Does Shelf Acetabuloplasty Influence Acetabular Growth and Remodeling?

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Abstract

Background Shelf acetabuloplasty has the potential to cause iatrogenic acetabular growth arrest, although accelerated acetabular growth has been reported based on plain radiographic evaluations in patients with Legg-Calvé-Perthes disease. Because plain radiographs may be limited in depicting actual acetabular morphology, it is unclear whether there are growth disturbances.

Questions/purposes We therefore determined (1) whether focal or generalized acetabular growth stimulation or retardation occurred based on CT analysis in combination with plain radiographic assessment; and (2) whether radiographically assessed femoral head deformity, subluxation, and acetabular dysplasia were associated with residual zonal rim dysplasia of the acetabulum.

Methods We examined 14 patients who had undergone shelf acetabuloplasty for “reducible subluxation” and underwent CT scans at a mean 7 years after surgery (range, 3–11 years). We measured radiographic indices reflecting acetabular depth and rim dysplasia on multiplanar

reformatted images in 10 radial planes and on plain radiographs and calculated their operation-to-control ratios to assess growth changes. The mean age at surgery was 9.3 years (range, 7–12 years).

Results We observed generalized accelerated growth in 11 hips and equivocal growth in three. None of the 14 hips showed an abrupt change in acetabular geometry. Despite improved acetabular depth in all hips, eight hips had focal rim dysplasia in the superior zone on CT examinations, and this was associated with a smaller center-edge angle, a greater deformity index, and preexisting acetabular dysplasia.

Conclusions Our observations support the notion that shelf acetabuloplasty has a favorable, stimulatory effect on acetabular growth. However, the possible persistence of preexisting zonal rim dysplasia should be considered.

Introduction

Shelf acetabuloplasty is a straightforward procedure that increases anterolateral coverage of the acetabulum by creating a roof just above the acetabular margin. This technique has been used as a salvage procedure for better coverage of subluxated femoral heads during late-stage Legg-Calvé-Perthes disease (LCPD) [14, 19, 26], but recent reports have suggested shelf acetabuloplasty can be performed for containment of subluxated hips in older children during the fragmentation stage [6, 7, 12, 28].

Previous studies reported that shelf acetabuloplasty increases acetabular cover [3, 12, 26], improves femoral head deformity [6, 14], prevents subluxation [7, 26], and restores hip movement [8, 12, 26], but concerns are still expressed that this procedure may cause iatrogenic growth disturbance at the anterolateral acetabular margin, where

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appositional growth deepens the acetabulum [18] as a result of the proximity between the shelf graft and the growing cartilage of the acetabulum [6, 22]. On the other hand, two studies reported accelerated growth of the lateral acetabulum postoperatively in the hips with reducible subluxation [7, 28], which suggests the shelf procedure has a stimulatory effect. However, in these studies, the authors used AP-view plain radiographs to evaluate acetabular remodeling; two-dimensional assessments may be limited in terms of depicting the true three-dimensional (3D) morphology of the remodeled acetabulum because one sees only the lateral-most structures projected on the planar image. Accordingly, it may be difficult to determine by plain radiography whether growth stimulation or retardation occurs focally at specific regions of the acetabulum or whether these processes involve the entire acetabulum, including the acetabular rim.

We therefore determined (1) whether focal or generalized acetabular growth stimulation or retardation occurred based on CT analysis in combination with plain radiographic assessment; and (2) whether any radiographic parameters of femoral head deformity, subluxation, and acetabular dysplasia were associated with residual zonal rim dysplasia of the acetabulum.

