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Acetabular skeletal assessment in developmental dysplasia of the hip: a study on transversal plane

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Abstract The purpose of this study was to assess the skeletal development and orientation of the acetabulum in patients with developmental dysplasia of the hip (DDH). We performed computed tomography (CT) on 27 patients with monolateral DDH. The average age of patients, all baby girls, was 10.2 months (range, 6–18 months). All hips were dislocatable or dislocated. In each case, the skeletal development of the dysplastic acetabulum was altered. We distinguished two principal types of skeletal development of the dysplastic acetabulum: type I (spherical) and

type II (elliptic or ovoid). The true acetabular anteversion was revealed. The CT study on the transversal plane assessed the skeletal development and orientation of the acetabulum. This global assessment and, in particular, the presence and value of true acetabular anteversion represent the basic study before indicating an innominate osteotomy.

Key words Developmental dysplasia • Hip • Acetabulum • Skeletal development • Computed tomography • Anteversion

Introduction

Some studies have investigated the anatomopathological characteristics of developmental dysplasia of the hip (DDH) [1–10]. The methods used have, however, differed and therefore the conclusions have not been the same. In particular, there are completely conflicting opinions about alterations in the skeletal development of the hip [7, 8, 11–20].

Badgley [11] was of the opinion that deficiency of the anterior acetabular rim was caused by excessive femoral anteversion. Stanisavljevic [9], in a study of pathologic anatomy, observed hypoplasia of the ileopubic or anterior acetabulum. Wilkinson [10] produced anterior dysplasia experimentally in rabbits. Again Badgley [11], pointing out the presence of hypoplasia of the posterior acetabular margin, stated that dysplasia in this anatomic structure can cause posterior dislocation even in the presence of

increased femoral anteversion. Stanisavljevic [9] and Ponseti [7] produced posterior dysplasia experimentally in rabbits. Lasda et al. [15] observed hypoplasia of the posterior acetabular edge in a patient with recurrent posterior congenital hip dislocation despite open reduction and innominate osteotomy.

It is, however, also known, on the basis of the results of the works quoted and the different responses to treatment of each case [21–26], that the manifestations of malformation and alterations in development after birth are different. Since it is believed that the success of the treatment requires the maintenance of a concentric reduction [27], it is consequently important to assess whether this has been adequately obtained. However, this is often not sufficient and it is in fact also necessary to identify the alterations in skeletal development that can prevent the reduction or keep it from being stable over time. Computed tomography (CT), without general anaesthesia, is the investigation

presently used to assess the concentricity of the reduction, once obtained. But, by means of CT, it is also possible to assess the characteristics of skeletal development of the acetabulum: sphericity, depth and percentage of spherical development. To clarify the various manifestations of skeletal development and orientation of the acetabulum in DDH, we assessed cases of DDH with monolateral manifestation at the beginning of treatment.

Materials and methods

The study enrolled 27 baby girls with radiographically proven unilateral DDH (dislocated and dislocatable). Informed consent was provided by their parents prior to entering the study. The study protocol had been reviewed by the Ethics Committee of Bambino Gesù Children's Hospital. The study was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki.

All patients underwent closed reduction and immobilization. CT of the acetabulum was performed 2–4 days after immobilization, without anaesthesia, using a Siemens Somatom DR-HC2 scanner (scan time, 3 s; reconstruction matrix, 512x512; voltage, 125 kV). To minimize radiation exposure, we obtained a scout-view and then a single 3- to 5-mm slice. The scans were evaluated by two staff members. The Y-shaped cartilage and both anterior and posterior portions of the acetabulum are showed by slice 1 of Padovani (Fig. 1) [6]. This slice allows the

