ORIGINAL PAPER
PŮVODNÍ PRÁCE

Does the Femoral CCD Angle Measurement in a Standard AP Projection Correlate with the True Anatomical Shape of the Femur?

Koreluje CCD úhel naměřený ve standardní AP projekci se skutečným anatomickým tvarem proximálního femuru?

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ABSTRACT

PURPOSE OF THE STUDY

This study aims to ascertain whether a high anteversion of the femoral neck can influence the measurement of the caput-collum-diaphyseal (CCD) angle on a plain anteroposterior (AP) radiograph of the proximal femur.

MATERIAL AND METHODS

We developed a new method of measuring the CCD angle and femoral neck version of the femur. This was done with the use of a computer program that utilised the measurement of the entire visualised area of femoral neck and shaft to calculate their long axis. Using this method, we measured the CCD angle and femoral neck version (FNV) of 100 photographed cadaveric femurs in two projections: The condylar line (CL) projection and the femoral neck (FN) projection. The same method was applied to 50 radiographs of the same femurs. The femurs were divided into three groups depending on the femoral neck version: Retro (FNV of <0°), Normal (FNV of 0–15°) and Ante (FNV of >15°)

RESULTS

We found a statistically significant difference in the CCD angle measured in the FN and CL projections in the Normal and Ante groups but not in the Retro group. There is a significant correlation between the increase in FNV and the difference between the measured CCD values in the FL and CL projections. The femoral neck version of our cadaveric femurs varied from -14. 4° to 31. 5° which is a range of more than 35°.

CONCLUSIONS

From the results, it is clear that with an increase in femoral neck anteversion, there is a statistically significant difference in the CCD angle measured between the two projections. This difference can be up to almost 10°. Surgeons should be aware of the limitation of the AP projection when planning for surgery on the hip.

Key words: femoral neck anteversion, CCD angle, templating, preoperative planning.

This study was supported by the following grants: TAČR EPSILON TH0301035, Motol Hospital, Czech Republic.

INTRODUCTION

Plain radiographs are the most commonly used radiographic method in orthopaedic practice and have been since its beginnings. While there are many more advanced methods of imaging the musculoskeletal system; plain radiographs offer quick and cheap way to diagnose common orthopaedic disorders. They are predominantly used in the planning stages of total hip arthroplasty (THA), proximal femoral osteotomies and a range of other procedures. Often, only a plain anteroposterior (AP) radiograph of the hip is used. Other projections are possible but not used in common practice. During the preoperative planning of THA, one of the measurements that affects the selection of the implant in case is the caput-collum-diaphyseal angle (CCD angle). This angle is defined as the angle between the femoral long axis (FLA) and the femoral neck axis (FNA). Boese et al. (2) in their meta-analysis of 21 studies showed that the measurement of CCD angle has a high variance and the measurement methods have marked inconsistencies. We have found no studies that evaluated the relationship between CCD measurement accuracy and the femoral neck version on AP radiographs. There have however been studies that attempted to ascertain methods of correcting the measured CCD angle using bi-planar radiographs (4, 7, 16).

As mentioned previously, the standard AP projection radiograph of the proximal femur is commonly used in diagnosis and preoperative planning. While the standard projection is supposed to provide consistent position of the proximal femur on radiographs (13), in clinical practice this is often not achieved due multiple factors. Some of these include exorotational contractures present in patients with severe hip arthritis or patient noncompliance with positioning during radiography. In addition to this, the anteversion of the femoral neck varies in the population, with pronounced racial differences as proved by Khamanarong et al. (12). The purpose of our investigation was to assess the range of femoral version

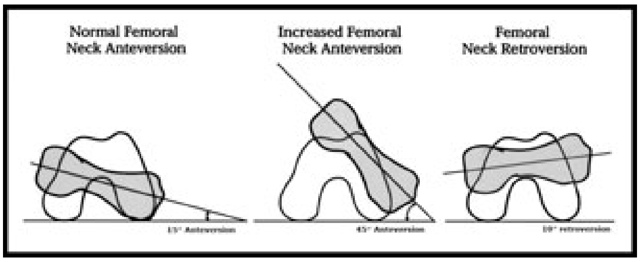

Fig. 1. Visualisation of femoral neck variations. The femoral neck version is defined by the line running through the long axis of the femoral neck and the line connecting the dorsal surfaces of the femoral condyles.

in our selected anatomical specimens and to evaluate how the femoral version affects the measurement of the CCD angle on AP radiographs.

