The Egyptian Journal of Radiology and Nuclear Medicine xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

The Egyptian Journal of Radiology and Nuclear Medicine

journal homepage: www.sciencedirect.com/locate/ejrnm

CT measurement of femoral anteversion angle in patients with unilateral developmental hip dysplasia: A comparative study between 2D and 3D techniques

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ARTICLE INFO

Article history:
Received 8 November 2016
Accepted 21 February 2017
Available online xxxx

Keywords:
Femoral anteversion angle (FAVA)
Developmental dysplasia of the hip (DDH)
3D computed tomography (CT)

ABSTRACT

Objective: To compare the accuracy of 2D and 3D CT measurements of femoral anteversion angle, in pediatric patients with developmental hip dysplasia.
Materials and methods: Twenty patients (20 hips) with unilateral non syndromic DDH were studies. CT scans were performed using a 16 slice CT scanner to measure the femoral anteversion angle (FAVA) using 2D & 3D techniques. Findings were correlated with the intra operative measurements.
Results: There was a significant difference between 2D & 3D methods. Results of clinical assessment were comparable to results of 3D CT assessment which range from 30 to 50° with a mean of 37.5°. Mean percent difference between 3D and intra operative measurement of FAVA was significantly lower than the corresponding value between 2D and intraoperative measurement of FAVA.
Conclusion: 3D is more accurate than 2D in measuring the degree of FAVA in DDH patients. It is easily applied and rapid and doesn't require sophisticated software.

1. Introduction

Femoral anteversion angle (FAVA) is the angle formed by a line anteriorly projecting from the femoral neck compared to the femoral shaft when the femur is examined along its long axis from top. Assessment entails measurement of the femoral neck angle with modifications made for rotation of the femoral condyles. Different techniques using either single or multiple axial slices Computed tomography (CT) techniques are usually applied, but these techniques show a wide range of accuracy and there is no agreement has been proposed to the most appropriate method [1–5]. Moreover, any changes in patient's position, such as flexion and rotation at the hip, have been reported to affect FAVA measurement [6].

Literature has reported that abnormal FAVA is the result of different pathological processes. Developmental dysplasia of the hip (DDH) is one of the most difficult three-dimensional (3D) deformities, which are associated with an abnormal femoral anteversion [7].

At our institution, as well as in most places worldwide, 2D measurement of FAVA is still considered the standard technique, however, both musculoskeletal radiologists and paediatric orthopaedic surgeons are aware that this technique might not be accurate due to the pelvic tilt associated with the dislocated hip. In 2012, Jia et al. [8], used 3D measurement of FAVA in their study to set the guidelines for the indications of femoral osteotomy, however, they never mentioned the reason behind using this technique.

Based on the previous two facts, we decided to conduct our study to prove the superiority of 3D over 2D particularly that they are done using the same CT protocol with no added cost or increase of the scan time.

The aim of this study was to interrogate the 2 dimensional (2D) and 3D CT measurements of FAVA in both the normal and abnormal sides and find out the most accurate method in correlation with the intra-operative findings. Proper preoperative assessment

Peer review under responsibility of The Egyptian Society of Radiology and Nuclear Medicine.

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http://dx.doi.org/10.1016/j.ejrnm.2017.02.007
0378-603X/

of FAVA gives the orthopaedic surgeon an idea about the degree of internal rotation required to maintain concentric femoral head reduction as over or under correction leads to posterior or anterior femoral head subluxation respectively.

2. Materials and methods

2.1. Materials

This cross-sectional study was conducted at the Radiology Department in collaboration with the Pediatric Orthopedic Unit at our university hospital, in a period of one year. Twenty patients (20 hips) with unilateral DDH were consecutively enrolled in this study during their visits to the Paediatric Orthopaedic Clinic. There were 17 females and 3 males. Fifteen patients had left sided DDH and 5 had right sided affection. The age range was 18–48 months and the mean age was 28.75 months.

