ANATOMIC STUDY OF THE PROXIMAL THIRD OF THE FEMUR: FEMOROACETABULAR IMPACT AND THE CAM EFFECT

Pedro José Labronici[1], Sergio Delmonte Alves[2], Anselmo Fernandes da Silva[3], Gilberto Ribeiro Giuberti[3], Rolix Hoffmann[4], Justino Nóbrega de Azevedo Neto[4], Jorge Luiz Mezzalira Penedo[5]

ABSTRACT

Objective: To analyze anatomical variations of the proximal end of femur that could cause a femoroacetabular impact. Methods: 199 skeletally mature anatomical specimens of femurs were used. The femurs were measured in order to determine the anteversion angle of the femoral neck, neckshaft angle, sphericity of the femoral head at anteroposterior and superoinferior, angle between epiphysis and the anterior femoral neck, angle between epiphysis and the neck at lateral plane, anteroposterior distance at 5mm of the head and neck junction and anteroposterior distance of the neck base. Results: we found that the impact subgroup presented a significantly larger junction diameter of 5mm (p = 0.0001) and cam-head (%) (p= 0.0001), while base-cam (%) (p = 0.0001) showed a significantly smaller diameter than the subgroup without impact. It was identified that cam-head (%) $\geq$ 80 e base-cam (%) $\leq$ 73 were identified as the optimal impact points. Conclusion: our study showed that the effect cam, caused by anatomical variations of the proximal femoral end focused the head-neck junction and base of the neck-junction head-neck. These rates can be predictive factors of the impact.

Keywords – *Osteoarthritis, hip; Hip joint/pathology; Femur*

INTRODUCTION

Primary osteoarthritis of the hip, also known as idiopathic, may be secondary to mechanical causes. It is most commonly caused by femoroacetabular impact in the final stages of osteoarthritis in the hips of both males and females[1,2]. In hips with no dysplasia, the cause of hip osteoarthritis has been suggested to be repetitive microtrauma in the region of the femoral head and neck against the acetabular rim[3]. This leads to the cam effect, in which the region between the increased femoral head and neck collides with the edge of the acetabulum. Several authors have cited the relationship between hip osteoarthritis and the deviation of the femoral head, called the pistol-grip deformity, and decreased femoral neck anteversion[4-7]. In these circumstances, the reduction in space may impact during flexion, and particularly during internal rotation. These findings can be seen on true anteroposterior and lateral radiographs[8]. This was demonstrated in the slippage of the proximal femoral epiphysis when a posterior displacement of the femoral head occurs and in cases of femoral neck fracture consolidation with mild rotation deformity[7,9]. The objective of this study was to analyze changes in the femoral neck in anatomical specimens that could indicate the femoroacetabular impact or cam effect. This study protocol was approved by the Ethics Committee of the Faculdade de Medicina de Petrópolis.

METHODS

One hundred and ninety-nine femurs were used from the Faculdade de Medicina de Petrópolis, RJ.

1 – Doctor of Medicine, Universidade Federal de São Paulo, Escola Paulista de Medicina; Head, Dr. Donato D'Ângelo's Orthopedics and Traumatology Clinic, Hospital Santa Teresa, Petrópolis, RJ, Brazil.
2 – Attending Physician, Hip Group, Dr. Donato D'Ângelo's Orthopedics and Traumatology Clinic, Hospital Santa Teresa, Petrópolis, RJ, Brazil.
3 – Resident, Orthopedics and Traumatology, Dr. Donato D'Ângelo's Orthopedics and Traumatology Clinic, Hospital Santa Teresa, Petrópolis, RJ, Brazil.
4 – Resident, Hip Group, Dr. Donato D'Ângelo's Orthopedics and Traumatology Clinic, Hospital Santa Teresa, Petrópolis, RJ, Brazil.
5 – Assistant Physician, Hip Surgery Group, National Institute of Traumatology and Orthopedics (INTO, Instituto Nacional de Traumatologia e Ortopedia), Rio de Janeiro, RJ, Brazil.

