THE ROLE OF TISSUE MODULUS IN MECHANICAL BONE ADAPTATION IN EARLY EXPERIMENTAL OSTEOARTHRITIS

INTRODUCTION
A knee injury such as tearing of the anterior cruciate ligament (ACL) results in a higher likelihood of developing post-traumatic osteoarthritis (OA). The aetiology of this disease involves a series of cascading events eventually affecting all the tissues of the joint including the cartilage, remaining ligaments, and the subchondral bone. Notably, bone has a remarkable capacity to adapt to new mechanical and physiological environments, and this can be reflected in bone mineral density measures early after injury [1]. Investigating micro-structural properties of bone, it has been shown in an experimental model of OA that substantial architectural changes occur within the first 12 wk of injury, including decreases in trabecular thickness and bone volume ratio of ~31% and ~35%, respectively [2]. Presumably, these morphological changes are accompanied by mechanical changes to the subchondral bone. Apparent-level mechanical properties of bone are affected largely by architecture, but also tissue properties of the bone play an important role. To distinguish between the role of bone architecture and tissue properties on apparent-level mechanical properties, the finite element (FE) method is a useful approach [3]. Thus, possible adaptation of bone tissue in post-traumatic OA can be assessed independently from the architectural changes. Understanding the role of tissue changes in OA is important for developing treatment strategies for the disease. Furthermore, for non-invasive assessment of bone strength using large-scale FE models, it is important to understand whether the assumption of constant tissue modulus in a disease such as post-traumatic OA is valid. It is hypothesized that tissue modulus does not occur in conjunction with architectural changes affecting the apparent-modulus strength. Thus, the purpose of this study was to investigate the apparent-level and tissue-level mechanical properties of periarticular subchondral cancellous bone in experimental OA.

METHODS
Unilateral ACL transection (ACLX) was performed on ten dogs randomly and were assigned to two equally sized groups: 3-wk (n=5) and 12-wk (n=5) post-ACLX. An additional two dogs were used as normal unoperated controls (n=4 limbs). All procedures were approved by the University of Calgary Animal Care Committee. Cylindrical bone cores were excised from the medial aspect of the distal femur in the knee joint after euthanasia and scanned using high resolution computed tomography (µCT) (34 µm nominal resolution) (Fig. 1). The bone cores were mechanically tested to failure using a novel compression device [4] under conditions of uniaxial compression to determine the experimental apparent-level elastic modulus ($E_{a,x}$). Simulation of these tests was done by FE analysis (0.3 Poisson’s ratio, 5000 MPa) using the corresponding µCT data of the mechanically tested specimens as input for the 24 specimen-specific models. Using an arbitrary tissue modulus ($E_t$) in the FE model, a simulated apparent-level modulus ($E_{a,s}$) was calculated. Average tissue modulus ($E_t$) was calculated from the comparison of the experimental and simulated results [3]:

$$E_{a,s} = (E_{a,x} / E_{t}) E_{a,e}$$  (1)

Statistical tests included a 2-way ANOVA, as well as a post hoc analysis by paired t-test (with a Bonferroni adjustment for multiple comparisons) at 3 and 12 wk post-ACLX.

RESULTS
The apparent-level elastic modulus was decreased in the ACLX limb compared to the contralateral control at 3-wk post-ACLX (Fig. 2), and this was significant (p<0.05) by 12-wk.

![Fig. 1: Architecture of the periarticular cancellous bone 12 wk post-ACLX.](image)

DISCUSSION & CONCLUSIONS
Although there were large changes in the apparent-level mechanical properties in the early-stage of experimental OA, the tissue modulus did not yet appear to be affected. This indicates that the assumption of constant tissue-modulus for large-scale non-invasive FE assessment of bone strength is valid in the early-stage of this disease. Thus, the architectural changes have the dominating affect on apparent-level mechanical properties. However, others have reported tissue modulus changes in later-stage development of OA [5], therefore tissue modulus variation may need to be accounted for in FE models at the later-stages of the disease. In conclusion, the predominant factor affecting apparent-level mechanical bone strength in early experimental OA are changes to the micro-architecture, and tissue modulus plays a less important role in the early-stage of the disease. To maintain normal cancellous bone following a traumatic injury, early intervention may be key to prevent the substantial architectural adaptation affecting bone strength.

REFERENCES:

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