MATERIAL AND METHODS

We used cadaveric dried adult femurs borrowed from the Anatomy Department of the 1st Faculty of Medicine, Charles University. We selected 100 femurs with a 50:50 left to right distribution. Due to the nature of the specimens, we were not able to ascertain the exact age or gender of the donors, but we know that all donors died between 1930 and 1980 and were from the Central European region. All were adult femurs and were of sufficient quality to allow for accurate measurements.

Anatomical measurement

Femoral neck version is defined as the angle between the posterior condylar line and the FNA (Fig. 1).

A number of methods exist for estimating the femoral neck anteversion. These are either clinical (19) or radiological, including methods for measurement on radiographs (6, 18), computed tomography (9, 22), ultrasound (3, 8, 21) or MRI (20). We have decided to establish our own method of measuring the FNA and FLA on photographs and radiographs due to the reported inaccuracy of already established methods (2).

Our first step was to obtain photographs of all femurs. Photo documentation was performed with the camera placed on a tripod; which was a set distance from the ground and the pictures taken at a consistent distance. We performed two photographs from the frontal view with the femurs placed on a horizontal surface. The first photograph was performed with both the femoral condyles in contact with the table to simulate a correct AP radiograph. This resembles when a patient is lying supine on an X-ray table with the back of his knee touching the table. We defined this as the “condylar line projection” (CLP). The posterior condylar line is defined as the line running tangentially to the posterior surface of the femoral condyles. The second photograph was performed in internal rotation of the femur with the head of the femur touching the horizontal surface. This allows establishment of the true CCD angle at 0° version of femoral neck. This was defined as the “femoral neck projection” (FNP).

Fig. 2. Photographs taken of all individual cadaveric femurs in three projections. Clockwise from top left: condylar line projection (CLP), Femoral neck projections (FNP) and axial projection.

Further photographs were taken in the axial plane of the femur. When performing photographs in the axial view, we ensured that the femoral condyles were in contact with the surface of the table. This was done to ensure that the posterior condylar line corresponded to the level of the table from which measurements were later taken. If the shape of the femur did not allow for the condyles to lie naturally on the surface of the table, a wedge was placed under the greater trochanter to lift it up and rotate it. This ensured that both the condyles were in contact with the table. Overall, of each of the 100 femurs, three photographs were taken (Fig. 2).

Using the photographs, we proceeded to measure the CCD angle of the femurs. To ensure consistency and repeatability of the measurement, we used the “ImageJ 1.52a” computer program from the National Institute of Health, USA, for measurement of the FLA and FNA on photographs and radiographs. The program allows for the calculation of a longitudinal axis of a selected object. In our case, this was the long axis of femur and the femoral neck together with the femoral head.

