New “L value” parameter simplifies and enhances hip ultrasound interpretation in the detection of developmental dysplasia of the hip

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Abstract

Purpose The purpose of this study was to simplify and enhance the ultrasound (US) analysis of the infant’s hip by introducing a novel parameter named “L value” into the widely used Graf method.

Methods We analysed 508 ultrasonographic images of the hips in infants aged three months. The images were first evaluated using the Graf measurements. On the same images, two additional measurements were performed in order to define the new parameter that was named L value. The threshold values of the new L value were identified based on the highest specificity as well as sensitivity for discrimination between the Graf groups. Those values were then used in order to reclassify the hips into three simplified groups. Inter-observer agreement was estimated by Cohen’s kappa coefficient.

Results The threshold values for the L value between Graf groups Ia and Ib was 0.46, between Ib and IIb was 0.68 and between IIb and IIc was 0.92. Correlation analysis between Graf’s classification and the values of the L value was performed and was proved to be statistically significant, $r=0.49$; $p<0.001$. After simplifying the classification into three newly defined groups of patients depending on the

degree of hip development, the correlation coefficient was much higher, $r=0.94$, $r^2=0.88$ for $p<0.001$. Inter-observer agreement for the L value was substantial.

Conclusions The new L value parameter in Graf’s ultrasound hip evaluation enables a faster, simpler, more reliable and more unbiased classification for developmental dysplasia of the hip as the L value changes proportionally with the hip maturity.

Introduction

Developmental dysplasia of the hip (DDH) is a common disease of the musculoskeletal system of a newborn [1–7]. DDH is a major cause underlying the early arthritis that often leads to a total hip replacement. DDH comprises the continuum that includes an immature hip, a hip with mild acetabular dysplasia and a pathologically developed hip, which means a severely dysplastic and eccentric hip [1, 2, 6–9].

The detection of DDH is multidisciplinary and includes not only orthopaedic specialists but also radiologists and paediatricians and is mostly based on ultrasonographic (US) evaluation [10]. Importantly, early diagnosis and treatment are necessary to achieve a proper hip development.

Graf’s method of diagnosing DDH is generally accepted, widely used, and relies on eight parameters: the alpha angle–bony roof angle, the beta angle–cartilage roof angle, the morphological form of the bony roof, the patient’s age, the degree of minimum expected maturation, the centering of the femoral head into the acetabulum, echogenicity of the hyaline cartilage (degeneration) and on the course of the cartilage acetabular roof [9]. Based on these eight parameters, the final Graf classification clusters patients into four

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main groups according to the values of the alpha angles (I–IV): groups Ia and Ib for the mature hips, IIa and IIb for the immature/dysplastic hips, and IIc, D, IIIa, IIIb and IV for the pathologically developed hips. Even though Graf's method is widely accepted, the subjective character of evaluation of the several parameters and known variability in angle measurements [10, 11] may lead to the misclassification of the analysed hip. This problem is particularly pronounced for hips classified as borderline cases between the two adjacent Graf groups where the decision about “to treat or not to treat” should be made [12].

Other methods of US evaluation have also been reported: Morin et al. [13] and later Gunay et al. [14] measured the percentage of the femoral head coverage; Harcke et al. [15] described a dynamic technique where the infant hip is examined during a set of specific movements, Terjesen et al. [16, 17] determine the amount of the femoral head covered by the osseous part of the acetabulum, while Suzuki et al. [18] analysed both hips simultaneously. These approaches can be used alone or as supplemental methods to the Graf method and can contribute to the reliability of the infant hip classifications.

The purpose of this study was to develop an additional, simplified US analysis of the infant's hip based on the widely used Graf method. The novelty of the simplified method is the newly introduced parameter, named “L value”.

Subjects and methods

Ultrasound images of the hips in 508 infants aged 12–16 weeks were analysed.

Ultrasound images were the standard frontal projection images according to Graf. Of 2,894 infant hip images collected during 2007 and 2008 at our department, 515 were randomly selected and then analysed retrospectively.

The inclusion criteria were technically well done US image with a standard plane (three landmarks visible: the lower limb of the ilium, the midportion of the acetabular roof and the acetabular labrum). Altogether seven images were excluded: one due to the associated anomaly in the patient's medical history and six due to technical errors.

All of the US images were performed with a 5- to 7.5-MHz linear transducer (LOGIQ P5/A5, GE Healthcare, UK).

The images were first evaluated using the Graf measurements and consequently the Graf group type was assigned to each hip.

On the same images, two additional measurements were performed in order to define the new parameter that was named L value. All measurements were done using an AutoCAD application. First, the two essential points for a new analysis were defined (Figs. 1 and 2a, b). The proximal

perichondrial point (PP) was defined as the most cranial point of the cartilaginous acetabular roof. Accordingly, it was the intersection point between the perichondrium of the cartilaginous roof and periosteum of the iliac bone. The lower iliac limb point (LIL) was defined as the most distal and the most medial point of the lower iliac limb.

