Algorithm for Automatic Angles Measurement and Screening for Developmental Dysplasia of the Hip (DDH)

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Abstract— **Developmental Dysplasia of the Hip (DDH) is a medical term represent the hip joint instability that appear mainly in infants. The examination for this condition can be done by ultrasound for children under 6 months old and by X-ray for children over 6 months old. Physician's assessment is based on certain angles derived from those images, namely the Acetabular Angle, and the Center Edge Angle. In this paper, we are presenting a novel, fully automatic algorithm for measuring the diagnostic angles of DDH from the X-ray images. Our algorithm consists of Automatic segmentation and extraction of anatomical landmarks from X-ray images. Both of Acetabular angle and Center edge angle are automatically calculated. The analysis included X-ray images for 16 children recruited for the purposed of this study. The automatically acquired angles accuracy for Acetabular Angle was around 85%, and an absolute deviation of 3.4°±3.3° compared to the physician's manually calculated angle. The results of this method are very promising for the future development of an automatic method for screening X-ray images DDH that complement and aid the physicians' manual methods.**

I. Introduction

Developmental dysplasia of the hip (DDH) represents a anatomic anomaly in which the femoral head and the acetabulum are in improper position and/or develop atypically [1]. In some instances, the ligaments of the hip joint may be loose and stretched. The degree of hip looseness, or instability, varies in DDH. The exact causes are not known; however, there are current notions that infants are more prone to hip dysplasia for the following reasons: 1) hip dysplasia is approximately 30 times more likely when there is a family history, 2) the fetuses' womb position can increase pressure on the hips, 3) infant supine positioning during the first year of life, and 4) the bones of an infant's hip joint are much softer than an adult hip joint [1, 2].

Approximately one out of every 20 full-term babies has some hip instability and two or three per thousand will require treatment [3, 4].

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Once DDH is suspected, either physical or imaging examination is used for diagnosis. When medical imaging are used for diagnosis; ultrasound are used for babies who are less than 6 months old and X-ray is used when the femoral head ossification becomes visible (i.e. usually after 6 months) [5].

Using X-ray, DDH is diagnosed according to the angles measured from a line drawn center of the femoral head to outer edge of the acetabular roof (Acetabular angle), and a vertical line drawn through center of femoral head (i.e. Center edge angle). The most important parts for DDH diagnosis in an X-ray image are Hilgenreiner's line, Perkin's

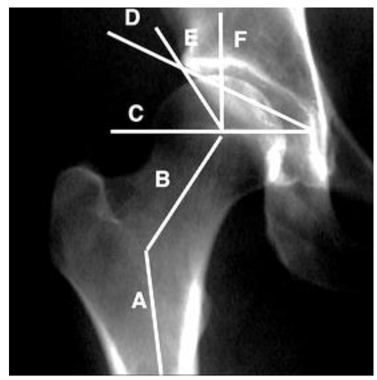

Fig. 1. Typical angles that are measured in the assessment of DDH. A: Femur. B: Greater Trochanter. C is Hilgenreines's line; D is tangential line to the acetabular roof ; E is Shenton's line; F is Perkin's lineAngle CD: Acetabular index (Acetabular index is the angle formed by the Acetabular Roof line and Hilgenreiner's line). Angle EF: Center-Edge Angle (one perpendicular to Hilgenreiner's line and the other towards the lateral edge of the acetabulum. These two lines formed the center-edge angle);

line, Acetabular angle, Shenton's line, and Center edge angle of Wiberg (illustrated in Fig. 1) [6].

These angles are usually measured manually from the X-ray images and used for DDH diagnosis, which is currently the accepted golden standard for DDH assessment. However, this method is time-consuming and labor intensive. Also, accuracy is subjective, based on experience of available physician.

A number of studies [7-10] have reported different automated segmentation methods of the pelvis and the femur bones. Methods either applied complex reconstruction techniques, or a cylindrical fitting method to perform the segmentation. However, none of these methods has reported a direct angle assessment technique for DDH angle assessment without manual intervention. Thus, in this paper we will present a novel technique for a fully automatic DDH angles measurement in order to minimize manual intervention and provide more accurate and reliable results.

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II. MATERIALS AND METHODS

DDH is diagnosed based on the Acetabular Angle (AA) and the Center Edge Angle (CEA). The AA is formed by the intersection of two lines; the tangential to the acetabular roof line and the Hilgenreiner's line (Fig.1). At birth, AA is approximately 30° and progressively decreases with joint maturation (see Table I [1]). The CEA represented by the angle formed of a line drawn from femoral head center to the acetabular roof outer edge, and a vertical line drawn through center of femoral head. It is usually used for children over 5 years old since the femoral head center is harder to define in children under that age. Most sources [4, 11] indicate that the CE angle should not exceed 20 degrees for children and should not exceed 25 degrees for adults.