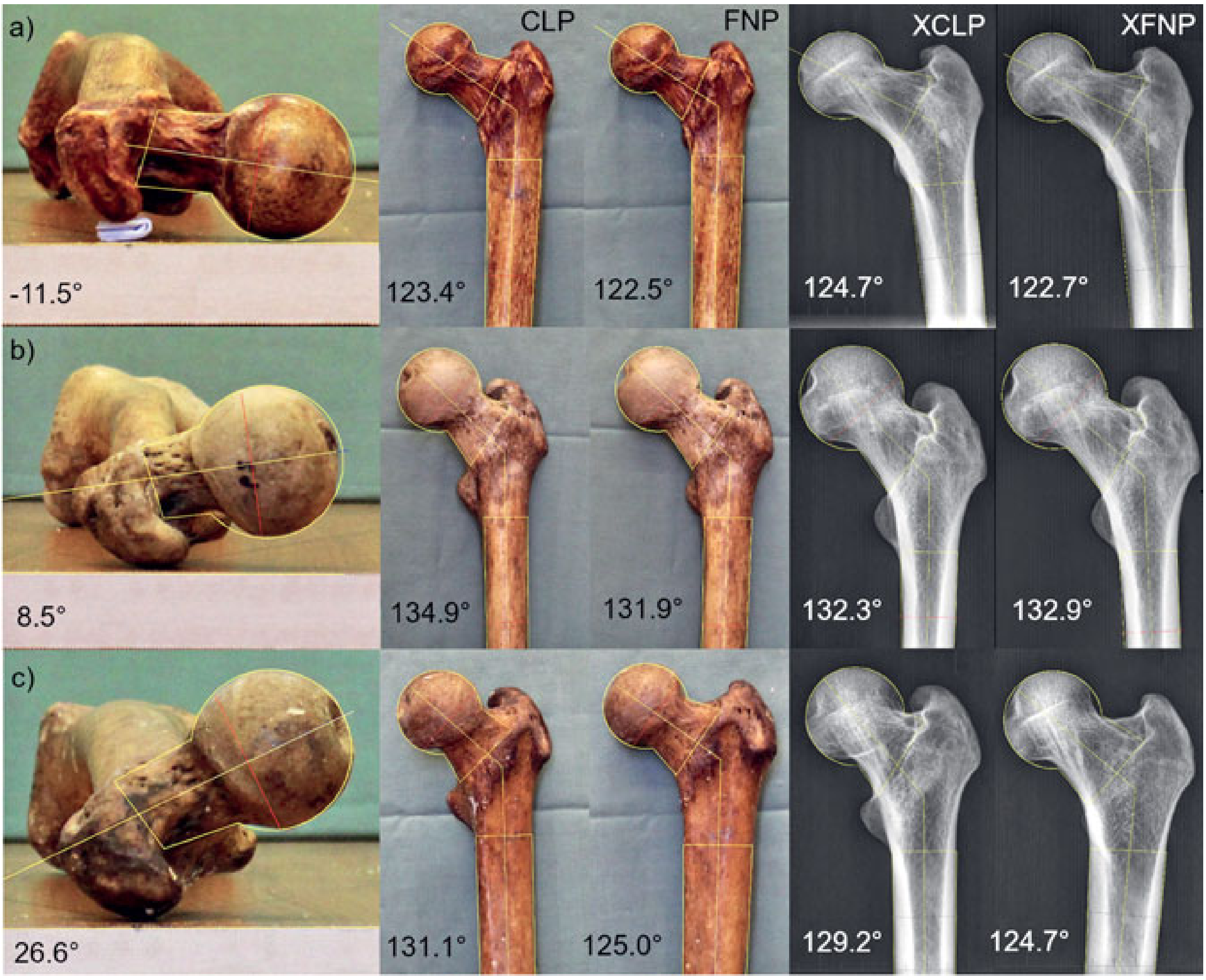

Fig. 3. Example of all measurements taken for 3 femurs, each from the a) Retro group, b) Normal group and c) Ante group. Left to right in each group are the: Axial projection, Condylar line projection (CLP), Femoral neck projection (FNP), X-ray condylar line projection (XCLP) and X-ray femoral neck projection (XFNP) The measurements are of the femoral neck version (FNV) in the axial projection and the caput-collum-diaphyseal (CCD) angle in all the other projections.

For the measurement of the FLA on the femoral photographs, we first overlaid a best-fit rectangle onto the femoral shaft visualised on the photograph. The maximum area of the femoral shaft was used; up to the level of the lesser trochanter. The ImageJ program then calculated the longitudinal axis of this rectangle. This was then assumed to be the FLA. The femoral head was defined by a best-fit circle, created from three points around its circumference. The femoral neck was defined by a rhomboid shape overlaid over the femoral neck. The borders of the femoral neck region were defined by the structures remaining at the attachments of the joint capsule. This is the region between the intertrochanteric line and the base of the femoral head. Once this region was bordered out, it was combined with the circle overlaying the femoral head. The program then proceeded to calculate the longitudinal axis of this area. This was assumed to be the FNA. Once both of the longitudinal axes were established, a line was then drawn out extending both axes and the angle between them was measured. This was taken to be the CCD angle of the measured femur**.** This process was done for the photographs of each femur in both the CLP and FNP projections (Fig. 3).