Fig. 1 Slice I as per Padovani and others [6]. A straight line was drawn through the center of the triradiate cartilages. A second and a third line were drawn from the center of the triradiate cartilage to the anterior and posterior edges of the acetabulum. A fourth line was drawn through the anterior and posterior edges of the acetabulum. By these lines, we obtained angles 1 and 2 and angle A (acetabular anteversion)

morphology and orientation of both the pathological and contralateral normal acetabula in the same patient to be observed [28, 29]. To analyse the acetabulum, a first line passing through the centre was drawn and used as the basic reference point (Fig. 1). A second and third line were drawn from the centre of the triradiate cartilage to the anterior and posterior margins of the acetabulum and a fourth line was drawn connecting these two margins. The intersection of these lines shows the angles 1 and 2 and the angle α (their sum) (Fig. 1). According to Gugenheim et al. [28], angle 1 is a function of the skeletal development of the anterior portion of the acetabulum or its anteversion. Angle 2 is dependent upon similar skeletal development of the posterior portion. The sum of these angles qualifies indirectly as the ability or inability of the dysplastic acetabulum to contain the femoral head, while angle A is a direct measurement of acetabular anteversion. In addition to determining the various angles, we evaluated morphological characteristics of the skeletal acetabulum. Since various authors have compared the cotyloid cavity to part of a concave sphere [11, 16, 21], its transverse section, at the level of the Y-shaped cartilage, is comparable to a portion of a circle, the geometrical limits of which consist in the margins of the acetabulum (Fig. 2). The line joining those margins (distance AB) constitutes the chord, while the part of the circumference thus identified is a segment of a circle representing the transverse section of the acetabulum.

The base triangles AB inscribed in the circle segment all have the same angle at the vertex (ACB). Therefore we can consider the point C which is in the centre of the arc and is the apex of a triangle whose height corresponds to the depth of the acetabulum. The angle ACB is the sum of angles 1 and 2 (angle α). By using trigonometric formulae, we calculated the following geometric characteristics for each circle segment:

- Sagitta (depth of the acetabulum): $CH = AB/2 \times \cotang \alpha/2$
- Radius of circle: $r = AB/2 \times \sin \alpha/2$
- Diameter: $CD = 2r$
- Volume of the spherical segment: $V = \pi r h^2 - 1/3 \pi h^3$

Fig. 2 Trigonometric formulae used to study the acetabulum

The measurements were gathered independently by two authors. We have taken into consideration the average of these measurements since no significant difference (paired t-test) was found between the results of the two observers (data not shown).

We evaluated a possible correlation between pathological and normal measurements using Pearson's correlation and examined the presence of significant differences using the paired t test. A value of $p \leq 0.05$ was considered significant.

Results

The morphology of the skeletal development of the normal acetabulum in the section considered is always ascribable to a part of the concave sphere (concave segment). On the dysplastic side this is confirmed in most cases (89%). However, in three observations (cases 17, 18 and 19) the morphological aspect showed a development rather similar to an ellipse.

The global statistical evaluation of the measurement of the normal anterior angle compared to the dysplastic one revealed no statistically significant differences ($p=0.4$, $T=-0.7$) (Table 1). That angle, on both the normal and dys-

plastic sides, showed an inverse correlation with the depth ($p=0.0008$; coefficient of correlation (c.c.)=-0.60 and $p=0.0002$; c.c.=-0.65 respectively) and with the volume (with $p=0.002$; c.c.=-0.56 in the normal one and $p=0.004$ in the dysplastic one). As far as the posterior angle is concerned (Table 1), a statistically significant difference ($p=0.05$; $T=1.99$) between the normal and the dysplastic sides, with a tendency of the latter side to be lower was deserved. It was only on the dysplastic side that the posterior angle was inversely correlated with the depth ($p=0.005$; c.c.=-0.51) and the volume ($p=0.05$; c.c.=-0.37).

The anteversion angle showed a minimal difference between the normal and dysplastic side (average=2.5°) ($p=0.01$ $T=-2.55$) (Table 1). Only in the dysplastic socket was this angle inversely correlated with the posterior angle ($p=0.0007$; c.c.=-0.61).

