Higher patient activity level and subchondral stiffening in asymptomatic cam femoroacetabular impingement subjects

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ABSTRACT

A cam deformity is proposed as a cause of idiopathic osteoarthritis. Increased subchondral bone mineral density (BMD) is associated with this degenerative process of osteoarthritis, and the patient’s activity level may contribute to it. Therefore, the correlation between activity level and subchondral BMD in subjects with cam deformity FAI was studied. In this study, 26 asymptomatic cam deformity subjects (Bump) were compared with 18 subjects with a normal alpha angle (Control). Anterosuperior subchondral femoral neck and acetabular rim BMD were measured using quantitative computed tomography. Activity level was determined using the UCLA activity score. The correlation between BMD and UCLA activity were analysed. The result was a significantly higher BMD for Bump subjects in almost all measured sections. The UCLA score of the Bump versus Control subjects were comparable (8.96 versus 8.77, \( P = 0.740 \)). While the controls showed no correlation between UCLA and BMD, a positive correlation was found for the Bump subjects on several femoral and acetabular impingement locations. These results support the conclusion that mechanical loading causes subchondral stiffening at the anterosuperior head–neck junction of the femur and anterosuperior acetabular rim. The absence of a correlation between BMD versus UCLA in the Controls supports the hypothesis that activity level may serve as a predictor for higher subchondral BMD in a cam deformity hip joint.

INTRODUCTION

Femoroacetabular impingement (FAI) is associated with osteoarthritic degeneration of the hip joint [1]. According to Harris et al. subclinical childhood diseases and abnormal bony morphology (like FAI) are responsible for up to 90% of idiopathic osteoarthritis cases [2]. It has been hypothesized that repetitive impingement between the cam deformity and the acetabular rim will lead to labral degeneration, labral tears, cartilage delamination and osteoarthritis [1, 3, 4]. However, 14–24% of the adult population (and up to 77% in male football players) has an asymptomatic FAI [5–7]. Of the patients with a symptomatic cam deformity, up to 80% have bilateral deformities, with only one-third having bilateral symptoms [8]. So far, the answer to ‘how, if and when’ a patient with a cam deformity progresses to become symptomatic or develops osteoarthritis is largely unknown.

Based on femoral and acetabular bone mineral density (BMD) imaging, it was found that the presence of the cam deformity predisposes to subchondral bone stiffening (demonstrated by elevated BMD levels), even in asymptomatic individuals [9–11]. Subchondral stiffness seems to result in elevated cartilage stress and plays an early role in the osteoarthritic cascade [3, 12]. One theory is that the stiffening of the subchondral bone is a result of the repetitive impingement at the level of the cam deformity [10, 11]. Besides (the location of) the cam deformity there are more factors involved in the abnormal contact...
mechanics of the hip joint, like tissue properties, joint motion and loading. The patient’s activity level will influence motion and loading and may be a factor in the progression of early (subchondral stiffening) to more severe (osteoarthritis) degeneration [10, 11]. This led us to the question of whether an association between activity level and subchondral BMD could be found in asymptomatic cam deformity patients and normal subjects. We hypothesized that an association between activity level and subchondral BMD could only be found for the cam deformity patients.

MATERIALS AND METHODS

Between 2010 and 2013, 46 asymptomatic volunteers were recruited for a prospective study. The inclusion criteria for this study were: age less than 50 years, no prior hip surgery or posttraumatic morphology, no arthritis in any joint and no history of hip or groin pain. Twenty-seven subjects were diagnosed by CT scan with a cam deformity (Bump group). The remaining 19 asymptomatic participants showed no sign of a cam deformity (Control group). Asymptomatic subjects and controls were primarily recruited from our healthcare institution and were employees or affiliates at the institution. Participation was voluntary and participants did not receive monetary compensation. The categorization between Bump or Control was based on their alpha angle as measured by a musculoskeletal radiologist (Table I) [13]. The alpha angle was measured in reformatted oblique CT slices at the traditional anterior femoral head–neck junction as well as at the anterosuperior junction, known as the 3:00 and 1:30 locations, respectively [13, 14].