TABLE I
ACETABULAR ANGLE (AA): NORMAL (MEAN ± STANDARD DEVIATION) VALUES FOR FEMALES AND MALES (IN DEGREES)

Age (months)	AA (females)	AA (males)
Newborn	28.8° ± 4.8°	26.4° ± 4.4°
3	25.0° ± 3.5°	22.0° ± 4.0°
6	23.2° ± 4.0°	20.3° ± 3.7°
12	21.2° ± 3.8°	19.8° ± 3.6°
24	18.0° ± 4.0°	19° ± 3.6°

A. Algorithm Block Diagram

The block diagram in Fig. 2 shows the proposed algorithm for measuring AA and CEA. The proposed algorithm was implemented using MATLAB.

After importing the X-ray images by MATLAB, the images were sorted left or the right side of the hips. Each side of the hips was processed separately: First by applying Canny edge detection, followed by Breadth First Search (BFS) and template matching. The Hough transform and eigenvalues of covariance matrices were finally found to calculate the DDH angles. These steps are detailed in the following subsections.

B. Canny Edge Detection

In the proposed algorithm, Canny edge detection was used to identify the edges of the bones that contribute in forming the DDH reported diagnostic angles. Canny edge detection is the most commonly used operator to detect the edges [12], and is applied in the following steps:

1. The image is smoothed using 2D Gaussian filter;
2. The gradient is found by applying Sobel operators;
3. The non-maxima suppression is performed;
4. Finally, double-thresholding and edge tracking by hysteresis is applied to include only the strong edge candidate.

C. BFS and Template matching:

Breadth First Search (BFS) is performed to detect possible femur head center locations candidates. Template matching is implemented to determine the exact femur head center from the candidates produced by BFS. This technique uses a circular convolution mask (template) to determine the center of the femur head [13].

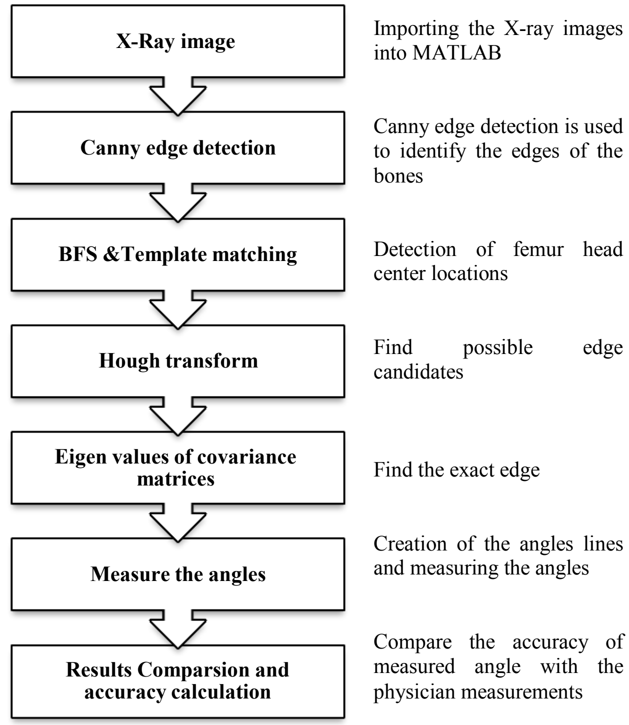

Fig. 2. Block diagram of the proposed algorithm to measure the acetabular and the center edge angles (AA and CEA) that used for DDH diagnosis.

D. Hough Transform

Hough transform was then performed on the resultant image to find possible edge candidates [7, 14]. For the exact edge detection, the lowest pixel for the inner edge candidates and eigenvalues of covariance matrices were identified, according to the method discussed in [15] for the outer edge candidates.

The resultant points are drawn on the X-ray image. Using these points; the algorithm draws the acetabular roof line and Hilgenreiner's line to calculate the acetabular angle. Then two lines are drawn from center of the femoral head: one is perpendicular to Hilgenreiner's line and the other towards the lateral edge of the acetabulum. These two lines form the center-edge angle.

Fig. 3 shows the images progressively resulting from applying each step of the proposed algorithm (subject ID #1 in the study).