The same procedure was done for the axial photographs of the femurs to measure the femoral neck version. Again, the femoral head was bordered out with a best-fit circle and a rhomboid shape was applied over the surface of the femoral neck. These areas were combined together as one region of interest and the ImageJ program calculated this shape's longitudinal axis. The line of the axis was then extended until it intersected the edge of the table. As the femoral condyles always lay on the surface of the table; the table level was assumed to the same as the posterior condylar line. The angle between the neck axis and the edge of the table was therefore measured and was set as the angle of femoral neck version (FNV) (Fig. 3). The measured FNV angle was then input into the Excel file and matched with the already measured CCD angle of the specific femur being measured. The CCD angle and FNV was thus measured for all the 100 femurs.

Table 1. Statistical values for all measured values with further subdivision into the groups by femoral neck version

	n	FNV	CLP	FNP	p	n	XCLP	XFNP	P
All	100	8.2 SD 8.3 (-14.4 - 31.5)	127.0 SD 5.9 (108.3-139.6)	124.7 SD 5.8 (104.6-136.4)	<0.05	50	127.2 SD 5.4 (110.2-136.7)	124.1 SD 5.1 (108.4-134.5)	<0.05
Retro	16	-4.5 SD 4.9 (-14.4 - -0.4)	124.2 SD 6.2 (113.1-135.3)	124.1 SD 6.3 (113.3-135.7)	0.69	5	125.2 SD 6.8 (115.2-133.8)	124.1 SD 6.2 (117.0-133.6)	0.25
Normal	61	7.4 SD 3.5 (0.2 - 15.0)	127.3 SD 6.0 (108.3-139.6)	125.3 SD 6.1 (104.6-136.4)	<0.05	22	127.4 SD 6.0 (110.2-136.7)	125.1 SD 5.9 (108.4-134.5)	<0.05
Ante	23	19 SD 4.7 (15.1 - 31.5)	128.2 SD 4.7 (119.3-137.1)	123.7 SD 4.7 (115.1-131.5)	<0.05	23	127.5 SD 4.6 (119.1-136.5)	123.2 SD 3.8 (114.3-129.8)	<0.05

Radiological measurement

We selected 50 femurs randomly to perform radiological measurements on.

Using an X-ray machine at our department, we performed radiographs of the 50 selected femurs in the CL and FN projections of the proximal femur. To differentiate these during data analysis we labelled these as XCLP and XFNP (Fig. 3). Care was taken to ensure that the femoral condyles were in contact with the X-ray table for the CL projection and the femoral head was in contact for the FN projection. Polystyrene wedges were used to correct the position if necessary. Using the digital radiographs, the CCD angles of the X-rayed femurs were measured using the same method as for the photographs. Selection of the femoral neck area for measurement was hampered slightly due to the nature of the X-ray where anatomical features overlap each other.

Analysis and statistical methods

We measured the mean, range and standard deviation for all values. In the initial part we also performed the Shapiro-Wilk test to ensure that our selection of femurs showed a normal distribution of their CCD angles and femoral neck version.

Using a paired t-test, we compared the measurements of the CCD angle in CLP and FNP in all femurs to see if there is a statistically significant difference. To evaluate how the measurement of the CCD angle changes with the femoral neck version, we separated the femurs into 3 groups depending on the measured femoral neck version on axial photographs. First group were femurs with retroversion of the neck labelled "Retro". Second group were femurs with an anteversion range of 0–15 degrees labelled "Normal". Third group were femurs with anteversion larger than 15 degrees, labelled "Ante" (Fig. 3). We again performed the paired t-test between the measured CCD angle in CLP and FNP in the individual groups.

