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# Computed Tomography: Role in Femoroacetabular Impingement

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Additional information is available at the end of the chapter

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## Abstract

Femoroacetabular impingement (FAI) physiopathology is still unclear; however, there is a consensus that a pathological mechanical contact between the femoral neck-head junction and the acetabulum leads to pain and cartilage damage. Computed tomography (CT) is useful in FAI diagnosis and surgical planning. In the present chapter, we will analyze the role of CT in FAI, with special emphasis on alignment and comparison of measurements related to epidemiological variables. We analyzed 101 CT of patients that consulted in our institution for a non-joint-or-bone-related reason. Prior to the measurement of acetabular variables, CT image must be corrected in three planes. Acetabular version is a gender- and age-related measurement. As age increased, acetabular version increased, and the same impact age has on Wiberg angle. Femoral FAI-related measurement is not related to epidemiological variables. CT has a very important role for a better understanding of hip anatomy, and further research using CT images should be encouraged.

**Keywords:** femoroacetabular impingement, computed tomography, femoral alpha angle, acetabular version angle, Wiberg angle

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## 1. Introduction

Femoroacetabular impingement (FAI) is a relatively new pathology, described in the early 1990s. FAI physiopathology is still unclear; however, there is a consensus that a pathological mechanical contact between the femoral neck-head junction and the acetabulum leads to pain, microinstability, joint cartilage damage and labrum tear. FAI diagnosis should be based on clinical evaluation and subsequent appropriate radiological confirmation that aim to detect excessive femoral head coverage (pincer-type) and/or insufficient femoral head-neck offset hip (cam-type) [1–3].

Computed tomography (CT) is a very useful tool in the diagnosis and surgical planning for FAI; however, normal values have not been still defined and lesser is the relation of these measurements according to gender, age weight and height [4–6].

In the present chapter, we will analyze the role of CT in FAI, with special emphasis on alignment and comparison of measurements related to gender, weight, height and age.

## 2. Methods

We analyzed 101 CT of patients that consulted in our institution for a non-joint-or-bone-related reason and who required an abdominal and pelvic CT for diagnosis. Before enrollment, volunteers completed a questionnaire, which included asking for current or historic hip-related pain and hip surgery. Positive answers led to the volunteers being excluded from the study.

In this population of 101 patients, we will perform an analysis regarding different situations related to femoroacetabular impingement in which CT has a fundamental role.

The images were obtained using a Siemens Multicut Computerized Tomography Machine, a model of Somaton Sensation 64®. In the study, a protocol of 1.5-mm cuts for every 0.3 mm was used, information that was later processed to 3-mm multiplanar reconstructions in bone window and 3D reconstructions, processed with 3D and INSPACE®, respectively.

## 3. CT radiological measures related to FAI

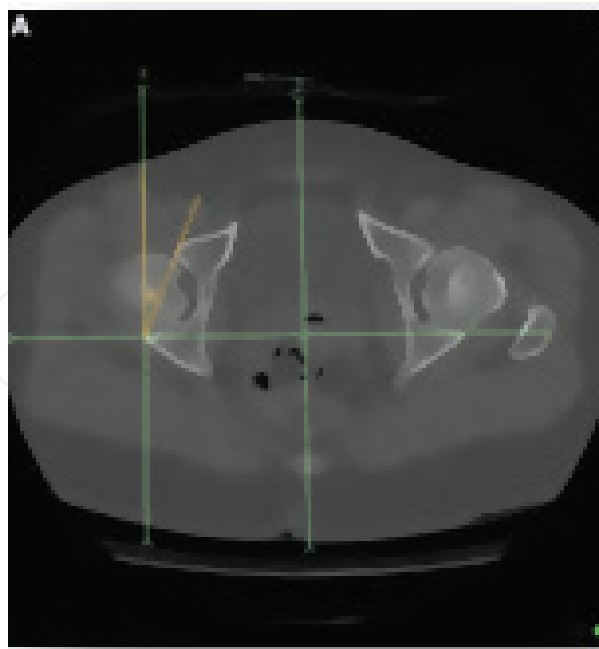
### 3.1. Acetabular version

The acetabular version is described as the acetabular orientation regarding the sagittal plane. It is considered normal that the acetabulum has an anterior orientation called anteversion [7].

The measurement is performed in an image obtained in CT in axial reconstruction. The angle is measured by drawing a line from the anterior border to the posterior border of the ipsilateral acetabulum and another vertical line which runs from the posterior edge of the acetabulum and is tangential to a horizontal line joining the posterior edges of the acetabulum (**Figure 1**). The measurement taken at the height where the acetabulum is deeper or in which the medial wall of the acetabulum is deeper corresponds to the “classic” measurement described for the diagnosis of acetabular dysplasia. It’s considered retroversion when the angle is  $\leq 15^\circ$  [8, 9].

### 3.2. Crossover sign

In a regular pelvis, the acetabulum is in anteversion so in an anterior-posterior (AP) X-ray and in a transparent reconstruction of a CT that simulates an AP X-ray, the anterior wall of the



**Figure 1.** It shows acetabular version angle measurement. It is measured by drawing a line from the anterior border to the posterior border of the ipsilateral acetabulum and another vertical line, which runs from the posterior edge of the acetabulum and is tangential to a horizontal line joining the posterior edges of the acetabulum.

acetabulum is always medial to the edge of the posterior wall. The sign is positive if in some portion the anterior border becomes lateral to the posterior border (**Figure 2**). This translates into an acetabular retroversion at the height where the crossover occurs and is associated with anterior focal over-coverage [9].

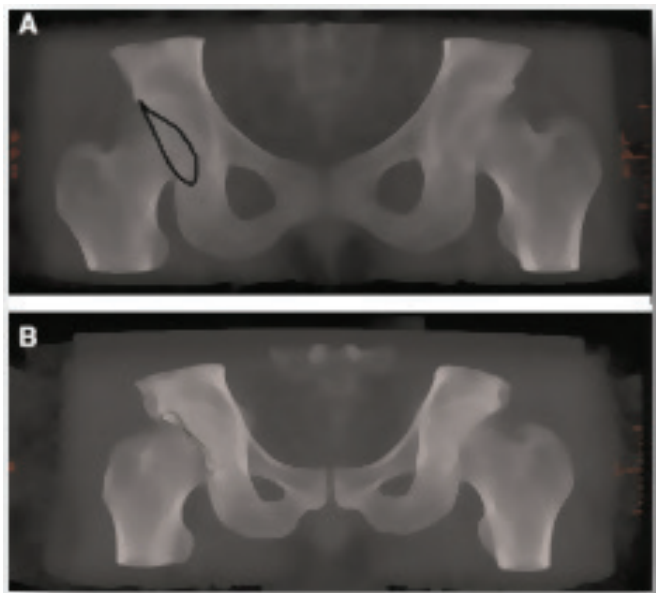
### 3.3. Center edge or Wiberg angle

The acetabular center-border angle is measured on an anteroposterior X-ray or in the reconstruction of a CT that simulates an AP X-ray.

