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CLINICAL ARTICLE

The Variation of the Pelvis in Unilateral Crowe Type IV Developmental Dysplasia of the Hip

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Objective: To investigate variation of the pelvis in unilateral Crowe type IV developmental dysplasia of the hip (DDH) and analyze the reliability of pelvic landmarks.

Methods: We retrospectively received preoperative anteroposterior pelvic radiographs for 89 adult patients with unilateral Crowe type IV DDH at our institution between September 2008 and May 2019. Forty-eight patients without a false acetabulum was type IVA and 41 with a false acetabulum was type IVB. The heights of the ilium, acetabulum, and ischium areas in affected and unaffected sides were measured. The ratios of the three areas in entire pelvis are calculated. The discrepancies of bilateral iliac crest, inferior sacroiliac articulation, teardrop, and ischial tuberosity on the bisector of the pelvis were also measured.

Results: The mean heights of the ilium, acetabulum, ischium areas in the affected side were 74.4, 88.6, and 37.0 mm, respectively, in type IVA group and 77.7, 83.5, and 37.8 mm, respectively, in type IVB group. The heights in the unaffected side were 82.1, 84.6, and 43.8 mm, respectively, in type IVA group and 84.6, 82.0, and 44.0 mm, respectively, in type IVB group. The ratios of the ilium, acetabulum, ischium areas in affected side of Crowe type IVA group were 0.37, 0.44, and 0.19, respectively, and the ratios in unaffected side were 0.39, 0.40, and 0.21, respectively. The ratios in affected side of Crowe type IVB group were 0.39, 0.42, and 0.19, respectively, and the ratios in unaffected side were 0.40, 0.39, and 0.21, respectively. The discrepancies of bilateral iliac crest, inferior sacroiliac articulation, teardrop, and ischial tuberosity on the line of the bisector of the pelvis in Crowe type IVA group were 5.6, 5.2, 2.0, and 7.1 mm, respectively. Those in Crowe type IVB group were 8.1, 3.5, 3.5, and 4.9 mm, respectively.

Conclusions: Pelvic asymmetry was a common occurrence in unilateral Crowe type IV DDH in adults. Furthermore, it should be reliable to use teardrop as pelvic landmark to balance leg length discrepancy in preoperative planning.

Key words: Developmental dysplasia of the hip; Pelvic landmarks; Preoperative planning; Total hip arthroplasty

Introduction

Unilateral Crowe type IV developmental dysplasia of the hip (DDH) consists of several morphologic anomalies both femoral and pelvic sides. Many studies concern the shape of the proximal femur and the acetabulum, including a narrower and stovepipe shaped medullary canal, a small diaphyseal diameter, excessive femoral anteversion, high neck-shaft angles and a shallow acetabulum[1–5]. However, few studies have explored the variation of the whole pelvic morphology in Crowe type IV DDH. These may include the pelvic asymmetry and rotation[6, 7].

Pelvic radiograph is widely used for measuring leg length discrepancy, and preoperative and intraoperative evaluations using the proper pelvic landmarks, including iliac

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crest, inferior sacroiliac articulation, teardrop, and ischial tuberosity[8–13]. All of these abnormalities may influence the pelvic landmarks, and then misguide the surgeon's preoperative plan.

Li *et al.* did not recommend the teardrop and ischial tuberosity were used as pelvic landmark to balance leg length discrepancy for unilateral DDH patients in preoperative planning and THA[14]. Bilgen *et al.* reported that using a line crossing the healthy hip's teardrop and parallel to a line joining the inferior sacroiliac articulation was useful for calculating leg length discrepancy in Crowe type II–IV DDH[8]. Meermans *et al.* demonstrated that the teardrop was more reliable than the bi-ischial line, particularly in patients with leg length discrepancy[15]. Woolson *et al.* reported that when measuring leg length discrepancy in THA, the acetabular teardrop can be used as a marker in the same way as the ischial tuberosity because the teardrop has a separate anatomic structure, and there will be no effect on the measurement of pelvic rotation in vertical position[16]. In our hospital, the teardrop was often used as the pelvic landmark to measure the leg length discrepancy in Crowe type IV DDH[17]. There is controversy regarding the proper pelvic landmarks to accurately measure the leg length discrepancy.

