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ORIGINAL STUDY

Natural history of shelf gap and paleo-acetabular depth after shelf acetabuloplasty for Perthes disease

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The purpose of this study was to evaluate the morphologic evolution of the shelf gap, acetabulum and femoral head after shelf acetabuloplasty in patients affected by Perthes disease.

54 patients operated for Perthes disease with shelf acetabuloplasty were retrospectively reviewed regarding the radiographic results. Three pelvic antero-posterior radiographs have been studied for each patient, one at 2 postoperative months, one at 1 postoperative year and one at the latest clinical follow up (mean 76 postoperative months).

The shelf gap decreased from 108% at 2 months to 104% at the last follow-up ($p<0.001$). There was an increase of the total acetabular depth to 168% by the presence of the shelf graft ($p<0.001$). The acetabular index of the operated side related to the contralateral side was 68% at 2 months due to the effect of the graft ($p<0.001$). The migration index of the shelf side was in mean -24% at 2 months and -3% at last follow-up ($p<0.001$). According to the Stulberg classification, there were 9 type 1 (17%), 20 type 2 (37%), 19 type 3 (35%), 5 type 4 (9%) and 1 type 5 (2%).

A progressive remodeling with shelf gap reduction was occurring during the following months after the surgery. An increase of the total acetabular depth and a decrease of the migration index without a lateral overgrowth of the paleo-acetabulum was observed. Shelf acetabuloplasty is a good procedure to prevent early osteoarthritis by a better femoral head coverage.

Keywords : Shelf acetabuloplasty ; Perthes disease ; hip remodeling.

INTRODUCTION

Perthes disease (PD) is an idiopathic avascular necrosis affecting the proximal epiphysis of the femur in the pediatric population *(1)*. Its peak of incidence is from 4 to 8 years of age, but could occasionally be present in younger or older patients *(2,3)*. It is bilateral in 8-24% of cases *(4,5)* and males are more affected than females in the ratio of 5:1 *(6)*.

The aim of the treatment is to maintain a satisfactory hip range of motion and to prevent any deformation of the femoral head.

Lateral shelf acetabuloplasty (SA) has the goal of better distributing the pressure on the cartilage of the femoral head by increasing the coverage of

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Figure 1. — Radiograph showing a shelf gap between the lateral margin of the acetabulum and the base of the shelf graft.

the acetabulum. Previous studies seem to prove that the shelf is a growth factor for the acetabulum *(7-11)*. The surgery has to be performed in the early stages of the disease and no longer as an exclusive rescue procedure *(2,12,13)*.

In the radiological follow-up of some patients operated by SA of our series, we discovered that the shelf graft appeared to be "higher" in relation to the anterolateral edge of the acetabulum (Figure 1). The "shelf gap" is defined as the vertical distance between the lateral margin of the acetabulum and the base of the shelf graft *(12)*.

This study was performed to analyse whether the shelf gap was increasing or decreasing with time after surgery. Another point of interest was to analyse the total depth of the acetabulum and the proportion of it represented by the shelf and by the paleo-acetabulum respectively and to see its evolution with time. Does an increase or a decrease of the shelf depth occur with time and a stimulation of lateral growth of the paleo-acetabulum? The last concern was about the femoral head. Did the surgery favour a better remodeling of the head thanks to a better acetabular coverage?

PATIENTS AND METHODS

We obtained the agreement of the local ethics committee of the hospital with the following number : B403201523492.

All the children treated by shelf acetabuloplasty (SA) for PD between December 2003 and May 2017 were retrospectively reviewed regarding the radiographic results. Patients with bilateral PD were excluded to be able to compare the pathological side to the normal side. The patients with less than 2 year-follow-up were also excluded. There were 54 patients available for this study with 44 males and 10 females. The clinical data of the patients are summarised in the Table I.

Table 1. — Clinical data of the patients

Patients (N=54)	Mean (range)
Age at the time of diagnosis	6 years (range, 2 - 13 years)
Age at the time of surgery	7 years (range, 3 - 13 years)
Delay between diagnosis and surgery	10 months (range, 0 – 62 months)
Sex (M/F)	44/10
Side (Right/Left)	31/23
Herring type -type A -type B -type B/C -type C	 6 (11%) 26 (48%) 1 (2%) 21 (39%)
Age at last follow-up	13 years (range, 7- 23 years)
Postoperative delay	76 months (range, 24-166 months)

The Herring classification (lateral pillar classification) was used for the affected hips at the time of fragmentation stage. All the hips were classified between Herring group A, in which the lateral column height is normal, group B, in which the lateral column is reduced to 50%, group C, in which it is reduced by more than 50% and group B/C, intermediate between B and C *(14,15)*.

