Ischial Spine Sign Reveals Acetabular Retroversion in Legg-Calvé-Perthes Disease

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Abstract

Background Acetabular retroversion has been identified in mature patients with sequelae of Legg-Calvé-Perthes (LCP) disease. Whether this is a contributing etiologic factor that leads to the disease process or result of the head deformity is not known. The prominence of the ischial spine (PRIS) sign, which reflects retroversion, can be observed before ossification of the anterior and posterior walls in a skeletally immature patient and could help determine whether the retroverted acetabulum is present before or after head involvement in patients with LCP disease.

Questions/purpose We therefore determined (1) the prevalence of the PRIS sign in patients with LCP disease compared with healthy control subjects, (2) whether the PRIS sign is seen at the time of head involvement in patients with LCP disease, and (3) the prevalence of bilaterality of the PRIS sign in patients with LCP disease and control subjects.

Patients and Methods Of 295 patients with LCP disease, 47 (49 hips) met our inclusion criteria. Of these, 39 (41 hips) had open triradiate cartilage and comprised the study group. Twenty-five pediatric patients with polytrauma

(50 hips) with standardized radiographs comprised the control group.

Results A positive PRIS sign was noted in 37 of the 41 skeletally immature hips compared with only 16 of the 50 control hips. We observed a positive PRIS sign early in the LCP disease process with eight of nine patients in the fragmentation phase having a positive PRIS sign. The PRIS sign was seen bilaterally in 25 of 39 patients with unilateral LCP disease and in only five of 25 control patients.

Conclusions Acetabular retroversion, as evidenced by a positive PRIS, was present in nine of 10 children with LCP disease. It is uncertain if retroversion is a cause or a sequela of the disease, but it was seen early in the disease process at the time of head involvement in the majority of patients.

Level of Evidence Level III, diagnostic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

LCP disease results in necrosis of the capital femoral epiphysis in the pediatric patient. The etiology of the disease is unclear, although some investigators attribute the cause to an undefined vascular insult [2]. Proposed risk factors include coagulopathy, low birth weight, and maternal tobacco use [3, 11]. The underlying cause of the disease is not well understood, but is likely multifactorial and may be associated with some underlying genetic or anatomic predisposition that places patients at a greater risk of having the disease develop.

Acetabular retroversion has been seen in 33% to 50% of adult patients with a history of childhood LCP disease [9, 10, 12]. It is unknown whether it is present before disease onset but has been described as potentially an

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Each author certifies that his or her institution approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Fig. 1 A standardized AP radiograph shows the pelvis of a 30-year-old man with a history of right LCP disease treated nonoperatively. Positive crossover signs can be seen bilaterally (black arrows). The patient also has bilateral PRIS signs (dotted arrows).

anatomic risk factor that could predispose patients to LCP disease [9, 10]. Acetabular retroversion can be seen on AP pelvic films as a crossover sign [17, 21]. On a normal hip radiograph, the projections of the anterior and posterior walls meet at the cranial aspect of the acetabulum [17, 18]. On the radiograph of a hip with a retroverted acetabulum, the projection of the anterior and posterior walls intersect distal to the roof of the acetabulum, creating a crossover sign, as initially described by Reynolds et al. [21] and later validated by Jamali et al. [17] (Fig. 1). This crossover sign cannot be seen in young children owing to lack of ossification of the anterior and posterior walls. The PRIS sign is described as an alternative measure of acetabular retroversion (Fig. 2). Kalberer et al. [18] reported a high correlation between the presence of the PRIS and crossover signs on standardized radiographs in adults. In other words, when the ischial spine is visible inside the pelvic inlet, there is a prominence of the ischial spine (or positive PRIS sign), which indicates acetabular retroversion. When the ischial spine is obscured behind the acetabulum (or negative PRIS sign), the acetabulum has normal version, as long as the radiographs are standardized [18]. In contrast to the crossover sign, the PRIS sign could be seen before ossification of the anterior and posterior walls in a skeletally immature patient, would be a radiographic sign of acetabular retroversion, and could help determine whether acetabular deformity is present before head involvement in patients with LCP disease.

