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BIOMECHANICAL CHARACTERISATION OF THE BONE-IMPLANT INTERFACE WITH NANOINDENTATION AND RAMAN SPECTROSCOPY

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Introduction

Implants are commonly used in dental and orthopedic surgery. However, failure rates remain high, because of a lack of primary stability (immediately after surgery) or of secondary stability (a few weeks/months after surgery). To anticipate implant failure and achieve a long-term osseointegration, the biomechanical properties of the bone-implant interface need to be better characterized [1]. Local biomechanical and structural properties of newly formed bone tissue around the implant surface were investigated using nanoindentation [2] and Raman spectroscopy and the results were compared to mature bone.

Methods

Sample: An *in vivo* bone-implant model has been developed using coin-shaped Ti6Al4V implant ($\varnothing=5\text{mm}$, $H=3\text{mm}$) surrounded with PTFE to create a $700\text{ }\mu\text{m}$ gap between the implant surface and mature bone tissue (Fig 1) [3]. After 10 weeks of osseointegration in a New Zealand white rabbit femur cortex, the femur was harvested with implant in place, embedded into PMMA and horizontally cut in the middle of the implant to expose the bone-implant interface. **Raman spectroscopy:** Lines with a length of $400\text{ }\mu\text{m}$ were scanned with infrared light (wavelength 785 nm) in mature and newly formed bone tissue (Fig 1). Spectra were averaged and analyzed to extract mineral and collagen molecular compositions as well as bone mineralization information. **Nanoindentation:** $3\text{ }\mu\text{m}$ -depth indents were realized on the same lines as for Raman spectroscopy. Values of the elastic modulus were extracted from the loading curves and averaged for each line and each region of interest.

Results

The mean value of the elastic modulus measured by nanoindentation was equal to $13.9 \pm 1.9\text{ GPa}$ (respectively $16.8 \pm 1.2\text{ GPa}$) in newly formed (respectively mature) bone tissue. Raman spectra obtained in mature and newly formed bone tissue exhibit different patterns (Fig 2). An increase in mineral-to-collagen and carbonate-to-mineral ratios was measured between newly formed bone and mature bone, respectively from 14 ± 1.5 to 18 ± 2.5 and from 0.17 ± 0.01 to 0.19 ± 0.02 , whereas the mineral crystallinity decreased from 0.060 ± 0.002 to $0.058 \pm 0.001\text{ a.u.}$

Discussion

This *in vivo* coin-shaped implant model is well adapted to study newly formed bone properties as it enables to easily distinguish newly formed bone tissue from mature bone tissue, which is not the case when using implants employed clinically [4].

The lower elastic moduli [2], mineral-to-collagen and carbonate-to-mineral ratios measured in newly formed bone tissue suggest that it is less mineralized than mature bone tissue. Further studies will investigate more samples at different time points to confirm the results and investigate the evolution of the bone properties during healing.

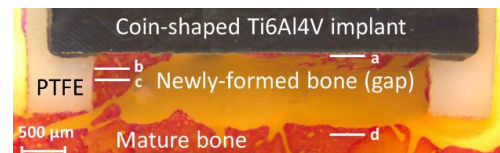


Figure 1: 2D image with bone colored in red and PMMA in yellow. Nanoindentation and Raman measurements were realized in newly formed bone (a, b, c) and mature bone tissue (d).

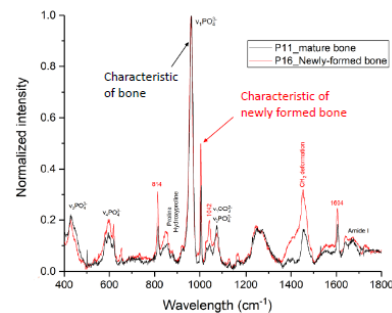


Figure 2: Raman spectra in newly formed bone (red) and mature bone (black).

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