The Stulberg's grading system was applied on the affected hips on the latest radiograph (five types at skeletal maturity) *(16)*.

Three pelvic antero-posterior radiographs were studied for each patient, one at 2 postoperative months (2M), one at 1 postoperative year (1Y) and one at the latest follow-up (LFU) (mean 76 postoperative months). For each radiograph, different parameters were measured as described in Figures 2, 3 and 4.

The radiographic measurements of the affected hip were always compared as ratios with the normal side to avoid errors due to variation in radiographic magnification.

The evolution of the shelf gap was measured by a ratio between the paleo-acetabulum height (PAh) and the shelf base height (S1h) (Figure 3).

Acetabular remodeling was analysed by the paleo-acetabulum depth (PAd) and the shelf depth (Sd) over time. The total acetabular depth (TAd) is the sum of PAd and Sd. A ratio between TAd and contralateral acetabular depth was done (Figure 2). The acetabular coverage was analysed using a ratio between the acetabular index (AI) of the operated hip and the contralateral acetabular index (Figure 4).

The remodeling of the femoral head and its subluxation was analysed by the classification of Stulberg at the last radiographic follow-up and by the migration index (MI) (we used a negative value in case of completely covered head).

All statistical analyses were performed using IBM SPSS statistics version 26. The p-value of significance was set at $p<0.05$ throughout the study. A Kolmogorov-Smirnov normality test was used to examine if variables were normally distributed.

To compare the results between 2M and 1Y, between 2M and LFU and finally between 1Y and LFU respectively, a paired Student t-test was performed. To compare total acetabular depth (TAd) and paleo-acetabular depth (PAd) with contralateral acetabular depth, a paired Student t-test was performed.

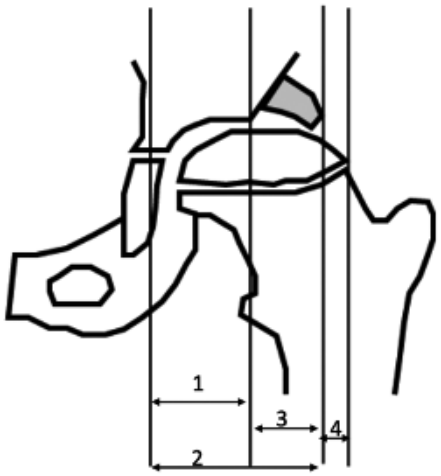

Figure 2. — The reference line was a vertical line from the lateral side of the inferior tip of teardrop. 1. Paleo-acetabulum depth **(PAd) :** was the distance between the reference line to a vertical line from the lateral osseous margin of the paleo-acetabulum. 2. Total acetabular depth **(TAd)** : was the distance between the reference line to a vertical line from lateral margin of the shelf. 3. Shelf depth (**Sd**) : was the distance between a vertical line from the margin of the paleo-acetabulum to a vertical line from lateral edge of the shelf. 4. Migration index (**MI**) : was the distance between the vertical line form the lateral edge of the shelf to a vertical line from the lateral edge of the femoral head epiphysis.

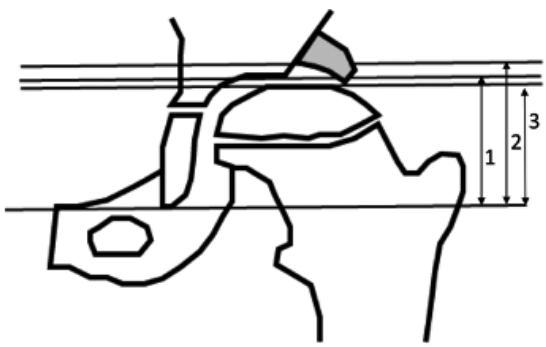

Figure 3. — The reference line was a line going from the inferior tip of both teardrops. 1. Paleo-acetabular height (**PAh**) was the distance between the reference line and a horizontal line from the lateral osseous margin of the acetabulum. 2. Shelf basis height (**S1h**) was the distance between the reference line and a horizontal line from the margin of the shelf. 3. Shelf tip height (**S2h**) was the distance between the reference line and a horizontal line from the tip of the shelf.

