the BIC ratio decreases and (ii) when the implant roughness decreases. Moreover, changing the implant material to get closer to the mechanical properties of bone (e.g. using metal-polymer composites) reduces the shear stress and the isostatic pressure.

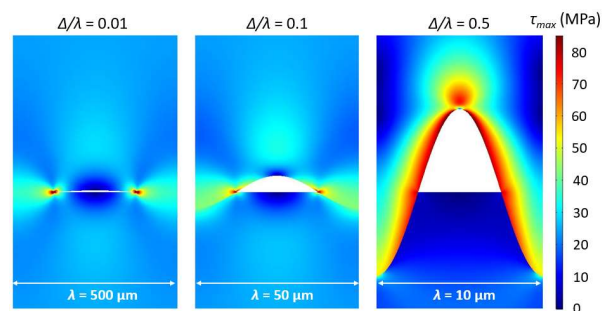


Figure 2: Spatial variation of the maximal shear stress τ_{max} around the BII for BIC = 50% and three values of the implant roughness ($\Delta/\lambda = 0.01, 0.1, \text{ and } 0.5$).

Discussion

This study enhances the clinical importance of maximizing the BIC ratio to minimize stress-shielding effects, and suggests that using adapted implant material such as the metal-polymer composite Ti-35BPA [3] could help to minimize stress-shielding effects. Future studies could use the equivalent stiffness of the BII determined herein in order to replace the complex behavior of the BII by a simple analytical model. It would also be of interest to introduce bone remodeling in our model to investigate the temporal changes occurring during healing, after the implant insertion.

References

1. Sumner et al, J Biomech, 48(5):797-800, 2015.
2. Raffa et al, J Orthop Res, 39(6):1174-83, 2021.
3. Okulov et al, Sci Rep, 7(1):20, 2017

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