As described in a previous study, the subject was assigned to the Bump group if the alpha angle was greater than 50° in the 3:00 location or greater than 60° in the 1:30 location [10]. Otherwise, they were assigned to the Control group. Of each subject, the body mass index (BMI) and activity level [using the 10-point University of California Los Angeles (UCLA) activity score] was recorded. Two subjects were excluded from the analysis for this study because of missing QCT data; one Control subject had degenerative lumbar spine abnormalities which affected QCT BMD measurements, one Bump subject moved away before a QCT was performed. The analysis and results are therefore based on 26 Bump and 18 Control subjects.

Measurement of bone mineral density

All subjects underwent bilateral CT scans from the iliac crest to the lesser trochanter, as well as the knees, and included a calibration phantom in the field of view (Model 3, Mindways Software, Austin, TX, USA). CT scans were acquired with slices in the transverse plane with a spacing of 0.5–0.625 mm and an in-plane resolution of 0.72–0.98 mm depending on the size of the subject. The CT image was reconstructed using the bone window of the scanner manufacturer. The 3:00 and 1:30 plane were measured according to Nötzi et al. and Rakhra et al. [13, 14]. The alpha angle was measured in these two planes using the point at which the anterior femoral head/neck contour deviated outside a circle defined by the femoral bearing surface. This point, the centre of the femoral head, and the neck axis defined the alpha angle and was used to discriminate Asymptomatic and Control subjects as described above. The QCT imaging technique for the measurement of acetabulum and femur subchondral BMD have been described in a previous report of our study group [10, 11]. Briefly, CT scans were automatically segmented to define regions the bone segments and create surface models [15]. Using custom software, the acetabulum was divided into wedge-shaped regions around the circumference and further divided into two levels based on the depth from the acetabular rim. The femoral head–neck junction region was similarly divided into regions around the circumference and included bone to a depth of 5 mm from the bone surface. In this study, only regions in the impingement region are considered, i.e. the anterosuperior quadrant of the acetabulum and the femur (Fig. 1). A mesh of tetrahedral elements was generated in each region of interest and the CT intensity was determined at the centroid of each element. This was converted to BMD using the calibration determined from the phantom in the scan, and a volume-average BMD was calculated for each region of interest. Reproducibility of the measurements was assessed by randomly selecting the affected hip of two subjects in each group and repeating the entire process by the same

| Table I. Patient demographics with P-values of the differences between Control and Bump subjects |
|-------------------------------------------------|---------------------------------|---------|---------|----------|----------|-----------|
| n                                      | Alpha angle 1:30 | Alpha angle 3:00 | Age     | BMI      | Male gender (n) | UCLA activity |
|-----------------------------------------|------------------|------------------|---------|----------|-----------------|---------------|
| Control                                 | 18               | 49.6° ± 4.3°     | 41.6° ± 5.0° | 33.2 ± 6.7 | 26.2 ± 3.0      | 89% (16)     | 8.77 ± 1.9 |
| Bump                                    | 26               | 65.2° ± 8.8°     | 57.5° ± 9.2° | 31.3 ± 6.3 | 25.3 ± 2.9      | 85% (22)     | 8.96 ± 1.6 |
| P-value                                  | <0.001           | <0.001           | 0.326   | 0.314    | 0.685           | 0.740        |
observer. Test–retest differences per zone were typically less than 10 mg/cc. The mean absolute difference was 7 mg/cc.

The study was conducted in accordance with the Helsinki declaration and approved by the research ethics board of the hospital. All subjects provided written informed consent prior to being enrolled.