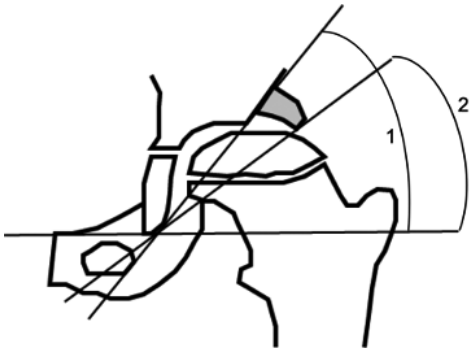

Figure 4. — The reference line was a line going from the inferior tip of both teardrops. 1. In absence of shelf, the acetabular index (**AI**) was the angle between the reference line and the line from tip of teardrop to the lateral edge of the acetabulum. 2. In presence of shelf, the acetabular index (**AI**) was the angle between the reference line and the line from tip of the shelf.

RESULTS

The mean age at the time of diagnosis was 6.2 years (range 2.1-13.2 years) and the mean age at the time of surgery was 7.2 years (range 3.4-13.5 years). According to the Herring classification, there were 6 type A (11%), 26 type B (48%), 1 type B/C (2%) and 21 type C (39%). According to the Stulberg classification, there were 9 type 1 (17%), 20 type 2 (37%), 19 type 3 (35%), 5 type 4 (9%) and 1 type 5 (2%) (Table II).

Table II. — Result of Stulberg classification at latest follow-up (LFU)

Patients (N=54)	N (percentage)
Stulberg classification	
-type I	9 (17%)
-type II	20 (37%)
-type III	19 (35%)
-type IV	5 (9%)
-type V	1 (2%)

The shelf gap decreased from 108% at 2M to 104% at LFU ($p<0.001$). The shelf tip height (S2h) increased from 87% at 2M to 93% at LFU ($p<0.001$) (Table III).

Concerning the acetabulum, there was an increase of the total acetabular depth (TAd) to 168% by the presence of the shelf graft by comparison with the contralateral side. This ratio decreased during the follow-up, from 168% (2M) to 134% at LFU ($p<0.001$). This was mainly due to a progressive reabsorption of the shelf graft : the Sd/TAd ratio decreased from 39% (2M) to 26% (LFU) ($p<0.001$). The acetabular index (AI) of the operated side related to the contralateral side was 68% at 2M due to the effect of the graft. But this ratio increased to 85% at LFU due mainly by the shelf graft reabsorption ($p<0.001$). The paleo-acetabular depth (PAd) compared to the contralateral side showed a little in-

Table III. — Result of radiographic parameters at 2M, 1Y and at LFU

	Radiograph at 2-postoperative months) (2M)	Radiograph at 1-postoperative year (1Y)	Radiograph at last follow-up (LFU)	p-value 2M versus 1Y 2M versus LFU 1Y versus LFU
Height of the shelf margin (related to acetabular height) (S1h/PAh)	108%	107%	104%	p=0.024 p<0.001 p<0.001
Height of the shelf tip (related to acetabular height) (S2h/PAh)	87%	89%	93%	NS p<0.001 p<0.001
Total acetabular depth (TAd) (related to contralateral acetabular depth)	168%	154%	134%	p<0.001 p<0.001 p<0.001
Shelf depth (Sd) related to paleo-acetabular depth (Sd/PAd)	39%	34%	26%	p<0.004 p<0.001 p<0.001
Migration index (MI)(shelf side)	-24%	-12%	-3%	p<0.001 p<0.001 p<0.001
Migration index (MI)(contralateral side)	13%	12%	14%	NS
Acetabular index (AI) related to contralateral acetabular index	68%	75%	85%	p=0.001 p<0.001 p<0.001

Table IV. — Values of the total acetabular depth (TAd) and of the paleo-acetabular depth (PAd) at latest follow-up (LFU)

	Last radiograph	p-value
Total acetabular depth (TAd) related to contralateral acetabular depth	134.4%	p<0.001
Paleo-acetabular depth (PAd) related to contralateral acetabular depth	101.4%	NS

crease (101.4%) of its depth that was however not statistically significant.

Subluxation of the femoral head decreased significantly. The migration index (MI) of the shelf side was in mean -24% at 2M and -3% at LFU (p<0.001). The migration index (MI) of the controlateral side did not change with time as we expected.

DISCUSSION

Shelf acetabuloplasty has been used in the past as a salvage procedure for coxa magna, hinge abduction or coxa irregularis in the late stage of the disease *(17,18)*. Recent studies confirm the importance of surgery in the early stage to prevent hip deformity *(3,12,13,19)*. The mean age at the time of surgery of our series was 7 years, which is in line with these studies.

