Three-dimensional computed tomography of the hip in the assessment of femoroacetabular impingement

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Abstract

Femoroacetabular impingement secondary to the cam effect is thought to be associated with an insufficient anterior concavity in the sagittal/axial plane of the femoral head-neck junction. Using three-dimensional computed tomography the anterior and posterior concavity of the femoral head-neck junction was assessed in 36 painful non-dysplastic hips (30 patients). The mean age of the symptomatic hips was 40.7 with 13 females and 17 males. Eighteen out of the 36 hips had a pistol grip deformity. Magnetic resonance gadolinium arthrography was performed to assess for labral and cartilage lesions. Alpha and beta angles measuring the anterior and posterior femoral head-neck junction concavities were also determined in 20 asymptomatic hips (12 patients; mean age 37, 5 females and 7 males) using three-dimensional computed tomography. The mean alpha angle for the symptomatic and the control group were: 66.4 versus 43.8 ($p = 0.001$), and for the beta angle 40.2 versus 43.8 ($p = 0.011$), respectively. All but one of the symptomatic hips had a labral tear with 61% of these hips having associated cartilage damage. Three-dimensional computed tomography represents an accurate tool to quantify the femoral head-neck concavity providing a non-invasive assessment of hips at risk of femoroacetabular impingement.

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Keywords: Three-dimensional computed tomography; Femoroacetabular impingement; Alpha angle and labral tears

Introduction

The most commonly used tools to investigate the young adult with hip pain are plain radiographs, magnetic resonance imaging and less commonly computed tomography. Since the introduction of gadolinium magnetic resonance arthrography [22] and newer techniques such as radial imaging, magnetic resonance imaging (MRI) is now commonly used in the evaluation of the painful non-arthritic hip [7,30]. One example is its use in the assessment of femoroacetabular impingement [13,28] associated with the cam-effect. This deformity is felt to be secondary to a lack of offset or absence of concavity on the anterior aspect of the femoral head-neck junction [8,28]. Although long recognized on the antero-posterior and frog lateral radiographs under various terminologies such as tilt [27], pistol grip [38] or subclinical slip [10], historically there has been no standardized means of quantifying this deformity. The main reason for this has become evident. Several investigators have now documented that the impingement abnormality is in the sagittal/axial plane [10,13,28,40] which can
be overlooked when viewed by standard radiographic projections in the frontal/oral plane.

Consequently it is only recently with sophisticated magnetic resonance imaging techniques [13,28] that efforts at quantifying this deformity have been successful. Although effective in this new application, MRI does not allow soft tissue transparency around the bone limiting the ability to provide a global visualization of the bony contour. In contrast, computed tomography does not require the injection of an intra-articular dye or the use of an Auto-CAD workstation [13] and is already well established in quantifying bony abnormalities of the hip joint [6,31,32] with an accuracy of 1–4.5° [1,6]. Computed tomography is minimally affected by patient positioning on the gantry or experience of the technologist, thus permitting the acquisition of reproducible images between patients. However, conventional two-dimensional computed tomography imaging are deficient in displaying subtle contour deformities arising on the periphery of the femoral head–neck junction and has inherent limitations in establishing the femoral head–neck axis [1]. More recently, multi-dimensional image post-processing has been introduced with the added advantage of facilitating determining the femoral neck axis [18] and permitting a better appreciation of bony contours in multiple planes [1]. By using radial multi-planar reformation and surface shaded display techniques which rotates the femur using the neck as a standardized axis of rotation one can view the anterior contour of the femoral head–neck junction in relation to the neck axis. These advancements make it possible to overcome the possible influences of varus or valgus angulations as well as anteverversion of the femoral neck in order to attain a more standardized perspective of the head–neck contour. To our knowledge, three-dimensional computed tomography has yet to be applied in the assessment of the concavity of the femoral head–neck junction in hips at risk of femoroacetabular impingement.

The purpose of this study was to develop and evaluate the capacity of three-dimensional computed tomography to assess the anterior and posterior concavities of the femoral head–neck junction in painful non-dysplastic hips.

**Materials and methods**

Thirty-six hips in 30 consecutive patients represent our study group. All of these patients presented with the following conditions: persistent hip pain for greater than 3 months duration, a positive impingement sign [8,15] with minimal response to non-operative management and normal appearing acetabulum, absence of acetabular dysplasia (center edge angle > 22°), protrusio or retroversion [33,36] or significant arthritis (≥ 2 on Kellgren’s scale [14]). In addition to a standard anteroposterior pelvic and frog lateral radiograph, magnetic resonance arthrography with gadolinium enhancement (MRA) [22] was performed to assess for labral and/or cartilage damage [35]. Pelvic computed tomography with multi-planar reformation was performed to measure contour at the anterior femoral head–neck junction.

