Three-dimensional computed tomography analysis and anteversion study after periacetabular osteotomy of pelvis in children

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Abstract

Purpose Three-dimensional computed tomography (CT) is the method of choice in understanding the morphological changes after periacetabular osteotomy in children. We studied different parameters and compared aspects of operated hip (OH) with non-operated hip (NOH) to define the maneuver that promotes normalization of the hip during repositioning of the acetabulum.

Methods A total of 22 patients with 25 OHs underwent CT control scans an average of 4 years after surgery. The patients, with a mean age of 6.8 years, had either Legg-Calvé-Perthes disease (12 cases) or dysplasia (10 cases). The measurements included the anterior and posterior coverage angles of the hip and version of the acetabulum on axial CT views. The 3D reconstructed images measured the inclination of the antero- and postero-lateral lips, the external rotation and the anterior inclination of the acetabulum.

Results The mean anterior coverage angle was 27° for OHs, 31° for NOHs, and 12° versus 10.3° for the posterior coverage angle. Acetabular anteversion was 2° for OHs (6.3° in the dysplastic OHs) and 6° for NOHs. The mean angle of inclination of the antero-lateral lip was 37° for OHs, 47° for NOHs, and the postero-lateral lip inclination

was 56° for OHs and 67° for NOHs. Inferior 3D views showed a mean internal acetabular rotation of 1.5° (4.8° in the dysplastic OH), 3° for NOH. The anterior acetabular inclination angle measured with lateral 3D views was 6° for OHs, 11° for NOHs.

Conclusion Our analysis demonstrated a mean anteversion of the acetabulum despite normalization of the anterior coverage of the hip, particularly in the dysplastic group, in which the osteotomized fragments had anteversion superior to NOH. The unexpected external rotation used to improve anterior coverage of a coxa magna in Legg-Calvé-Perthes disease was responsible for the retroversion and the decrease of the posterior coverage.

Keywords 3D CT scan · Retroversion · Quadruple osteotomy · Anteversion · Pelvic osteotomy

Introduction

Many different pelvic osteotomies have been used to improve femoral head coverage; all focused on the restoration of a more normal hip morphology. The peroperative positioning of the acetabular fragment can, however, hardly be checked using conventional techniques, and it has been demonstrated that correction of one parameter during acetabular displacement could create insufficiency in others. Therefore more attention should be devoted to a method for correct positioning of the acetabulum after osteotomy.

Plain radiographs have been the standard means of documenting lateral coverage following osteotomies; but antero-posterior radiographs do not provide enough information about the orientation of the acetabulum in the sagittal and transverse plans. Computed tomography (CT)

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provides a powerful means of precisely measuring and assessing critical factors; of better understanding the concept of coverage in 3D; and of avoiding over or insufficient mobilization of the acetabular fragment, or a maneuver promoting morphological disorders [1–4].

If the goal of the pelvic osteotomy is to normalize the anatomy of the hip, it is more interesting to compare the aspect of the operated hip (OH) with that of the non-operated hip (NOH). However, we attempt to determine, in a group of patients who had undergone 3D CT scan analysis, the relationship between the different anatomic acetabular parameters after periacetabular osteotomy and repositioning of the acetabulum. The postoperative assessment of 3D changes evaluates the appropriate maneuver for displacement of the osteotomized fragment to avoid unintended positions of the acetabulum, such as excessive external rotation and retroversion of the acetabulum or insufficient posterior coverage of the hip. Particular attention has been devoted to the results of dysplastic hips, in a series including Legg-Perthes disease, in order to determine whether greater correction of anterior or lateral deficiencies promotes deficiencies in other parameters, particularly at the version of the acetabulum.

Materials and methods

Between 1993 and 2003, 22 patients with 25 OHs underwent CT control scans after juxta-acetabular osteotomy using an anterior approach [5]. They were 13 boys and 9 girls—14 left hips, 5 right and 3 bilateral—with a mean age of 6.85 years at surgery (2–14 years). In 10 patients, 11 hips were dysplastic; among them 5 patients aged under 5 years had lateral subluxation or dislocation after treatment with DDH, and 5 older than 5 years had acetabular deficiency with a lateral center edge angle between -7° and 15° . In 12 patients, 14 hips had Legg-Calvé-Perthes disease: 1 of type III, 8 of type IV, and 5 type V of Stulberg classification [6]; 1 patient under 5 years of age was Stulberg type IV and the patients over 8 years old were Stulberg type V. When significant displacement of the acetabulum was required, in elder patients, a quadruple osteotomy was performed with osteotomy of the ischial spine.