The measurements of the chord (distance between the anterior and posterior margin) and of the sagitta (depth of the socket) were always found to be less on the dysplastic side (with a statistical significance, $p=0.001$; $T=7.51$ for the chord and $p=0.0004$; $T=3.94$ for the sagitta). Furthermore, also the radius constructed on the skeletal development of the dysplastic socket was smaller than the normal one ($p=0.001$ $T=8.04$). The consequence of these

Table 1 Descriptive statistics of the acetabular measurement of 27 cases

Variable	Mean	SD	Min	Max	Coeff. of variation
AGE	11.926	6.354	6	36	53.283
NAA	63.185	9.446	46	88	14.95
PAA	64.037	10.65	46	88	16.631
NPA	51.704	6.871	36	64	13.29
PPA	48.593	9.099	28	64	18.725
NA	15.556	3.08	10	21	19.801
PA	18.148	4.753	8	30	26.191
NR	9.299	2.798	3.51	15.08	30.087
PR	7.273	2.155	2.52	11.68	29.633
NC	16.704	5.757	7	30	34.464
PC	13.111	4.577	5	23	34.909
NS	5.574	2.854	1.71	13.51	51.201
PS	4.691	2.582	1.22	9.95	55.034
NSD	0.292	0.088	0.12	0.49	30.262
PSD	0.313	0.119	0.15	0.63	38.072
NV	1077.074	1459.453	36	6062	135.502
PV	583	721.799	13	2475	123.808
PVNV	0.549	0.199	0.23	0.98	36.28

NAA = normal anterior angle

NPA = normal posterior angle

NA = normal anteversion

NR = normal radius

NC = normal chord

NS = normal sagitta

NSD = normal Sagitta/Diameter

NV = normal volume

PVNV = pathologic volume/normal volume

PAA = pathologic anterior angle

PPA = pathologic posterior angle

PA = pathologic anteversion

PR = pathologic radius

PC = pathologic chord

PS = pathologic sagitta

PSD = pathologic Sagitta/Diameter

PV = pathologic volume

last results is that the containment capacity with regard to skeletal development, represented by the volume of the spherical segment, was on average 55% of normal. With regard to the possibility of inscribing a circumference, it is possible to distinguish a spherical skeletal acetabular development (so-called type I acetabulum) and an ellipsoidal one (so-called type II acetabulum). In the case of spherical development, on the basis of the CH/CD ratio (CH, sagitta or depth of the osseous socket; CD, diameter of the sphere it belongs to) we identified two subtypes of socket (IA and IB).

The type IA socket (13 cases; Table 2) had a skeletal development corresponding to a sphere cut at less than one third of its diameter ($CH/CD < 0.33$) (Fig. 3a, b). The socket was characterised by a barely noticeable concavity, and morphologically had a smooth rim anteriorly and posteriorly. The dysplastic acetabulum appeared more open than normal. In fact, there was a significant difference between the normal sagitta and the pathological one ($p=0.0006$; $T=4.63$). The dysplastic socket was always shallower than the normal one with a significant difference of the anterior angle ($p=0.01$; $T=-2.83$) but no significant difference of the posterior angle ($p=0.9$; $T=0.06$). It should, however, be noted that there was no significant

difference between normal and dysplastic CH/CD ($p=0.1$; $T=1.46$).

Type IB socket (11 cases; Table 3) corresponded to a sphere cut at or above one third of its diameter ($CH/CD \geq 0.33$) (Fig. 4). The socket was characterised by a clearly marked concavity. In this type of socket there was no significant difference between the sagitta or depth of the skeletal development of the acetabulum of the normal side and of the dysplastic side ($p=0.4$; $T=0.78$). The posterior part had a peculiar aspect: in the initial segment it was concave while at the posterior extremity it was flat and convex. This latter aspect confirms what was already noted by Gugenheim et al. [28]. In this type of socket, the mean of the anterior and posterior angles was less than on the normal side (t test between the normal anterior angle and the dysplastic one, $p=0.07$). There was also a significant difference between normal and dysplastic CH/CD ($p=0.001$).

In type II (3 cases, aged 12, 12 and 13 months), where skeletal development corresponded to an ellipse, more serious morphological alterations were found in both the anterior and posterior angles than in the anteversion (the small number of cases did not permit statistical assessment) (Fig. 5a, b).