The mean age for our symptomatic group was 40.7 years old, range 25–54, which consisted of 13 females and 17 males. One male patient had a history of slipped capital femoral epiphysis as a child treated in traction. One another patient had a previous hip arthroscopy. A recent traumatic event was recorded in 3 patients with the others recalling no specific event with the pain described as gradual in onset. Only two patients had evidence of arthritis on the contralateral side (Fig. 1).

**Three-dimensional computed tomography**

The hips were scanned with the patient supine by helical technique with 3 mm collimation and a 2 mm reconstruction interval using the General Electric (Milwaukee WI) Hi Speed CT/I single detector gantry. Images were transferred by intranet to the TerraRecon Aquarius three-dimensional graphic workstation (TeraRecon Inc., San Mateo, CA). The images were loaded into a three-dimensional surface rendering of the bony pelvis and the backboard of the gantry was subtracted by free hand region of interest masking. The workstation was used to create three-dimensional surface rendered and two-dimensional reformations of the hip. The three-dimensional surface rendered image of the pelvis was initially viewed from the lateral perspective of the hip. The model was then obliquely turned to look down the barrel of the femoral neck while keeping the neck in the center of the field of view. The bone of the femoral shaft and intertrochanteric region were removed using the cut plane tool of the workstation, to visualize a 15–20 mm section of the neck at the head–neck junction. By this maneuver, corrections were made for the double oblique orientation of the femoral neck in the frontal and sagittal planes. The cut plane of the reconstruction was restricted to 15–20 mm showing the area of transition between the femoral head and neck. By using the neck as the axis of rotation, the femoral head–neck contour transition was treated as an independent variable. In practice, the femoral head and acetabulum should not be specifically accommodated when determining the rotational axis, as the head will not be collinear with the neck in certain individuals, which was the case for one patient with history of slipped capital femoral epiphysis (Fig. 2).

With the rotational axis determined, the cut plane width was then restored to full viewing the entire scan volume of the hip bony context. The model was then loaded into the two-dimensional batch reconstruction mode with the workstation set to render radial reconstructions across the femoral neck axis using an arc of 180° and rendering 50 slices. The auto-flip option was deslected to avoid sudden changes in the display orientation of the reformation. The renderings were...
created as two-dimensional multi-planar reformations of 10–20 mm thickness, or Raysum reformations of 10–60 mm (average 30–50) thickness. The images were saved to DICOM digital output and archived within GE Centricity PACS (General Electric, Milwaukee, WI). At either the Aquarius workstation or the Centricity PACS workstation, an anterior facing para-axial section was selected using the reference box as the guide for the spatial orientation (Fig. 3). The contour of the femoral head was then overlaid with a perfect circle centered over the head and the neck axis was defined as a line parallel to the anterior femoral neck cortex joining the center of the circle overlaid over the head and the neck axis was defined as a line parallel to the anterior femoral neck cortex joining the center of the circle overlaid over the femoral head (Fig. 4). The alpha angle as described by Nötzli [28] was drawn from the center point of the femoral head to the anterior edge of the femoral neck where the edge of the anterior cortex exceeded the radius of the femoral head. In this manner a numerical description of the anterior concavity was created that allowed comparison of normal hips with abnormally contoured hips using a standardized methodology. The posterior concavity of the hip was also measured using the same image and head diameter, and termed the beta angle. The point where the posterior femoral neck surface intersected the head radius was chosen. A larger angle for either the alpha or beta corresponded to diminished concavity or lack of offset at that head–neck junction. All measurements were done by one board certified radiologist experienced in musculoskeletal imaging and three-dimensional rendering technique.

The same alpha and beta measurements were made in a control group of normal asymptomatic patients with IRB approval for retrospective review. This group consisted of randomly selected patients who had a thin section pelvic computer tomography (5 mm slice of thickness or less) at our institution for other medical reasons. Patients with hip osteoarthritis and synovial pit formations were excluded from the control population. This group consisted of 12 patients (20 hips), 7 males and 5 females with a mean age of 37 (18–70). Alpha and beta angles for controls were performed at the Aquarius workstation as described above for the patient group.