The CT scans were performed at an average of 4 years after the surgery (between 1 and 10 years), using a GE HiSpeed dual slices CT/NX scanner, rapidly obtaining 1-mm helical scans at a 1:1 pitch (120 kvp, 1 s, mA 300, 512 matrix). The images were reconstructed to produce 3D images that could be rotated in all directions.

1. The axial views show the anterior acetabular indices, which are the angles formed by a line drawn through

Fig. 1 Angle 1 represents the anterior acetabular index, angle 2 the posterior acetabular index, and angle 3 the acetabular version formed between the triradiate reference line (RL) and the bisector of angle 1 + 2 (bis)

the triradiate baseline and the anterior acetabular wall. The posterior acetabular index is the angle formed by the triradiate baseline and a line from the triradiate cartilage to the posterior acetabular lip. The addition of the anterior and posterior acetabular indices is the axial acetabular index, which represents the depth of the acetabulum. The angle of version, as described by Buckley et al. [7] and others [8, 9], is the angle formed by the line bisecting the axial acetabular index and the triradiate baseline (Fig. 1). The acetabulum is considered anteverted or retroverted whether the angle of version is anterior or posterior to the triradiate baseline.

The anterior coverage angle, as described by Weiner et al. [10], is formed by the vertical line drawn from the tip A of the anterior acetabular lip and the line that joins A to the centre of the femoral head. To avoid errors related to malposition of the child in the CT, the vertical line must be perpendicular to the line of posterior edges of the two ilia. The posterior coverage angle is formed by the vertical line drawn from the tip P of the posterior acetabular lip and the line that joins P to the femoral head centre (Fig. 2).

2. 3D CT images, as used by Frick et al. [1], allow measurement of the acetabular lip inclination. The horizontal reference line is perpendicular to the sacrum–pubic symphysis axis. The anterior view shows the antero–lateral acetabular lip angle (ALAL), named α , which is formed by a line along the antero–lateral rim of the acetabulum and the horizontal reference line (Fig. 3). The posterior view measures the postero–lateral acetabular lip angle (PLAL), named β , which is formed by the line of the postero–lateral rim and the horizontal reference line (Fig. 4).

The inferior 3D CT view provides information about the transverse rotation of the acetabulum in horizontal plan.

Fig. 2 The anterior coverage angle is formed by the vertical line drawn from the tip of the anterior lip of the acetabulum A, and the line that joined A to the centre of the femoral head C. The posterior coverage angle is formed by the vertical line drawn from the tip of the posterior acetabular lip P, and the line that joined P to the femoral head centre C

Fig. 3 Anterior 3D view shows the antero-lateral acetabular lip angle (ALAL) at the left hip of a 4-year-old boy with Legg-Calvé-Perthes disease who was operated on. The angle (α) is formed between the antero-lateral rim of the acetabulum and the horizontal reference line, which is perpendicular to the sacrum-pubic symphysis axis; it is 42° at operated hip and 50° at non-operated side

The rotation is the angle formed by the baseline along the plan of the proximal ilium, and a line from the anterior inferior iliac spine to the most inferior ischial portion of the acetabulum (Fig. 5). The acetabulum is considered rotated externally or internally, whether the angle is situated lateral or medial to the plan of the ilium.

Fig. 4 Posterior 3D view shows the postero-lateral acetabular lip angle (PLAL) at the left operated hip. The angle (β) is formed between the postero-lateral rim of the acetabulum and the horizontal reference line, which is perpendicular to the sacrum-pubic symphysis axis; it is 45° at the operated hip and 70° at non-operated side

Fig. 5 Inferior 3D view evaluates the angle of transverse rotation of the acetabulum; it is formed by a line along the plane of the ilium and a line from the anterior inferior iliac spine AIIS to the ischial tuberosity (IT); it demonstrates the presence of anteversion at the left operated side

The lateral 3D CT view provides information about the anterior inclination of the acetabulum (acetabular extension) in order to analyze sagittal repositioning. The lateral acetabular inclination is the angle formed by a line from the ischial spine to the antero-lateral edge of the acetabulum and the horizontal reference line. The latter is perpendicular to a line connecting the anterior superior iliac spine and the pubic symphysis (Fig. 6).