Through the PP we first drew the horizontal line (iliac line) which is parallel to the os ilium silhouette (the iliac silhouette above the bony rim is straight and parallel to the transducer), and vertical to it, the line through the LIL. Then we measured the two distances. The distance on the horizontal line from PP to the line intersection point was named “X”, and the distance on the vertical line from the line intersection point to LIL was named “Y”. The new parameter, the L value, was calculated as X/Y ratio, meaning $L = X/Y$.

The receiver-operating characteristic (ROC) analysis identified the threshold values of the new L criterion based on the highest specificity as well as sensitivity for discrimination between the Graf groups. Those values were then used in order to reclassify the hips into three groups. A level of $p < 0.05$ was defined as the statistically significant

Fig. 1 Determination of the X and Y variables. The proximal perichondrial point (PP) is the intersection point between the perichondrium of the cartilaginous roof and periosteum of the iliac bone. the lower iliac limb point (LIL) is the most distal and the most medial point of the lower iliac limb. The point of the intersection of the horizontal line (iliac line) drawn through the PP and the vertical line drawn through the LIL was the line intersection point (I). The distance on the horizontal line from PP to I was named X. The distance from I to LIL was named Y. X and Y form a reverse L shape

Fig. 2 a, b Schematic presentation of determination of the X and Y variables for a mature (a) and for a dysplastic (b) hip. PP proximal perichondrial point, LIL lower iliac limb point

item. Inter-observer agreement was estimated by Cohen's kappa coefficient. Graphic presentations were performed using Microsoft Excel.

The data obtained were analysed by software package Statistica 8.1 (StatSoft Inc., Tulsa, OK, USA) licensed to the Faculty of Kinesiology, University of Zagreb. The descriptive statistical methods, the frequencies, the ROC analysis as well as the correlation analysis were used with a significance level set at $p < 0.05$. Sample size was estimated performing power analysis to be higher than 80. Inter-observer agreement was estimated by Cohen's kappa coefficient.

Results

Of 508 infant hip images included in the study, 262 (52%) were female and 246 (48%) were male. The overall mean age was 12.5 weeks.

According to Graf's analysis the majority of the 508 hips measured were mature hips (Table 1).

In the first step of the data analysis the L values obtained were analysed by means of ROC analysis. The ROC analysis enabled us to identify the cutoff values of the new L criterion based on the highest specificity as well as

sensitivity for discrimination between the Graf groups. Those cutoff values were then used in order to reclassify the hips, firstly into four groups (Table 2). The cutoff for the L value between Graf groups Ia and Ib was 0.46 (sensitivity 93.91%, specificity 94.67%), between Ib and IIb the threshold L value was 0.68 (sensitivity 100%, specificity 86.61%) and between IIb and IIc the threshold L value was 0.92 (sensitivity 92.59%, specificity 100%). As our patients were all older than three months, we did not have any Graf IIa group hips. Also, in severely decentred joint groups we only had one IIIa hip.

The correlation analysis between the Graf classification and the values of the L value was performed and proved to be statistically significant, $r = 0.49$; $p < 0.001$ (Fig. 3).

The correlation analysis between the Graf groups and the L values shows that the L values obtained do discriminate the groups to some extent. The overlapping of the groups (Table 3) raised the question about the necessity of the four group classification so in the next step all mature hips were classified into one group defined by the cutoff point of the L value that was lower than or equal to 0.68.

In the last step trying to explore the possible use of the L value in the future, the correlation analysis was repeated between the three newly defined groups of patients depending on the degree of hip development and the traditional groups defined according to the Graf method (now in Graf's method in this case Ia and Ib were merged). In this case the correlation coefficient was much higher, $r = 0.94$, $r^2 = 0.88$ for $p < 0.001$ (Fig. 4).

With the sample of 508 hips that were analysed for this study the observed correlation could be interpreted with 97.8% of confidence and with a margin of error of 5.6% according to the sample size calculations. The exact power of the correlations calculated by power analysis was 0.9763 for the given sample size.

At the end, in order to overcome a possible bias caused by a single observer, two additional observers performed measurements of Graf's alpha angle and L values in a double-blind manner on 100 randomly selected hips from the study. Inter-observer agreement was moderate for Graf analysis and substantial for the L value (Table 4).

Table 1 Distribution of hips by Graf type

Graf type	Number of hips	Percentage
Ia	319	62.8
Ib	115	22.6
IIb	44	8.7
IIc	29	5.7
IIIa	1	0.2

Table 2 The cutoff values of a new L variable applied to the groups according to the Graf classification

Graf's diagnosis according to L value	L value
Ia	<0.46
Ib	0.46–0.68
IIb	0.69–0.92
IIc	>0.92

Fig. 3 Correlation analysis between the classification of the hips according to the traditional Graf groups and the newly introduced L values

Discussion

A novel approach for evaluation of infant hips was developed and is described. The new parameter named L value was introduced into the widely used Graf method.