Study conducted at Dr. Donato D'Ângelo's Orthopedics and Traumatology Clinic, Hospital Santa Teresa, Petrópolis, RJ, and Faculdade de Medicina de Petrópolis, Petrópolis, RJ, Brazil.
Correspondence: Av. Roberto Silveira, 187, apt. 601 – 25685-040 – Petrópolis, RJ. Tel.: (24) 2242-5571. E-mail: plabronici@globo.com

Femurs with prior deformities, or signs of fracture or wear on the femoral head were excluded. One hundred and three of the anatomical specimens were from the right side and 96 were from the left. The femurs were measured to determine the angle of femoral neck anteversion (FNA), cervico-diaphyseal angle (CD), sphericity of the femoral head from the anteroposterior and superior-inferior, the angle between the epiphysis and the anterior femoral neck, the angle between the epiphysis and the neck in profile, the anteroposterior distance 5mm from the junction of the head and neck, and the anteroposterior distance from the base of the neck. All these distances and angles were measured with a caliper and goniometer. Table 1 provides the means, standard deviations (SD), medians, and minima and maxima of the measurements and angulations of the femora of the total sample.

The anatomical specimens were separately analyzed by three evaluators to observe the frequency of impacted bone according to the evaluator and the number of evaluators. Tables 2 and 3 show the frequency (n) and percentage (%) of impacted bone by evaluator and number of evaluators, respectively.

Table 1 – Overview of the measurements and angulations of the femora.

Variable	n	Mean	SD	Median	Minimum	Maximum
FNA angle	199	10.8	5.8	10	-2	32
CD angle	199	127.0	6.0	128	110	145
AP sphericity	199	44.0	3.3	44	33.5	54
SI sphericity	199	43.5	3.5	44	33	54
5 mm diameter head-neck junction	199	33.1	4.0	34	23	42
Diameter base-neck	199	25.6	2.4	25	19.5	34
Head-neck AP angle	199	95.0	7.5	94	78	121
Head-neck profile angle	199	93.0	6.9	92	75	118

SD – Standard deviation
Source: Faculdade de Medicina de Petrópolis

Table 2 – Frequency of impacted bone according to the evaluator.

Evaluator	n	%
1	23	11.6
2	45	22.6
3	55	27.6

Source: Faculdade de Medicina de Petrópolis

Table 3 – Frequency of impacted bone according to the number of evaluators.

Impacted bone	n	%
No impacted bone	119	59.8
By one evaluator	48	24.1
By two evaluators	21	10.6
By three evaluators	11	5.5

Source: Faculdade de Medicina de Petrópolis

Statistical Methodology

Statistical analysis was performed using the Mann-Whitney test to test for differences in the measurements and angulations of femurs between two subgroups, with and without impacted bone, according to three evaluators. A nonparametric test was used since the measurements and angulations did not have a normal distribution (Gaussian distribution) due to the dispersion of data and/or lack of symmetry of the distribution. The criterion for determining significance was set at 5%.

RESULTS

This study aimed to draw a general profile of 199 femurs. The percentages between the cam and the head, the base of the femoral neck and the cam, and the base of the femoral neck and head are shown in Table 4, in Figures 1 (a and b) and 2 (a and b).

Our second objective was to test for significant differences in the measurements and angulations of femurs between subgroups with and without impacted bone. The classification of impacted bone was calculated using three criteria:

– Impact- 1: at least one evaluator described the presence of impacted bone (80 bones);

– Impact- 2: at least two evaluators described the presence of impacted bone (32 bones);

– Impact- 3: all three evaluators described the presence of impacted bone (11 bones).

We use the impact - 2 classification where two evaluators reported the presence of impacted bone in the same anatomical specimen.