**Magnetic resonance imaging with gadolinium arthrography**

Magnetic resonance imaging with gadolinium arthrography (MRA) was performed using the Siemens (Erlangen Germany) 1.5 Tesla Sonata MRI scanner using a technique previously described [3]. The hip was injected from the anterior approach using sterile technique and fluoroscopic guidance to localize the femoral neck. Para axial, para coronal, and para sagittal fat saturated images were obtained using the spine and body array coils. Gradient echo 2D FLASH T1W images were obtained using TR = 701 ms, TE = 11 ms; flip angle 60, 256 x 100 matrix; 3 mm slice thickness and one excitation using a 200 mm field of view. The criteria of Schmid [35] and Leunig [22] were used to diagnosis cartilage and labral lesions.

**Statistical analysis**

The inter- and intra-observer reliability of the alpha angle measurement was tested with two radiologists one with experience with three-dimensional computer tomography (observer 1) and the other recently
trained in the technique of three-dimensional computed tomography (observer 2). Values of 0.00-0.20 represent slight agreement, 0.21-0.40 fair agreement, 0.41-0.60 moderate agreement, and 0.61-0.80 substantial agreement. Above 0.80 is considered almost perfect agreement. Most clinical measures fall into the "moderate" agreement range [16,17,19].

Since angles have limited ranges we used the parametric Student t-test when comparing both groups' three-dimensional computer tomography measurements. Standard deviations were also calculated (SD). The association between variables was tested using the Pearson correlation coefficient after a normal distribution was confirmed. Ninety-five percent confidence intervals were provided.

Results

Alpha and beta angle

The mean alpha angle was significantly greater in the symptomatic group: 66.4 (39–94) SD ± 17.2 and 43.8 (39.3–48.3) SD ± 4.46 for the control group (p = 0.001). The mean beta angle was significantly smaller in the symptomatic group compared to the control group: 40.2 (SD ± 5.4) versus 43.8 (SD ± 3.9) respectively (p = 0.011). In the symptomatic group, an increasing alpha angle was not associated with a decreasing beta angle (r = 0.11). For the alpha and beta, the greater the angle the less concavity/offset and vice versa (Tables 1 and 2). The alpha to beta ratio was significantly greater in the symptomatic group compared to the control group: 1.68 (SD ± 0.51) and 1.01 (SD ± 0.13), respectively (p = 0.001). To examine if the alpha/beta ratio was more sensitive than the alpha angle alone in diagnosing hips at risk of impingement, we used a ratio greater than 1.25 as our cutoff. The cutoff of 1.25 was chosen in order to have 100% specificity as was the case in using a cutoff value of >50.5 [28] for the alpha angle when comparing controls and symptomatic. Twenty-nine out of the 36 hips had a ratio greater than 1.25 compared to 26 out of 36 hips with an alpha angle >50.5, giving a sensitivity of 81% compared to 72%, respectively (95% Confidence interval: -12% to 30%). This means that the use of the alpha angle alone might have a sensitivity up to 12% more than the ratio; while the ratio alone might have a sensitivity up to 30% more than the alpha angle. This difference was not significantly different (p = 0.12).

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<tr>
<td>Mean (SD)</td>
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<td>66.4 (17.2)</td>
<td>1.68 (0.51)</td>
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There was no correlation between age and the alpha angle ($p = 0.268$). The males had a significantly greater alpha angles than the females in the symptomatic group: 73.3 versus 58.7 ($p = 0.009$) but not in the control group: 43.7 versus 43.8 ($p = 0.22$). The alpha angles in the symptomatic females were significantly greater than in the control females ($p = 0.01$).

The inter-class correlation coefficient of reliability was 0.60 (moderate agreement). The intra-class correlation was 0.80 and 0.54 for observers 1 and 2.

**Prevalence of acetabular labral and cartilage lesions on MRI**

Thirty-five out of the 36 hips had a labral tear (in two of these the labrum was calcified); cartilage lesions (ulcerated or delaminated) were present in 13 hips. At the time of surgical intervention in 21 patients (23 hips), the majority of labral tears and cartilage damage were located in the antero-superior quadrant that is from the 12 to 2 o’clock position (Fig. 5). All tears were confirmed and all but one cartilage lesion was present at the time of surgery.