Patients and Methods

We retrospectively identified all 25 children with unilateral LCPD who underwent shelf acetabuloplasty between 1999 and 2005. Surgical indications included an age of 7 years or older at surgery, “reducible subluxation” [6] of hips during the fragmentation stage, and hip abduction by greater than 45° without hinge abduction under anesthesia. A prospective database was established for the 3D assessment of acetabular remodeling in these patients. We excluded four of the 25 patients who did not reach the residual stage (stage of healed epiphysis) and three who were lost to followup. Full explanations were provided to the remaining 18 parents regarding the amount of useful information gained by CT examination and the disadvantages of radiation exposure. Four parents refused a CT examination. The remaining 14 patients underwent a CT examination a minimum of 3 years after surgery (mean, 7 years; range, 3–11 years). There were 13 boys and one girl. Mean age at surgery was 9.3 years (range, 7–12 years). Hips at the time of surgery were Group III (four hips) or IV (10 hips) according to the Catterall classification [5]; Type B (four hips), Type B/C border (five hips), or Type C (five hips) according to the lateral pillar classification of Herring et al. [9]; and of Type B (14 hips) according to the Salter-Thompson classification [20]. The study had Institutional Review Board approval.

All surgeries were performed or supervised by a senior surgeon (IHC). The surgical technique used was the ‘iliac splitting-expanding shelf’ procedure, as previously described [28]. Briefly, the hip capsule was exposed using the anterior approach and the oblique head of the rectus femoris divided from the direct head. A curvilinear trough was made on the lateral iliac cortex just above the joint capsule from the anterior border of the ilium, including the anteroinferior iliac spine, through the midpoint between the anterior gluteal line and the sciatic notch. An osteotomy was started to cut the anterior iliac ridge into medial and lateral halves and continued until it reached an imaginary line vertical to the curvilinear trough ending at the midpoint between the anterior gluteal line and the sciatic notch. Then the outer iliac wall, hinged superiorly at the midpoint between the trough and the iliac crest, was split completely and raised laterally using a laminar spreader and a cortical bone plate harvested from the inner wall of the ilium was inserted into the trough covering the anterosuperolateral aspect of the femoral head. Cancellous bone chips mixed with calcium sulfate tablets (OsteoSet®; Wright Medical Technology, Arlington, TN, USA) were then packed into the triangular space formed by the raised outer iliac wall, the inferior cortical bone plate, and medial host iliac bone. We then sutured the divided oblique head of the rectus femoris back to the direct head to further stabilize the inferior bone plate. Before wound closure, we placed the hip through a full range of hip motion to confirm the absence of impingement between the femoral head and the shelf graft.

Postoperatively we applied bilateral short leg casts with a connecting bar in abduction for an average of 5 weeks (range, 3–6 weeks). Patients were allowed to sit as soon as it could be tolerated. Patients were readmitted for physiotherapy for several days. After removal of casts, supervised physiotherapy began with gentle passive hip ROM in the whirlpool and then progressed to standing with the assistance of a tilt table, parallel bar walking, and crutch walking. Full weightbearing with crutches was allowed from 8 weeks postoperatively. Most patients could walk without crutches around 12 weeks postoperatively.

CT was performed by using a 16-channel multidetector CT scanner (Somatom Sensation 16; Siemens, Erlangen, Germany) or a 64-channel multidetector CT scanner (Brilliance CT; Philips Medical System, Best, The Netherlands). Scanning parameters consisted of a 0.75 × 16 beam collimation or 0.625 × 64 beam collimation, a field of view to fit, 100 or 120 kV, and 120–200 mA, depending on the patient’s size. The mean effective dose equivalent was 5.3 mSv ± 1.6 (SD) (range, 2.7–8.2 mSv) per examination.

Three authors (WJY, HJM, IHC) independently evaluated all radiographs. On AP-view plain radiographs, lateral acetabular depth was defined as the distance between the

true lateral acetabular margin and the medial-most acetabular floor. Lateral acetabular depth growth was calculated as a percentage of preoperative lateral acetabular depth. Modified acetabular roof angle, defined as the angle between a horizontal line parallel to the interteardrop line and a line connecting the summit of the sourcil and true lateral edge of the acetabulum (Fig. 1), was measured to assess lateral acetabular dysplasia. This angle was a modification of the acetabular index angle of the weight-bearing zone described by Tönnis et al. [24]. We used this modified index because the medial end of the sourcil was not clear in some radiographs and because the original acetabular index angle of Tönnis could not be applied to multiplanar reformatted (MPR) images. When downward slanting was present at the acetabular margin, this angle was defined to be positive, and conversely when upward slanting (indicative of rim dysplasia) was present, the angle was defined to be negative. The Sharp angle [21] was also measured to evaluate acetabular dysplasia.