The objective of this study was to assess (1) the prevalence of the PRIS sign in patients with LCP disease compared with healthy control subjects, (2) whether the PRIS sign is present at the time of head involvement in patients with LCP disease,

Fig. 2A–B (A) A premeasurement radiograph shows the right ischial spine sign (PRIS) of a 7-year-old boy with onset of right LCP disease at age 4, treated nonoperatively. The presence of a crossover sign cannot be assessed owing to incomplete ossification of the anterior and posterior walls of the acetabulum. (B) The size of the bilateral PRIS signs can be seen on this postmeasurement radiograph.

and (3) the prevalence of bilaterality of the PRIS sign in patients with LCP disease and control subjects.

Patients and Methods

We conducted a retrospective cohort study to compare presence of the PRIS sign in pediatric patients with and without LCP disease. Using a database of diagnosis codes, we identified all 295 patients with LCP disease treated between 1995 and 2008. For this study, we included patients with a confirmed diagnosis of LCP disease. We reviewed the AP pelvic supine radiographs from all 295 patients. We included patients treated with soft tissue releases, casting, activity restrictions, or bracing, as these

procedures were considered to have a minimal effect on acetabular version. We excluded patients with a previous femoral or innominate osteotomy performed for treatment of LCP disease, as these surgeries could alter acetabular version [8].

Of 295 patients with LCP disease, 47 (49 hips) met our inclusion criteria. Of these patients, eight (eight hips) had closed triradiate cartilage whereas the other 39 (41 hips) were immature. Despite multiple radiographs reviewed per patient, 248 patients had no standardized radiographs, typically owing to asymmetric pelvic rotation and inclination from contractures associated with LCP disease. In cases where a patient had more than one radiograph that was standardized, we used the earliest radiograph. We obtained institutional review board approval for all aspects of this study.

The mean age of the 39 skeletally immature patients at the time of obtaining the radiograph was 7 years (range, 4–12 years). The mean age of patients at disease onset was 5 years (range, 2–10 years). Two patients had bilateral disease. The mean time from diagnosis to obtaining the radiograph was 2 years (range, 0–9 years). Disease stages at the time of the radiograph were initial (one hip), fragmentation (nine hips), reossification (13 hips), residual (15 hips), and indeterminate (three hips). As many hips were evaluated after the fragmentation stage, lateral pillar classification was available for only 32 hips and revealed eight hips with lateral pillar A, 12 hips with B, six hips with B/C, and six hips with C.

A control group was comprised of a series of pediatric patients with polytrauma who underwent imaging studies in the emergency department. Using a pediatric trauma registry, 768 pediatric patients were identified who underwent evaluation for acute trauma between 2006 and 2008. Of those, 211 had supine AP pelvis imaging as part of their trauma workup. We excluded patients with a history of hip complaints or injury to the hip or pelvis. Fifty hips in 25 patients had standardized radiographs, according to the criteria of Siebenrock et al. [23]. The mean age of the control patients at the time of the AP pelvis radiographs was 14 years (range, 2–19 years). On average, the patients with LCP disease were younger than those in the control group. The gender distribution was similar: five of the 25 control patients were female (20%) compared with six of the 39 patients with LCP disease (15%).

We considered the PRIS sign positive if the ischial spine protruded beyond the pelvic rim into the pelvic inlet on a standardized radiograph, and was considered large if the ischial spine protruded more than 3 mm beyond the pelvic rim. We considered radiographs to be standardized only if they met strict criteria for symmetric pelvic rotation and inclination, as outlined by Siebenrock et al. [23]. Specifically, the pelvis had to be oriented without rotation, with

the tip of the coccyx pointing toward the symphysis pubis, and symmetric appearance of the obturator foramina [5, 17, 23]. We considered pelvic inclination to be symmetric if the distance from the coccyx to the symphysis pubis was less than 2 cm or if the distance from the sacrococcygeal joint to the symphysis pubis was 3 cm to 5 cm [18, 20, 23]. We excluded radiographs with bone landmarks obscured by bowel gas or pelvic shields.