Approval for the study was obtained from the local ethical committee and informed consent was obtained from the parents of all the study subjects.

All recruited patients were subjected to detailed history taking and complete physical examinationt. All patients with syndromic DDH and patients with previous hip surgery were excluded.

2.2. Methods

2.2.1. CT scan protocol

CT scans were performed using a 16 slice CT scanner (Activion, Toshiba Medical, Tokyo, Japan). The scanning parameters were:

Standard resolution, 120 kVp, 20–100 mAs, 0.75 s rotation time, 1 × 16 mm collimation, 15 pitch (pf 0.938/hp 15), Filter: fc17 soft, 1 mm slice thickness, 0.8 mm increments, Window: ww 300/wl 50 soft and ww 1500/wl 200 bone, 15 s scan time, 17 mGy $CTDI_{vol}$ and 495 total DLP mGy.cm.

We used the same technique described by Jia et al. [8].

"Contiguous slices were obtained from the upper rim of the acetabulum to the lesser trochanter. Another scan went through the distal femur which included bilateral inner and outer condyles of the femur. The patients were placed in a supine position with hips extended and thighs horizontal and parallel" [8]. The lower limbs were strapped to the table to prevent movements during acquisition.

The automated exposure control (AEC) system for Toshiba multidetector CT scanners (Sure Exposure) was applied to limit radiation dose according to the patient's attenuation and eventually to reduce the radiation hazards to the patient while maintaining an optimal diagnostic image quality.

2.2.2. Imaging evaluation and post processing

The FAVA on both sides was measured in all patients using 2D and 3D techniques.

To determine the FAVA using the 2D method, 2 images of superimposed femoral neck axis and femoral condylar axis were acquired and the angle was measured (Fig. 1).

For the femoral neck axis we selected the slice displaying the middle of the femoral neck (on which the anterior and posterior cortices were parallel to each other).

For the axis of the femoral condyles, we selected a slice through the most prominent point of the condyles. The FAVA was measured as the angle subtended by the femoral neck axis and the posterior bicondylar axis (Fig. 1).

The images were then reformatted to produce 3D images in the coronal, sagittal, and oblique axial planes (1.00-mm slice thickness, 0.8-mm reconstruction interval).

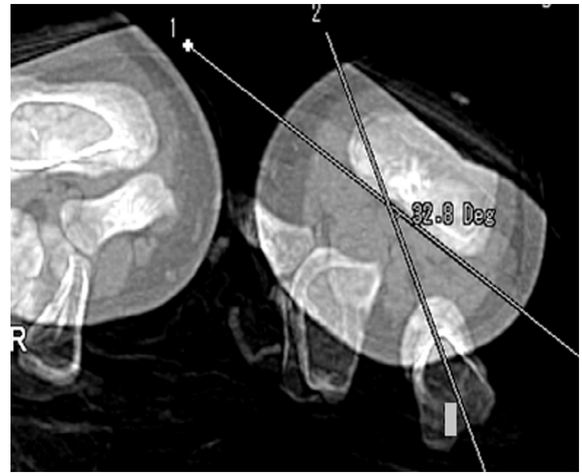

Fig. 1. FAVA measurement using 2D technique in a patient with left DDH. Two superimposed images are used to measure FAVA, the femoral neck axis and femoral posterior bicondylar axis images. The FAVA is the angle between the femoral posterior bicondylar axis (line 1) and the femoral neck axis (line 2). FAVA = 32.8°.

After the images of both proximal and distal femur was reformatted, the 3D images of both the proximal femur and that of the medial and femoral condyles were superimposed on an image (Fig. 2). The most inferior points of both the medial and lateral condyles and that of the greater trochanter situated in the middle between medial and lateral condyles were joined by a horizontal line (Fig. 3). The FAVA was the angle formed by the horizontal line and the line that joins the femoral head center with the midpoint of the femoral neck's narrowest part (Fig. 3). If the femoral head's epiphysis was still cartilaginous, tiny or decentered, the axial line of the femoral neck was considered as the tangential line [8].

