journal homepage: www.intl.elsevierhealth.com/journals/cmpb

Toward automated classification of acetabular shape in ultrasound for diagnosis of DDH: Contour alpha angle and the rounding index

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ARTICLE INFO

Article history:
Received 24 July 2015
Received in revised form
4 March 2016
Accepted 10 March 2016

Keywords:
Developmental Dysplasia of the Hip (DDH)
Classification of DDH
2D ultrasound
Alpha angle
Acetabular coverage
Rounding index

ABSTRACT

Background and objectives: The diagnosis of Developmental Dysplasia of the Hip (DDH) in infants is currently made primarily by ultrasound. However, two-dimensional ultrasound (2DUS) images capture only an incomplete portion of the acetabular shape, and the alpha and beta angles measured on 2DUS for the Graf classification technique show high inter-scan and inter-observer variability. This variability relates partly to the manual determination of the apex point separating the acetabular roof from the ilium during index measurement. This study proposes a new 2DUS image processing technique for semi-automated tracing of the bony surface followed by automatic calculation of two indices: a contour-based alpha angle (α_A), and a new modality-independent quantitative rounding index (M). The new index M is independent of the apex point, and can be directly extended to 3D surface models.

Methods: We tested the proposed indices on a dataset of 114 2DUS scans of infant hips aged between 4 and 183 days scanned using a 12 MHz linear transducer. We calculated the manual alpha angle (α_M), coverage, contour-based alpha angle and rounding index for each of the recordings and statistically evaluated these indices based on regression analysis, area under the receiver operating characteristic curve (AUC) and analysis of variance (ANOVA).

Results: Processing time for calculating α_A and M was similar to manual alpha angle measurement, ~30 s per image. Reliability of the new indices was high, with inter-observer intraclass correlation coefficients (ICC) 0.90 for α_A and 0.89 for M. For a diagnostic test classifying hips as normal or dysplastic, AUC was 93.0% for α_A vs. 92.7% for α_M, 91.6% for M alone, and up to 95.7% for combination of M with α_M, α_A or coverage.

Conclusions: The rounding index provides complimentary information to conventional indices such as alpha angle and coverage. Calculation of the contour-based alpha angle and rounding index is rapid, shows potential to improve the reliability and accuracy of DDH diagnosis from 2DUS, and could be extended to 3D ultrasound in future.

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http://dx.doi.org/10.1016/j.cmpb.2016.03.013

1. Introduction

Developmental Dysplasia of the Hip (DDH) is a common congenital musculoskeletal condition affecting up to 3% of the population [1], characterized by a lax or dislocated hip joint, which if not treated early enough leads to premature osteoarthritis. About 1/3 of hip replacement surgeries in patients less than 60 years old are due to DDH [1]. Diagnosis of hip dysplasia is usually based on the shape of the acetabulum (the "socket" of the ball-and-socket hip joint) and the position of the femoral head relative to it. Although DDH can be diagnosed on physical examination via Ortolani and Barlow maneuvers, these are highly subjective and lack sensitivity for mild dysplasia [2–5], hence image aided diagnosis is preferred. Ultrasound imaging is recommended over radiographs since it avoids ionizing radiation and can visualize cartilage, while femoral heads are non-ossified in infancy and thus not visible on radiographs [2].

Ultrasound diagnosis of DDH most commonly uses the Graf technique, which is based on measurement of a bone angle (alpha) and a soft tissue angle (beta) from a coronal 2D ultrasound image of the hip. The Graf technique classifies alpha angles greater than 60° as normal and less than 43° as severely dysplastic [6]. A fundamental limitation of this approach is that it uses a 2D image to represent a complex 3D structure, leading to subjectivity in measurement and consequently high inter-scan variability. Since the ultrasound probes are hand-held, no two ultrasound scans are exactly alike and a slight variation in probe orientation can give a vastly different view of the acetabulum. Jaremko et al. [7] have shown that this variability can lead to incorrect classification of DDH in half of infants and up to three-quarters of neonates. Another source for inter-observer variability in the Graf technique arises from variations in manual selection of the apex point. The apex point, which marks the separation of the ilium and the acetabulum, is used as the vertex to calculate the alpha and beta angles. The radiographic angles most similar to the alpha angle, the center-edge angle (CEA) and acetabular angle (AA), also have values dependent on definitions of lateral acetabular margin [8].

Other indices that could avoid these difficulties, and consider other aspects of the deformity of hip dysplasia, have been investigated. An alternate technique that measures a γ-angle in ultrasound images to assess the femoral head coverage was proposed by Yavuz et al. [9]. Supplementary measures to the alpha angle such as arc length, coverage and acetabular radius of curvature have been examined by Cheng et al. [10]. These methods of quantifying acetabular rounding had higher inter-observer variability than alpha angle and femoral head coverage.

All of these alternative indices quantifying DDH are still susceptible to inter-scan and inter-observer variance as they depend on manually determined landmarks. This study proposes an alternative method of ultrasound image processing: instead of the user making measurements on the image, he/she supervises generation of the acetabular surface contour, and indices of dysplasia that are geometric properties of the acetabular shape are automatically generated. We propose two such automated indices: a contour alpha angle α_C and the rounding index M.

The rounding index M is based on kurtosis and skewness of acetabular convexity, a way to mathematically quantify the intrinsic rounding of the acetabulum that can classify the acetabular shape. The index is independent of apex point (or any other manual landmarks) and hence is less subjective. It is modality-independent and can be easily computed from 2D contours of the acetabulum derived from any imaging modality. The index can also be extended to surface models generated from 3D ultrasound [11,12].

In this study, we assess the feasibility and potential value of automated 2D ultrasound image processing in DDH by this approach, measuring reliability and diagnostic accuracy of: (i) a contour-based alpha angle (α_A); and (ii) the rounding index (M), compared to conventional ultrasound indices of DDH, namely alpha angle (α_M) and acetabular coverage (AC).

2. Methods

2.1. Index calculation

An overview of our computational approach is shown in Fig. 1. The algorithm was implemented using MATLAB 2012 (The MathWorks, Natick, MA, USA) and calculations adapted to open-source Python (Anaconda Distribution 2.1.0, Continuum Analytics Inc. Austin, TX, USA). The initial step in the workflow is to obtain a contour (in 2D) or point mesh (in 3D) representing the acetabular surface. Each point on the contour or mesh has a convexity value associated with it. These calculated convexity values are automatically clustered by magnitude using k-means clustering [13]. The cluster of points with highest convexity values are then used to calculate the rounding index (M), comprised of terms denoting kurtosis (K), skewness (ψ) and the convexity ratio (C). The normalized value of the index is used to classify the hips into diagnostic categories from normal to dysplastic.

2.2. Acetabular surface segmentation

The acetabular contour is segmented automatically based on 2 user defined end points of the acetabulum (shown in Fig. 1) placed at the edge of the acetabular roof and ilium (where the acetabulum is closest to the femoral head). The graph based segmentation algorithm determines acetabular contour as shortest path between the two endpoints based on a customized cost function [11].

2.3. Determining the convexity cluster

The convexity cluster is determined automatically from the acetabular surface contour from a 2D image or from a 2D slice obtained from 3D ultrasound data. Convexity value at a point is defined as the perpendicular distance (Fig. 2(a), line D) from that point to the line segment joining the end points of the contour on that slice (Fig. 2(a), line L). The endpoints are the edges of the echogenic line representing the acetabular contour on the ultrasound image or slice of interest. The collection of all points on the contour is clustered using the k-means