Therefore, we conducted a study to radiologically examine the effect of Crowe type IV on pelvic development in adults with unilateral DDH. This study aimed: (i) to observe whether pelvic asymmetry in unilateral Crowe type IV DDH was universally presented; (ii) to investigate the development of the ilium, acetabulum, and ischium areas in unilateral Crowe type IV DDH; (iii) to analyze the reliability of pelvic landmarks to balance leg length discrepancy for unilateral DDH patients in preoperative planning.

Patients and Methods

Inclusion and Exclusion Criteria

The inclusion criteria were: (i) adult patients with unilateral Crowe type IV DDH; (ii) patients with preoperative anteroposterior (AP) pelvic radiographs; (iii) patients divided into two groups based on whether or not there is a false acetabulum; (iv) outcome measures are height of ilium area, height of acetabulum area, height of ischium area, width of ilium, and the discrepancies of bilateral iliac crest, inferior sacroiliac articulation, teardrop, and ischial tuberosity on the line of the bisector of the pelvis; (v) retrospective study. The exclusion criteria included: (i) patients with prior pelvic surgery; (ii) patients with residual DDH (infection and trauma); (iii) patients with a history of cerebral palsy and poliomyelitis.

TABLE 1 Patient demographic characteristics

Variable	Type IVA	Type IVB	*P* values
Patients (n)	48	41	
Gender (n)			0.779
Male	3	2	
Female	45	39	
Age (years)*	38.6 ± 12.0	38.5 ± 9.8	0.983
Height (cm)*	158.3 ± 6.3	158.6 ± 6.6	0.685
Weight (kg)*	56.6 ± 9.7	58.0 ± 10.5	0.527
BMI (kg/m^2)*	22.5 ± 2.9	23.0 ± 3.5	0.593
Affected side (n)			0.019
Right	34	19	
Left	14	22	

*Values are expressed as the mean and standard deviation. BMI, body mass index.

Patients' Data

According the inclusion and exclusion criteria, a total of 89 patients with unilateral Crowe type IV DDH were included in the study between September 2008 and May 2019. Our hospital's institution review board approved the study. The ethics committee of our hospital, the General Hospital of Chinese People's Liberation Army, approved the study protocol. All the study participants provided written informed consent for the study.

Groups According to Whether or Not There Was a False Acetabulum

All of the 89 patients were divided into two groups according to whether or not there was a false acetabulum[18, 19]. Forty-eight patients without a false acetabulum was type IVA and 41 with a false acetabulum was type IVB. Patient demographic characteristics of the two groups were showed in the Table 1. The two groups showed no significant difference in terms of gender, age, height, weight, and body mass index.

Radiograph Data

A standardized radiographic technique was performed for all received AP pelvic radiographs. All radiographs were performed in the supine position. A film focus distance of 1.2 m was used with the beam between the pubic symphysis and a line connecting the anterior superior iliac spine with the pelvis in neutral rotation[20, 21]. The longitudinal rotation of the pelvis was verified as correct when the tip of coccyx was in line with pubic symphysis.

All the radiographs were viewed and measured on a picture archiving and communication system (PACS). Both sides of the pelvis were separated into three areas by vertical lines drawn over the bisector of the pelvis (a line connecting middle point of the lower edge of fifth lumbar vertebrae with pubic symphysis) from ischial tuberosity, from teardrop, from inferior sacroiliac articulation, from iliac crest. The area containing the iliac wing was ilium area, the acetabulum as acetabulum area, and the ischium as ischium area[8]. The height of each area was calculated as a proportion of the height of the entire pelvis on the same side of the body to nullify the confounding effects of patient body size.