2.2.3. Intra-operative assessment and FAVA evaluation

After reduction of the femoral head inside the acetabulum, the FAVA was determined clinically by internally rotating the femoral shaft until the head is well seated inside the acetabulum. The FAVA was measured using a goniometer to measure the angle between the axis of the foot and a vertical line to the horizontal plane.

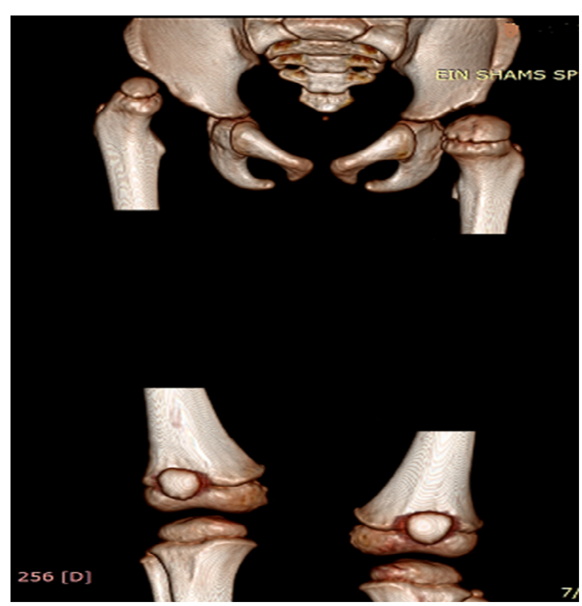

Fig. 2. Reconstructed 3D image of the proximal femur and distal femur.

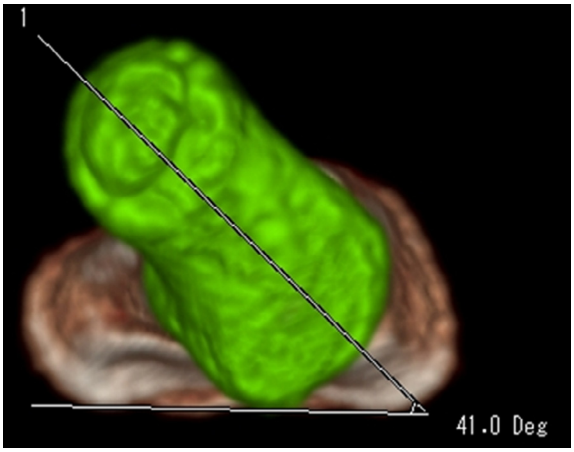

Fig. 3. FAVA measurement using 3D technique, the femoral head and neck axis (green) image is superimposed on the posterior bicondylar axis image (brown). The angle is measured between a line passing through the centers of the femoral head and neck and a line passing tangential to the lateral, medial condyles and the lowest point of the greater trochanter. FAVA = 41°.

3. Results

We measured the FAVA in both normal and abnormal sides using 2D and 3D techniques and both methods were compared to each other (Table 1).

All statistical analysis was performed using statistical Package of Social Software Program (SPSS) version 15. Paired *t* test was used to compare between the 2D and 3D techniques in both the normal and the abnormal sides.

Statistical significance was set at 0.05. There was a significant difference between the 2D and 3D techniques in the abnormal side more than the normal side (P value was 0.001 and 0.002 respectively) (Table 2).

The results of the intra-operative measurements are summarized in Table 3. They are comparable to the results of 3D assessment of FAVA which range from 30° to 50° degrees with a mean of 37.5°.

The mean percent difference between 3D method and intra operative measurement of FAVA was significantly lower than the corresponding value between 2D method and intra-operative measurement of FAVA. This makes 3D technique significantly comparable to intraoperative measurement than the 2D technique.

4. Discussion

The measurement of FAVA is vital for the diagnosis of intoeing, DDH, cerebral palsy and for decision making of patients who would benefit from of derotational osteotomy of the femur [5].