Statistical analysis
Patient demographic data distributions were symmetrically distributed and are expressed as a mean with standard deviation. BMD data was also measured in a 1.6 cm³ region of the cancellous bone of the fifth lumbar vertebral body (L5 BMD) and used as a covariate to control for potential systemic differences in acetabular or femoral BMD due to various demographic factors (to e.g. age, weight, diet, activity level or genetic factors). For the BMD analysis between the groups a one-way ANCOVA (with L5 BMD as covariate), specific differences between groups were tested using a post-hoc Student’s t test with a Bonferroni correction. The correlation between UCLA activity score and femoral and acetabular BMD was examined using a Pearson correlation. Additional relationships between BMD versus BMI, age and gender were examined in step-wise regression; these showed scarce to no correlations. Differences were considered statistically significant at \( P < 0.05 \). All statistical analyses were performed using SPSS software (Version 23.0, SPSS Inc. Chicago, IL).

RESULTS
Patient demographics are shown in Table I. There was no significant difference in gender distribution (89% versus 85% male, \( P = 0.685 \)), BMI (26.2 versus 25.3, \( P = 0.314 \)), age (33.2 versus 31.3, \( P = 0.326 \)) and UCLA (8.77 versus 8.96, \( P = 0.740 \)) between Control and Bump subjects. The mean alpha angle of Control patients was 49.6° ± 4.3° and 41.6° ± 5.0° at the 1:30 and 3:00 position, respectively, for Bump patients this was significantly higher at 65.2° ± 8.8° and 57.5° ± 9.2° respectively (\( P < 0.001 \)).

Mean BMD and the differences between groups are represented in Table II. The femoral BMD of Bump subjects was significantly higher (after correction for L5 BMD) in all sections, except section 4 (\( P = 0.190 \)), compared with Control subjects. The mean BMD is significantly higher for the Bump subjects at section 12 (16%, \( P = 0.013 \)), 1 (28%, \( P = 0.001 \)), 2 (28%, \( P = 0.001 \)) and 3 (28%, \( P = 0.027 \)). On the acetabular side the mean BMD was significantly higher for Bump subjects at level 1, section 12 (18%, \( P = 0.004 \)), 1 (15%, \( P = 0.003 \)), 2 (19%, \( P = 0.001 \)), 3 (25%, \( P < 0.001 \)) and 4 (24%, \( P < 0.001 \)).

On level 2 of the acetabulum higher BMD for the Bump subjects is found in section 1 (20%, \( P = 0.011 \)), 2 (20%,

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**Fig. 1.** Femur and acetabular bone sections defined by segmentation of the CT image. Sections of interest were defined in the antero-superior acetabulum (B) and the antero-superior head–neck junction of the femur (A).
The BMD at section 12 of Level 2 did not significantly differ between subjects in the Bump and Control groups \((P = 0.055)\). The BMD at section 12 of Level 2 did not significantly differ between subjects in the Bump and Control groups \((P = 0.055)\).

| Table II. BMD values (mg/cc) of the impingement location on the femoral head and acetabulum with adjustment for the covariate (BMD L5) |
| --- |
| **Control** | **Bump** | **Difference in BMD** |
|  | Mean | SD | Mean | SD | Mean | % | P-value | 95% CI |
| **Femoral head** |  |  |  |  |  |  |  |  |
| Section 12 | 276 ± 69 | 322 ± 63 | 46 | 16% | 0.013 | [10, 81] |
| Section 1 | 328 ± 88 | 423 ± 98 | 95 | 28% | 0.001 | [41, 148] |
| Section 2 | 347 ± 100 | 445 ± 92 | 97 | 28% | 0.001 | [43, 152] |
| Section 3 | 280 ± 112 | 358 ± 115 | 78 | 28% | 0.027 | [9, 147] |
| Section 4 | 233 ± 76 | 264 ± 89 | 30 | 13% | 0.190 | [-15, 76] |
| **Acetabulum** |  |  |  |  |  |  |  |  |
| **Level 1** |  |  |  |  |  |  |  |  |
| Section 12 | 458 ± 97 | 542 ± 108 | 84 | 18% | 0.004 | [28, 140] |
| Section 1 | 611 ± 103 | 703 ± 96 | 91 | 15% | 0.003 | [34, 149] |
| Section 2 | 520 ± 70 | 619 ± 102 | 99 | 19% | 0.001 | [45, 152] |
| Section 3 | 503 ± 92 | 628 ± 98 | 125 | 25% | <0.001 | [70, 180] |
| Section 4 | 575 ± 107 | 715 ± 110 | 140 | 24% | <0.001 | [80, 199] |
| **Level 2** |  |  |  |  |  |  |  |  |
| Section 12 | 304 ± 73 | 350 ± 97 | 46 | 15% | 0.055 | [−1, 93] |
| Section 1 | 377 ± 91 | 454 ± 111 | 77 | 20% | 0.011 | [18, 136] |
| Section 2 | 372 ± 63 | 439 ± 83 | 67 | 18% | 0.005 | [21, 113] |
| Section 3 | 400 ± 60 | 466 ± 76 | 66 | 17% | 0.003 | [24, 107] |
| Section 4 | 445 ± 73 | 549 ± 89 | 104 | 23% | <0.001 | [58, 150] |