Fig. 6 **a** Lateral 3D view of the pelvis measures the anterior acetabular rotation in the non-operated side. The angle of lateral acetabular inclination is formed by a line from the ischial spine IS to the antero-lateral edge of the acetabulum and the horizontal reference which is perpendicular to a line joining the anterior inferior iliac spine AIIS to the pubic symphysis (PS). **b** Lateral 3D view of the left operated side shows a small angle of acetabular inclination in comparison with the non-operated side. Also, the acetabulum is more inclined anteriorly

Statistical analysis

Descriptive data include the mean with the standard deviation of angles on the operated and contralateral sides. Operated and control angles were compared using a paired *t*-test. A *P* value less than 0.05 was considered significant. Statistical analysis was performed using STATA 7.

Results

All procedures were performed by senior staff, without participation of the operator surgeon; measurements were obtained by the software of the scanner.

In part I of our study, at axial views, the mean value of the anterior acetabular index was 55°, and for the posterior acetabular index 51°; average axial acetabular index was thus 106°. Consequently, the average acetabular version of the OHs was $= 106^\circ/2 - 51^\circ = +2^\circ$ (SD: 7.41°), and 6° for the NOHs (−3° to 14°) (SD: 6.81°). Among the 25 OHs, 16 were anteverted (average 6°), 8 retroverted (average −3°), and 1 had an important retroversion of −14°. If we consider the 11 dysplastic hips and exclude the Legg-Calvé-Perthes disease, the anteversion was 6.3° (0°–21°) for the OH.

The mean anterior coverage angle was 31° (SD: 21.64°) for NOHs and 27° (SD: 13.05°) for OHs; it was 33.5° for non-operated dysplastic hips and 35° for operated

dysplastic hips. In those with Legg-Calvé-Perthes disease, it was 29° for NOHs versus 21° for OHs. The mean posterior coverage angle was 10.3° (SD: 3.3°) for NOHs versus 12° (SD: 5.6°) for OHs. In dysplastic hips it was 7° for NOHs versus 3.5° for OHs.

In part II, the 3D CT scan images showed that the mean antero-lateral acetabular lip inclination α was 47° (SD: 8.27°) versus 37° for OHs (SD: 6.43°). β inclination of the postero-lateral acetabular lip had an average of 67° (SD: 6.14°) for NOHs and 56° (SD: 6.93°) for OHs. In the dysplastic group, the angle α was 34° for OHs and 47° for NOHs, the angle β was 52° for OHs and 72° for NOHs.

The inferior views demonstrated a mean internal rotation angle of 3° for NOHs (SD: 3.01°) and 1.5° for the OHs (SD: 3.17°). Among them 18 cases had a mean 3° internal rotation and 7 a 2° external rotation. The operated dysplastic hips had an average 4.8° internal rotation. The lateral views showed a mean acetabular inclination of 11° (SD: 5.59°) for NOHs and 6° for OHs (SD: 7.65°).

Discussion

The accuracy of the repositioning of the acetabular fragment peroperatively is not well defined. This should be improved in the future by developing intraoperative scanning methods for its optimal positioning, designed to avoid other deficiencies while correcting the dysplasia. Ganz [11,

[12] stated that the acetabulum should be rotated anteriorly and laterally, and medialized as necessary to obtain the best coverage judged by radiographic techniques and hip motion after provisional fixation. Tonnis [13, 14] used vertically placed K-wire to monitor transverse plane rotation intraoperatively, and the figure-of-four maneuver with temporal internal fixation of the hip was used by Pol Le Coeur [15]. While these authors demonstrated the ease of their methods to displace the acetabular fragment and achieve correction of the dysplasia, many others [1, 2, 16] have demonstrated the presence of unintended position of the acetabulum postoperatively, leading to excessive external rotation, retroversion or decreased posterior coverage. We believe that the assessment to obtain normalization of the acetabular deficiencies should analyze all the parameters around the femoral head and compare the final aspect of the osteotomized acetabulum to the opposite NOH.

The major unintended aspect of the acetabulum after repositioning is the retroversion; we, however, believe that the decrease of acetabular anteversion is related to any maneuver resulting in external rotation of the acetabular fragment. This fact was concluded by Frick et al. [1], who observed external rotation in all of the patients, with an average 11.8° external rotation of the acetabulum after pelvic osteotomy using the figure-of-four technique. In our series, we avoided this maneuver and Salter's [17], both of which cause an external rotation of the distal fragment. The external rotation of the hip that we identified, as described by Frick et al, with inferior 3D CT views of the pelvis, was not excessive in our series, because the mean transverse rotation angle of the acetabulum was 1.5° internal rotation in the OH, and 3° internal rotation in the NOH.