Table 2 Descriptive statistics of 13 cases with acetabulum Type I A

Variable	Mean	SD	Min	Max	Coeff. of variation
AGE	9.769	3.833	6	18	39.236
NAA	68.462	8.637	56	88	12.616
PAA	72	8.524	64	88	11.84
NPA	53.462	7.709	36	64	14.421
PPA	53.308	9.232	35	64	17.318
NA	15.692	3.276	10	20	20.875
PA	16.769	5.372	8	28	32.035
NR	8.251	1.874	4.44	12.12	22.708
PR	6.8	1.483	3.17	9.1	21.803
NC	13.923	3.475	7	21	24.96
PC	11.077	2.753	5	17	24.85
NS	3.947	1.342	1.71	6.06	34.008
PS	2.92	1.068	1.22	5.84	36.57
NSD	0.235	0.057	0.12	0.33	24.133
PSD	0.211	0.045	1.15	0.32	21.259
NV	403.615	316.024	36	1165	78.298
PV	190.462	186.692	13	766	99.021
PVNV	0.485	0.169	0.26	0.84	34.787

NAA = normal anterior angle

NPA = normal posterior angle

NA = normal anteversion

NR = normal radius

NC = normal chord

NS = normal sagitta

NSD = normal Sagitta/Diameter

NV = normal volume

PVNV = pathologic volume/normal volume

PAA = pathologic anterior angle

PPA = pathologic posterior angle

PA = pathologic anteversion

PR = pathologic radius

PC = pathologic chord

PS = pathologic sagitta

PSD = pathologic Sagitta/Diameter

PV = pathologic volume

Fig. 3a, b. **a** Schematic draw of type IA socket. **b** CT slice in a patient of 7 months with DDH (dislocatable) of the right hip. Example of type IA spherical shallow socket

Table 3 Descriptive statistics of 11 cases with acetabulum Type I B

Variable	Mean	SD	Min	Max	Coeff. of variation
AGE	14.364	8.64	6	36	60.154
NAA	61.091	5.612	50	72	9.186
PAA	57.727	5.934	52	72	10.28
NPA	49.727	5.968	38	58	12.002
PPA	45	5.158	36	54	11.461
NA	15.636	3.107	12	21	19.871
PA	18.364	2.618	13	22	14.257
NR	9.424	2.968	3.51	13.68	31.497
PR	7.185	2.587	2.52	11.14	36.004
NC	17.364	5.372	7	25	30.936
PC	14	5.158	5	22	36.839
NS	5.909	1.772	3.26	8.43	29.989
PS	5.688	2.286	2.61	9.56	40.19
NSD	0.321	0.066	0.23	0.46	20.55
PSD	0.395	0.051	0.33	0.5	12.991
NV	1003.909	796.833	81	2381	79.373
PV	765.455	797.952	35	2274	104.246
PVNV	0.652	0.202	0.42	0.98	30.949

NAA = normal anterior angle

NPA = normal posterior angle

NA = normal antversion

NR = normal radius

NC = normal chord

NS = normal sagitta

NSD = normal Sagitta/Diameter

NV = normal volume

PVNV = pathologic volume/normal volume

PAA = pathologic anterior angle

PPA = pathologic posterior angle

PA = pathologic antversion

PR = pathologic radius

PC = pathologic chord

PS = pathologic sagitta

PSD = pathologic Sagitta/Diameter

PV = pathologic volume

Fig. 4a, b. **a** Schematic draw of type IB socket. **b** CT slice in a patient of 8 months with DDH (dislocatable) of the right hip. Example of type IB spherical deep socket

Fig. 5a, b. **a** Schematic draw of type II ovoidal deep socket. **b** CT slice in a patient of 12 months with DDH (dislocatable). Example of type II socket. This is the case with anterior dislocation due to real malorientation of the acetabulum and anteversion of the femoral neck of nearly 90°

Discussion

The skeletal development of the anterior component of the acetabulum seems to be directly correlated with the increase in the depth and volume of the socket, on both the normal and dysplastic sides. This result shows the importance, on both the normal and dysplastic sides, of the skeletal development of the pubic component in order to obtain the normal deepening of the socket, as described by Ralis and McKibbin [8] in anatomical studies. The skeletal development of the posterior part seems to be correlated with the increase of the depth and volume of the socket on the dysplastic side only.