The difference in BMD between Control and Bump subjects are shown. \(P\)-values and the 95% confidence interval of the BMD differences between the groups are given (ANCOVA; see text for details).

The mean activity level based on UCLA score did not differ between Control versus Bump subjects (8.77 versus 8.96, \(P = 0.740\)). Correlations between UCLA and BMD, within the two groups, are represented in Table III and Fig. 2. In the Control group, no significant correlations could be found between acetabular or femoral BMD and UCLA scores (Table III). In the Bump group, there was a significant positive correlation between UCLA activity and femoral subchondral BMD. This correlation was found in sections 1 \((R = 0.506, P = 0.006)\) and 12 \((R = 0.457, P = 0.012)\) (Fig. 2A). On the acetabular side, significant correlations were found at section 12 of level 1 \((R = 0.398, P = 0.027)\) and level 2 \((R = 0.417, P = 0.021)\) and section 3 of level 2 \((R = 0.353, P = 0.045)\) (Fig. 2B).

**DISCUSSION**

FAI is strongly associated with the occurrence of degeneration of the hip joint [1]. Before osteoarthritis occurs, orthopaedic surgeons tend to treat the symptoms of early FAI damage (i.e. cartilage and labral damage) with hip arthroscopy. The number of hip arthroscopy procedures has significantly increased in recent years, with the majority of these patients between 20 and 39 years old [8, 16]. The question is, does this intervention prevent progression of degeneration in these hip joints or has the degeneration already started before the patient becomes symptomatic? Therefore, better insight into the pathomechanism of FAI is needed to be able to intervene (with surgery or lifestyle...
advice) before degeneration occurs. It is well-established that increased subchondral BMD leads to increased joint stresses [12, 17]. We hypothesized that the activity level alters the subchondral BMD of patients with FAI. Therefore, this study examines subchondral BMD and its correlation with UCLA activity in cam deformity FAI and Control subjects.

It was found that femoral and acetabular BMD were significantly higher in cam deformity subjects compared with Control subjects, which indicates subchondral stiffening. Based on the comparable demographics between the two groups similar subchondral BMD results were expected. Subchondral stiffening plays an important role in the osteoarthritic cascade, this might be an indication of pre-osteoarthritic changes [3]. Furthermore, the UCLA activity score showed a significant positive correlation with BMD in the cam deformity subjects in several impingement sections of femur and acetabulum. At the level of the acetabulum, the correlation between UCLA score and BMD was only significant at section 12 (Fig. 1), instead of the true impingement rim level. In the subjects without a cam deformity, no correlation between the UCLA score and BMD could be shown.