We used the projection of the ischial spine to evaluate acetabular version in patients with LCP disease (Fig. 2). This study assumes that the PRIS sign reflects acetabular retroversion in a child, just as it correlates with the crossover sign and acetabular retroversion in an adult [18]. The PRIS sign does not depend on ossification of the anterior and posterior walls and can be used in skeletally immature patients. The PRIS sign can be determined from a standardized AP pelvis film, which is cost-effective, readily available, does not require an anesthetic in a child, and delivers less radiation than some forms of axial imaging. Two authors (RJS, ANL) rated the ischial spine projection for a representative sample of 20 hips from the control group (of the total of 50 hips) and 20 hips from the patient group (of the total of 41 skeletally immature hips). One author (ANL) rated the same 40 hips on two occasions. Using these data, we performed a kappa analysis with an unweighted kappa coefficient to calculate interobserver and intraobserver reliability. For the ischial spine projection, the kappa coefficients were 0.77 for intraobserver reliability and 0.79 for interobserver reliability. In this series, only eight of the 49 hips were skeletally mature and could be assessed for the crossover and ischial spine signs. Thus, the crossover sign was not included in the interobserver and intraobserver reliability analysis. Kappa values have been reported for the crossover sign, with 0.67 to 0.70 for intraobserver and of 0.63 to 0.70 for interobserver reliability [17].

We used Pearson chi square analysis to assess differences between patients and control subjects regarding open triradiate cartilage, stage of disease, lateral pillar classification, and PRIS sign. We used a two-tailed Student t-test to compare patient age between patients and control subjects. We performed all data analysis on JMPIN 4.0.4 (SAS Institute, Cary, NC, USA).

Results

In skeletally immature patients with LCP disease, a greater percentage of affected hips ($p < 0.001$) had a positive PRIS sign than control hips: 37 of 41 affected hips (90%) versus 16 of 50 control hips (32%) (Fig. 3). Only two patients (two hips) had no PRIS sign on the affected side. Similarly, a greater percentage of the hips with LCP

Fig. 3 The graph shows the percentage of hips with a PRIS sign in patients with LCP disease with open and closed triradiate cartilage compared with control subjects with normal hips who had radiographs taken for a history of polytrauma.

disease ($p < 0.001$) had a PRIS sign greater than 3 mm than did the control hips: 23 of 41 (56%) versus 10 of the 50 hips (20%), respectively.

We observed a positive PRIS sign early in the LCP disease process. Eight of nine patients in the fragmentation stage and one patient who presented during the initial stage of disease had a positive PRIS sign. All 13 patients in the reossification phase had a positive PRIS sign. Because the PRIS sign was seen in 90% of hips with LCP disease, no correlation could be made between PRIS sign and stage of disease, age at the time of the radiograph, lateral pillar classification, or closure of the triradiate cartilage.

A greater percentage of patients with unilateral LCP disease ($p = 0.002$) had bilateral PRIS signs compared with the control patients: 25 of 39 (64%) versus six of 25 (24%). The unaffected hip in the LCP disease group also more frequently ($p = 0.001$) had a positive PRIS sign compared with the control patients. The length of the PRIS sign on the affected side was larger than the unaffected side in 17 hips, the same in four hips, and the unaffected side was larger in four hips.

Discussion

Retroversion has been noted in adult patients with a history of LCP disease [9, 10, 11]. It is unclear whether this is a result of the disease or whether acetabular retroversion predates femoral head involvement. The prominence of the PRIS sign, which reflects retroversion, can be observed before ossification of the anterior and posterior walls in a skeletally immature patient and could help determine whether the retroverted acetabulum is present before or after head involvement in patients with LCP disease. The purpose of this study was to assess the occurrence of retroversion and its bilaterality in skeletally immature patients

with LCP disease and to compare these findings with those of healthy pediatric control patients.