Three-dimensional radiographic indices were measured on MPR images obtained in 10 radial planes set at 20° intervals centered at the base of the acetabular fossa using image-processing software, V-works (CyberMed, Seoul, Korea) (Fig. 2). Three-dimensional radiographic indices

(radial acetabular depth, radial acetabular angle, and radial acetabular roof angle) were defined like corresponding two-dimensional indices, that is, lateral acetabular depth, sharp angle, and modified acetabular roof angle, but were measured on MPR images. Unaffected contralateral, normal hips were used as controls for calculating the operation-to-control ratios of three-dimensional indices. Intrarater and interrater reliability analyses were performed on measurements obtained from MPR images using intra-class correlation coefficients (ICCs). Two raters (WJY, HJM) independently assessed 10 randomly selected hips on two occasions 3 weeks apart. The ICCs between the two raters were 0.84 (95% CI, 0.79–0.87) and 0.81 (95% CI, 0.76–0.85) for the first and second sessions, respectively. The ICCs between the two sessions were 0.92 (95% CI, 0.87–0.95) and 0.91 (95% CI, 0.86–0.93) for the first and second raters, respectively. Original measurements of CT radial indices made by the first rater were used for the data analysis.

Fig. 1 The acetabular depth (and the radial acetabular depth) is the distance between the true lateral edge of the acetabulum and the medial most acetabular floor (A). The modified acetabular roof angle (and the radial acetabular roof angle) (B) is measured by drawing a horizontal line parallel to the interteardrop line (a) and a second line connecting the summit of the weightbearing portion of the acetabulum (sourcil) and the true lateral edge of the acetabulum (b). Sharp angle (and the radial acetabular angle) is the angle between a horizontal line drawn parallel to the interteardrop line and a line connecting the inferior teardrop and true lateral edge of the acetabulum (C).

Fig. 2 A surface-rendered CT image showing how multiplanar reformatted (MPR) images are plotted on the acetabulum. Acetabula are set, corresponding to a clock face, with the base of the acetabular fossa (middle of the incision acetabular notch) at the 6 o'clock position and the acetabular roof at 12 o'clock. Ten MPR images are obtained from the radial sections set at 20° intervals centered at the base of the acetabular fossa. Sections 1 and 2 correspond to the anteroinferior rim, 3 to the anterior rim, 4 to the anterosuperior rim, 5 to the superoanterior rim, 6 to the superoposterior rim, 7 to the posterosuperior rim, 8 to the posterior rim, and sections 9 and 10 to the posteroinferior rim.

To determine whether any focal structural change had occurred at a specific zone of the acetabulum, changing patterns of 3D indices and their operation-to-control ratios as determined in radial planes were scrutinized. The maintenance of operation-to-control ratios at a constant level in all radial planes was considered to indicate no focal structural acetabular change. However, if operation-to-control ratios differed significantly ($p < 0.05$) at specific acetabular regions, hips were further analyzed to identify associated factors. Because focal dysplasia of the acetabular rim was noted on CT examinations, hips were dichotomized based on the presence of a positive ($n = 8$) versus negative ($n = 6$) radial acetabular roof angle in the superior zones (the fifth and sixth radial planes). The two groups were compared with respect to radiographic parameters indicating femoral head deformity at the time of CT examinations (deformity index of Nelson et al. [17] and Stulberg et al. classification [23]), the relationship between the femoral head and the acetabulum at time of CT examinations (medial joint space between the medial-most femoral head and the acetabular fossa, superior joint space, acetabulum-head index [11], and center-edge angle [CEA] of Wiberg [25]), preexisting femoral head deformity (sphericity index [28] measured on intraoperative arthrograms), and preexisting acetabular dysplasia (modified acetabular roof angle).

