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Mechanical characterisation of femoral cancellous bone samples with metastases

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Introduction

Bone metastases, frequently arising from breast or lung cancer, often affect the femur and can lead to severe skeletal complications such as pathological fractures and spinal cord compression^{1,2}. While CT imaging is used to assess metastatic bone lesions, it provides primarily qualitative data. Finite element models based on quantitative imaging have been proposed³ to predict fracture risk, but they often rely on mechanical properties derived from density of healthy bone. However, metastatic lesions can alter the microarchitecture of cancellous bone, potentially affecting its mechanical behaviour at the structural level. The aim of this study is to determine the local properties of the metastasis within the femoral cancellous bone in order to implement them in a finite element model.

Methods

The bone samples (N=13) used in this study were collected at the Hospices Civils de Lyon and originated from prophylactic surgeries or femoral prosthetic replacements. The specimens were stored at -80°C. The morning before testing, they are thawed by placing them in the refrigerator at +4°C. Samples are analysed by a clinician to identify metastatic areas. For each sample, 3 cylindrical samples are taken (healthy zone, metastatic zone, transition zone) in the Main Trabecular Direction (MTD), determined from a scan (Skyscan 1076). The samples are cut using a bench drill (PROMAC 210Z), a Meunier modification of Bordier trephine (diameter D=7.5mm) and a low speed saw (ISOMET BUEHLER) to cut samples so that their maximum length L_{max} satisfies L_{max}=2*D. Samples undergo a mechanical testing protocol based on uniaxial compression combined with tomodensitometric imaging (micro-CT, Skyscan 1174). Scans are taken at different compression levels (0N, 10N, 40N, 90N, 140N, 200N), and performed at 0.6 to 0.8 degree rotations for 180 degrees (50 kV to 800 μA; 0.5mm aluminium filter), with a nominal isotropic voxel size of 18 μm before loading and 33 μm, followed by analysis with CTAn software. Elastic modulus (E) is calculated from the stress-strain curves.

Discussion

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Three pre-tests were carried out on a human femoral head specimen obtained from a prosthetic replacement due to fracture, enabling the protocol to be finalised and validated. We obtained $E(\text{MPa}) = 116.27 \pm 21.95$, bone volume fraction (%) = 37 ± 8 , trabecular separation (μm) = 734 ± 278 , trabecular thickness (μm) = 335 ± 76 , trabecular number (1/mm) = 1.16 ± 0.34 , and degree of anisotropy = 0.49 ± 0.05 .

The mechanical characterisation of the three regions (metastatic, healthy, and transition) is expected to highlight potential differences and irregularities. Particular attention will be paid to the relationship between mechanical properties and microarchitectural features.

Conclusion

This study aims to enhance the understanding of how mechanical and structural parameters evolve across metastatic, transition, and healthy bone regions, offering new insights into the local impact of bone metastases on cancellous bone integrity. Integrating these findings into finite element models could improve their accuracy. In the long term, this work aims to contribute to better-informed therapeutic decision-making for patients with metastatic bone disease.

References

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