After finding the acetabular angle and the center edge angle; the measurement accuracy was calculated as:

$$Accuracy = (1 - MSE) \times 100\%$$

$$\text{Where } MSE = \left|\frac{True\ Angle - Measured\ Angle}{True\ Angle}\right|$$

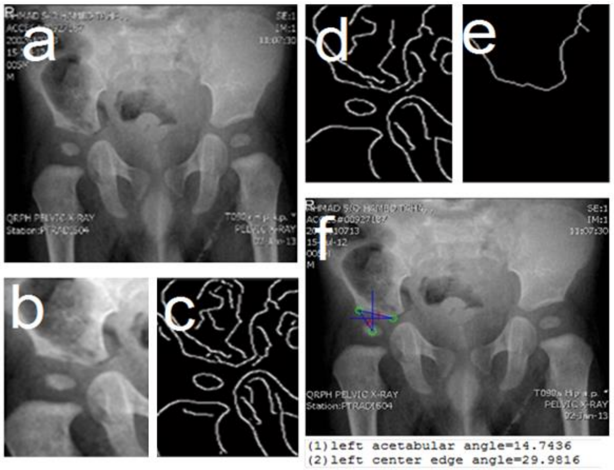

Fig. 3. The resultant image produced by applying each step of our proposed algorithm on subject ID #1: a) original image for bilateral DDH. b) The acetabulum and femoral head cropped image for the left side of the hip. c) The acetabulum and femoral head cropped image after applying the canny edge detection. d) The acetabulum and femoral head cropped image after thresholding. e) The acetabular bone border detection after applying BFS and template matching. f) Finally, after finding the femur head center and the acetabulum edge locations, lines drawn to measure the acetabular angle and the center edge angle.

III. Demographical Data

The algorithm was applied to the X-ray images from 16 children recruited for the study. Signed consents were acquired from parents of the children to be included in the study. Images were collected at King Hussain Medical Center, Royal Medical Services (RMS), Amman, Jordan. Although the reported practice for X-ray diagnosis used for DDH diagnosis is for infants 6 months or older [3], the common practice at this particular hospital is to use X-rays on children who are over 3 months old. Table II shows the demographical data for the children used in this study.

TABLE II
The Demographical Data for the Infants Used in This Study

Subject ID	Gender	Age (months)	Group
1	Male	5	DDH
2	Female	22	Normal
3	Female	10	Normal
4	Female	7	DDH
5	Male	4	Normal
6	Female	4	DDH
7	Female	4	DDH
8	Male	4	Normal
9	Female	5	DDH
10	Female	7	DDH
11	Female	5	Normal
12	Male	6	DDH
13	Female	4	Normal
14	Female	27	Normal
15	Male	5	Normal
16	Female	5	DDH

IV. Results

The algorithm was applied to the X-ray images collected from the subject group presented in Table II. These measured angles were compared to the angles found manually by the physician's assessment (true angles). The physician was blind to the objectives of the study.

Fig. 4 illustrates the true versus measured Left Acetabular Angles (TLAA vs MLAA). The angles were sorted by gender first, then by age, since the normal range of acetabular angles varies by gender and age, as shown in Table I. The absolute error in measurement was 2.95±2.04°, and an average accuracy of 85.4%.

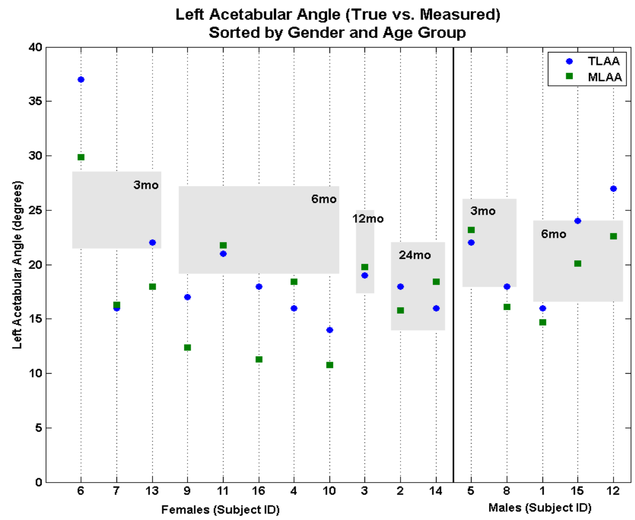

Fig. 4. True versus measured Left Acetabular Angles for the 16 subjects in the study, sorted by gender then age. Shaded areas represent the normal range for the Acetabular Angle. Angles outside the shaded area are diagnosed as DDH by a physician.

Fig. 5 illustrates the true versus measured Right Acetabular Angles (TRAA vs MRAA). The absolute error in measurement was 3.78±4.19°, and an average accuracy of 83.6%.