We used the nonparametric Friedman test to determine if there had been focal growth changes of the acetabulum by comparing the operation-to-control ratios calculated from each radial plane. To determine general growth changes of the acetabulum, we compared radiographic measurements between two paired groups (operation versus control side and before versus after the operation) using the Wilcoxon signed rank test. The Mann-Whitney U test was used to determine the associations between the radiographic parameters and zonal rim dysplasia of the acetabulum. All statistical analyses were conducted using SPSS Version 17.0 (SPSS Inc, Chicago, IL, USA).

Results

Evaluations of generalized acetabular growth using plain radiographs revealed that lateral acetabular depth growth in operated hips was either equivalent to ($n = 3$) or greater than ($n = 11$) that in control hips. Sharp angles decreased from preoperative values by 6° in operated and control hips. Modified acetabular roof angles averaged -3° (range, -20° to 14°) preoperatively and -4° (range, -20° to 11°) at followup, whereas in control hips they increased ($p = 0.002$) from 6° (range, 0° – 12°) to 11° (range, 8° – 17°). Eight hips had a negative modified acetabular roof angle (an upward slanting acetabular rim) with a median value of

-7° (range, -20° to -3°) before operation, and this angle worsened ($p = 0.012$) at followup (median value, -11° ; range, -20° to -4°). The remaining six hips had a positive angle (median value, 5° ; range, 3° – 14°) before surgery and this did not change ($p = 0.600$) at followup (median value, 5° ; range, 0° – 11°). Radial acetabular depths were minimal at anterior acetabular rims and increased gradually to peak in the fifth radial plane and then decreased gradually at posterior rims. The operation-to-control ratios averaged 1.09 (range, 0.98–1.18). Radial acetabular angles peaked at anterior rims, decreased gradually until the acetabular portions equivalent to the fifth radial plane, and were maintained at posterior rims. Radial acetabular roof angles peaked at the superior rim and were minimal at anterior and posterior rims (Fig. 3). Five of seven hips operated on at < 9 years of age had a Stulberg II deformity and the remaining two had a Stulberg III deformity, whereas eight of nine hips operated on at > 9 years of age had a Stulberg III deformity and the remaining one had a Stulberg IV deformity (Table 1).

Evaluations of focal acetabular changes using 3D surface-rendering images and MPR images demonstrated shelf grafts disappeared either completely ($n = 6$) or partially ($n = 8$). In the cases of partial disappearance, shelf grafts were observed on MPR images in the fourth and/or fifth radial planes. True anterolateral acetabular margins underneath shelf grafts were smoothly contiguous with middle and posterior margins without obvious localized overgrowth or undergrowth in all hips. We found no differences ($p = 0.084$) in the operation-to-control ratios of radial acetabular depths between the radial planes. The operation-to-control ratios of radial acetabular angles also were similar ($p = 0.093$) between the radial planes although the operation-to-control ratios of radial acetabular roof angles were smaller ($p < 0.001$) in the superior acetabular rim (from the fourth to the eighth radial planes).

When we dichotomized hips based on the presence of a negative ($n = 8$; Fig. 4) versus positive ($n = 6$; Fig. 5) radial acetabular roof angle in the fifth and sixth radial planes, hips with a negative angle had a smaller CEA of Wiberg ($p = 0.043$) and a greater deformity index ($p = 0.004$) at followup, and these hips had smaller ($p < 0.001$) modified acetabular roof angles preoperatively than the hips with a positive angle (Table 2).