From the center of the femoral head, a line is drawn that goes to the edge of the acetabulum. The other line is a vertical line from the center of the femoral head, which is perpendicular to a horizontal line passing between the ischial tuberosities (**Figure 3**). A Wiberg angle is considered normal between 20 and 40°; angles less than 20° are associated with hip dysplasia. Angles greater than 40° are associated with deep thigh and therefore there is global overcoverage [8].

### 3.4. Femoral alpha angle

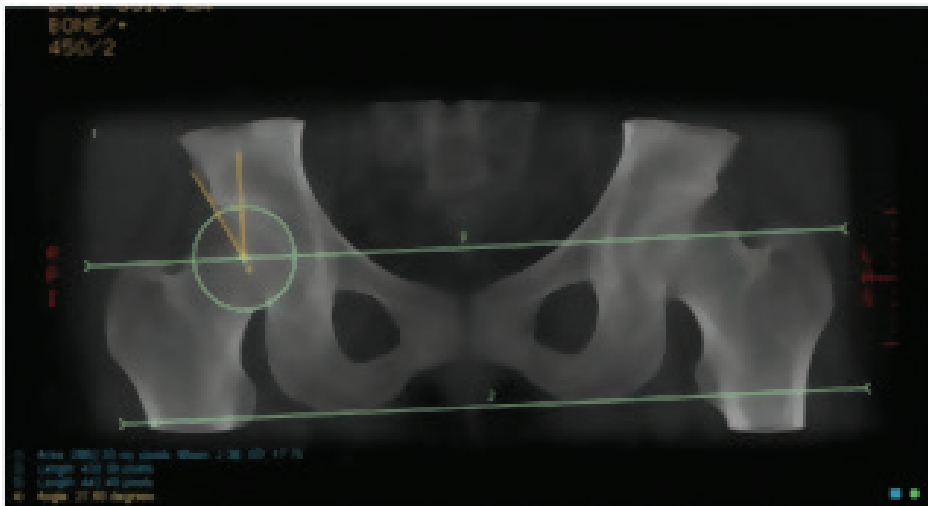
It is an angle formed at the intersection of a line that goes from the axis of the femoral neck and another line extending from the center of the femoral head to the point where a circumference, imagined on the femoral head, is intercepted with the anterior perimeter of the femoral neck (**Figure 4**) [10].



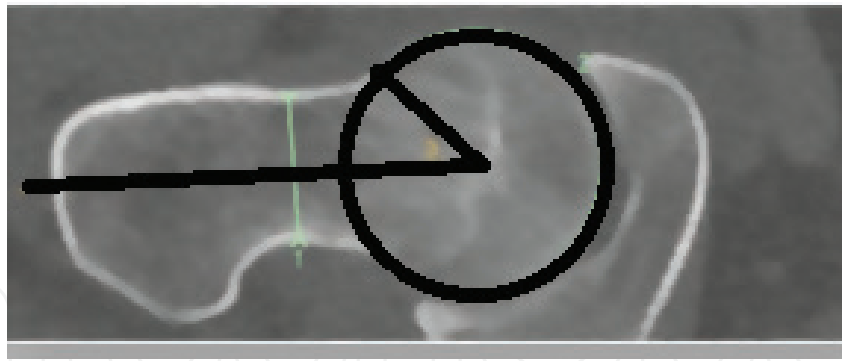
**Figure 2.** It shows a crossover sign. In a normal AP view of the pelvis, the anterior wall of the acetabulum is always medial to the edge of the posterior wall (A). It is positive when the posterior wall becomes medial to the anterior wall of the acetabulum (B).

The normal value of this angle is controversial, even more controversial than the value that must be considered pathological. Notzli et al. [11], in a paper from 2002, suggests 50% as a pathological value in a study that was performed by measuring the alpha angle in magnetic resonance imaging (MRI) and in which only the average difference test was applied between the groups. Tannast et al. [9], in a review published in 2007, uses the same value but now in CT.

Beaulé et al. [4] proposed a 50.5° CT cutoff value in a study in which they compared symptomatic and asymptomatic patients. Five years later, he published an article in which he points



**Figure 3.** It shows Wiberg angle measurement. It is considered normal between 20 and 40°.



**Figure 4.** The alpha angle was measured in an axial oblique cut of the neck. The normal value of this angle is controversial.

out that in MRI the average alpha angle in asymptomatic patients is  $50.15^\circ$  [12]. Allen et al., on X-rays and Kang et al., in CT, arbitrarily define the angle value at  $55.5$  and  $55^\circ$ , respectively, as pathological, arguing the findings in asymptomatic and inter-intraobserver measurement variability [8, 13].

In a study carried out by our working group, it was determined that if the cutoff value was  $50^\circ$  in CT, 28% of the asymptomatic population should be classified with a pathological alpha value [14]. Finally, Pollard et al. [15], in 2010, in a study carried out on X-rays, establishes that the normal average value of the alpha angle is 95% between  $46$  and  $49^\circ$ , that is, very close to the  $50^\circ$  proposed.

The initial studies that established pathological cutoff values between  $50$  and  $55^\circ$  for the alpha angle have been invalidated by subsequent studies in healthy populations in which higher values have been found for the angle described by Notzli; in addition, they lack the methodology suitable for setting cut values in diagnostic tests [11].

We conducted an investigation in which our cohort of 101 asymptomatic patients was compared to a cohort of patients who were operated on with femoroacetabular impingement. This cohort presented hip pain referred to the inguinal region, positive flexion adduction internal rotation (FADIR) on physical examination and positive lidocaine test. In our center, the lidocaine test is performed by a radiologist specialized in the musculoskeletal region, who, under ultrasound, infiltrates intra-articular lidocaine. Before and after infiltration, a FADIR test is performed and the test is considered positive when the patient subjectively reported a decrease of more than 50% of the pain. In addition, it was considered as an inclusion requirement, the presence of intraoperative bump. Patients with previous hip surgeries, with a history of hip dysplasia, and in whom only acetabular surgical gestures were performed, were excluded.