The natural history of the shelf gap in patients affected by PD have never been studied in the literature. The definition of shelf gap was given by Yoo et al. in 2009 *(12)* but the authors did not describe its evolution with time.

Our first question was if the shelf gap would increase by a progressive absorption or decrease by a progressive remodeling. We observed that, when the gap was present, a progressive remodeling with gap reduction occurred during the following months after the surgery. An increase of the total acetabular depth (TAd) and a decrease of the migration index (MI) was observed in a significant way at 2 postoperative months (2M). At one year (1Y) and at the final control (LFU) there was a slight decrease due to a progressive reabsorption of the lateral edge of the shelf graft. We did not find a lateral overgrowth of the paleo-acetabulum stimulated by the shelf. This result is in contradiction to the results of Domzalski et al *(10)* and more recently by Carsi et

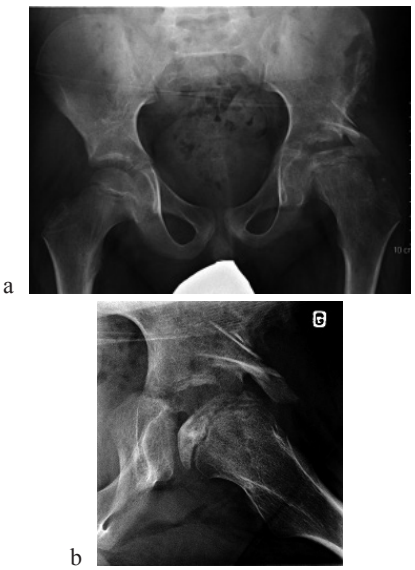

Figure 5. — Two post-operative months (2M). (a) : Anteroposterior pelvic radiograph. The patient was classified Herring B at the fragmentation stage. As it is shown, a shelf gap is present at this stage. An augmentation of TAd and a reduction of MI is also seen. (b) : Lateral view of the left hip. The shelf gap is better appreciated.

Figure 6. — One post-operative year (1Y). (a) : Anteroposterior pelvic X-ray. A progressive reabsorption of the shelf is observed. The TAd and MI is always bigger compared to the contralateral side. (b) : Lateral view of the left hip. A progressive remodeling with reduction of the gap is seen.

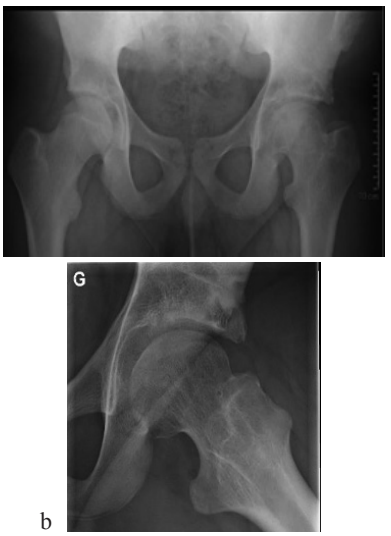

Figure 7. — Last follow-up, 7 post-operative years (LFU). (a) : Anteroposterior pelvic radiograph. Better remodeling of the head with a good coverage by the acetabulum despite the partial reabsorption of the shelf. No gap is seen at this stage. (b) : Lateral view of the left hip. A spherical femoral head and no shelf gap is observed.

al *(11)* during the 3 postoperative years. The femoral head subluxation improved with time, confirmed by a better migration index (MI).

In our series, most of the hips were classified as Herring B or C at the fragmentation stage, suggesting a worse prognosis *(14,15,20,21)*. Using Stulberg's classification at the last follow up we showed good results in terms of risk of osteoarthritis. There were 54% of class I and class II of Stulberg respectively (spherical congruency) with good prognosis. There were 35% of class III (aspherical congruency) with mild risk of early osteoarthritis. There were 9% of class IV and 2% of class V respectively (poor prognosis) with moderate and severe risk of early osteoarthritis. We confirmed as previous studies that shelf acetabuloplasty is a good procedure to prevent early osteoarthritis by a better femoral head coverage *(7,11)*.

Figures 5, 6 and 7 are show the radiographs of a case of our series.

The strength of the study is our large series of patients. The limitation is that we analysed just an anteroposterior pelvic radiograph compared to some studies using CT-scan (9) but radioprotection is an important issue in children.

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