Effects of Bone Marrow Lesions on Bone Properties and Contact Mechanics in the Knee

Centre for Doctoral Training in Medical and Biological Engineering

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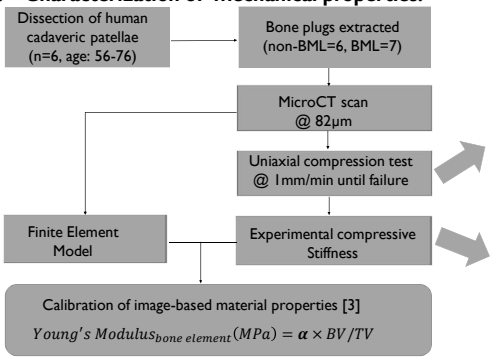
1. INTRODUCTION

- Osteoarthritis (OA) is a degenerative disease affecting joints and is one of the lead causes of pain and disability in adults [1].
- Bone marrow lesions (BMLs) are a common part of subchondral bone involvement in OA.
- BMLs are radiological features defined on fat suppressed T2 MRI images as areas of ill-delineated hyper signal intensities in comparison to unaffected areas [2] suggesting a change in tissue content and properties in the affected regions.
- However, it is not known if the presence of BMLs alters the mechanical behavior of the bone, which could in turn affect OA progression.

AIM: To characterize the mechanical properties of underlying bone in BML regions, using a combined experimental and computational approach, and subsequently investigate the effect of BMLs on knee joint mechanics.

2. METHODOLOGY

I. Characterization of mechanical properties:



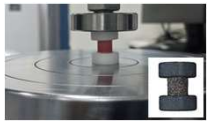


Figure 1: Example of experimental compression test setup and corresponding FE model.

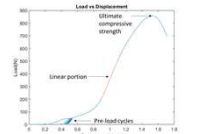


Figure 2: Example load vs displacement graph to calculate experimental compressive stiffness.

II. Finite Element models of knee joint with and without BMLs

- Three Specimen-specific FE models of tibiofemoral joints were built from CT images of human cadaveric knees.
- Models validated against experimental contact mechanics tests as per Cooper et al [4].
- Load and boundary conditions were applied as shown in Figure 3.
- Cartilage was assigned neo-hookean hyperelastic material properties and the bone elements were assigned individual Young's modulus values using the α derived for non-BML bone.
- Replicates of each model were created with a simulated 8mm radius half-sphere BML. In these models, the bone elements in the BML area were assigned Young's modulus values using the derived α for BML.
- The maximum von Mises stress in the bone and cartilage contact pressure were compared for the two groups.

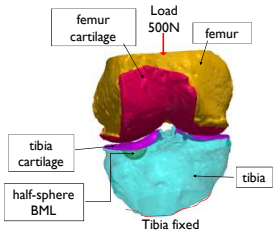


Figure 3: Schematic of finite element model set up showing bones, cartilage, load and boundary conditions.

3. RESULTS

I. Mechanical properties: non-BML vs BML regions

- **Different α values** were obtained for the **BML (176 MPa)** and **non-BML (92 MPa)** groups, suggesting a different greyscale-stiffness relationship in the BML region.

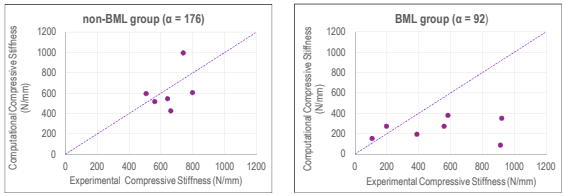


Figure 4: Graphs showing computational compressive stiffness plotted against experimental compressive stiffness for non-BML and BML groups.

- **Poorer agreement** between computational and experimental compressive stiffness in the **BML group (RMS error 55%)** compared to the **non-BML group (25%).**

II. Finite Element Models

- The presence of the **BML** lead to up to **88% increase in the maximum von Mises stress** in the tibial bone compared to the corresponding non-BML model, with the highest stresses seen in the regions around the BML.
- The presence of the **BML altered the distribution of contact pressure** in the overlying tibial cartilage (Figure 5).

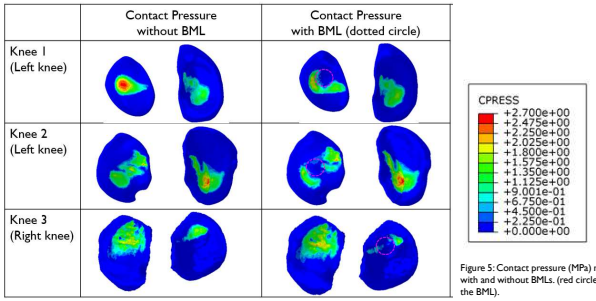


Figure 5: Contact pressure (MPa) maps for knee models with and without BMLs. (red circles indicate location of the BML).

4. CONCLUSIONS

- The results of this study show that bone in areas affected by BMLs have altered density-stiffness relationship to bone in unaffected regions.
- It also shows that the presence of a BML alters the normal joint mechanics with increased stress in the bone in the affected compartment and altered distribution of contact pressure in the overlying cartilage.
- This study provides for the first time, physical mechanical data on BMLs enabling their representation in models.
- The findings from the knee models suggest the presence of BMLs in the tibial bone affect the joint contact mechanics and may therefore be a factor in the progression of OA.

References

(1) Arthritis Research UK. State of Musculoskeletal Health, 2018; (2) Roemer et al. Osteoarthritis Cartilage, 2009.; (3) Mengoni et al. JMBBM, 2015.; (4) Cooper et al. JMBBM, 2020.

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