Our study is limited in several ways. First, we had a small study population because it was difficult to obtain standardized radiographs. Although each of the 295 patients with LCP disease had many radiographs from presentation onward, because of our strict standardization criteria, most of the radiographs (87%) were not of sufficient quality to assess the PRIS sign owing to pelvic rotation, tilt, or obscured bone landmarks. Similarly, only 88% of radiographs reviewed from the control population were nonstandardized. Second, on average the control patients were older than the patients with LCP disease, and we were unable to match patients by age. The uniform finding of the PRIS sign across all stages of the disease and the small numbers did not allow us to rigorously examine factors such as disease severity. We have no standardized, three-dimensional, cross-sectional imaging that would allow for exact calculation of the cranial and central acetabular version [6, 7]. Finally, the study has a limited number of patients with LCP disease and closed triradiate cartilages (eight hips, six with a positive crossover sign). Although five of the six patients with a positive crossover sign also had a positive PRIS sign, the numbers are too small to draw any direct comparison between the crossover and PRIS signs in the population with LCP disease. Instead, we rely on a previously published series of 1010 adult patients that shows as an indicator of retroversion, the PRIS sign has a sensitivity of 91%, a specificity of 98%, a positive predictive value of 98%, and a negative predictive value of 92% [16].

We found a high prevalence of acetabular retroversion as evidenced by a positive PRIS sign in skeletally immature patients with early and late LCP disease. We found a positive PRIS sign was more common in hips affected by LCP disease compared with healthy control subjects. Ninety percent of hips with LCP disease had a PRIS sign. Because it was seen early in the disease process, the question that arises from the study is whether acetabular retroversion potentially could be an anatomic risk factor that predisposes to LCP disease. This relationship was described previously [8, 9]. Acetabular retroversion leads to overcoverage of the femoral head by the anterior wall of the acetabulum [2, 13, 26], and it is the overhanging rim that theoretically could impinge in flexion and internal rotation against the retinacular vessels resulting in micro-trauma to the vascular supply of the femoral head [2, 26] (Fig. 4). The presence of acetabular retroversion in patients with LCP disease is a clinically important question as it may affect treatment strategies. If acetabular retroversion is present at the time of LCP, then an osteotomy that causes more retroversion and increased anterior coverage (such as a Salter osteotomy) should not be used for containment of

the hip with LCP [8]. To obtain lateral but not worsen anterior overcoverage, a Shelf, triple, Ganz, or varus femoral osteotomy would be the preferred methods of containment so as to avoid iatrogenic acetabular retroversion. Herring et al. reported more Stulberg class I or II results (65%) in the surgical group treated with femoral osteotomy compared with the Salter osteotomy group (57% Stulberg classes I and II), and currently a varus osteotomy is the preferred surgical treatment at their institution [14, 15]. Further prospective work focused on the femoral varus osteotomy for treatment of LCP disease [25].

Based on the presence of a crossover sign, others have reported an incidence of acetabular retroversion in adult patients with LCP disease ranging from 33% to 50% [7, 8, 12, 22]. Our prevalence of retroversion based on the PRIS sign (90%) was greater than what has been reported previously for adults, and one could conclude that the differences could be related to continued growth and acetabular development after onset of the disease process.

Retroversion of the acetabulum, as evidenced by the PRIS sign, was seen early in the disease process. Nine of the 10 patients presenting during the initial or

fragmentation stage had a positive PRIS sign. Our findings of retroversion early during the disease process differ from those of Sankar and Flynn (Table 1) [22]. They retrospectively compared routine MR images of pediatric patients with AP pelvis radiographs showing the crossover sign in adults with a history of LCP disease [22]. They found only one of 53 patients in the pediatric group had acetabular retroversion, but that 30% of patients (five of 16 hips) in the adult group had a positive crossover sign. Thus, they suggest that retroversion in LCP disease likely develops as a response to a deformed femoral head [22]. There are several possibilities why Sankar and Flynn did not detect acetabular retroversion on routine pediatric axial scans. First, anteversion measurements from axial imaging such as CT or MR scans using standard protocols are just as likely as radiographs to be affected by projection errors owing to pelvic tilt. Three-dimensional CT scans, prone axial scans, and other special algorithms are proposed to correct for pelvic tilt in the measurement of acetabular version, but these are more complicated than routine axial imaging [6, 7, 19, 24]. Second, Sankar and Flynn [22] evaluated acetabular retroversion through the center of the

Fig. 4A–B The diagrams show the damage to the lateral epiphyseal vessels through anterior wall overcoverage (acetabular retroversion). **(A)** The cartilaginous extent of the anterior acetabular wall is shown. The lateral epiphyseal vessels are drawn at the head-neck junction. **(B)** With extremes of motion (flexion and internal rotation), the vessels may sustain mechanical trauma from the anterior wall of the acetabulum.