The alpha angle was measured in an axial oblique cut of the neck, determining three levels, cephalic third, middle and caudal femoral neck, and measurements were made in the center of these levels. The measurement performed in the middle third was compared for the purposes

of this study. In the case of controls, the measurement was performed on both hips and the average between right and left was registered. Regarding the cases, the value of the angle of the operated hip was registered.

A logistic regression model was estimated, in which the presence of FAI (case/control) was used as the dependent variable and the alpha angle measurement as the independent variable. A Hosmer-Lemeshow goodness-of-fit test was done to test logistic regression assumptions (this is considered appropriate if  $p > 0.15$ ) [16]. The receiver operating characteristics (ROC) curve was calculated and interpreted according to Hosmer and Lemeshow recommendations [17, 18]. A significance level of 0.05 was established and 95% confidence interval is reported. All analyses were performed using Stata v11.2 (StataCorp LP, College Station, Texas, USA).

Nearly, 38 patients with femoroacetabular impingement were recruited, who had an alpha angle of  $66.78^\circ (\pm 12.23^\circ)$ , while the cohort of 101 asymptomatic patients had an average alpha angle of  $47.81^\circ (\pm 5.30^\circ)$ . The relationship between controls and cases is 3:1.

When estimating a logistic regression model, an odds ratio of 1.28 [1.18–1.39] was obtained, which implies that as the alpha angle measurement increases  $1^\circ$ , the risk of having FAI type cam increases by 28% compared to having  $1^\circ$  less.

The ROC curve has an area under the curve of 0.96 [0.93–0.99], which gives an excellent level of discrimination. The angle of  $57^\circ$  is the value that maximizes the sensitivity 92.11% and the specificity 95.05%, correctly classifying 94% of our sample.

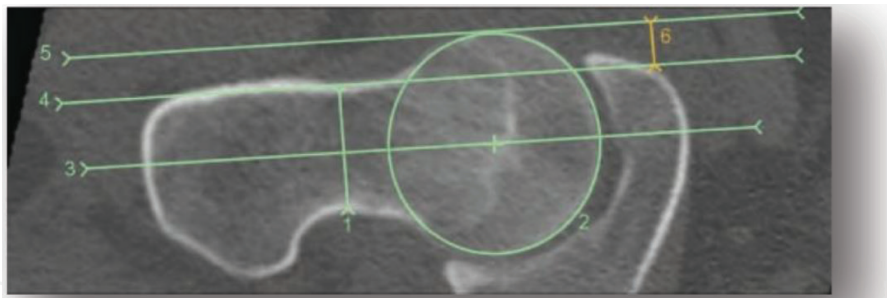
The study by Sutter et al. [19] included 53 healthy individuals and 53 pathological patients, measuring the alpha angle in different time radii, finding a sensitivity between 72 and 76% and specificity between 73 and 80%, with an angle of  $60^\circ$  as the cut in the anterosuperior region. This finding is similar to that found in our work in which the cut value is higher than the  $50$ – $55^\circ$  angle proposed initially and uses a similar methodology. However, the measurement of the alpha angle in radians is not the measurement that is used daily in clinical practice; it is more commonly used for research purposes, and in the relation, they used one control for each case.

The value of the alpha angle measured in an axial oblique femoral neck reconstruction has a high discriminative power for the diagnosis of symptomatic FAI type cam. The finding of an alpha angle value above  $57^\circ$  is suggestive of symptomatic FAI type cam.

### 3.5. Femoral offset

The femoral head-neck offset is the distance between the anterior margin of the femoral neck and the anterior margin of the femoral head (**Figure 5**). As the sphere shape of the femoral head is lost, the offset decreases, and so it is a measure related to FAI type cam. Kang et al. [8] report that an offset smaller than 8 mm is considered pathological, whereas Tannast et al. [9] mention that a distance less than 10 mm is related to FAI.





**Figure 5.** It shows femoral offset measurement. The distance between the anterior margin of the femoral neck and the anterior margin of the femoral head is shown.

#### 4. Measurement analysis in CT by image correction in two or three planes

The multiplanar reconstructions of the 101 asymptomatic individuals included the axial planes to the pelvis and axial slants to the femoral neck. Since the pelvis has a spatial arrangement in three dimensions and considering the deviations by the position of the pelvis in relation to the table of the tomographer, the axial reconstructions and in the three dimensions were corrected in three planes [20, 21], that is to say corrected the rotation, the lateral inclination and the tilting of the pelvis. For the latter, differences between genders were considered, setting a distance of 3 cm between the sacrococcygeal junction and upper border of the pubis in men and 6 cm in women [22]. The evaluation of the images and the measurements were made by radiologists and orthopedic surgeons, using the software Osirix® v4.0.

Our hypothesis is that if acetabular measurements, like Wiberg angle and acetabular version angle, are performed without correction in three planes, the retroversion measures of the pelvis are significantly different, which can lead to misdiagnosis of acetabular overcoverage, meaning pincer-type impingement.

Non-parametric median test was used to compare both groups. A significance level of 0.05 was established and 95% confidence interval was reported. All analyses were performed using Stata v11.2 (StataCorp LP, College Station, Texas, USA).

When analyzing the Wiberg angle, the average value without correction is  $38.8^{\circ} (\pm 7.54)$ , while when correcting in three planes, the average value of the angle increases to  $39.4^{\circ} (\pm 7.59)$ . Although the average difference between the two measurements is  $0.6^{\circ} (\pm 2.9^{\circ})$  and range:  $-6.9-14$ , this is significant when applying a comparison test for medians ( $p = 0.01$ ).

Secondly, acetabular retroversion measures were analyzed. Acetabular version angle was measured in six levels of cephalic to caudal, every 3 mm from the upper edge of the acetabular to distal. The sixth measurement coincides with the classic measure of acetabular version, which is performed where the acetabulum is deeper. The measurement was performed as proposed by Kang et al. [8].



The average value of acetabular version angle is shown in **Table 1**. It is evident that the angle value is consistently lower in the measurements made with the pelvis corrected in three planes. The average difference is  $-07.6^{\circ} (\pm 08.0^{\circ})$ , this difference being significant (test,  $p < 0.00$ ). The detail of the differences for each level is shown in **Table 1**.

In conclusion, the correction in three planes is important to standardize the measures. Failure to correct the spatial position of the pelvis in the patient overestimates the anteversion and decreases the lateral coverage angle. This is important because it can modify the diagnosis and/or surgical planning.