**Discussion**

Femoroacetabular impingement can either result from an over-coverage of the acetabulum [36] as in cases of acetabular retroversion diagnosed on anteroposterior pelvic radiograph [33], or secondary to an insufficient femoral head-neck offset. As reproduced in this study and described by others [8, 13], the lack of offset between the femoral head and neck is on the anterior and anterolateral surfaces. The impingement is anatomically related to the difference between the maximal anterior radius of the head-neck junction and the radius of the acetabulum. The repeated contact of the femoral head-neck junction within the acetabulum leads to shearing of the labrum and adjacent acetabular cartilage from the underlying subchondral acetabular bone leading to delamination [5, 20]. The location of the damage is constantly seen along the anterior superior rim of the acetabulum where the femoral head-neck junction impacts.

Notzli [28] using tilted para-axial magnetic resonance imaging defined an alpha greater than 50° as potentially abnormal with the alpha angle for the symptomatic and control group measuring 74° and 42°, respectively. Our findings using three-dimensional computed tomography have closely reproduced Notzli’s data, adding validity to the alpha angle measurement for diagnosing femoroacetabular impingement secondary to a deficient anterior femoral concavity. Our data also validate three-dimensional pelvic computed tomography as an efficient non-invasive means of assessing the contour of the head-neck junction. However because there was only moderate agreement between the observers, it is preferable to have the measurements performed by one experienced radiologist.

Unlike Notzli [28], we did not use range of motion as a screening tool in assessing patients for the measurement of the alpha angle explaining why some of our patients had an alpha angle less than 50.5°.

What is also interesting is that most of the patients also had an associated labral and/or cartilage lesions in the anterior superiorlateral quadrant of the acetabulum which Siebenrock [36] also reported in anterior femoroacetabular impingement secondary to acetabular retroversion. While acetabular labral tears have been commonly associated with acetabular dysplasia [22] or a traumatic event [29], our study as well as others [13,22] illustrate the important prevalence of abnormality of the waist of the femoral head and neck in association with
labral pathology. This is especially important when one considers joint preserving procedures such as hip arthroscopy [4] and the potential to intervene in the development of hip arthritis, where tears of the labrum have long been suspected of being within the continuum leading to arthritis [2,12,24,39].

The lack of femoral head–neck offset has been long recognized in the frontal plane as the “pistol grip” deformity characterized by a flattening of the anterolateral aspect of the femoral neck area [38]. Its relationship to hip osteoarthritis has long been postulated [27] and felt by Harris to be present in 40% of cases of so-called idiopathic arthritis [11]. These findings were reaffirmed more recently by Goodman and associates [10] where a lack of concavity at the anterior/anterolateral aspect of the head and neck was associated with a higher risk of developing of hip arthritis before the age of 55. As part of the deformity, they noted that, with a decreased concavity at the anterior head–neck junction, there was a reciprocal increase in the posterior concavity of the head–neck junction which Stulberg also described with the pistol grip deformity [38]. The use of three-dimensional computed tomography has permitted the quantification of this deformity, however we did not find a significant relationship between an increasing alpha angle and decreasing beta angle. Although this does not exclude the possibility of a silent disruption of the proximal epiphysis of the femur as a plausible cause for the development of this femoral head–neck abnormality in some individuals, other mechanisms such an abnormal epiphyseal extension may be more prevalent [37]. We must also stress that femoral anteverision was not evaluated in our study, and, as in the study by Notzli et al. [28] our focus was the concavity/waist of the femoral head–neck junction. Others however have shown that decreased femoral anteversion can be associated with impingement [13] and the development of hip arthritis [39].

Three-dimensional computed tomography represents an accurate tool to assess abnormalities of the femoral head–neck junction with moderate reliability and which can easily applied in most institutions using commonly available post-processing workstations. In addition, computed tomography with three-dimensional surface rendering provides a virtual reality confirmation of the offset deformity for both the surgeon and patient which is very difficult with two-dimensional reconstruction. Although the measurement technique described here used the Terarecon workstation, other workstations available through Seimens or General Electric have the capacity for radial reformation once the femoral neck is placed as the center of rotation. How this is achieved is workstation dependent, but in general, for the Teracon and G.E. Advantage workstations, it is necessary to manually rotate the CT volume of acquisition so that the user looks down the barrel of the femoral neck. In the future, the capacity to easily visualize the impinge-

ment area of the head–neck junction could permit simulation of joint motions and provide a better understanding of this potential of hip pain and could also permit a real time visualization of impinging areas [34]. More information is needed to define plain radiographic measurements such as those used to define acetabular dysplasia [21,23,25,26] in order to properly diagnosis femoroacetabular impingement and provide appropriate treatment.

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References


