Teardrop And Sourcil Line (TSL): A Novel Radiographic Sign That Predicts Residual Acetabular Dysplasia in DDH After Closed Reduction

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Abstract

Background: Residual acetabular dysplasia (RAD) is a major problem of developmental dysplasia of the hip (DDH) after closed reduction (CR). Several parameters have been investigated as ways of predicting RAD; however, early prediction of RAD remains controversial. The purpose of this study was to evaluate the radiographic sign of teardrop and sourcil line (TSL) in pediatric patients with DDH to enable prediction of RAD after CR early.

Methods: One hundred and twenty-five hips with DDH treated with CR and followed up for at least 2 years were included in this study. The mean age at CR was 18.3 months (range, 9 to 32 months) and the average follow-up time was 44.2 months (range, 24 to 83 months). The acetabular index (AI) was measured at different time points. RAD was determined according to the modified Severin criteria. The cases were divided into two groups according to whether TSL became continuous or not. The relationships among TSL, AI and RAD were analyzed.

Results: The RAD incidence was 73.6% (92/125) at the last follow-up. AI at CR and TSL were the prognostic factors for RAD ($p=0.017$ and 0.001 , respectively). Thirty-four hips showed a continuous TSL. The mean time when TSL became continuous after CR was 20.9 months (range, 8 to 57 months). There was a lower RAD rate in the TSL continuous group ($p<0.001$). There was no statistical difference in the AI at CR between the TSL continuous and discontinuous groups; however, the level of AI after CR was lower in the TSL continuous group. In the TSL continuous group, there was no significant difference in the time at which TSL became continuous after CR between RAD and non-RAD hips.

Conclusions: The TSL continuous group had a lower AI and incidence of RAD than the discontinuous group. The TSL can be a predictive factor of RAD in DDH after CR and can predict RAD at an earlier time than AI measurement.

Background

Developmental dysplasia of the hip (DDH) is one of the most common developmental deformities of the lower extremities and one of the leading causes of future osteoarthritis and hip arthroplasty, including hip dislocation, subluxation and acetabular dysplasia [1, 2]. The key to treatment is early diagnosis and achieving stable concentric reduction. Although the popular method of sonographic hip screening can diagnose DDH as early as possible, delayed diagnoses still occur in some children [3, 4]. Closed reduction (CR) and spica cast immobilization is one of the main methods used to treat DDH. However, residual acetabular dysplasia (RAD) after CR is still a major problem in clinical practice, and pelvic osteotomy is indicated if RAD persists [5–8]. To establish early and reliable predictors of RAD, several radiographic parameters have been investigated such as the acetabular index (AI), central edge angle (CEA) etc. But, determination of the time when a further procedure is required remains controversial because these parameters need to be observed over a long time period [8–16]. Surgeons need some radiographic parameter that will predict future changes in RAD after CR that will enable earlier correction of the RAD.

The acetabular teardrop is a landmark seen in the inferior medial acetabulum on the anteroposterior (AP) X-ray of the pelvis. The sourcil is a curved area of dense bone on the weight-bearing surface of the acetabulum and represents a stress distribution within the hip joint indirectly. Both the teardrop and sourcil are correlated with the development of the acetabulum [8, 16–20], so we wondered if the smoothly curved line produced along the lateral margin of the teardrop that follows the curve of the sourcil (teardrop and sourcil line, TSL) (Fig. 1) could predict the outcome of DDH after CR. To the best of our knowledge, no previous research has combined the teardrop and sourcil to evaluate DDH after CR.

In this study, we retrospectively reviewed dislocated hips treated by CR in our hospital with a follow-up time of at least 2 years. The purpose of this study was to evaluate the new radiographic sign of TSL in pediatric patients with DDH and predict RAD after CR earlier.

Methods

Patients

This retrospective study was approved by the local institutional review board. Hip dislocation cases were collected from October 2011 to December 2017. The inclusion criteria were: (1) dislocation-type DDH treated with CR and spica casting under general anesthesia; (2) at least 2 years of follow-up. Children with neuromuscular disease, endocrine disease, once treated, information incomplete, and hips treated with open reduction because of redislocation immediately after CR were excluded.

A total of 104 patients (125 hips) were enrolled; there were 91 female (87.5%) and 13 male (12.5%) patients. Eighty-three hips (80%) were in patients with unilateral DDH, 21 hips (20%) were bilateral. Of the 83 unilateral cases, 51 (61%) were left hips and 32 (39%) were right hips. The mean age was 18.3 ± 3.9 months (range, 9 to 32 months) at CR and the average follow-up time was 44.2 ± 14.5 months (range, 24 to 83 months). An osteotomy was performed in 31 (25%) of the 125 hips at a mean age of 54.9 ± 8.8 months (range, 39 to 79 months). The osteotomies included 1 Pemberton osteotomy, 27 Salter osteotomies and 3 combined Salter and femoral osteotomies.