Level	Not corrected	Three-plane corrected	Average difference
1	11.4° (-15.0 to 45.7°)	02.7° (-25.8 to 35.9°)	-08.8° (-15.0 to 45.7°)
2	17.4° (-12.1 to 45.9°)	07.8° (-24.3 to 37.2°)	-09.7° (-12.1 to 45.9°)
3	20.9° (-0.64 to 20.9°)	13.5° (-15.3 to 31.6°)	-08.6° (-0.64 to 20.9°)
4	21.2° ( 00.1 to 38.0°)	15.2° (-12.8 to 31.3°)	-06.4° (00.1 to 38.0°)
5	20.7° ( 30.9 to 35.5°)	15.8° (-06.9 to 30.7°)	-05.0° (30.9 to 35.5°)
6	20.0° ( 05.6 to 34.8°)	15.5° ( 00.8 to 30.1°)	-04.1° (05.6 to 34.8°)

Three-plane corrected CT shows lower angle value in each level.

**Table 1.** It shows median and range of the acetabular version angle by level. Acetabular version angle increased from proximal to distal.

5. Measurement analysis related to impingement according to epidemiological variables

There are physiological differences in the anatomy of the hip according to epidemiological characteristics. It is known that women have greater acetabular anteversion, greater acetabular inclination and greater femoral anteversion. It is therefore presumed that normal values in FAI-related measurements vary between genders [23]. On the other hand, Dudda et al. [24] found that white women had a significantly lower mean alpha angle and a higher average value at the center edge angle as compared to women born in China. This finding suggests that the measures vary between different races, so it is also a variable to consider [24]. Finally, we found a directly proportional increase between the measurement of the acetabular edge center angle and age [25].

In this section, the relationship between three FAI-related variables (acetabular version angle, Wiberg angle and alpha angle) and the epidemiological variables, gender, age, height and weight will be analyzed. A multivariate analysis is applied using Wards’s linkage cluster analysis. After clustering, groups will be compared using regression models and non-parametric median test. A significance level of 0.05 was established and 95% confidence interval is reported. All analyses were performed using Stata v11.2 (StataCorp LP, College Station, Texas, USA).

## 5.1. Acetabular version angle

### 5.1.1. Results

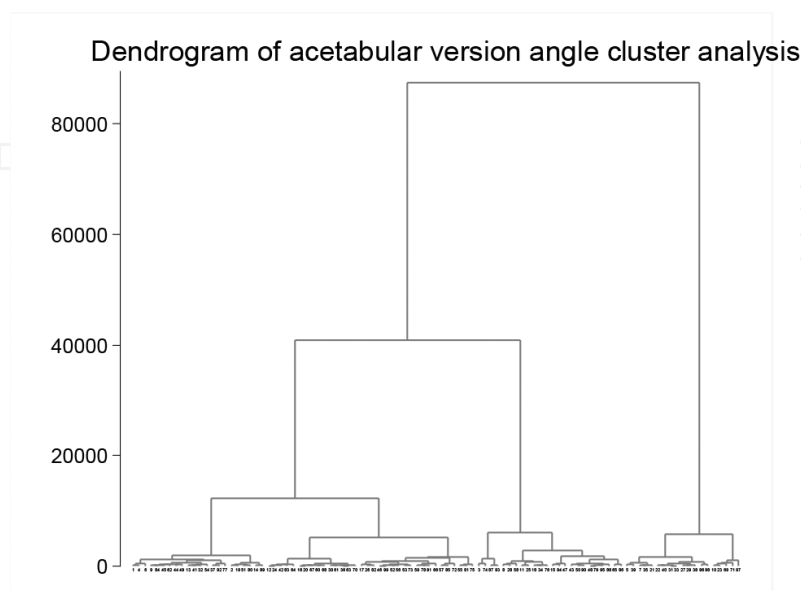
The variables used in this analysis are the acetabular version angles measured from level one to six bilateral in the three-plane correction.

Ninety-nine patients were included. Cluster analysis separated two groups of patients (see **Figure 6**). In group 2, 19 patients were assigned; this group presented lower values of acetabular version (acetabulum plus retroversion) with statistical significance in the 14 measured levels (see **Table 2**).

When observing the epidemiological variables, group 2 presents an average age lower than group 1, which is statistically significant and with high power ( $\alpha = 0.02$  and  $1-\beta = 0.86$ ). The age distribution by the group is shown in **Figure 7**. The differences in weight ( $\alpha = 0.03$  and  $1-\beta = 0.59$ ) and height ( $\alpha = 0.05$ ,  $1-\beta = 0.64$ ) are statistically significant but the power is moderate. Differences in BMI were not significant ( $\alpha = 0.13$  and  $1-\beta = 0.35$ ). Regarding gender, it is observed that there are more women in group 2, this association being significant ( $\alpha = 0.01$  and  $1-\beta = 0.74$ ) (see **Tables 3** and **4**).

When estimating a multivariate logistic regression model with the variables age and sex as independent variables, age has an OR of 1.06 [1.01–1.11] (goodness of fit test = 0.62) and being male has an OR of 4.80 [1.58–14.64] to belong to group 1. The area under the ROC curve is of 0.76 [0.63–0.89].

When estimating a logistic regression model using age as an independent variable, we obtain an OR of 1.06 [1.01–1.11]. The area under the curve is 0.68 [0.55–0.80]. The cut value that maximizes sensitivity and specificity is 34 years, being 58.75 and 73.68%, respectively, correctly