Two independent investigators (YQD and JYS), who were familiar with digital measurement, performed the radiographic measurements. All of the measurements were repeated 4 weeks later to assess the intra-observer reliability.

Measurement Details

Four measurements were made bilaterally on AP pelvic radiographs of each patient (Fig. 1):

Height of Ilium Area

A vertical line (Line a) was drawn from iliac crest vertex to the bisector of the pelvis (Line k), and a vertical line (Line b) was drawn from inferior sacroiliac articulation to the Line k. The height of ilium area (Line m) was defined as the vertical distance between Line a and Line b.

Height of Acetabulum Area

A vertical line (Line c) was drawn from teardrop to the Line k. The height of acetabulum area (Line n) was defined as the vertical distance between the Line b and Line c.

Height of Ischium Area

A vertical line (Line d) was drawn from ischial tuberosity to Line k. The height of ischium area (Line o) was defined as the vertical distance between Line c and Line d.

Width of Ilium

A line (Line e) was passed through the inferior sacroiliac articulation, parallel to the Line k. The other line (Line f) was passed through the lateral margin of the ilium, parallel to the Line k. The distance between the two lines was defined as width of ilium (Line p).

Another four measurements were also made on radiographs: the discrepancies of bilateral pelvic landmarks (iliac crest, inferior sacroiliac articulation, teardrop, and ischial tuberosity) on the line of the bisector of the pelvis (Fig. 1).

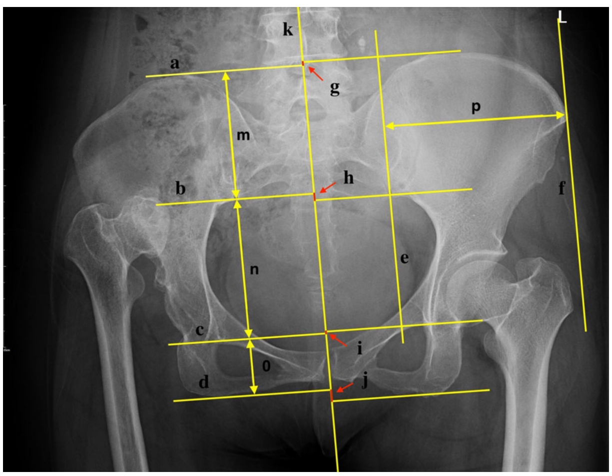

Fig 1 Measurement parameters determined on AP pelvic radiographs: (m) height of ilium area, (n) height of acetabulum area, (O) height of ischium area, (p) width of ilium, (g) the discrepancy of iliac crest, (h) the discrepancy of inferior sacroiliac articulation, (i) the discrepancy of teardrop, (j) the discrepancy of ischial tuberosity.

The Discrepancy of Iliac Crest

The discrepancy of iliac crest (Line g) was defined as the distance between bilateral Line a on the line of the bisector of the pelvis (Line k).

The Discrepancy of Inferior Sacroiliac Articulation

The discrepancy of inferior sacroiliac articulation (Line h) was defined as the distance between bilateral Line b on the line of the bisector of the pelvis (Line k).

The Discrepancy of Teardrop

The discrepancy of teardrop (Line i) was defined as the distance between bilateral Line c on the line of the bisector of the pelvis (Line k).

The Discrepancy of Ischial Tuberosity

The discrepancy of ischial tuberosity (Line j) was defined as the distance between bilateral Line d on the line of the bisector of the pelvis (Line k).

Statistical Analysis

Categorical data were compared using a chi-squared test. The paired samples test or Wilcoxon test was used to compare continuous data between the affected and unaffected sides. The independent-samples *t* test or Mann–Whitney U test was used to compare continuous data between the type IVA and type IVB groups. The Kruskal–Wallis H test was used to compared continuous data between the discrepancy of bilateral iliac crest, inferior sacroiliac articulation, teardrop, and ischial tuberosity on the line of the bisector of the pelvis. The intraclass correlation coefficients (ICC) of interobserver and intraobserver reliabilities were calculated. The variations of the different measurements: 0.81 to 1.00 was regarded as nearly perfect reliability; 0.61 to 0.80, strong reliability; 0.41 to 0.60, moderate; 0.21 to 0.40, fair; and 0 to 0.20, poor. All tests were performed using SPSS (IBM Corp, Armonk, NY. USA). A *P*-value <0.05 was considered significant in all analysis. The Kruskal–Wallis H test in the study was tested in a Bonferroni-adjusted, two-side 0.05/6 = 0.008 significance level. The scatterplot was drawn by GraphPad Prism software (GraphPad software, La Jolla, CA, USA).

