Subchondral Bone Properties Of Cam-type Femoroacetabular Impingement Deformities

Ahmed Alnabelseya, MSc¹, Ifaz Haider, BSc¹, Andrew D. Speirs, PhD¹, Paul E. Beaule, M.D.², Hanspeter Frei, PhD¹.  
¹Carleton University, Ottawa, ON, Canada, ²Division of Orthopedic Surgery, University of Ottawa, Ottawa, ON, Canada.


Introduction: Morphological deformities of the hip joint may be responsible for up to 90% of idiopathic hip osteoarthritis [1]. Characterized by a non-spherical extension of the articular surface of the anterolateral femoral head/neck junction, cam-type deformities are the most common. These deformities may result in a decreased range of motion and lead to repeated abnormal contact between the femur and the antero-superior acetabular rim and labrum, known as femoroacetabular impingement (FAI). Cartilage and labrum degeneration with subsequent cleavage of the cartilage layer and changes in the acetabular subchondral bone have been reported in patients diagnosed with FAI [2]. The cartilage of the cam deformity shows signs of degeneration and the subchondral bone BMD is up to 78% higher compared with normal subchondral bone [3,4]. This is in contrast to the subchondral bone of osteoarthritic cartilage where the bone may be hypomineralized [5]. However, it is not known if this increased BMD of the cam deformity is due to hypermineralisation and/or a change in subchondral bone micro-architecture. From a clinical and biomechanical perspective, the increased BMD likely results in an increased subchondral bone stiffness which further exacerbates the contact stresses associated with abnormal contact between the femur and acetabular rim. In order to help identifying the developmental pathway and disease progression, the goal of this study was to determine the bone tissue modulus and the micro-architecture of the subchondral bone of cam type FAI deformities.

Methods: Osteochondral bone biopsies, 10 mm in diameter with a height of approximately 3 mm, were obtained from the cam deformity of symptomatic FAI patients (n= 10) during resection surgery. Control specimens (n= 8) were harvested from the antero-superior femoral head near the head and neck junction from normal cadaveric femurs. The study was approved by the institutional ethics review board and the surgical subjects gave informed consent. The articular cartilage was removed from the specimens and the subchondral bone was cut parallel to the cartilage surface to an average thickness of 1.30 mm (SD 0.3 mm) and a width of 2.11 mm (SD 0.38 mm) with a diamond tip saw obtaining a beam with a rectangular shape to facilitate mechanical testing. The cut specimen were then μCT scanned with a resulting voxel edge length of 9 μm. The μCT images were segmented based on voxel intensity and were used for the analysis of the trabecular architecture and to generate micro finite element (μFE) models (Figure 1). Following imaging, the specimens underwent a three-point bending test using a materials testing machine and a custom made miniature three-point bending setup. Subsequently, the three-point bending tests were simulated using μFE analyses to separate the effects of bone volume fraction and trabecular architecture from the bone tissue modulus. A displacement corresponding to 80% of the linear portion of the experimental load-displacement data was applied to the μFE model and the bone tissue modulus was matched to obtain the experimental reaction load at the corresponding displacement. Bone volume fraction (BV/TV), mean trabecular thickness (mean Tb.Th), mean trabecular
spacing (mean Tb.Sp) and connectivity density were determined using BoneJ [6]. Bone tissue modulus and trabecular architecture were compared between the cam FAI deformities and the normal controls using a one-way MANOVA.

**Results:** There was a large variation in subchondral bone tissue moduli in both the surgical FAI and the control group (Figure 2). The mean bone tissue modulus of the cam type FAI deformities (E= 5.40 GPa ; SD 2.89 GPa) was significantly higher (p= 0.02) compared with the normal controls (E= 2.47 GPa ; SD 1.37 GPa). There was no statistical significant difference (p= 0.86) in bone volume fraction between the groups with a BV/TV of 0.42 (SD 0.10) and 0.41 (SD 0.11) for the cam deformities and the normal controls respectively. None of the other measured trabecular architectural parameters were statistically significant different between the two groups (p> 0.32).

**Discussion:** Although the cartilage from cam FAI deformities exhibit biomechanical properties consistent with osteoarthritis, the subchondral bone tissue modulus was more than double compared with normal controls. This is in contrast to the decreased subchondral tissue modulus observed in patients with pre-arthritic cartilage damage [7]. Given the strong relationship between mineral content and Young’s modulus of bone tissue together with the increased BMD, observed in the subchondral bone of cam deformities, suggest that this bone is hypermineralized when compared with normal controls [3,8]. There was no difference in micro-architectural parameters, which is in contrast to the subchondral bone of osteoarthritic cartilage [9]. This suggests, together with the increased tissue modulus, that the developmental pathway leading to the deformity is different compared with the changes occur due to cartilage degeneration. The cam deformity may form due to a malformed epiphyseal growth plate and its mineralization results in subchondral bone in that area [10].

**Significance:** This investigation showed that the subchondral bone tissue modulus of the cam FAI deformity is more than twice that of normal controls, suggesting a higher mineral content. This stiffer bone likely further exacerbates the contact stresses between the femur and acetabular rim. The increased stiffness and normal trabecular architecture of cam deformities found in this investigation provide important information, which may help to identify the developmental pathway.
Figure 1: μFE model of a control specimen.

Figure 2: Subchondral bone trabecular architecture and tissue modulus for the normal controls and the cam-type FAI deformity (error bars SD).