Discussion

A modest amount of literature is available on the role of shelf acetabuloplasty in LCPD. Shelf acetabuloplasty has been used as a salvage procedure for hips with coxa magna, coxa irregularis, or hinge abduction during the late disease

Fig. 3A–C Plots of 3D geometric acetabular variables measured on multiplanar reformatted (MPR) images in 10 radial planes; (A) radial acetabular depth, (B) radial acetabular angle, and (C) radial acetabular roof angle. The error bars represent 95% confidence intervals.

stage [14, 19, 26]. Recent reports have suggested shelf acetabuloplasty is also indicated for the containment of subluxated hips in older children during the early and transitional disease stages [6, 7, 12, 28]. By preventing subluxation and stimulating lateral acetabular growth in hips with “reducible subluxation,” this procedure is believed to be beneficial during hip remodeling. However, these studies of acetabular remodeling were conducted using only AP-view plain radiographs, which may make it difficult to understand true acetabular growth response in the sagittal and axial planes. We therefore asked whether focal or generalized acetabular growth stimulation or retardation occurred based on CT analysis in combination with plain radiographic assessment and whether any

radiographic parameters of femoral head deformity, subluxation, and acetabular dysplasia were associated with residual zonal rim dysplasia of the acetabulum.

We acknowledge the present study has the following limitations. First, the sample size was small. In fact, only 14 of 25 patients who underwent shelf acetabuloplasty between 1999 and 2005 were examined, which introduces the possibility of selection bias. Seven patients who did not reach the residual stage or who were lost to followup and four patients who refused a CT examination were excluded. Nevertheless, measurements of 3D radial indices in the remaining 14 patients in a prospective manner were reliable. More importantly, we were able to determine by CT whether zonal dysplasia of the acetabular rim occurred

Table 1. Radiographic indices measured on plain radiographs

Patient number	Age (years)	Acetabulum*			Femoral head		Femoral head-acetabulum relationship*					Presence of shelf grafts	
		At surgery	Final	LAD (mm)	Sharp angle (°)	MRA (°)	DI	Stulberg type	MJS (mm)	SJS (mm)	CEA (°)		AHI (%)
1	7.0	10.2		45 (40)	40 (39)	-15 (10)	0.45	III	10 (8)	7 (5)	0 (18)	57.1 (73.8)	Partial
2	7.3	18.8		51 (46)	44 (44)	-5 (13)	0.24	II	9 (8)	4 (5)	17 (27)	77.8 (72.9)	None
3	8.4	15.7		48 (40)	42 (45)	5 (9)	0.21	II	7 (6)	4 (4)	17 (20)	74.7 (78.5)	None
4	8.4	19.1		51 (48)	36 (42)	11 (12)	0.15	II	7 (6)	4 (4)	15 (33)	76.4 (85.2)	Partial
5	8.5	13.8		59 (50)	39 (35)	4 (8)	0.30	II	10 (8)	5 (4)	19 (33)	80.4 (82.4)	None
6	8.6	11.8		40 (38)	46 (51)	3 (11)	0.20	II	10 (8)	6 (5)	21 (25)	70.2 (81.4)	Partial
7	8.9	15.7		55 (50)	36 (39)	-9 (17)	0.30	III	8 (6)	4 (4)	13 (35)	80.4 (86.4)	Partial
8	9.3	16.5		54 (50)	40 (48)	-16 (9)	0.46	III	9 (8)	3 (4)	14 (14)	78.6 (76.6)	None
9	9.5	18.2		59 (53)	38 (41)	-7 (14)	0.37	III	12 (10)	3 (3)	16 (32)	80.1 (81.3)	None
10	10.0	15.2		58 (54)	40 (38)	2 (12)	0.16	III	8 (10)	5 (4)	17 (39)	73.7 (84.9)	Partial
11	10.3	17.1		55 (54)	41 (37)	-4 (11)	0.37	III	12 (9)	4 (4)	16 (27)	80.2 (82.0)	Partial
12	10.3	16.4		54 (47)	37 (46)	-16 (14)	0.30	IV	13 (7)	4 (3)	21 (35)	63.9 (82.5)	Partial
13	11.5	18.3		50 (44)	43 (52)	-20 (11)	0.33	III	14 (6)	5 (3)	-5 (31)	57.3 (85.8)	Partial
14	12.3	18.3		54 (46)	40 (38)	8 (10)	0.26	III	11 (9)	5 (5)	23 (22)	86.0 (75.3)	None
Overall†	9.3 ± 2.2	16.1 ± 2.6		52 ± 6 (47 ± 5)	40 ± 3 (43 ± 5)	-4 ± 10 (11 ± 3)	0.29 ± 0.10	NA	10 ± 2 (8 ± 1)	5 ± 1 (4 ± 1)	15 ± 8 (28 ± 7)	74.1 ± 8.9 (80.6 ± 4.5)	NA
‡	NA	NA		< 0.001	0.086	< 0.001	NA	NA	< 0.001	0.136	0.001	0.032	NA

