

COMBINING EXPERIMENTAL AND NUMERICAL APPROACHES TO ASSESS THE TANGENTIAL DEBONDING OF COIN-SHAPED IMPLANTS

Yoann Hériveaux (1), Sophie Le Cann (2), Katharina Immel (2,3), Elsa Vennat (1), Vu-Hieu Nguyen (4), Roger A. Sauer (3,5,6) and Guillaume Haïat (2)

1. Université Paris-Saclay, CentraleSupélec, ENS Paris-Saclay, CNRS, LMPS, France ; 2. CNRS, MSME UMR 8208 France ; 3. AICES, RWTH Aachen University, Germany ; 4. Université Paris-Est Créteil, MSME UMR 8208, France ; 5. Faculty of Civil and Environmental Engineering, Gdansk University of Technology, Poland ; 6. Dept. of Mechanical Engineering, Indian Institute of Technology Guwahati, Assam, India.

Introduction

While cementless implants are now widely used clinically, surgical failures still occur and are difficult to anticipate. Assessing the biomechanical strength of the bone-implant interface (BII) may improve the understanding of osseointegration processes and help to prevent failures [1]. The aim of this study is to combine experimental and numerical approaches to investigate the behavior of a BII submitted to torsional loading.

Methods

Specimens. Four standardized 3D-printed coin-shaped implants (TiAl6V4, Ø5mm, H3mm) with an arithmetic average roughness $Ra = 20.8\mu\text{m}$ were osseointegrated for 15 weeks in the cortical bone of sheep tarsi.

Torsion tests. A mode III cleavage test was performed on each specimen (Fig. 1a) using a dedicated device (Fig. 1b), similarly as in [2]. The implant was fixed on the device by a wrench screwed to a torque sensor and the bone rotated at $0.03^\circ/\text{s}$ until complete debonding, while recording the normal force and the torque.

Numerical modelling. The torque variation during such tests was simulated using a finite element model previously developed by our group [3]. To describe the adhesion and debonding phenomena, a modified Coulomb's law was introduced, using a varying friction coefficient to represent the transition from an unbroken to a broken BII. All parameters, including the bone Young's modulus and the normal force, were optimized to minimize the difference between experimental and numerical torques; except for the force, directly set based on experimental measurements.

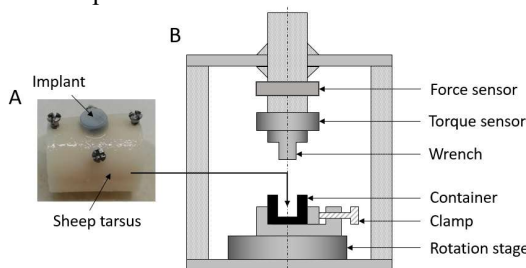


Figure 1: Typical bone-implant specimen (A); Schematic representation of the torsion test device (B).

Results

Experimentally, the torque first increases almost linearly with the twisting angle, then reaches a maximum around 1° ($0.48\text{--}0.72\text{N.m}$), and finally

decreases to reach a constant value (Fig. 2). The normal compressive force increases from around $10\text{--}15\text{N}$ to $30\text{--}40\text{N}$ during the debonding, before stabilizing around the same angle as the torque. A good agreement was obtained between numerical and experimental torques, with mean numerical friction coefficients of 8.9 for the unbroken state, and of 1.2 for the broken state.

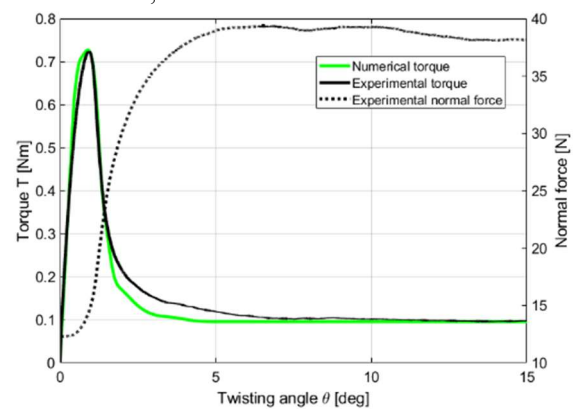


Figure 2: Evolution of the experimental torque and normal force and of the numerical torque as a function of the twisting angle for a typical specimen.

Discussion

The higher values of the maximal torques obtained herein compared to previous tests [2] may be explained by the higher roughness of the implants. Moreover, the significant increase of the normal force during the test and the high numerical friction coefficients suggest the presence of bone debris at the interface, which may be generated by the progressive debonding of the BII. Future studies should consider different BII configurations (e.g. implant roughness, healing time) to better understand their influence on the implant osseointegration.

References

1. Mathieu et al, J Biomech 47(1):3–13, 2014.
2. Mathieu et al, J Mech Behav Biomed Mater, 8:194, 2012.
3. Immel et al, Biomech Model Mechanobiol, 19:1091–1108, 2020

Acknowledgements

Funding by Paris Ile-de-France Region (DIM “Respire” and F2M Federation), the CNRS (MITI interdisciplinary program) and the EU H2020 research and innovation programme (the MSCA-IF Bomb project #797764 and the ERC-CoG BoneImplant project #682001).