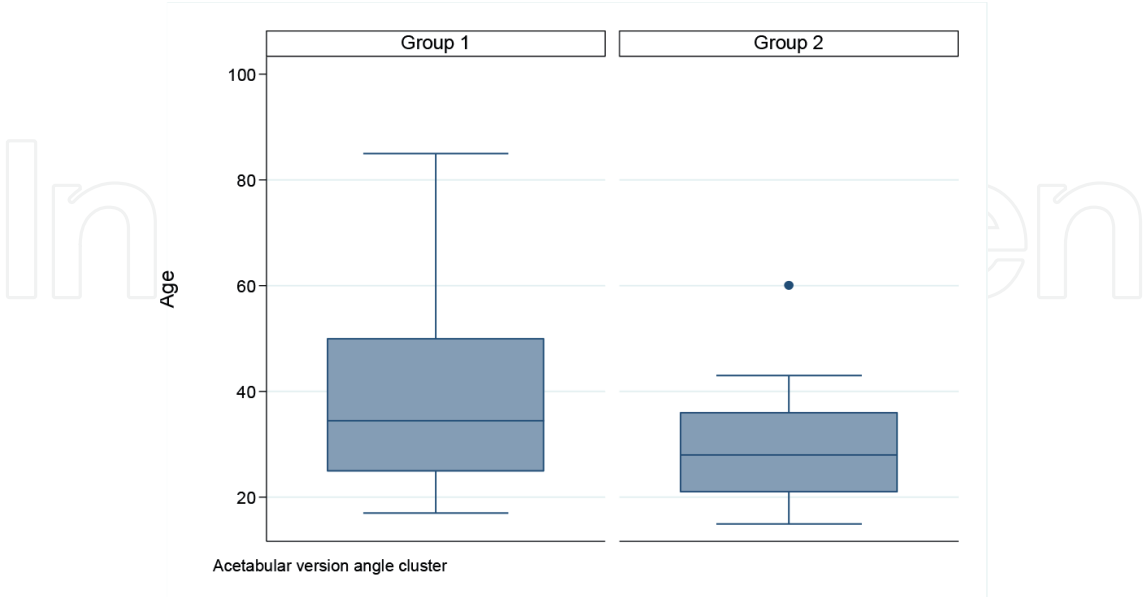


**Figure 6.** A dendrogram showing cluster analysis of acetabular version angle, and two groups are identified.

Variable	Group 1	Group 2	Total	P
N	80 (80.81%)	19 (19.19%)	99	0.00
VERSION 3P L1 R.	5.80(±9.26)	-11.48(±4.80)	2.48(±10.96)	0.00
VERSION 3P L1 L.	7.17(±9.74)	-14.22(±5.58)	3.06(±12.40)	0.00
VERSION 3P L2 R.	10.25(±8.02)	-6.98(±4.97)	6.94(±10.14)	0.00
VERSION 3P L2 L.	10.78(±8.49)	-8.68(±5.60)	7.04(±11.10)	0.00
VERSION 3P L3 R.	14.72(±7.58)	-1.39(±6.00)	11.62(±9.67)	0.00
VERSION 3P L3 L.	15.26(±6.77)	-3.48(±6.36)	11.66(±9.97)	0.00
VERSION 3P L4 R.	16.76(±6.11)	3.05(±6.08)	14.13(±8.14)	0.00
VERSION 3P L4 L.	17.30(±4.96)	1.9(±7.09)	14.34(±8.14)	0.00
VERSION 3P L5 R.	17.29(±5.26)	8.12(±4.49)	15.53(±6.26)	0.00
VERSION 3P L5 L.	17.67(±4.33)	7.74(±3.57)	15.77(±5.73)	0.00
VERSION 3P L6 R.	17.08(±4.87)	9.58(±3.88)	15.64(±5.54)	0.00
VERSION 3P L6 L.	17.43(±4.10)	9.99(±3.26)	16.00(±4.92)	0.00
VERSION 3P L7 R.	16.80(±5.16)	10.51(±3.38)	15.59(±5.46)	0.00
VERSION 3P L7 L.	17.04(±4.05)	10.51(±3.42)	15.78(±4.69)	0.00

The probability obtained in the test of median comparison is shown in the last column, and at each level the differences reach statistical significance. R= right, L = left, 3p = 3-plane corrected CT and L = level.

**Table 2.** It shows the mean and standard deviation of acetabular version angle by the group that results from the cluster analysis.



**Figure 7.** It shows age distribution among both groups resulting from cluster analysis of the acetabular version angle.

	Group 1	Group 2	Total
Age	38.36 ( $\pm 14.84$ )	29.42 ( $\pm 10.46$ )	36.65 ( $\pm 14.50$ )
Weight (kg)	73.09 ( $\pm 12.96$ )	65.58 ( $\pm 12.58$ )	71.66 ( $\pm 13.16$ )
Height (Mts.)	1.69 ( $\pm 0.09$ )	1.64 ( $\pm 0.09$ )	1.68 ( $\pm 0.09$ )
BMI	25.59 ( $\pm 3.33$ )	24.24 ( $\pm 3.44$ )	25.33 ( $\pm 3.38$ )

BMI= body mass index, kg = kilograms and mts = meters.

**Table 3.** It shows mean and standard deviation of epidemiological variables by the group that results from the cluster analysis of acetabular version angle.

Group	Female	Male	Total
1	26 (32.50%)	54 (67.50%)	80
2	13 (68.42%)	6 (31.58%)	19

**Table 4.** It shows gender distribution among both groups that results from the cluster analysis of acetabular version angle .

classifying 70.31% of the sample. In the case of 40 years, the sensitivity decreases to 54.05% and the specificity increases to 77.78%, so having 40 years or more gives you an OR of 6.28 [1.36–29.04] belonging in group 1.

In the estimation of a multinomial regression model, it was observed that the relative risk of having a unilateral positive crossover sign given that the individual belongs to group 2 is 1.05 [0.11–9.72] and bilateral is 7.13 [2.32–21.90].

When estimating a multivariate logistic regression model, including the dichotomized age of 40 years and the presence of a sign of crossover (positive, unilateral and bilateral), it appears that being under 40 years old has an OR of 4.90 [1.02–23.68] and the sign of positive crossover has an OR of 2.40 [1.34–4.30] belonging in group 2. This model presents an area under the curve of 0.77 [0.67–0.87].

### 5.1.2. Discussion

In the acetabular version, it was observed that group 1 consistently presented in each level measured medians of angle in a more forward position than group 2. Group 2 presented an average age significantly lower than group 1 and with high statistical power. This suggests that the acetabular orientation varies with age. The calculated OR shows that for each year you grow older, there is a 6% chance of belonging to the group with more predatory acetabulum. Interestingly, the cut point was found at age 34, since the disease is generally described in women who are about 40 years old; therefore, it is possible that the acetabulum that remained retroverted after the age of 30 years is the one that eventually causes the symptomatology.

Likewise, the resulting groups differ in the proportion of individuals by gender, with the number of men in group 1 being more significant, with statistical significance and high power. This suggests that there are differences in acetabular orientation by gender. The individuals included in group 1 are in greater proportion in men, that is to say, male individuals have more anteverse acetabulum than women, which agrees with the literature described for FAI, where the majority of the patients with pincer impingement are women [9, 26].

Ito et al. [27] reports in a cross-sectional study that there is no difference in the version angle regarding age or sex. The number of individuals recruited for the study was 24 symptomatic and 24 healthy. The comparison was performed by ANOVA test, grouping sex and age dichotomized at 40 years old. The difference of their results with respect to this report may be due to the size of the sample used since each group studied contains a maximum of eight individuals.