The novel L value is a simplified, reliable and unbiased approach for detecting DDH. On standard Graf infant hip projections, the L value is determined by the ratio of two distances that are clearly defined anatomically and easily distinguishable during the US recording. The L value is negatively correlated to the Graf classification meaning that in the case of mature, healthy hips the L value is significantly lower than in dysplastic and pathologically developed hips. By means of the ROC analysis, the cutoff L values were identified which distinguished in the best manner the groups according to the standard Graf classification (Table 2).

When comparing the four Graf groups to the four groups classified according to the L value, the correlation was statistically significant ($r=0.49$ for $p<0.001$) (Fig. 3). However, we observed that there is a large overlap between the distribution of the L value in patient groups Ia and Ib according to Graf and we tried to form only three groups in respect of hip development (Table 3). The first group

represents mature hips, the second group represents dysplastic hips, while the third group represents pathologically developed hips. These three groups of hips have an important practical value in making treatment decisions as all hips from the first group of mature hips require no treatment; the second group consisting of the dysplastic hips requires maturation treatment and follow-up; and the third group of pathologically developed hips needs retention/reduction treatment. The classification into three groups according to the L value proved to be in close correlation to the Graf method ($r=0.94$ for $p<0.001$) (Fig. 4).

The determination coefficient originating from the above-mentioned correlation was 0.88 explaining 88% of the variance. That variance was expected and originated from reclassifying some of the hips and moving some of the mature hips to the dysplastic group.

That is to say, there was an overlap between the distribution of the L value in Graf patient groups Ib and IIb (Fig. 3). By applying the cutoff value of 0.68 between the Ib mature and IIb dysplastic hips, we extracted 13% of hips from the Ib group into the new L value-based dysplastic group together with all hips from the IIb group (Fig. 3). In this way, no hip from the IIb group was

Table 3 New classification of the hips based on the L value

Degree of hip development according to the new classification	L value	According to Graf
Mature hips	≤ 0.68	Ia+most of Ib
Dysplastic hips	0.69–0.92	IIb+some previously Ib
Pathologically developed hips	>0.92	IIc+III+IV

Fig. 4 Results of the correlation analysis between the hips classified according to the Graf method and according to the new L value. On the X axis, Graf's diagnosis is defined: 1 mature hips (Graf Ia+Ib), 2 dysplastic hips (Graf IIb), 3 pathologically developed hips (Graf IIC

and worse), and on the Y axis, L values are defined: 1 mature hips (L value ≤ 0.68), 2 dysplastic hips (L value $0.681-0.92$), 3 pathologically developed hips (L value >0.92)

considered well developed allowing a possible oversight, and some maybe borderline hips from group Ib were included into the novel L value-based dysplastic group.

There are a few limitations in this study that need to be acknowledged. Although the exact power of the correlations, calculated by power analysis, was 0.9763 for the given sample size (508 hips were analysed for this study), a larger sample size would be needed if we wanted to analyse all Graf hip types (for example hips in Graf group IV which are relatively rare). Also, taking into consideration the so-called maturation curve of an infant's hip, we included in our study infants aged three months to exclude physiologically immature hips, although the ideal time for diagnostic workup and treatment is four to eight weeks.

To confirm the reliability of the L value, we investigated the inter-observer agreement according to the Cohen's kappa value between the two observers. The kappa coefficient was significantly higher for the L value measurements than for

the Graf measurements, which demonstrated a superior inter-observer agreement (Table 4). As the higher kappa value for the L value was achieved after only ten initial images, the simplicity of the application of the L value was confirmed.

The kappa coefficient for measurements of inter-observer agreement for the L value was substantial (0.73), in the case of the Graf measurements it was described to be moderate (kappa 0.42), while it was previously reported that the inter-observer agreement for Graf's classification indicates moderate to substantial kappa values (kappa 0.55–0.71) [10, 11].

Conclusion

In conclusion, use of the new L value parameter in Graf's ultrasound evaluation of infant hips make it possible to perform a faster, simpler, more reliable and more unbiased classification for DDH.

The L value changes proportionally with the hip maturity. In the future, with the development of computer software that would calculate the ratio of two distances which define the L value, it will be possible to define PP and LIL points easily during the US evaluation. Further research of L values is needed, but we are proposing the use of the L value as an auxiliary value in detecting DDH.

Table 4 Inter-observer agreement for Graf's alpha angle and the L value

	Kappa coefficient	
	Mean value	Standard deviation
Alpha angle	0.417	0.167
L value	0.726	0.180

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