Results

Interobserver and Intraobserver Reliabilities

The ICC for interobserver and intraobserver reliabilities were nearly perfect for all of the measurements (ICC > 0.81).

Height of Ilium Area

In Crowe type IVA group, the mean height of the ilium area was significantly lower in the affected side than the unaffected side (74.4 *vs* 82.1 mm, $P < 0.001$). In Crowe type IVB group, the value in the affected side was also significantly

TABLE 2 Each area height and the width of ilium (mm)

	Type IVA (n = 48)			Type IVB (n = 41)			
Parameter	Affected	Unaffected	*P*	Affected	Unaffected	*P*	*P**
The height of ilium area	74.4 ± 10.1	82.1 ± 8.9	<0.001	77.7 ± 8.9	84.6 ± 9.4	<0.001	0.110
The height of acetabulum area	88.6 ± 9.8	84.6 ± 10.7	<0.001	83.5 ± 9.9	82.0 ± 10.0	0.032	0.018
The height of ischium area	37.0 ± 4.6	43.8 ± 5.7	<0.001	37.8 ± 5.0	44.0 ± 6.8	<0.001	0.434
The height of entire pelvis	200.0 ± 16.8	210.5 ± 16.5	<0.001	199.1 ± 13.4	210.6 ± 13.9	<0.001	0.778
The width of ilium	87.6 ± 11.0	105.0 ± 11.5	<0.001	98.6 ± 11.3	100.2 ± 11.1	0.387	<0.001

Values are expressed as the mean and standard deviation; * *P* value means the differences between the affected sides of type IVA and type IVB groups.

TABLE 3 The ratios for each area

	Type IVA (n = 48)			Type IVB (n = 41)			
Parameter	Affected	Unaffected	*P*	Affected	Unaffected	*P*	*P**
Ilium area	0.37 ± 0.03	0.39 ± 0.02	<0.001	0.39 ± 0.03	0.40 ± 0.03	<0.001	0.005
Acetabulum area	0.44 ± 0.04	0.40 ± 0.04	<0.001	0.42 ± 0.05	0.39 ± 0.05	<0.001	0.010
Ischium area	0.19 ± 0.02	0.21 ± 0.02	<0.001	0.19 ± 0.02	0.21 ± 0.03	<0.001	0.281

Values are expressed as the mean and standard deviation; * *P* value means the differences between the affected sides of type IVA and type IVB groups.

lower than the unaffected side (77.7 *vs* 84.6 mm, $P < 0.001$). The height of the ilium area in affected side of Crowe type IVB group was higher than that in affected side of Crowe type IVA group, but there was no significant difference ($P = 0.110$). The ratio of the ilium area was significantly smaller in the affected side of Crowe type IVA group than in the unaffected side (0.37 *vs* 0.39, $P < 0.001$). The value in the affected side of Crowe type IVB group was also significantly lower than in the unaffected side (0.39 *vs* 0.40, $P < 0.001$). The ratio of the ilium area in affected side of Crowe type IVB group was significantly greater than that in affected side of Crowe type IVA group ($P = 0.005$).