In the next part of the study, we used the paired t-test to compare the measured CCD angles of individual femurs in photographs and radiographs. We performed this test to confirm that there is no statistically significant difference of CCD angle measurements in both CLP and FNP between the radiographs and photographs.

Lastly, to show that with increasing femoral neck version, the difference between the measured CCD values in both projections increased, we calculated the Pearson correlation coefficient which showed a value of 0.67. This means that there is a strong correlation between the two measured values.

The statistical analysis was performed with the Statistica 10 program from the StatSoft company.

RESULTS

We performed a Shapiro-Wilk test of the femoral CCD angles in the FN projection and for the femoral neck version angles of all the measured femurs. Both showed a normal distribution with a W value of 0.977 and 0.984 respectively.

When we measured all the femurs, we found a statistically significant difference between the CCD angle values measured in the CL and FN projections. This statistically significant difference was present in both in the Photographic group and the Radiographic group. We compared the measured values on individual femurs between the photographic and radiographic measurements and found no statistically significant difference. This means that the results obtained by measuring the CCD values on both the photographs and radiographs can be considered identical.

After separating the femurs into groups by the femoral neck version, we again evaluated whether the difference between the measured CCD values on the FN and CL projections was statistically significant. We found that this was the case in the ante and normal groups, but the retro group did not show a statistically significant difference. This was true in both the Photograph and the radiograph measurements. The measured CCD values are shown in Table 1. The table is separated into the Photographic and Radiographic groups along with a separation into the Retro, Normal and Ante groups by femoral neck version. We noticed that with an increasing FNV, the difference between the measured CCD value in the FN and CL projections increased. We evaluated the relationship between these two variables and found that there is a strong Pearson correlation coefficient ($r = 0.67$). A graph (Fig. 4) visualises the relationship of these two values with a correlation line and 95% confidence bands.

DISCUSSION

From the results, it is absolutely clear that with an increase in FNV, there is a statistically significant difference in the CCD angle measured in the CN and FN projections.

When evaluating the radiological methods used for the measurement of femoral neck version, the Rippstein-Dunlop method (18) has been noted to be the most reli-