Treatment Procedure

CR was performed under general anesthesia, and adductor longus tenotomy was applied when hip abduction was limited. Subsequent immobilization was achieved with a human position hip spica cast, keeping the hips in 90–100° flexion and 40–50° abduction. MRI was used to evaluate the adequacy of reduction within 3 days post-operation. After 3 months the spica cast was changed to a fixed abduction brace, which remained in place for 3–6 months.

Radiologic Assessment

Picture Archiving and Communication System (PACS) imaging technology was used to measure the acetabular index (AI) at different time points. We used the lateral osseous margin of the acetabular roof instead of the lateral end of the sourcil when measuring the AI on the anteroposterior (AP) pelvis radiograph. RAD was determined according to the modified Severin criteria [21]: grades I and II were classified as satisfactory and grades III to VI were classified as unsatisfactory. The degree of hip dislocation was classified by the International Hip Dysplasia Institute (IHDI) classification [22]. RAD and TSL were judged at the last follow-up or before osteotomy surgery. The time when TSL became continuous after CR was recorded. The cases were divided into two groups according to whether TSL became continuous or not. Two independent doctors measured and collected all data.

Statistical Analysis

The data were analyzed using IBM SPSS Statistics Version 19.0 (IBM Corporation, Armonk, NY, USA). Continuous variables were collected as the mean $\pm$ *SD*. Categorical data were analyzed with the χ^2 test. Continuous results were analyzed using the *t*-test. Binary logistic regression analysis was used to determine the prognostic factors for RAD. Differences were considered significant when $p < 0.05$.

Results

Demographic data for the total of 125 hips are shown in Table 1. The mean AI at CR was $38.5^\circ \pm 4.3^\circ$ (range, 27.6° to 47.6°). The RAD incidence was 73.6% (92/125), non-RAD incidence was 26.4% (33/125) (Table 2). Patients who developed RAD had a significantly larger AI, greater age and higher IHDI grade at CR, but a lower rate of continuous TSL than those who did not ($p = 0.006, 0.035, 0.049$ and 0.000 , respectively) (Table 3). The power of the prognostic factors for RAD of AI, age and IHDI grade at CR, and TSL were determined by binary logistic regression analysis, and the results showed that AI at CR and TSL were the prognostic factors for RAD ($p = 0.017$ and 0.001 , respectively) (Table 4) (Fig. 2).

Table 1 Demographic data

Sex (no. of patients)	
Male	13(12.5%)
Female	91(87.5%)
Side (no. of patients)	
Right	32(30.8%)
Left	51(49.0%)
Bilateral	21(20.2%)
IHDI grade (no. of hips)	
III	65(52%)
IV	60 (48%)
Age at CR* (mo)	18.3 (9-32)
Duration of follow-up* (mo)	44.2 (24-83)
Type of ostotomy (no. of hips)	
Pemberton	1 (3.2%)
Salter	27(87.1%)
Salter +femoral	3(9.7%)
Age at ostotomy * (mo)	54.9 (39-79)

* The values are given as the mean, with the range in parentheses.

Table 2
Radiologic Outcomes Using modified Severin Classification^[21]

Grade	Description	No. of hips
I	Normal appearance	4
II	Mild deformity of femoral head and neck or acetabulum	29
III	Dysplasia or moderate deformity of femoral head and neck or acetabulum, or both	88
IV	Subluxation of the femoral head	4
V	Articulation of the femoral head with a false acetabulum	0
VI	Redislocation	0

Table 3
AI, age, sex, side and IHDI grade at CR and the continuous of TSL in two outcome groups

	AI at CR ($\bar{x} \pm s, ^\circ$)	Age at CR ($\bar{x} \pm s, \text{mo}$)	Sex* male female	Side* left right	IHDI* III IV	TSL* yes no
RAD	39.1 $\pm$ 4.0	18.7 $\pm$ 4.0	4 29	53 39	43 49	17 75
Non-RAD	36.7 $\pm$ 4.7	17.1 $\pm$ 3.3	10 82	19 14	22 11	17 16
<i>p</i>	0.006	0.035	0.845	0.997	0.049	0.000
* No. of hips						

Table 4
Binary logistic regression analysis of prognostic factors for RAD

	β	χ^2	<i>p</i>	<i>OR</i>	95% <i>CI</i> for <i>OR</i> lower upper	
AI at CR	0.135	5.653	0.017	1.145	1.024	1.280
Age at CR	0.099	1.925	0.165	1.105	0.960	1.271
IHDI grade	-0.776	2.291	0.130	0.460	0.169	1.257
TSL	-1.540	10.178	0.001	0.214	0.083	0.552
<i>OR</i> , odds ratio.						