Height of Acetabulum Area

In Crowe type IVA group, the mean height of the acetabulum area in the affected side was significantly higher than the unaffected side (88.6 *vs* 84.6 mm, $P < 0.001$). In Crowe type IVB group, the value in the affected side was also significantly higher than the unaffected side (83.5 *vs* 82.0 mm, $P = 0.032$). The height of the acetabulum area in affected side of Crowe type IVB group was significantly lower than that in affected side of Crowe type IVA group (5.1 mm, $P = 0.018$). The ratio of the acetabulum area in the affected side was significantly larger than in the unaffected side for Crowe type IVA group (0.44 *vs* 0.40, $P < 0.001$). The value in the affected side was also significantly larger than in the unaffected side for Crowe type IVB group (0.42 *vs* 0.39, $P < 0.001$). The ratio of the acetabulum area in affected side of Crowe type IVB group was significantly smaller than that in affected side of Crowe type IVA group ($P = 0.010$).

Height of Ischium Area

In Crowe type IVA group, the mean height of the ischium area in the affected side was significantly lower than the unaffected side (37.0 *vs* 43.8 mm, $P < 0.001$). In Crowe type IVB group, the value in the affected side was also significantly lower than the unaffected side (37.8 *vs* 44.0 mm, $P < 0.001$). There was no significant difference in the height of ischium area of the affected side between the type IVA and IVB groups ($P = 0.434$). The ratio of the ischium area in the affected side was significantly smaller than the unaffected side for Crowe type IVA group (0.19 *vs* 0.21, $P < 0.001$). The value in the affected side was also significantly smaller than in the unaffected side for Crowe type IVB group (0.19 *vs* 0.21, $P < 0.001$). The difference of the ratio of the ischium area of affected side in Crowe type IVB and IVB groups was not significant ($P = 0.281$).

Height of the Entire Pelvis

The mean height of the entire pelvis in the affected side was significantly lower than the unaffected side for Crowe type IVA group (200.0 *vs* 210.5 mm, $P < 0.001$). The values in the affected side was also significantly lower than the unaffected side for Crowe type IVB group (199.1 *vs* 210.6 mm,

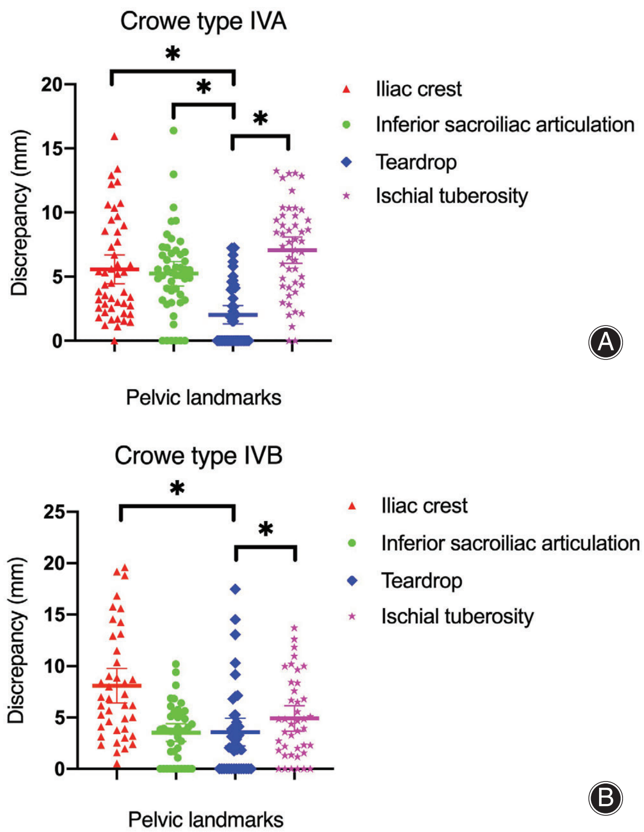

Fig 2 Scatterplot showed the discrepancies of bilateral iliac crest, inferior sacroiliac articulation, teardrop, and ischial tuberosity on the line of the bisector of the pelvis in the Crowe type IVA group (A) and type IVB group (B).

$P < 0.001$). However, the difference between the height of the entire pelvis of the affected side between the type IVA and IVB groups was not significant ($P = 0.778$).