On the other hand, the estimation of the multinomial regression model shows that there is an association between the clusters formed and the presence of crossover sign. Thus, belonging to group 2 (retroverted acetabulum) increases the relative risk for the presence of both bilateral and unilateral positive crossover sign. This finding suggests that there may be “physiological” crossover at an early age so it is not always pathological. Thus, the development of the pathology will depend on the load applied by each individual in this overcoverage and on how it evolves as it reaches the age, that is, if the acetabulum is oriented anteriorly.

## 5.2. Wiberg angle

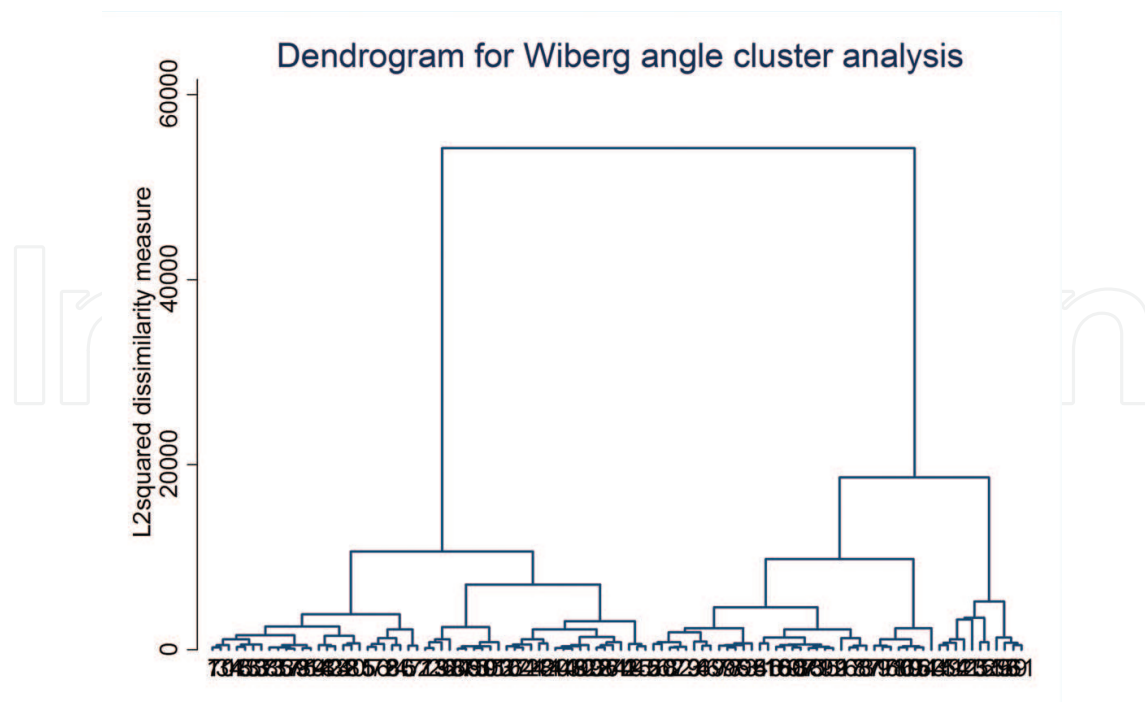
### 5.2.1. Results

The variables used in this analysis are the Wiberg angle measured in coronal CT in bilateral form and corrected in three planes.

The result of the analysis is presented in the dendrogram (see **Figure 8**), where the presence of two groups with greater distances is observed. When creating these two groups, it is observed that group 1 has average values of acetabular version angle significantly larger than group 2 (see **Table 5**).

When observing the epidemiological variables, it is observed that group 2 presents an average age lower than group 1; this finding is significant and has a high power ( $\alpha = 0.00$  and  $1-\beta = 0.99$ ). The distribution of age is shown in **Figure 9**. The differences found in weight and BMI are also significant however the power is moderate, with  $\alpha = 0.05$   $1-\beta = 0.52$  and  $\alpha = 0.02$  and  $\beta = 0.64$ , respectively. Finally, the differences found in size are not statistically significant ( $\alpha = 0.52$ ,  $\beta = 0.09$ ); the same occurs with the higher proportion of males in group 1 ( $\alpha = 0.99$ ,  $\beta = 0.09$ ) (see **Tables 6 and 7**).

When estimating a logistic regression model, age has an OR of 1.08 [1.04–1.12] (goodness of fit test = 0.30) belonging to group 1, with an area under the ROC curve of 0.74 [0.64–0.84]. The cut value that maximizes sensitivity and specificity is 38 years, being 64.58 and 83.02%,



**Figure 8.** A dendrogram showing cluster analysis of Wiberg angle, and two groups are identified.

respectively, correctly ranking 74.26% of the sample. In the case of the 40 years, the sensitivity remains at 60.42% and the specificity decreases to 83.02%, whereby being 40 years or older has an OR of 7.46 [2.97–18.75] belonging to group 1.

### 5.2.2. Discussion

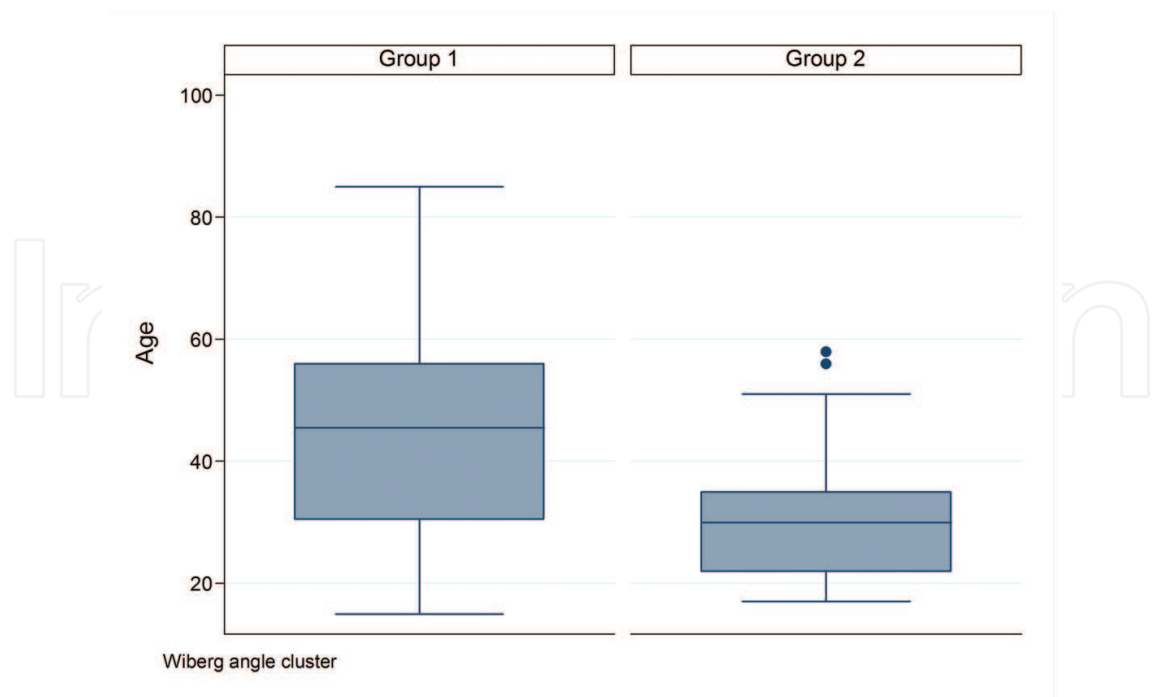
In the conglomerate analysis of the Wiberg angle, a correlation with age is also observed, showing that as the age increases the average value of the Wiberg angle does as well. For each completed year, the probability of belonging to the group with higher Wiberg angle increases by 6%. The cut value found is 6 years longer than in the case of the acetabular version angle,