Table 5 provides the mean, standard deviation (SD), median, minimum and maximum measurements and angulations of the femurs, according to the subgroup (with and without impacted bone) and the corresponding descriptive level (p) of the Mann-Whitney test for impact-2.
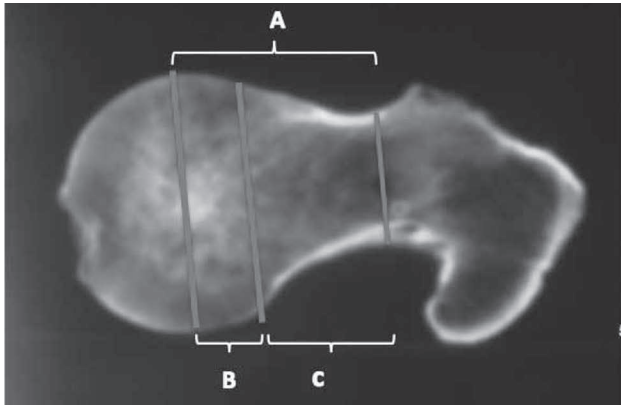
Figure 1a – Tomographic slice of a specimen with anterior impacted bone, where A: head and base of the femoral neck; B: head and cam, and C: base of the femoral neck and cam.

Figure 1b – Photograph of the same specimen.

Figure 2a – Tomographic slice of a specimen without anterior impacted bone, where A: head and base of the femoral neck; B: head and cam, and C: base of the femoral neck and cam.
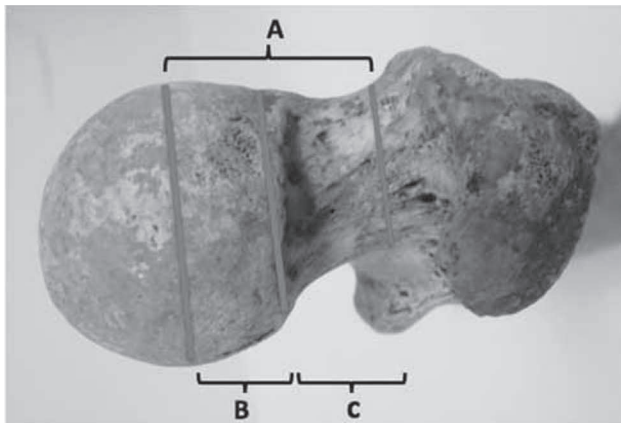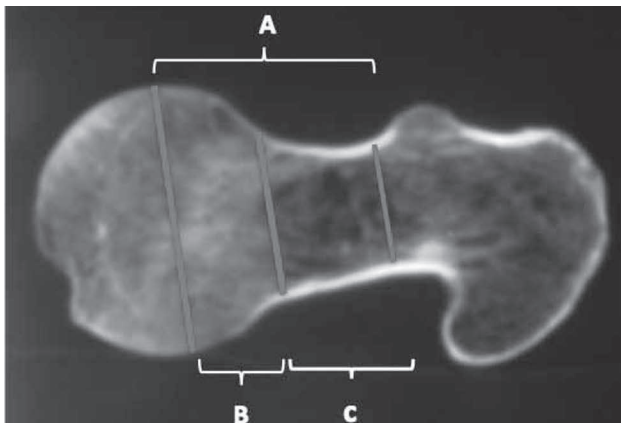
The impacted bone subgroup was observed to have an SI sphericity (p = 0.040), a diameter of 5 mm (p = 0.0001) and a significantly larger cam-head (%) (p = 0.0001) and a significantly smaller base-cam (%) (p = 0.0001) than the subgroup without impact-2. There is no difference at the 5% significance level between the two subgroups for the other measures studied.
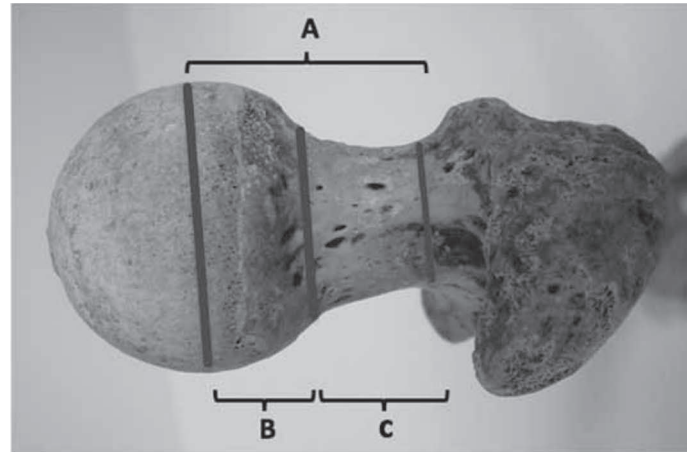
Figure 2b – Photograph of the same specimen.