* Data are presented as operated sides (control sides); † values are presented as means ± SDs; ‡ Wilcoxon signed rank test between operated and control hips; LAD = lateral acetabular depth; MRA = modified acetabular roof angle; DI = deformity index; MJS = medial joint space; SJS = superior joint space; CEA = center-edge angle of Wiberg; AHI = acetabulum-head index; NA = not applicable.

Fig. 4A–D Images of a 9-year-old boy with preexisting lateral acetabular dysplasia (Case 7). **(A)** Plain radiograph showing a subluxated femoral head in the late fragmentation stage. **(B)** Plain radiograph taken at 6.8 years after shelf acetabuloplasty showing suspicious lateral dysplasia (arrow) despite accelerated acetabular

depth growth. **(C)** A 3D surface-rendering image demonstrating a shelf graft (arrow) covering the anterolateral area of the hip. **(D)** A multiplanar reformatted (MPR) image demonstrating the acetabular margin (arrow) underneath the shelf graft remained dysplastic.

despite an overall impression of accelerated acetabular growth. Second, our indications for shelf acetabuloplasty were limited to an older age (mean, 9 years; range, 7–12 years) and “reducible subluxation” with rather advanced collapse of the femoral head in the fragmentation

stage and thus, our results may not be applicable to different stages such as to stages of sclerosis with pre- or little collapse of the head or stages later than the fragmentation stage or to cases of severe deformity with hinge abduction. Furthermore, our results may not be applicable to adolescent-onset

Fig. 5A–D Images of an 8-year-old boy without preexisting lateral acetabular dysplasia (Case 4). **(A)** Plain radiograph showing a subluxated femoral head in the fragmentation stage. **(B)** Plain radiograph taken at 10.7 years after shelf acetabuloplasty showing a well-remodeled

acetabulum. **(C)** A 3D surface-rendering image demonstrating a shelf graft (arrow) covering the anterolateral area of the hip. **(D)** A multiplanar reformatted (MPR) image obtained at Section 5 demonstrating a well-remodeled acetabular margin (arrow) underneath the shelf graft.

LCPD with an onset at more than 12 years of age. Third, we measured the CEA as an index indicating the relationship between the femoral head and acetabulum.

However, the CEA measures the sum of femoral head subluxation and the degree of acetabular dysplasia. Thus, it cannot be judged whether an abnormal CEA means

Table 2. Presence of dysplastic acetabular rim in three-dimensional CT scans and associated two-dimensional radiographic variables

Age at surgery and radiographic variables	Dysplastic acetabular rim*		p value†
	No (n = 6)	Yes (n = 8)	
Age at surgery (years)	8.5 (7 to 11.5)	9.4 (8.4 to 12.3)	0.755
Acetabular roof angle (°)‡	5 (3 to 14)	−7 (−20 to −3)	< 0.001
Sphericity index (%)‡	76 (73 to 84)	74 (71 to 76)	0.445
Deformity index [19]	0.21 (0.15 to 0.30)	0.35 (0.24 to 0.46)	0.004
CEA (°)	18 (15 to 23)	15 (−5 to 21)	0.042
Acetabulum-head index [12] (%)	76 (70 to 86)	78 (57 to 80)	0.662
Medial joint space (mm)	9 (7 to 11)	11 (9 to 14)	0.142
Superior joint space (mm)	5 (4 to 6)	4 (3 to 7)	0.228
Stulberg type	II (4 patients), III (2 patients)	II (1 patient), III (6 patients), IV (1 patient)	NA