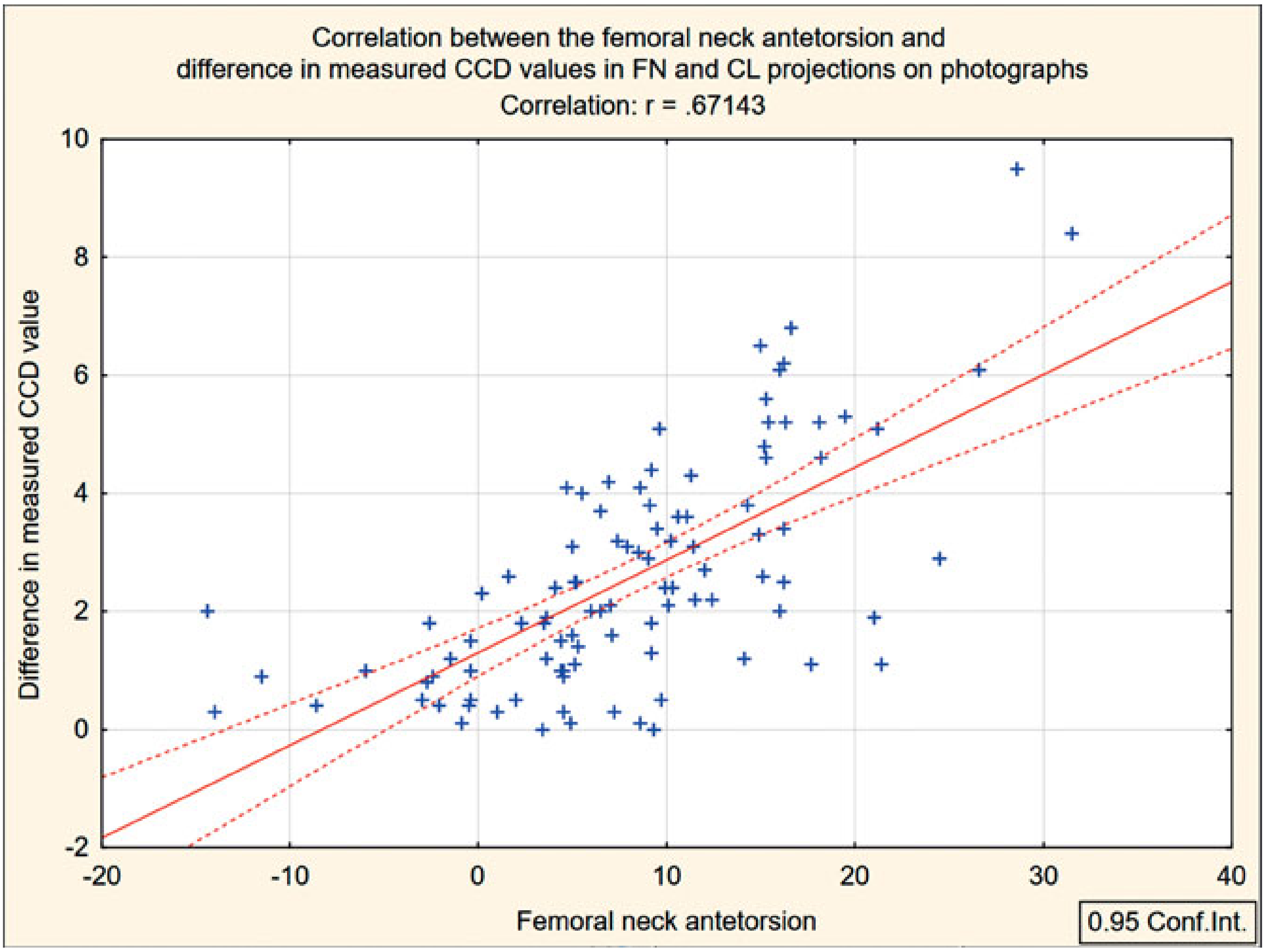

Fig. 4. Graph showing the correlation between the femoral neck anteversion and the difference between the measured CCD values in the FN and CL projections on photographs along with a Pearson correlation line and the 95% confidence interval dashed lines.

able (10). In their study, Hoiseth et al. also however noted that there does not seem to be a concise and replicable method for its measurement. This is due to the fact that the selection of reference landmarks is often arbitrary and repeated measurements may yield varying results (2).

We therefore decided to use our own method of measurement that we developed for this study and that was designed to be reproducible with maximal consistency. The classic evaluation of the FNA is done by defining the femoral neck centre at the narrowest point, then the femoral head centre and drawing a line between them. The placement of this line however, showed significant intra-observer variability when we performed our initial measurements. In our method, we used the combined femoral head and neck area to calculate the femoral neck axis. To calculate the femoral long axis, the complete area of femoral shaft of proximal femur shown on photographs or radiographs was used. We then utilised computer measurement of the long axis of a highlighted object to obtain the axes of the femoral neck and shaft.

We selected this method due to the inconsistencies and seemingly arbitrary placement of lines during the measurement of axis by other studies; where a line was usually placed through the narrowest part of the femoral neck or through the femoral shaft at specified levels. By using the entire femoral neck and a large portion of the femoral shaft for the measurement of their axis, we eliminated the arbitrary selection and placement of a line through the neck or shaft of femur.

When we compare our measured CCD values to those reported in other studies, we find that our mean value of 124.7° in the FN projection is smaller than the mean value of 128.5 in the rotation-corrected value in the meta-analysis by Boese et al. (2) Some studies do show similar results (5, 14, 15) and some of these radiological assessments were made with the femoral neck being parallel to the detector similarly as in our study. We are not certain why our reported values were lower than the mean reported by Boese et al. (2), one possibility being the projectional errors present in other studies that we have highlighted in our study.