Wiberg angle	Group 1	Group 2	Total	P
N	48 (47.52%)	53 (52.48%)	101	
3-P corrected R.	45.18 ( $\pm 6.00$ )	33.70 ( $\pm 4.14$ )	39.16 ( $\pm 7.68$ )	0.00
3-P Corrected L.	46.36 ( $\pm 4.94$ )	33.89 ( $\pm 3.41$ )	39.82 ( $\pm 7.53$ )	0.00
Coronal R.	44.47 ( $\pm 5.62$ )	33.73 ( $\pm 4.65$ )	38.83 ( $\pm 7.43$ )	0.00
Coronal L.	45.09 ( $\pm 5.78$ )	33.22 ( $\pm 3.92$ )	38.86 ( $\pm 7.69$ )	0.00

The probability obtained in the test of median comparison is shown in the last column, and at each level the differences reach statistical significance. R = right, L = left and 3-p = 3-plane corrected.

**Table 5.** It shows mean and standard deviation of Wiberg angle by the group that results from the cluster analysis.





**Figure 9.** It shows age distribution among both groups, resulting from cluster analysis of Wiberg angle.

	Group 1	Group 2	Total
Age	43.54 (±15.81)	30.74 (±9.76)	36.82 (±14.43)
Weight (kg)	74.23 (±13.14)	69.09 (±12.58)	71.56 (±13.04)
Height (mts)	1.68 (±0.09)	1.67 (±0.08)	1.68 (±0.09)
BMI	26.14 (±3.36)	24.63 (±3.20)	25.35 (±3.35)

BMI = body mass index, kg = kilograms and mts = meters.

**Table 6.** It shows mean and standard deviation of epidemiological variables by the group that results from the cluster analysis of Wiberg angle.

Wiberg cluster	Female	Male
1	19 (39.58%)	29 (60.42%)
2	22 (41.51%)	31 (58.49%)
TOTAL	41 (40.69%)	60 (59.41%)

**Table 7.** It shows gender distribution among both groups that result from the cluster analysis of Wiberg angle.

which implies that the acetabular coverage increases later. This finding is consistent with what was described by Konishi et al. [28], where it is mentioned that the angle increases with age.

### 5.3. Alpha angle

#### 5.3.1. Results

The variables used in this analysis correspond to alpha femoral angle measurements. In an axial oblique cut of the femoral neck, it was divided into thirds from cephalic to caudal. The measurement was made at the second third in the anterosuperior region, that is to say, using the clock handle form, from 1:00 to 3:00. This measurement was made in both hips.

Hundred patients were included. Cluster analysis separated two groups of patients. In group 2, 13 patients were assigned, which presented higher alpha angle values with statistical significance in 16 of the 18 measurement levels analyzed (see **Table 8**). The result of the analysis is presented in the dendrogram (**Figure 10**), where we observe the presence of two groups that have greater distances.

Variable	Group 1	Group 2	Total	P (ranksum)
N	87 (87.00%)	13 (13.00%)	100	0.00
ALPHA N1 R.	48.14 ( $\pm 8.78$ )	65.00 ( $\pm 6.43$ )	50.33 ( $\pm 10.22$ )	0.00
ALPHA N1 L.	47.12 ( $\pm 7.19$ )	61.57 ( $\pm 7.64$ )	49.00 ( $\pm 8.71$ )	0.00
ALPHA N2 R.	46.45 ( $\pm 5.90$ )	53.64 ( $\pm 9.05$ )	47.39 ( $\pm 6.78$ )	0.00
ALPHA N2 L.	47.14 ( $\pm 4.93$ )	56.08 ( $\pm 7.56$ )	48.30 ( $\pm 6.10$ )	0.00
ALPHA N3 R.	37.73 ( $\pm 5.27$ )	40.12 ( $\pm 3.91$ )	38.04 ( $\pm 5.16$ )	0.13
ALPHA N3 L.	39.57 ( $\pm 4.86$ )	40.93 ( $\pm 3.44$ )	39.74 ( $\pm 4.71$ )	0.19
ALPHA 1:00 R.	50.28 ( $\pm 6.92$ )	64.46 ( $\pm 9.63$ )	52.12 ( $\pm 8.71$ )	0.00
ALPHA 1:00 L.	50.77 ( $\pm 6.16$ )	67.31 ( $\pm 7.55$ )	52.92 ( $\pm 8.43$ )	0.00
ALPHA 1:30 R.	51.68 ( $\pm 7.14$ )	66.62 ( $\pm 5.16$ )	53.62 ( $\pm 8.54$ )	0.00
ALPHA 1:30 L.	52.85 ( $\pm 6.34$ )	65.77 ( $\pm 6.62$ )	54.53 ( $\pm 7.70$ )	0.00
ALPHA 2:00 R.	50.51 ( $\pm 6.44$ )	61.62 ( $\pm 4.87$ )	51.95 ( $\pm 7.27$ )	0.00
ALPHA 2:00 L.	50.74 ( $\pm 5.45$ )	60.85 ( $\pm 8.23$ )	52.05 ( $\pm 6.76$ )	0.00
ALPHA 2:30 R.	48.20 ( $\pm 5.54$ )	59.92 ( $\pm 6.87$ )	49.72 ( $\pm 6.93$ )	0.00
ALPHA 2:30 L.	47.28 ( $\pm 4.53$ )	56.38 ( $\pm 9.70$ )	48.46 ( $\pm 6.22$ )	0.00
ALPHA 3:00 R.	46.02 ( $\pm 5.09$ )	56.93 ( $\pm 7.86$ )	47.44 ( $\pm 6.60$ )	0.00
ALPHA 3:00 L.	45.34 ( $\pm 5.75$ )	52.38 ( $\pm 9.20$ )	46.26 ( $\pm 6.68$ )	0.01
ALPHA 3:30 R.	44.74 ( $\pm 5.29$ )	51.15 ( $\pm 9.33$ )	45.57 ( $\pm 6.29$ )	0.02
ALPHA 3:30 L.	44.43 ( $\pm 4.34$ )	48.08 ( $\pm 6.05$ )	44.90 ( $\pm 4.72$ )	0.0

The probability obtained in the test of median comparison is shown in the last column, and at each level the differences reach statistical significance. R = right and L = left.