Width of Ilium

The mean width of ilium in the affected side was significantly smaller than the unaffected side for Crowe type IVA group (87.6 *vs* 105.0 mm, $P < 0.001$). However, there was no significant difference in Crowe type IVB group (98.6 *vs* 100.2 mm, $P = 0.387$). The width of ilium in affected side of Crowe type IVB group was significantly greater than that in the affected side of Crowe type IVA group ($P < 0.001$).

All the results were showed in Tables 2 and 3.

The Discrepancies of Bilateral Pelvic Landmarks

The discrepancies of bilateral iliac crest, inferior sacroiliac articulation, teardrop, and ischial tuberosity on the line of the bisector of the pelvis in Crowe type IVA group were 5.6, 5.2, 2.0, and 7.1 mm, respectively (teardrop *vs* iliac crest, 3.6 mm, $P < 0.001$; teardrop *vs* inferior sacroiliac articulation, 3.2 mm, $P < 0.001$; teardrop *vs* ischial tuberosity, 5.1 mm, $P < 0.001$) (Fig. 2A). Those in Crowe type IVB group were 8.1, 3.5, 3.5, and 4.9 mm, respectively (teardrop *vs* iliac crest, 4.6 mm, $P < 0.001$; teardrop *vs* inferior sacroiliac articulation, $P = 1.000$; teardrop *vs* ischial tuberosity, $P = 0.389$) (Fig. 2B).

Discussion

Although the morphologic features around the hip in Crowe type IV DDH have been well described[1, 2, 5, 22], the morphologic variation of the entire pelvis in unilateral Crowe type IV DDH are not well characterized and the pelvic landmarks association with morphologic features of the pelvis are also unclear. We focused on the development of the pelvis and the reliability of pelvic landmarks in the patients with unilateral Crowe type IV DDH on AP pelvic radiographs.

The Variation of Pelvis in Developmental Dysplasia of the Hip

The structural abnormalities exist throughout the pelvis in DDH, and the morphologic abnormalities of the acetabulum are not solely resulted in local dysplasia around the hip, but are influenced by the morphologic features of the entire pelvis[23]. A study of 83 cases of unilateral late-diagnosed (older than 4 months of age) DDH showed the pelvic asymmetry was evident in DDH, possibly secondary to growth of pelvic disturbance in the triradiate cartilage[6]. The pelvic asymmetry was also a common occurrence in adults DDH according to our study. Fujii *et al.* found the internal rotation from the iliac crest through ischial tuberosity in DDH group was significantly greater than that in normal group by using the computed tomography (CT) measurement[23]. Bilgen *et al.* divided unilateral pelvic dysplasia into three areas with the following four lines in Crowe type II, III, and IV DDH: connecting the bilateral iliac crest vertex, connecting the bilateral inferior sacroiliac articulation, connecting the bilateral teardrop, and connecting the bilateral ischial tuberosity. They showed the height of acetabular area of affected side was significantly larger than that of the contralateral side, which is thought to originate from the effect created in the distal acetabulum, with an increased reactionary effect on the iliopsoas capsule and upward tension of dislocation femoral head on the capsule[8]. In our study, we got the same results in the height of acetabular area in Crowe type IV DDH. However, compared with the bilateral discrepancy of the height of acetabular area in Crowe type IVA group, the bilateral discrepancy in Crowe type IVB group was narrower. The bilateral discrepancy of the height of ilium area in Crowe type IVB group was also narrower than that in Crowe type IVA group. The width of ilium of affected side was closer to the unaffected side in Crowe type IVB group. In type IVB DDH, the femoral heads articulate with the iliac wing to form a pseudarthrosis, the false acetabulum may be an important factor to facilitate the development of the ilium area. The presence and absence of a false acetabulum in Crowe type IV DDH are associated with different loading patterns and different soft tissue condition, which may result in different morphologic features of the pelvis and the femur[2, 19]. However, the false acetabulum has no effect on the development of ischium area. According to our results, the height of the ischium area in the affected side was significantly lower than that in the unaffected side, which may be due to the absence of the growth-stimulating of the centralized pressure from femoral head to result in abnormal development of the ischium and the pubis in the axial plane after the femoral head dislocated.