Table 1. Comparison of results for acetabular version

Study	Number of skeletally immature patients	Mode of study	Outcome measure	Acetabular retroversion	Unaffected hip	Conclusion
Sankar and Flynn [22]	53	Routine axial MR	Central version < 0°	1/53 hips (2%)	0/53 hips (0%)	LCP → retroversion
Current study	39	Standardized AP pelvis	Positive ischial spine sign	37/41 hips (90%)	25/37 hips (68%)	Retroversion → LCP

acetabulum, not through the cranial aspect. Jamali et al. [17] described cranial acetabular version, measured 5 mm distal to the acetabular roof, which corresponds to a crossover sign on standardized AP pelvis radiographs [17, 20]. Central acetabular version on axial imaging does not correspond to the crossover sign on standardized AP pelvis radiographs [17, 18]. Finally, Sankar and Flynn defined acetabular retroversion as an angle less than 0° [22]. Normal central acetabular version in the child is similar to that in the adult, with the literature reporting normal values from 8° to 20°, with typically any angle less than 10° considered retroverted [1, 16, 17, 21]. Sankar and Flynn identified only one patient with severe retroversion (less than 0°), but perhaps other children with LCP disease with mild or moderate retroversion (0° to 10°) were considered to have normal version. The above explanations may reconcile the apparent discrepancy between our results and those of Sankar and Flynn for acetabular retroversion in skeletally immature patients with LCP disease.

We found the unaffected hip in patients with LCP disease more frequently had a positive PRIS sign when compared with control subjects. Berg et al. reported the prevalence of contralateral retroversion in patients with LCP disease was 31%, and our data support this finding [4]. Furthermore, a larger PRIS sign was seen more commonly in the affected hip than in the unaffected hip in patients with unilateral LCP disease. This finding would argue in favor of retroversion as a contributing risk factor present bilaterally before onset of LCP disease.

We found acetabular retroversion is more common in pediatric patients with LCP disease than in pediatric control subjects in our patient population. Using the PRIS sign as a measure of acetabular retroversion, young patients in early stages of LCP disease have evidence of a retroverted acetabulum. This supports the theory that retroversion may play a critical role in the pathogenesis of LCP disease and the acetabular abnormality should be taken into account during treatment of the disorder. It also may open new avenues for research regarding diagnosis and treatment of LCP disease. Further work however, perhaps using axial imaging under a protocol to standardize pelvic tilt, is required to clarify the importance of acetabular retroversion in LCP disease.