FAVA usually decreases with age [9]. Between 3 and 12 months of age, FAVA is 39° gradually decreasing with time to be close to 16° in adult life [10,11]. There are multiple methods for measuring FAVA which have been developed over several years, yet with different results. Measurement using a 2D slice images was studied by Egund and Palmer [12]. 2D images acquired by CT, MR or US are the most common conventional methods used to measure FAVA [2,5,13]. Hermann and Egund evaluated faulty patient positioning, with improper abduction, flexion and rotation of the hip in their study [6]. Because of its availability and high accuracy; CT has achieved widespread popularity in the last two decades. However, using the 2D CT to measure of the FAVA was problematic because the femur has a complicated 3D anatomical structure [14]. The determination of the femoral neck axis was the first and most prominent source of error. This error happens when the center of the femoral neck was depicted either too superior or too inferior or with poor accuracy if an improper choice of a slice was made [15]. Murphy et al have also reported this inconsistency of the neck axis as a source of major error [5]. Apparently, using only one image of the femoral neck in the axial plane is not sufficient to depict the 3D axis of the femoral neck which passes in an oblique manner through this axial cut. To get rid of this problem; Murphy and Hoiseth have selected the head and neck centers from variable image slices for better definition of the axis of the neck [5,15]. The determination of the shaft axis was another source of inaccuracy. Most CT techniques are expected to scan alongside the axis of the femoral shaft, but this is clinically not applicable [14]. The final inaccuracy was the depiction of the condylar line. If the line tangentially joining the medial and lateral femoral condyles posteriorly was not adjusted on the same image slice, then there was also a probability of inaccuracy [14]. Owing to the irregular contour of the femoral neck we faced some problems when we tried to accurately delineate the center of femoral neck using the 2D technique. It was extremely difficult to decide which the best slice that accurately represented the femoral neck center. Kim et al., as

Table 1
FAVA measured in both the normal and abnormal sides using 2D and 3D techniques.

Gender	Normal side 2D	Normal side 3D	Abnormal side 2D	Abnormal side 3D
1. Female	LT 15	LT 25	RT 17	RT 31
2. Male	RT 15	RT 45	LT 20	LT 35
3. Female	RT 26	RT 34	LT 27	LT 37
4. Female	RT 45	RT 47	LT 58	LT 58
5. Female	RT 17	RT 32	LT 20	LT 38
6. Female	RT 35	RT 37	LT 42	LT 38
7. Male	RT 37	RT 35	LT 33	LT 42
8. Female	RT 37	RT 39	LT 40	LT 42
9. Female	RT 29	RT 41	LT 25	LT 45
10. Female	LT 33	LT 30	RT 34	RT 35
11. Female	LT 8	LT 40	RT 25	RT 43
12. Female	RT 34	RT 33	LT 33	LT 42
13. Female	RT 16	RT 33	LT 26	LT 42
14. Female	RT 15	RT 35	LT 23	LT 44
15. Female	RT 13	RT 41	LT 21	LT 45
16. Female	RT 17	RT 32	LT 5	LT 34
17. Female	LT 25	LT 30	RT 46	RT 49
18. Male	RT 37	RT 31	LT 44	LT 45
19. Female	RT 45	RT 38	LT 65	LT 61
20. Female	LT 25	LT 28	RT 20	RT 38

Please cite this article in press as: Shalaby MH et al. . Egypt J Radiol Nucl Med (2017), http://dx.doi.org/10.1016/j.ejrnm.2017.02.007

Table 2
Statistical analysis of the results using paired *t* test.

		Minimum	Maximum	Mean	SD.	Paired *t* test	P value
Normal	2D	8	45	25.00	11.427	−3.731	0.002*
N = 20	3D	25	47	36.47	5.805		
Abnormal	2D	5	65	32.72	14.418	−3.904	0.001*
N = 20	3D	31	61	41.24	6.790		

* Significant.