There were 34 hips that displayed continuous TSL. The mean time when TSL became continuous after CR was 20.9 ± 11.8 months (range, 8 to 57 months). There were no significant differences in AI, age, gender, location or IHDI grade at CR between the TSL continuous group and TSL discontinuous group (Table 5). However, the decrease in AI, especially 6 months post-CR, was faster and the mean values of AI after CR at different time points were lower in the TSL continuous group (Fig. 3) (Table 6). The TSL continuous group had a lower incidence of RAD than the TSL discontinuous group ($p < 0.001$) (Table 5). In the TSL continuous group, there was no significant difference in the time when TSL became continuous after CR between RAD and non-RAD hips (19.5 ± 8.3 vs. 22.4 ± 14.6 months, $p = 0.485$).

Table 5
AI, age, sex, side and IHDI grade at CR and RAD in two TSL groups

TSL	AI at CR	Age at CR	Sex*		Side*		IHDI*	RAD*		
	($\bar{x} \pm s, ^\circ$)	($\bar{x} \pm s, \text{mo}$)	male	female	left	right	III	IV	yes	no
continuous	37.4 $\pm$ 4.3	17.5 $\pm$ 2.9	6	28	19	15	16	18	17	17
discontinuous	38.9 $\pm$ 4.3	18.6 $\pm$ 4.2	8	83	53	38	49	42	16	75
<i>p</i>	0.100	0.170	0.162		0.812		0.499		0.000	
* No. of hips										

Table 6
the change of AI after CR in two TSL groups

TSL	0 year*	0.5year*	1 year*	1.5 year *	2 year*	3 year*
continuous [#]	37.4 $\pm$ 4.3	27.7 $\pm$ 4.4	27.4 $\pm$ 3.3	26.8 $\pm$ 4.3	25.4 $\pm$ 4.2	24.4 $\pm$ 5.6
discontinuous [#]	38.9 $\pm$ 4.3	31.1 $\pm$ 4.9	31.5 $\pm$ 4.0	31.1 $\pm$ 4.0	29.5 $\pm$ 4.4	28.2 $\pm$ 5.2
<i>p</i>	0.100	0.001	0.000	0.000	0.000	0.006
* the time point of post CR;						
[#] the values are given as the mean and the standard deviation.						

Discussion

RAD represents one of the most frequent causes of secondary osteoarthritis of the hip and is not rare in DDH patients. More than one-third of DDH patients treated with CR have an outcome of RAD, and there is a higher prevalence of RAD with increasing age at reduction. In our study the incidence of RAD was 73.6% (92/125), higher than reported in previous studies [6, 9, 23]. This might be the result of the shorter follow-up time (44.2 $\pm$ 14.5 months) and older age (18.3 $\pm$ 3.9 months) of the cohort at CR.

RAD is often asymptomatic and the diagnosis relies on radiography. Several radiographic parameters such as AI, CEA, centre-head distance discrepancy (CHDD) and Reimer's index (RI) have been investigated for predicting RAD. However, there are some disadvantages to those parameters: the measurements of CEA, CHDD and RI are influenced by the shape of the femoral head and the center of the femoral head must be identified precisely. If the ossific nucleus of the femoral head has not appeared, is irregular or is very small, the measurement is unreliable. In addition, CEA is validated for patients aged ≥ 4 years and CHDD is useless in bilateral cases [8, 9, 14].

AI is one of the most popular parameters for predicting RAD [6, 15], and a multi-center study suggested that AI would be the best predictor [9]. The measurement of AI is based on a horizontal Hilgenreiner line

that runs through the triradiate cartilage and a line extending from the superolateral margin of the triradiate cartilage to the most lateral ossified margin of the acetabulum. However, the Hilgenreiner line is difficult to measure after ossification of the triradiate cartilage when the patient is older than 8 years, and it is difficult to mark the exact lateral bony margin of the acetabulum because of irregular and indistinct bony shadows on radiographs of dysplastic hips. Furthermore, the value of AI can be affected by the position in which the radiograph was taken, and it is difficult to keep an uncooperative child in the correct position for the radiograph. With increasing lumbar lordosis, which corresponds to the extent of pelvic extension, the AI increases, and with decreasing lordosis or pelvic flexion, the AI decreases. Similarly, if the pelvis is rotated about the longitudinal body axis, the AI toward the side of the rotation decreases and the AI on the opposite side increases [20]. It is often necessary to follow up the AI for a long time to decide when to initiate the following procedure because the development of the acetabulum is a long and slow process. The surgeon needs an earlier and more definitive index to help determine when to carry out the next step of treatment to promote the development of the hip.