References

- Atkinson HD, Johal KS, Willis-Owen C, Zadow S, Oakeshott RD. Differences in hip morphology between the sexes in patients undergoing hip resurfacing. *J Orthop Surg Res*. 2010; 5:76.
- Atsumi T, Yamano K, Muraki M, Yoshihara S, Kajihara T. The blood supply of the lateral epiphyseal arteries in Perthes' disease. *J Bone Joint Surg Br*. 2000;82:392–398.
- Bahmanyar S, Montgomery SM, Weiss RJ, Ekblom A. Maternal smoking during pregnancy, other prenatal and perinatal factors, and the risk of Legg-Calve-Perthes disease. *Pediatrics*. 2008; 122:e459–464.
- Berg RP, Galantay R, Eijer H. Retroversion of the contralateral adult acetabulum after previous Perthes' disease. *Acta Orthop Belg*. 2010;76:42–47.
- Clohisy JC, Carlisle JC, Beaulieu PE, Kim YJ, Trousdale RT, Sierra RJ, Leunig M, Schoenecker PL, Millis MB. A systematic approach to the plain radiographic evaluation of the young adult hip. *J Bone Joint Surg Am*. 2008;90(suppl 4):47–66.
- Dandachli W, Islam SU, Liu M, Richards R, Hall-Craggs M, Witt J. Three-dimensional CT analysis to determine acetabular retroversion and the implications for the management of femoro-acetabular impingement. *J Bone Joint Surg Br*. 2009;91: 1031–1036.
- Dandachli W, Kannan V, Richards R, Shah Z, Hall-Craggs M, Witt J. Analysis of cover of the femoral head in normal and dysplastic hips: new CT-based technique. *J Bone Joint Surg Br*. 2008;90:1428–1434.
- Dora C, Mascard E, Mladenov K, Seringe R. Retroversion of the acetabular dome after Salter and triple pelvic osteotomy for congenital dislocation of the hip. *J Pediatr Orthop B*. 2002;11: 34–40.
- Eijer H. Towards a better understanding of the aetiology of Legg-Calve-Perthes' disease: acetabular retroversion may cause abnormal loading of dorsal femoral head-neck junction with restricted blood supply to the femoral epiphysis. *Med Hypotheses*. 2007;68:995–997.
- Eijer H, Berg RP, Haverkamp D, Pecasse GA. Hip deformity in symptomatic adult Perthes' disease. *Acta Orthop Belg*. 2006;72: 683–692.
- Eldridge J, Dilley A, Austin H, EL-Jamil M, Wolstein L, Doris J, Hooper WC, Meehan PL, Evatt B. The role of protein C, protein S, and resistance to activated protein C in Legg-Perthes disease. *Pediatrics*. 2001;107:1329–1334.
- Ezoe M, Naito M, Inoue T. The prevalence of acetabular retroversion among various disorders of the hip. *J Bone Joint Surg Am*. 2006;88:372–379.
- Giori NJ, Trousdale RT. Acetabular retroversion is associated with osteoarthritis of the hip. *Clin Orthop Relat Res*. 2003;417: 263–269.
- Herring JA, Kim HT, Browne R. Legg-Calve-Perthes disease. Part I: Classification of radiographs with use of the modified lateral pillar and Stulberg classifications. *J Bone Joint Surg Am*. 2004;86:2103–2120.
- Herring JA, Kim HT, Browne R. Legg-Calve-Perthes disease. Part II: Prospective multicenter study of the effect of treatment on outcome. *J Bone Joint Surg Am*. 2004;86:2121–2134.
- Hoiseth A, Reikeras O, Fonstelién E. Lack of correlation between femoral neck anteversion and acetabular orientation: radiography and computed tomography in cadavers and in vivo. *Acta Orthop Scand*. 1989;60:93–96.
- Jamali AA, Mladenov K, Meyer DC, Martinez A, Beck M, Ganz R, Leunig M. Anteroposterior pelvic radiographs to assess acetabular retroversion: high validity of the "cross-over-sign". *J Orthop Res*. 2007;25:758–765.
- Kalberer F, Sierra RJ, Madan SS, Ganz R, Leunig M. Ischial spine projection into the pelvis: a new sign for acetabular retroversion. *Clin Orthop Relat Res*. 2008;466:677–683.
- Kim SS, Frick SL, Wenger DR. Anteversion of the acetabulum in developmental dysplasia of the hip: analysis with computed tomography. *J Pediatr Orthop*. 1999;19:438–442.
- Li PL, Ganz R. Morphologic features of congenital acetabular dysplasia: one in six is retroverted. *Clin Orthop Relat Res*. 2003;416:245–253.

21. Reynolds D, Lucas J, Klaue K. Retroversion of the acetabulum: a cause of hip pain. *J Bone Joint Surg Br.* 1999;81:281–288.
22. Sankar WN, Flynn JM. The development of acetabular retroversion in children with Legg-Calve-Perthes disease. *J Pediatr Orthop.* 2008;28:440–443.
23. Siebenrock KA, Kalbermatten DF, Ganz R. Effect of pelvic tilt on acetabular retroversion: a study of pelves from cadavers. *Clin Orthop Relat Res.* 2003;407:241–248.
24. Visser JD, Jonkers A, Hillen B. Hip joint measurements with computerized tomography. *J Pediatr Orthop.* 1982;2:143–146.
25. Wiig O. Perthes' disease in Norway: a prospective study on 425 patients. *Acta Orthop Suppl.* 2009;80:1–44.
26. Zhang JF, Yang CJ, Wu T, Li JH, Xu ZS, Chen Y. A two-degree-of-freedom hip exoskeleton device for an immature animal model of exercise-induced Legg-Calve-Perthes disease. *Proc Inst Mech Eng H.* 2009;223:1059–1068.