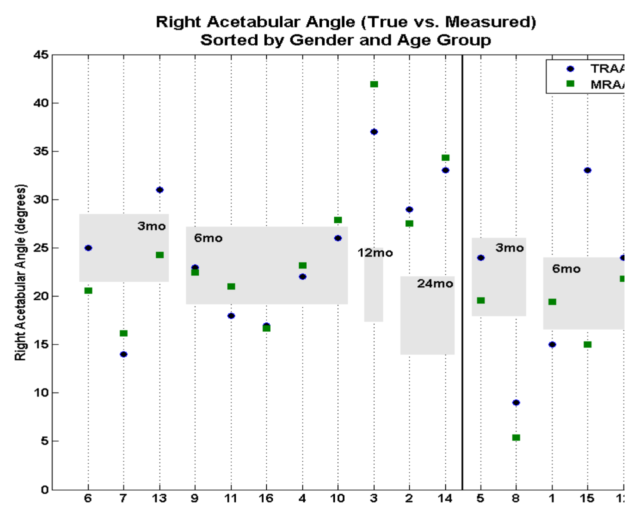

Fig. 5. True versus measured Right Acetabular Angles for the 16 subjects in the study, sorted by gender then age. Shaded areas represent the normal range for the Acetabular Angle. Angles outside the shaded area are diagnosed as DDH by a physician.

Fig. 6 illustrates the true versus measured Edge Angles (TLCEA vs MLCEA). The absolute error in measurement was 4.53±3.00°, and an average accuracy of 45.8%.

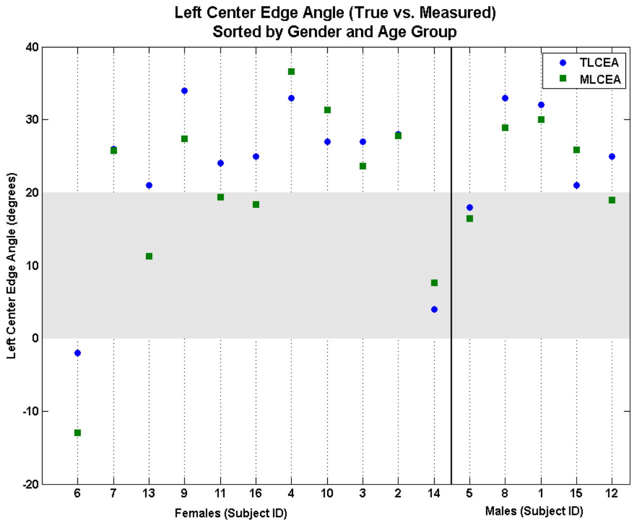

Fig. 6. True versus measured Left Center Edge Angles for the 16 subjects in the study, sorted by gender then age. Shaded areas represent the normal range for the Center Edge Angle.

Fig. 7 illustrates the true versus measure Right Center Edge Angles (TRCEA vs MRCEA). The absolute error in measurement was 3.64±3.87°, and an average accuracy of 78.4%.

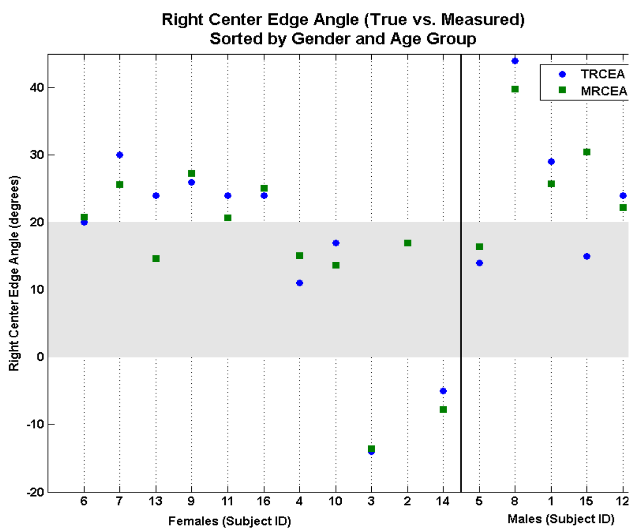

Fig. 7. True versus measured Right Center Edge Angles for the 16 subjects in the study, sorted by gender then age. Shaded areas represent the normal range for the Center Edge Angle.

V. Discussion and Conclusion

The objective of the study was to develop an automatic algorithm to measure the main angles used for DDH diagnosis using X-ray images. The results were compared with expert knowledge obtained from manual assessment of the DDH condition. The results showed a very good accuracy for the Acetabular Angle (around 85% accuracy, with an absolute deviation of 3.4°±3.3° for both left and right Acetabular Angle measurements). Whereas it was lower when calculating the Center Edge angle (between 46% to 78.4% for left and right side of the hip, respectively). This can result from the incomplete development of femur head for infants less than 6 months old, which makes it possible for automatic algorithms to miscalculate the angles, as Fig. 6 shows. As a general trend, the deviation of the measurement decreases with the increasing age of the study group.

The proposed algorithm to automatically measure the DDH angles from X-ray shows promise to apply the method for automatic screening. Moreover, the results can be notably improved using large scale study in the future.

In conclusion, replacing manual assessment methods with new automated techniques is extremely beneficial for the medical field as it saves a lot of time and effort. It has been shown here that automatically calculating the Acetabular Angles from X-ray images is a promising technique in DDH screening and diagnosis.

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