Table 3
Intraoperative measurements of FAVA.

Patient number	FAVA (degrees)
1	40
2	35
3	35
4	45
5	30
6	30
7	40
8	40
9	40
10	30
11	40
12	40
13	40
14	35
15	40
16	30
17	40
18	40
19	50
20	30

well suffered similar inherent difficulty for the following causes: inadequacy in choosing the proper anatomic feature in the femur itself, failure of conversion the uni and biplanar data into a 3D system in a mathematically reliable model, radial asymmetry of the femoral neck cross section, thus an accurate and definite neck center could not be depicted by any combination of biplane calculations of the femoral neck [14]. Abel et al, 1994 developed a 3D method using a 3D reformatted image. This supplies better results than the 2D technique by using overlapping axial slices to estimate the axis of both the head and neck. Yet, it was inadequate to demonstrate an accurate 3D anatomy of the femur with boundary images of 2D cuts [16]. Kim et al developed another method for measuring FAVA. They used the 3D rendering technique and placed the anatomical features on a reformatted femur in the long axis and the FAVA is finally measured. Both the sagittal and the coronal planes are applied to confirm that the femur is reformatted in the long axis. However, this technique is tedious and time consuming and needs an experienced technologist. [14] Recently Jia et al., described a simple 3D technique to measure the FAVA in patients with unilateral DDH [8]. We used this method in our study as it was easily applied and didn't require special software. In our study, the femoral head was frequently either small or decentered or unossified making it hardly visualized using the 2D technique. To solve this problem using the 3D technique, we considered the line passing through the femoral neck center as the femoral neck axis. This method was described by Jia et al. [8] and it was adopted in our study. In our study we observed that because of dislocated hips, we had a difficulty in properly positioning our patients on table. Thus the axial images of the femoral condyles and the femoral neck could not be properly superimposed to measure FAVA using the 2D technique. (Fig. 1) On the contrary, using the 3D technique, we had the flexibility to superimpose both axial images and get an accurate measurement of the FAVA. We had 2 patients below 19 months of age who had FAVA < 15° using the 2D technique. Knowing that the average FAVA is 39° between 3 and 12 months of age [10,11], this aroused our suspicion about the utility of 2D technique in measuring FAVA in patients with DDH. The FAVA measured by 3D technique was more accurate than that measured by 2D technique when both were compared by intra operative findings. In order to minimize the hazards of radiation exposure, we used the AEC system to minimize the radiation doses as much as possible as well as reducing the scan time without affecting the image quality. We have to admit that to evaluate the degree of anteversion clinically we used to measure the degree of internal rotation of the limb required to maintain stable reduction of the hip using a goniometer which is a rough method and depend on the clinical sense of the operating surgeon. However, this is the method used by most surgeons to determine the degree of anteversion intra operatively.

This study concludes that 3D technique is more accurate than 2D technique in measuring FAVA in DDH patients. It is easily applied, simple, rapid and is also comparable to intra-operative clinical assessment. We limited this study to unilateral cases to be able to compare the superiority of 3D in DDH as compare to the normal side, we also limited it to non syndromic DDH to again eliminate any other factors; however, given the clear results concluded from this study, we recommend 3D to replace 2D technique in measuring FAVA in all pathologies.

To our knowledge, this is the first study in English literature that directly proves the superiority of 3D over 2D technique of measuring FAVA in unilateral DDH. This is in line with Jia et al. study that used the 3D technique in setting indications of femoral osteotomy, however, they did not study its superiority over 2D.

Conflict of interest

We have no conflict of interest to declare.

Acknowledgements

The authors would like to thank Dr. Amira M. Gadallah, Assistant Professor at the National Research Center, Cairo, Egypt for performing the statistical analysis of this study.

The authors would also like to thank Dr. Antoine Moussally, CT application Manager, for his great help in the technical aspect of this study.

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