Table 4 – Description of the ratios between the variables.

Variables	n	Mean	SD	Median	Minimum	Maximum
CAM – HEAD (%)	199	75.3	6.9	76	57.5	92.2
BASE – CAM (%)	199	77.8	7.7	78.3	58.8	96.2
BASE – HEAD (%)	199	58.2	4.4	57.8	44.7	72.7

SD = Standard deviation
Source: Faculdade de Medicina de Petrópolis

Our third objective was to identify the optimal cut-off point for the 5 mm diameter to the head-neck junction, cam-head (%) and base-cam (%) related to impact. The ROC (receiver operator characteristic) curve expresses the relationship between sensitivity and specificity, and can be used to choose the best cut-off point. In this study sample, according to the ROC curve, we found that 5 mm diameter to the head-neck junction ≥ 35.5, cam-head (%) ≥ 80 and base-cam (%) ≤ 73 were the optimal points for the impact according to criterion 2.

Table 6 provides measurements accuracy for the cut-off of 5 mm diameter to the head-neck junction, cam-head (%), and impact.

DISCUSSION

The measures tested here had as their main objective to identify and quantify the abnormal contour of the head-neck junction and the possible variations observed between the femoral head and neck. Using these measures, differences were observed between groups with and without changes in the anterior region within the head and neck junction.

Abnormalities within the head-neck junction in skeletally mature individuals have been associated

Table 5 – Statistical analysis of measurements and angulations of femurs according to impact-2.

Variable	Impact-2	n	Mean	SD	Median	Minimum	Maximum	p
FNA angle	yes	32	12.1	5.9	10	2	28	0.25
	no	167	10.6	5.8	10	-2	32	
CD angle	yes	32	128.3	5.6	128	111	140	0.20
	no	167	126.8	6.1	128	110	145	
AP sphericity	yes	32	45.0	2.3	45	40	50	0.058
	no	167	43.8	3.4	44	33.5	54	
SI sphericity	yes	32	44.5	2.9	45	38	50	0.040
	no	167	43.3	3.6	44	33	54	
5 mm diameter head-neck junction	yes	32	37.0	2.8	37	30	42	0.0001
	no	167	32.4	3.8	32.2	23	40	
Diameter base-neck	yes	32	26.3	2.7	26	19.5	34	0.054
	no	167	25.4	2.3	25	20	32	
Head-neck AP angle	yes	32	93.2	8.9	93	80	121	0.18
	no	167	95.3	7.2	94	78	116	
Head-neck profile angle	yes	32	91.6	8.0	93	75	108	0.45
	no	167	93.3	6.6	92	76	118	
Cam-head (%)	yes	32	82.3	4.8	82.6	69.8	92.2	0.0001
	no	167	74.0	6.5	73.9	57.5	89.5	
Base-cam (%)	yes	32	71.1	6.3	68.4	60.2	87	0.0001
	no	167	79.1	7.2	79.4	58.8	96.2	
AP/SI	yes	32	1.013	0.037	1	0.978	1.158	0.48
	no	167	1.012	0.030	1	0.950	1.158	
Base/Head (%)	yes	32	58.4	4.3	57.3	45.3	68	0.91
	no	167	58.2	4.4	58	44.7	72.7	
SD: Standard deviation								

Source: Faculdade de Medicina de Petrópolis

Table 6 – Measures of accuracy of 5 mm diameter to the head--neck junction, cam-head (%), and base-cam (%) for the classification of impact.

