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Bone density is higher in cam-type femoroacetabular impingement deformities compared to normal subchondral bone

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SUMMARY

Objective: Cam-type femoroacetabular impingement (FAI) deformities have been associated with early osteoarthritic degeneration of the hip. Degeneration depends on many factors such as joint morphology and dynamics of motion. Bone mineral density (BMD) appears to be a manifestation of the above, and may be a potentiator. Thus the goal of this study was to assess subchondral BMD of cam deformities in symptomatic and asymptomatic FAI subjects, and to compare to normal controls.

Methods: Subjects undergoing surgical correction of a symptomatic cam-type deformity were recruited ("Surgical"). Asymptomatic volunteers were also recruited and classified as normal ("Control") or having a deformity ("Bump") based on their alpha angle measurement. All subjects ($n = 12$ per group) underwent computed tomography (CT) with a calibration phantom. BMD was determined in volumes of interest around the femoral head and neck to a depth of 5 mm. BMD was compared between groups in each section using spine BMD as a covariate.

Results: No differences were seen between groups in the peripheral bearing surface. The Bump group exhibited higher BMD than Controls within the head/neck junction ($P < 0.05$). When compared to normal subchondral bone in the peripheral level of Controls, BMD in the deformity was up to 78% higher in Bump subjects and up to 47% higher in Surgical subjects ($P < 0.05$).

Conclusion: Subchondral BMD of cam deformities is higher than that of normal subchondral bone in the peripheral region of the femoral head, regardless of symptom status. The expected increased subchondral stiffness may increase contact stresses in the joint tissues leading to accelerated degeneration.

Introduction

Femoroacetabular impingement (FAI) has been associated with premature osteoarthritic (OA) degeneration of the hip joint and may be responsible for up to 90% of idiopathic hip OA cases[1,2]. Cam-type FAI results from a morphological, convex deformity at the antero-superior femoral head–neck junction. It has been hypothesized that so-called idiopathic hip OA may be largely due to repeated abnormal contact between the deformity and acetabulum in undiagnosed FAI[2]. Our previous study showed increased subchondral bone mineral density (BMD) on the acetabular side in subjects with a cam deformity which was associated with the degree of deformity[3]. This suggests that BMD changes in the acetabulum play a role in OA degeneration of the acetabular cartilage associated with FAI[1] and could be a disease potentiator.

On the femoral side the convex deformity results in a morphological incongruity of the bearing surface which could result in elevated contact stresses. The presence of a cam deformity is assessed by the alpha angle, a measure of deviation of the femoral head–neck contour outside a spherical envelope[4,5]. The genesis of the cam deformity is unknown, although possible mechanisms include a slipped capital femoral epiphysis[6] or abnormal development of the growth plate prior to skeletal maturity[7,8]. The aetiology of cam deformity development may lead to elevated BMD in the antero-superior region of the femoral head–neck junction i.e., within the deformity. Since bone stiffness increases exponentially with BMD[9], the associated stiffening of this subchondral bone could exacerbate abnormal contact stresses of incongruent articular surfaces. Previous studies have reported elevated femoral neck bone density in hip OA subjects[10,11], however the two-dimensional nature of the dual energy X-ray absorptiometry (DEXA) employed

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could not resolve BMD distribution in the anterior–posterior direction.

The goal of this observational study was to measure the subchondral bone density in the femoral head, especially near the head/neck junction by extending the methods of our previous study[3]. It is hypothesized that subchondral BMD within the femoral cam deformity is elevated compared to normal subchondral bone.

Materials & methods

The study subjects and computed tomography (CT) scans are the same as in our previous study[3]. Briefly, 12 subjects in three groups underwent bilateral CT scans from the fifth lumbar vertebra to the lesser trochanter as well as the knees. The first group consisted of subjects scheduled for surgical correction of a symptomatic cam deformity ("Surgical"); the second group consisted of asymptomatic volunteers with a cam deformity ("Bump"); and the third consisted of asymptomatic control subjects ("Control"). Bump and Control subjects were recruited from the general asymptomatic population and assigned to the corresponding group based on the alpha angle[3]. The CT scan included a calibration phantom to allow calculation of BMD.