The correlation between the increasing difference between measured CCD values in the two projections as the anteversion increases is logical. With increasing anteversion of the femoral neck, the overlap of proximal femoral structures on an AP radiograph makes the CCD angle measurement more difficult. We would expect a similar trend with increasing retroversion of the femoral neck but this was not shown in our results, most likely due to the small sample of femurs with significant femoral neck retroversion.

Our results show that there is a large variability in femoral neck version. This correlates with reports published by Khamanarong et al. (12) and as reported by Kaiser et al. (11) The variability of the femoral neck version can lead to misleading measurements of the CCD angle as we have proven in this study. There can be a difference of up to 9.5°between the "true" CCD value and the one measured on an AP radiograph of the proximal femur. The fact that the version of the femoral neck cannot be known pre-operatively from a plain hip radiograph means that the CCD angle measurement must be taken only as a rough estimate. While mathematical methods have been developed to correct the measured CCD angle; they however require highly standardised multiple bi-planar X-rays made using special equipment (4, 7). This makes them uncommon in common practice. The common plain AP radiograph is sufficient for most uses, with the knowledge of its limitations.

A properly performed standard AP radiograph of the hip is performed with the patient in a supine and the whole limb rotated internally by 15° (13) to attempt to compensate for the femoral neck version. Not only is the internal rotation of the limb only approximate, quite often the internal rotation is not possible in patients with osteoarthritis where internal rotation is one of the first limitations in patient range of movement (1). The CL projection as we have described for our specimens can be achieved clinically by having the patient lie supine with their legs below the knee hanging freely over the edge of the X-ray table. This position assumes that the femoral condyles are in a parallel position to the X-ray table. While this position has more consistency there are still limitations. As our study has shown however, the CL projection does not allow for reliable CCD angle measurement. Performing an AP radiograph in the FN projection as we have described it in our specimens – with the X-ray beam parallel to the femoral neck, is technically impossible in a clinical setting.

To gain full information about the three-dimensional anatomical shape of the proximal femur and acetabulum, a CT examination would need to be performed. To measure the femoral neck version however, the whole of the femur would need to be visualised including the femoral condyles which are used as reference values. This is not practicable neither ethically or in a practical sense due to the increased radiation exposure to the patient and limited clinical gain. A CT of the proximal femur is sufficient to visualise any bony defects, measure the CCD angle and give the surgeon sufficient information about the hip anatomy. This is sufficient for preoperative planning even without the knowledge of femoral neck version.

In their study from 2015, Park et al. (17) showed that the implanted stem anteversion follows the preoperative anteversion of neck geometry. Even from clinical experience, orthopaedic surgeons know that while cemented implants allow for the modification of postoperative femoral neck anteversion, modern cementless press-fit stems do not. The shape of the proximal femur dictates the position of the stem post-operatively and any attempt to force the anteversion of the implant may lead to insufficient primary fixation or periprosthetic fracture intraoperatively. As the anteversion of the femoral neck becomes known during the dislocation of the femoral head, the anteversion of the acetabular cup should be implanted accordingly.

CONCLUSIONS

Our study has shown that there is a large variability in the femoral neck version, which can significantly influence the measured CCD angle. We have shown that with increasing femoral neck anteversion, the difference in measured values between the FN and CL projections increases and the differences are statistically significant even in femurs with a neck version of 0–15°.

Our study proves that the standard AP radiograph does not show the true shape of the proximal femur. The preoperative planning using an AP radiograph must therefore always be an adjunct to the surgeon who should be ready to adapt to anatomical factors found intra-operatively. The surgeon must respect the anatomical relationship between the acetabulum and femoral head and neck and attempt to place the implants accordingly.

Based on our study, our recommendation is not to rely on a single hip radiograph in preoperative planning. In cases where there is clear hip dysplasia or where abnormal anatomical factors are suspected, a CT scan of the hip should be performed to assess the anatomical structures more clearly. An unexpected anatomical situation can arise even when a CT scan was performed and if the selected implant does not correlate well with the anatomical features, a selection of alternative implants should be available.

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