**Table 8.** It shows mean and standard deviation of alpha angle by a group that results from the cluster analysis.

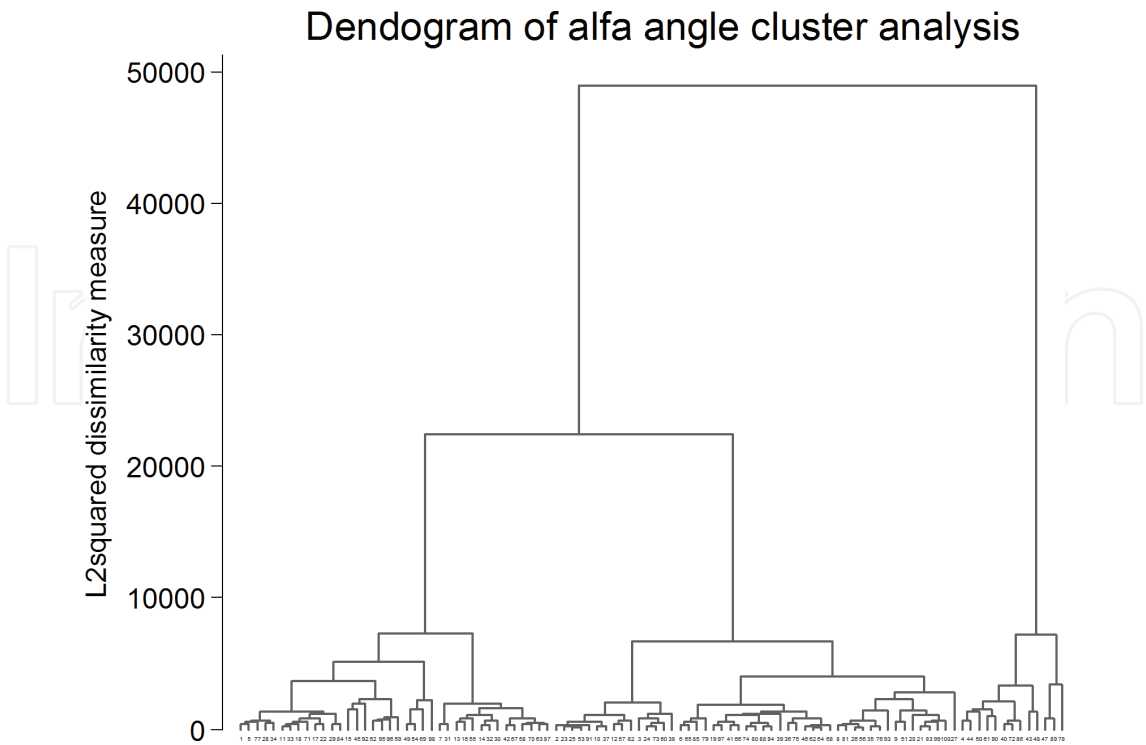


Figure 10. A dendrogram showing cluster analysis of femoral alpha angle, and two groups are identified.

In the measurements of the alpha angle by levels, the difference was significantly greater in group 2 in levels 1 and 2 bilaterally. However, although the average value in group 2 was higher, the difference in level 3 was not significant, either to the right or to the left. In the measurements of the alpha angle by radians, the difference in all hourly radii was significant bilaterally, the average being consistently higher in group 2.

Observing the epidemiological variables, it is observed that group 2 has a higher average age, but the difference is not significant ( $\alpha = 0.22$ ,  $1-\beta = 0.44$ ). The differences in size, weight and BMI are minimal and therefore are not statistically significant [(height,  $\alpha = 0.36$ ,  $1-\beta = 0.46$ ), weight,  $\alpha = 0.19$ ,  $1-\beta = 0.52$  and BMI,  $\alpha = 0.29$ ;  $1-\beta = 0.99$ ]. The distributions of these variables by groups can be observed in graphs 17, 18, 19 and 20. As for gender, it is observed that in

	Group 1	Group 2	Total
Age	36.40 (±14.89)	40.15 (±11.33)	36.89 (±14.49)
Weight (kg)	70.87 (±13.42)	75.00 (±09.72)	71.41 (±13.03)
Height (Mts)	1.67 (±0.09)	1.70 (±0.10)	1.67 (±0.09)
BMI	25.23 (±3.51)	25.98 (±2.06)	25.33 (±3.36)

BMI = body mass index, Kg = kilograms and mts = meters.

Table 9. It shows mean and standard deviation of epidemiological variables by a group that results from the cluster analysis of Wiberg angle.

Group	Female	Male	Total
1	39 (44.83%)	48 (55.17%)	87
2	2 (15.83%)	11 (84.62%)	13

**Table 10.** It shows gender distribution among both groups that result from the cluster analysis of the alpha angle.

group 2, there is a greater proportion of men than in group 1, however, this is not significant ( $p = 0.07$ ) (see **Tables 9** and **10**).

### 5.3.2. Discussion

The variables measured in the femur are not related to the epidemiological variables analyzed: age, gender, height, weight and body mass index, which is consistent with the literature reviewed [29, 30].

## 6. Conclusions

- CT is an important tool for FAI diagnosis and surgical planning.
- CT has a very important role for a better understanding of hip anatomy; further research using CT images should be encouraged.
- The pathological value of the alpha value is controversial. We think that over  $57^\circ$  should be considered pathological. Cases between  $50$  and  $57^\circ$  should be analyzed with caution.
- To overlook the correction in three planes overestimates the acetabular anteversion and underestimates the lateral coverage in a significant way.
- Acetabular version is a gender- and age-related measurement. As age increases, acetabular version increases. Women have lesser acetabular version angle.
- Wiberg angle is an age-related measurement. As age increased, the Wiberg angle increased.
- Femoral FAI-related measurement is not related to gender, age, weight and height.
- FAI measurement is not related to weight and height.

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