The Reliability of Pelvic Landmarks for Leg Length Discrepancy

Pelvic radiograph is widely used for measuring leg length discrepancy, and preoperative and intraoperative evaluations using the proper pelvic landmarks, including iliac crest, inferior sacroiliac articulation, teardrop, and ischial tuberosity. The pelvic asymmetry and rotation may influence the pelvic landmarks in Crowe type IV DDH. Li *et al.* did not recommend the teardrop and ischial tuberosity be used as landmarks to balance leg length discrepancy for unilateral DDH patients in preoperative planning and THA by measuring the vertical distance from the teardrop to the line across the bottom edges of bilateral ischial tuberosity[14]. However, the variation of ischial tuberosity was not considered in the measurement in this study. The using a line crossing the healthy hip's teardrop and parallel to a line joining the inferior sacroiliac articulation is useful for calculating leg length discrepancy for unilateral Crowe type IV DDH patients in preoperative planning due to the distance between the above parallel line crossing the teardrop, and the teardrop in the affected side was approximately 10.04 mm according to the study by Bilgen *et al*[8]. Meermans *et al.* demonstrated that the teardrop was more reliable than the bi-ischial line, particularly in patients with leg length discrepancy[15]. And the teardrop has a separate anatomic structure, and thus there will be no effect on the measurement of pelvic rotation in the vertical position[16]. In our study, we selected the line of the bisector of the pelvis as the base line to analyze the variation of the pelvic landmarks. The discrepancies of bilateral teardrop on the line of the bisector of the pelvis was significantly smaller than that of iliac crest, inferior sacroiliac articulation, and ischial tuberosity in Crowe type IVA group, and smaller than that of iliac crest and ischial tuberosity in Crowe type IVB group. Therefore, we suggest that it should be reliable to use teardrop as pelvic landmark to balance leg length discrepancy for unilateral Crowe IV DDH patients in preoperative planning and THA.

The Development of the Teardrop

Appearance of a teardrop figure in AP pelvic radiographs is directly related to the growth and development of the acetabulum[24]. Therefore, the anatomic abnormality of the teardrop is associated with DDH in adult patients. The teardrop may be seen between 6 and 24 months of age in the literature[25–27]. Albinana *et al.* stated that there was progressive widening of the teardrop in the affected side, the increase was first in the superior width at 2 years of age and then the inferior width at 10 years old in children[25]. Erkula *et al.* found the V-shaped teardrop was directly related to hip dysplasia in child patients[24]. According to our observation, the V-shape teardrop was also a common occurrence in adults DDH and should be identified by surgeons.

Limitations of the Study

We acknowledge that our study has a number of limitations. First, this is a retrospective study. Second, we selected the patients with unilateral Crowe type IV DDH, but there are no healthy patients to compare. Although we compared the variation of the pelvis on both affected and unaffected sides, it is unclear whether there is a difference between the unaffected side and the healthy pelvis. Third, we were unable to measure the actual parameter of the pelvis on 2D AP pelvic radiographs. CT could nullify the confounding effects of the pelvic rotation and provide precise measurements to determine the variation of the pelvis in both coronal and sagittal planes. However, all the parameters are vertical distance excepted the width of ilium, the ratios of the three areas in the entire pelvis are calculated to ensure the results were reliable. The AP radiographs are the most frequently the first, and sometimes the only, imaging studies performed on patients seeking treatment for hip disease because it is faster and more universally accessible.

Conclusions

The pelvic asymmetry was a common occurrence in adults unilateral Crowe type IV DDH. The false acetabulum may facilitate the development of the ilium and acetabular areas. Furthermore, it should be reliable to use the teardrop as a pelvic landmark to balance leg length discrepancy for unilateral Crowe IV DDH patients in preoperative planning and THA.

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