Measurement of femoral bone density

Variation of BMD within the femoral head and at the head/neck junction was assessed by measurement of CT image intensity in standardized volumes of interest defined by subject anatomy. First, the proximal femur region of each hip in each patient was semi-automatically segmented from the CT scan (ITK-Snap, v2.2, itksnap.org). Various landmarks were used to standardize the volumes of interest, determined from either the surface model or identified directly on CT slices (Fig. 1). The femoral head centre and radius were calculated from a least-squares best-fit sphere of the bearing surface of the segmented surface model. The neck of the surface model was sliced with an oblique sagittal plane such that the neck axis was defined from the head centre to the centroid of the resulting contour. Similarly, a contour was generated by a slice through the proximal shaft of the segmented surface model, below the lesser trochanter. The medial and lateral epicondyles were identified directly on axial CT slices. The mid-point of these landmarks and the centroid of the proximal shaft contour defined the shaft axis. The local anterior axis was defined perpendicular to the shaft axis and the neck axis, and differs slightly from the normal anterior direction due to the anteversion of the femoral neck. A reference, oblique transverse plane was created with a normal perpendicular to both the neck and local anterior axes (Fig. 1). Planes perpendicular to the neck axis were used to divide the proximal femur into two levels. The distal and proximal levels correspond to the head/neck junction and peripheral bearing surface, respectively (Fig. 2). The first level was centred on a point representing an alpha angle of 60°, approximately the mean alpha angle of the Surgical group[3], and had a width of 50% of the femoral head radius. The proximal boundary of this region was therefore offset from the head centre by 25% of the radius. This is close to the extension of the epiphyseal scar, which was assumed to mark the border of a normal bearing surface, which ranges from 11% to 44% of the head radius in the antero-superior region[12]. The peripheral bearing surface extended from the supero-medial plane of the previous level and included half the remaining portion of the head (Fig. 2) and is considered as the periphery of the normal bearing surface. A volume was created in each level by offsetting the segmented surface model inwards, i.e., towards the neck axis, by 5 mm. This thickness was chosen to focus on the dense subchondral bone layer. The volumes were then partitioned into 30° sections by

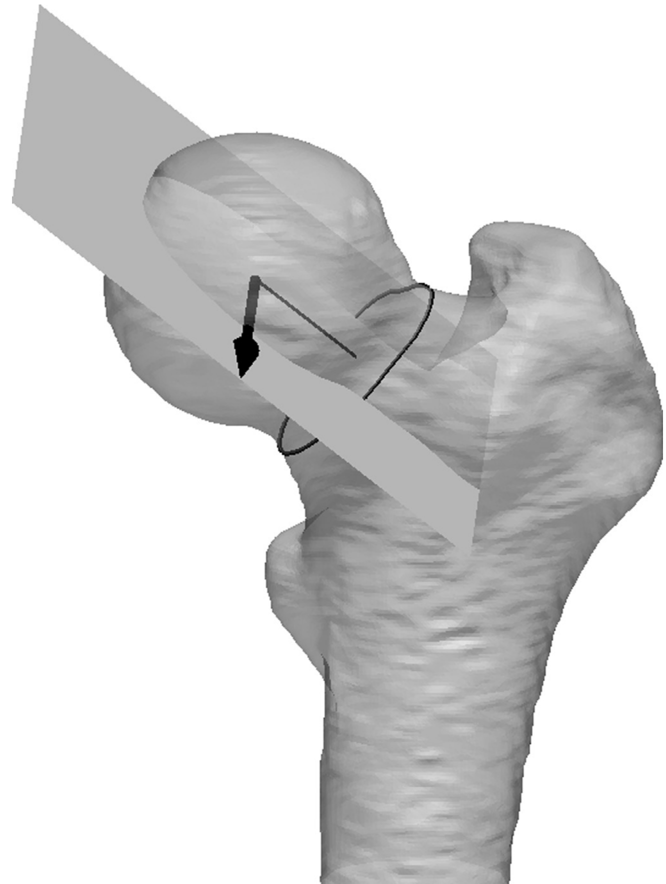

Fig. 1. Landmarks used in the definition of the regions of interest used for measurement of BMD. The centroid of the contour in the neck was used to define the neck axis. The reference plane is defined by the neck axis (black line) and anterior axis (arrow) through the centre of the femoral head. See text for details.

incrementally rotating the reference oblique transverse plane about the neck axis. This resulted in 12 sections around the circumference such that the reference plane divided Sections 1 and 12 anteriorly (Fig. 2). The head/neck junction was similarly divided although only Sections 1–3 and 12 were considered in the analysis since cam deformities are known to be centred in the antero-superior quadrant of the femur[5] (Fig. 2). This region may be considered an infero-medial extension of the anterior bearing surface due to the deformity. Section 4 at this level is generally the region in which the superior retinacular arteries penetrate the supero-medial femoral head and is outside the region typically containing the cam deformity and was therefore excluded. Similarly Section 11 is inferior to the deformity and was excluded from the analysis. A tetrahedral volume mesh was created in each section (Netgen Mesh Generator, v4.9.13, http://sourceforge.net/apps/mediawiki/netgen-mesher) with approximately 10,000 elements per section. The CT intensity (Hounsfield Units, HU) was sampled in each tetrahedral element by linear interpolation to the element centroid using a custom program (Matlab Image Processing Toolbox, v2009b). Each CT scan was calibrated using the phantom according to the manufacturer's directions to convert tetrahedral HU to K_2HPO_4-equivalent BMD. The mean BMD in each section was calculated as the volume-average density of all tetrahedral elements in the section.

Subjects were expected to exhibit general bone density differences due to various factors such as body weight and activity level.