The contribution of vigorous activity to the development of FAI is widely accepted [18, 19]. In particular activities which involve repetitive flexion combined with internal rotation cause repetitive impingement between the femoral neck and anterosuperior acetabular rim. While the relationship between activity and BMD is widely analysed with respect to osteoporosis and aging, less is known about this relationship in a pre-osteoarthritic, cam deformed hip joint [20–22]. Physical activity plays an important role in skeletal health, as bone mass is responsive to mechanical loads placed on the skeleton [21, 22]. Activity level has

| Femoral head | Control R | Control R² | Control P-value | Bump R | Bump R² | Bump P-value |
|--------------|-----------|------------|-----------------|--------|---------|--------------|
| Section 12   | 0.300     | 0.090      | N/S             | 0.506  | 0.256   | 0.006        |
| Section 1    | 0.325     | 0.106      | N/S             | 0.457  | 0.209   | 0.012        |
| Section 2    | 0.280     | 0.078      | N/S             | 0.136  | 0.018   | N/S          |
| Section 3    | 0.346     | 0.120      | N/S             | -0.183 | 0.033   | N/S          |
| Section 4    | 0.281     | 0.079      | N/S             | 0.216  | 0.047   | N/S          |

P-values of significant correlations (P < 0.05) are given, otherwise noted as N/S.
been reported as a risk factor for the development of the cam deformity [19, 23]. In a cross-sectional study of young adolescents before and after physeal closure, Carsen et al. found that those with a higher activity level were at greater risk of having a cam deformity at the time of skeletal maturation [19]. A higher activity level in combination with a cam deformity likely leads to local mechanical joint overload over time [12, 24]. Besides the increased loading as a result of true impingement, a systematic review of finite elements studies shows that during a stand-to-sit activity elevated subchondral stresses are found in the whole cam deformity joint model, while control models showed normal stresses [17]. In previous studies from our group, it was found that having a cam deformity is also strongly correlated with increased BMD [10, 11]. This is in agreement with our results of higher subchondral BMD in our cam subjects. There is a strong clinical suggestion that this joint overload and subchondral stiffening is a substantial risk factor for early hip osteoarthritis however, literature cannot support this causality yet. Studies have shown that the severity of the cam morphology (as measured by the alpha angle) is a significant risk factor for the onset of hip symptoms [7, 8, 25, 26]. This does not explain how, in the face of the apparent similar mechanical effects due to the cam deformity, some cam deformity subjects remain asymptomatic. More research is needed to assess how the onset of hip symptoms interacts with the level and progression of osteoarthritic changes within the hip.

There are limitations to this study. The limited available outcome measures and demographics only allow to demonstrate a correlation between UCLA activity score and subchondral BMD. A cause–effect relation between activity and BMD cannot be proven without considering all influential factors on BMD. Furthermore one could argue that the measurement of activity as a risk factor for developing OA preferably needs a more detailed assessment instead of the UCLA activity score [27]. The UCLA activity score, however, is the most often used activity score and therefore allows the easiest comparison between studies. It also receives a positive rating for construct validity and good results for reliability [27] and has a strong positive correlation with average steps per day, which makes it a valuable tool to assess differences between the two groups in this study [28, 29]. Matheny et al. showed that the UCLA score was predictive for the age of having hip preservation surgery in hip dysplasia; patients with a higher UCLA score presented for surgery at a significantly younger age [30]. UCLA remains a general score which does not differentiate between high activities with repetitive impingement activities or without. There were no consecutive measurements.

Fig. 2. Pearson’s correlation results of Bump subjects in femur (A) and acetabulum (B). Correlation between BMD and UCLA are significant ($P < 0.05$) in the sections marked red. All other non-marked sections and all sections of the Control group did not show significant correlations.
for BMD and UCLA. As this study focused on comparison between groups and did not measure an intervention effect within groups, we assumed that a single measurement represents a true representation of BMD and UCLA and allows a reliable comparison. Another limitation is the relatively small number of subjects making it difficult to establish cut-off values for BMD in regard to what defines normal versus abnormal. As subjects are expected to exhibit individual BMD differences, BMD within the spine was included as a covariate to minimize this influence. Consequently, using these corrected measures reflects the influence of the mechanical impingement on the bone and cartilage status.

This study shows an association between activity level and BMD in cam deformity patients. Although this study does not provide a cause–effect relationship, activity level might be associated with the subchondral stiffening of a cam deformed hip joint. Stronger evidence is needed to determine the right moment and the right intervention to prevent rather than palliate cam-induced degeneration.

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CONFLICT OF INTEREST STATEMENT

None declared.

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