It is obvious and of importance that the external rotation maneuver improves anterior coverage, but promotes retroversion of the acetabulum at the same time. To avoid this unexpected retroversion, the acetabular fragment should be displaced laterally in a frontal plane (adduction), with any concomitant rotation in the transverse plane. In fact, despite the normalization of the anterior coverage of the hip, we have demonstrated anteversion of the acetabulum in the whole group of patients (2° in OH, 6° in NOH), particularly when considering the group with dysplastic hips, in whom all the osteotomized fragments remained anteversed with an average value (6.3°) similar or slightly superior to that in NOHs (6°). The difference in the values of anteversion between the dysplastic group (6.3°) and the whole group of patients (2°) could be related to unexpected external rotation used to improve anterior coverage of a coxa magna in Legg-Calvé-Perthes disease. However, this unexpected maneuver was responsible for the slight overcorrection of the anterior

coverage angle in the whole group (31° in NOH, 27° in OH), being more important in patients with Legg-Calvé-Perthes disease (29° in NOH, 21° in OH), but this angle remained normalized in the dysplastic group (33.5° in NOH, 35° in OH).

The posterior coverage angle in the 2D axial-plane could also contribute to the definition of the acetabular version, because any retroversion of the acetabular fragment decreases the posterior coverage of the hip. Although Azuma et al. [2, 16] reported an average one-grade improvement in anterior coverage at the expense of a one-grade decrease in posterior coverage, we observed no such effect in our study. We believe that decreased posterior coverage is related more to external transverse rotation than anterior rotation of the acetabular fragment and one-grade of external transverse rotation costs one grade in posterior coverage. The 2D axial views proved, however, that the posterior coverage angle at OH remained sufficient (12° in OH vs 10.3° in NOH) and was greater in dysplastic hips (3.5° OH vs 7° NOH) where all the acetabuli were anteversed (from 0° to 21°).

While the acetabular indices (anterior and posterior) on the axial view represent the depth of the acetabulum, the simultaneous changes in the position of the acetabulum into anterior rotation (extension) and lateral inclination (adduction) evaluate the covered area of the hip. However, the 3D anterior lip inclination angle (α) value demonstrated better lateral coverage in OH than NOH (47° vs 37° in OH) as well as for the posterior lip inclination angle (β) (67° vs 56° in OH). Also the anterior rotation (extension) of the acetabulum measured with the lateral acetabular inclination angle exceeded anterior repositioning in NOH (6° OH vs 11° NOH). This slight overcorrection at the anterior coverage area, which was observed also in the dysplastic hips for the angles α (47° vs 34° in OH) and β (72° vs 52° in OH), did not change the anteversion but facilitated the positioning of the acetabulum in great adduction and extension.

Analysis of the 3D CT views demonstrated the normalization of different parameters around the femoral head (Fig. 7) and emphasized the mobilization of the osteotomized acetabulum in two directions, anteriorly (extension) and laterally (adduction). To achieve lateral inclination, the acetabular fragment should be displaced in a frontal plane, in such a manner that the inner iliac wing comes to lie horizontally below the proximal iliac bone. While the external transverse rotation should be omitted during the reorientation, the internal rotation could be beneficial, when necessary, to increase the anteversion of the acetabulum. However, despite the important lateral inclination of the acetabulum, the anterior inferior iliac spine (noted with the 3D inferior view) remained in the axis of the iliac bone or inside it, as in the dysplastic group

Fig. 7 3D views of a 17-year-old boy operated on at age 7 years with a juxta-acetabular osteotomy for a *left* hip dysplasia. Anterior (a) and posterior (b) views show a well-inclined lip angle relative to the contralateral side. c Inferior view shows internal rotation of the *left* acetabulum, demonstrating the presence of anteversion. d Lateral view demonstrates a well-inclined anterior acetabular fragment

where the osteotomized fragment had a 4.8° internal rotation (3° for NOH), and the anteversion ranged between 0° and 21° (-3° to 14° for NOH), demonstrating the increase of anteversion. This maneuver, which avoids posterior morphological abnormalities and retroversion of the acetabulum, could extend the indications of the acetabular redirection osteotomy to include patients with neuromuscular disorders.

Conclusion

We conclude that retroversion and decrease of posterior coverage of the hip are secondary to external rotation of the osteotomized fragment. Cases with slight retroversion were related to unexpected external rotation in those with Legg-Calvé-Perthes disease with coxa magna. However, mobilization of the acetabulum, particularly in dysplastic hips, should be oriented anteriorly with the fragment lying laterally. This maneuver could improve, when necessary, the anteversion of the acetabulum and extend the indications to those with neuromuscular diseases.

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