Measure	Sensitivity (%)	Specificity (%)	+PV (%)	-PV (%)	Accuracy (%)
5 mm diameter ≥ 35,5	71.87	76.05	36.51	93.38	75.38
Cam-head ≥ 80%	78.12	81.44	44.64	95.10	80.90
Base-head ≤ 73%	71.87	76.65	37.10	93.43	75.88

+PV: positive predictive value
-PV: negative predictive value
Source: Faculdade de Medicina de Petrópolis

with osteoarthritis of the hip[4,6,7,10,11]. As long as patients have no history of hip disease, the etiology of the deformity remains uncertain, but several researchers have linked subclinical displacement of the femoral epiphysis with the risk of osteoarthritis[5,7,11,12]. Stulberg et al.[11] introduced the term pistol-grip deformity to describe the radiographic appearance of the abnormal head-neck in the anteroposterior view. They noted that this deformity is found predominantly in active males and is present in many patients with so-called idiopathic arthritis, but did not, however,

elucidate the pathological mechanism involved. Goodman et al.[7] showed that the main deformation in the subclinical displacement of the femoral epiphysis is in the sagittal plane, predominantly anterior, and that without a quantitative or objective definition, descriptions such as pistol-grip and post-slip cannot be used to determine the severity of the deformity or to distinguish normal from pathological forms. In our study, of the 199 anatomical specimens analyzed, no significant deviation was found between the femoral head and neck that would justify anterior impact and therefore be the main factor in the development of osteoarthritis.

Crestani et al.[2] demonstrated that the axis of the femoral neck clearly shows how changes in its contour can affect the function of the articular surface of the femoral head. Enlargement of the anterior neck reduces the anatomic concavity of the neck, which may cause impact. To date, an acceptable method for identifying hips that are at risk or criteria demonstrating the abnormal relationship between the head and neck have not been defined. Lateral radiographs are

used to quantify the offset of the anterolateral portion in the cephalocervical-femoral junction and to assess the sphericity of the femoral head[13]. Meyer et al.[14] concluded that the Dunn view with 45° and 90° and lateral cross-table view are more accurate for this evaluation. The offset is measured in the cross-table view using the method described by Eijer et al.[15]. Murray[5] used anteroposterior radiographs to characterize the tilt deformity of the femoral head. He drew a line in the axis of the femoral neck using the midpoint between the trochanter and the narrowest portion of the femoral neck as demarcations and then calculated the ratio of the femoral head, dividing the width of the head by the axis. The critique of this technique is that it did not distinguish between standards for a normal and abnormal femoral head-neck junction. In their technique, Nötzli et al.[16] used magnetic resonance imaging to draw a line in the narrowest region of the femoral neck to the center of the femoral head. After the anterior margin is defined, it is measured by the alpha angle. In addition, the width of the head-neck junction is measured in two different places. Using this technique, they demonstrated that there was significantly less concavity at the femoral head-neck junction in patients with impacted hips than in normal hips[16].

Our results demonstrated that in the 199 anatomical specimens, the subgroup classified as having impacted bone had 5 mm diameter to the head-neck junction (p = 0.0001) and significantly higher head-neck percentage (p = 0.0001), than the group without impacted bone.

In this sample, we also observed that, according to the ROC curve, the specimens with a ratio of 80% or more to the head-neck and a ratio of 73% or less between the head-neck junction and the base of the femoral neck present the possibility of developing an impacted femur.

CONCLUSION

Our study showed that the cam effect, caused by anatomical variations of the proximal femur, was localized at the head-neck junction (%) ≥ 80 and the base of the neck and head-neck junction (%) ≤ 73. These indices may be predictive factors of impacted bone.

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