This difference between the normal and dysplastic sides in skeletal development appears to confirm, in our cases, also the more frequent occurrence of posterior dislocatability of the femoral epiphysis. In fact we only found an anterior dislocation in one case. However this occurrence was due to a real malorientation of the acetabulum and to anteversion of nearly 90° of the neck of the femur (one of the

sockets with ellipsoid development). In most cases, even the differences between the normal and pathological angles of anteversion are not due to a real malorientation of the acetabulum but depend on the altered development of the posterior component. In fact, the angle of anteversion on the dysplastic side only was inversely correlated with the posterior angle ($p=0.0007$). However, we noticed that the dysplastic socket was always smaller than the normal one. In most cases (87%), the skeletal development was ascribable to a part of a sphere (type I socket) and only in three cases to an ellipse (type II socket).

Spherical development may manifest itself in two different ways. The type IA (or shallow) socket is always shallow and with barely noticeable concavity. The type IB (or deep) socket, although always smaller than the normal one, is proportionally deeper.

Ralis and McKibbin [8] observed that the acetabulum becomes progressively deeper during foetal life until it is one third of a sphere at the time of birth. Progressive deepening is observed subsequently, as the child grows. According to these authors, there should be a shallow-so-

cket type of skeletal development at the age of our patients. In fact, although dysplastic, the type IA socket is not so different from the development characteristics of the normal side. However the persistence in this age group of a type IB or deep socket might be the result of a greater alteration in the articular relation between epiphysis and socket. In fact, in cases where that deepening was so increased that it has an ellipsoidal development, the gravity of the pathology leads us to suspect teratological forms.

The type of skeletal development observed is the result of the mechanical stimuli received by the acetabular cartilage during the phases of development; the greater the dynamic alterations of the ratio between epiphysis and socket, the greater the alteration in the skeletal development of the acetabulum.

The data reported do not refer to the cartilaginous portion of the acetabulum but they enable us to assess how the ossification process of the acetabulum took place up to the time of treatment. Acetabula that tend to deepen, but in a way not in harmony with the sphericity of the epiphysis (in fact they are smaller and out of proportion to the development of the anterior and posterior components compared to the normal) are the ones that call for greater attention and consideration on the development potential of the residual cartilage. The need for complementary operations (osteotomy of the femur or pelvis), even after obtaining a good congruence of the epiphysis in the acetabulum, could depend on the incapacity of the resid-

ual cartilage (dysplastic from birth) to respond adequately to mechanical stimuli. To permit the ossification process of the residual cartilage of the acetabulum to take place in the best way, it is, however, necessary to restore a mechanically suitable articular relation. For this reason, it is important to continue studying instrumental evaluations of the joint before and during treatment.

We believe that the evaluations reported in this study can be of assistance in interpreting the different aspects of the skeletal development on transversal plane of a dysplastic acetabulum in DDH that are also finalized to find a correlation of future development of dysplasia in adults. In conclusion, we are aware of the historically established importance, in any pre-operative plan, of close hip assessment using standard frontal radiography. This allows measurement of the lateral extent and inclination of the acetabular roof, of the CE angle and of the femoral neck inclination. Just as important is study in the transversal plane, not only of femoral anteversion but also of the acetabulum cavity. As for the latter, the transverse projection provides us with a good deal of information on acetabulum anteversion, development of the bony posterior portion of the acetabulum, its depth and therefore on its ability to contain the femur. These two procedures give us the opportunity to identify clearly the dysplastic skeletal components that may cause progression to dislocation or residual subluxation, thus allowing a well thought out, complete operative plan.

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