Values are presented as medians (ranges); * a dysplastic acetabular rim was deemed present when the radial acetabular roof angle was negative on sectional images in the fifth and sixth radial planes that represent the superior portion of the acetabular rim; †Mann-Whitney U test; ‡these two indices were measured before operation; all others were assessed at followup examinations; CEA = center-edge angle of Wiberg; NA = not applicable.

subluxation, acetabular dysplasia, or both. Moreover, the difficulty in setting the center of the femoral head is obvious in deformed femoral head as observed in LCPD. Fourth, we acknowledge that CT has the disadvantages of poor contrast for soft tissues such as cartilage and labrum and presents a radiation hazard despite this imaging modality being helpful for determining whether focal/generalized growth stimulation or retardation of acetabula had occurred and for localizing acetabular zonal dysplasia in three dimensions.

Our study demonstrates that an accelerated acetabular growth observed on AP-view plain radiographs reflects a generalized growth of the entire acetabulum in all 3D planes, suggesting shelf acetabuloplasty has beneficial potentials and effects in terms of generalized growth stimulation of the acetabulum. It could be argued that greater acetabular depth growth might not be caused by shelf acetabuloplasty per se but rather that it occurred as a result of natural increases in acetabular growth in the LCPD hips [4, 6, 13, 27]. However, acetabular depths measured before operation were similar between the operation side and the control side in our series. In a comparative study between femoral varus osteotomy and shelf acetabuloplasty [7], a stimulatory effect on the lateral acetabular growth was observed only in the hips treated by shelf acetabuloplasty.

We observed no structural change of the acetabulum associated with focal growth disturbance. In fact, we suspect iatrogenic growth disturbance associated with shelf acetabuloplasty is likely to be rare. Because the hip capsule attaches just above the labrum, which is continuous with the periphery of acetabular cartilage [2, 16, 18], direct injury to growing cartilage at the acetabular periphery should not occur if the graft is placed just above the joint capsule as is the case for most of the techniques currently used. Moreover,

the probability of ischemic damage to the acetabular or triradiate cartilage caused by osteotomy appears to be slight, because rich extraosseous and intraosseous anastomoses are present among the branches of the superior gluteal, inferior gluteal, and obturator arteries that supply the acetabulum [1, 15]. The risk of physeal cartilage damage may increase in rare conditions when the graft is placed beneath the capsular attachment [10] or when the capsule is dissected from the acetabular wall to find an appropriate graft placement site in cases with a false acetabulum [22].

Eleven of our 14 hips showed accelerated acetabular growth without demonstrating any focal over- or under-growth. However, we observed ideal remodeling of the entire acetabulum with downward slanting at its margin (rim) from anterior to posterior in only six hips. The remaining eight hips had zonal rim dysplasia localized at the superior zone based on the CT examinations. Persistent dysplasia of the acetabular margin without remodeling may be caused by advanced age at surgery (mean, 9 years) and, thus, inadequate acetabular remodeling power and insufficient remodeling time. Considering that these hips had a small CEA and a greater deformity index, shelf grafts might not be capable of relieving compressive forces on the acetabular margin despite supporting the labrum during acetabular rim growth and, thus, compressive stress from the femoral head appeared to be maintained even after surgery in these hips. In this regard, we believe shelf acetabuloplasty as a containment surgery might be more effective if performed in hips with downward slanting at the acetabular margin at a stage earlier than the transitional stage (the late fragmentation and early reossification stages) in older children. When a patient presents during the transitional period with a preexisting dysplastic change at the lateral acetabular margin, we believe a form of pelvic osteotomy capable of

instantaneously relieving compression at the acetabular periphery and labrum may be better indicated.

In conclusion, our observations validate the notion that shelf acetabuloplasty has a favorable, stimulatory effect on generalized growth of the entire acetabulum without focal growth arrest. However, it should be recognized that the remodeling capacity of the superior acetabular margin is limited and that zonal rim dysplasia may persist postoperatively in hips with a preexisting dysplastic rim.

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