Considering the limitations of singular prognosticating factors, Kim et al. [8] tried to combine the orientation of the sourcil and CHDD to predict the RAD and created a risk scale. However, a limitation to this approach has been raised in that CHDD is only useful in unilateral cases [23].

The acetabular teardrop is a landmark seen in the inferior medial acetabulum on the AP X-ray of the pelvis. The timing of its appearance and configuration of the teardrop have been correlated with various pediatric hip disorders and could predict the outcome of DDH after CR [16–19]. The sourcil is a curved area of dense bone on the weight-bearing surface of the acetabulum and represents a stress distribution within the hip joint indirectly. In a normal hip, the sourcil is uniformly thick and semilunar in shape, with a horizontal or downward orientation. However, in the dysplastic hip, the orientation of the sourcil is upward, suggesting an uneven distribution of stress within the hip joint. The shape and orientation of the sourcil have also been used to predict RAD [8, 20].

In this study, we tried to find a more reliable and easier parameter to measure. TSL is the curve that makes up the lateral margin of the teardrop and the curve of the sourcil. The results showed that a continuous TSL can be a predictor of RAD ($p = 0.001$). Compared to CHDD, CEA, RI and AI, TSL is not influenced by the shape of femoral head, does not require identification of the exact point at the center of the femoral head and the lateral bony margin of the acetabulum, and can be used in bilateral cases. The improvement of AI post-reduction by a certain age is a reliable predictive factor of the need for later acetabuloplasty [7, 8], and many studies have focused on the cutoff values of AI at different time points post-reduction to predict RAD [6, 9, 15]. In this study, there was no significant difference in the initial AI between the TSL continuous group and discontinuous group, but the level of AI after CR was lower in the TSL continuous group. This meant AI was more likely to become normal in the TSL continuous group and TSL could predict the potential of AI improvement after CR, so that TSL can be an earlier factor than AI for predicting RAD. However, in the TSL continuous group, there was no significant difference between RAD and non-RAD hips at the time point when TSL became continuous after CR (19.5 ± 8.3 vs. 22.4 ± 14.6

months, $p = 0.485$). Unlike other parameters, there is not a cutoff value of the time when TSL becomes continuous after CR that determines progression to RAD.

The present study had limitations. It was a single center retrospective study, the number of patients was small and the follow-up time was short. Theoretically, there is an upper time limit for TSL becoming continuous after CR that would predict whether RAD occurs or not, but we did not find such a cutoff value in this study. More patients and longer follow-up will be needed in order to further analyze the effectiveness of TSL as a predictive factor.

Conclusion

In conclusion, compared to other parameters, TSL is more visual, easier to measure and useful in bilateral cases. Hence, we suggest that TSL can be an earlier predictor of RAD in DDH after CR than AI.

Abbreviations

RAD: Residual acetabular dysplasia; DDH: Developmental dysplasia of the hip; CR: Closed reduction; TSL: Teardrop and sourcil line; AI: Acetabular index; PACS: Picture archiving and communication system; AP: Anteroposterior; IHDI : International Hip Dysplasia Institute; CHDD : Centre-head distance discrepancy; RI: Reimer's index

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of The Children's Hospital of Fudan University (Shanghai, China).

Consent for publication

Not applicable

Availability of data and materials

The datasets used and analysed during the current study available from the corresponding author on reasonable request. If requested (please contact ningbo@fudan.edu.cn).

Competing interests

The authors have no conflicts of interest to declare.

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Authors' contributions

Peng Huang and Dahui Wang contributed equally to this work. All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Dahui Wang, Yueqiang Mo, Yiming Zheng and Bo Ning. The first draft of the manuscript was written by Peng Huang and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

Figure 1

A The pre-operation imaging of 16 months old boy with left side dislocation; B Sixty-five months post operation, the TSL of right side is continuous, but left side is discontinuous

Figure 2

Serial anteroposterior radiograph of one patient from pre-operation to the last FU. A The pre-operation imaging of 15 months old girl with left side dislocation; B Fourteen months post operation, the TSL of left side become continuous but upward; C Forty-three months post operation, the TSL of left side continuous and downward

Figure 3

The decrease of AI after CR in two groups. The initial AI has no significant difference in two groups, but the mean values of AI after CR at different time points were lower in the TSL continuous group