CLINICAL ORTHOPAEDICS AND RELATED RESEARCH
Number 458, pp. 150–158

The Proximal Femoral Growth Plate in Perthes Disease

Marcin E. Domzalski, MD[*]*; Muharrem Inan, MD*[*,†]*; James T. Guille, MD*[‡]*;*
Joseph Glutting, PhD[*]*; and S. Jay Kumar, MD*[*]

We hypothesized the extent of involvement of the proximal femoral growth plate in Perthes disease determined the final radiographic outcome after containment by shelf acetabuloplasty. We retrospectively evaluated the extent of growth plate involvement using a modified version of the method described by Yasuda and Tamura. In our modification, we used only the epiphyseal border for measurements, which was clearly visible as a thin white line, unlike Yasuda and Tamura who used the metaphyseal and epiphyseal borders. We could not clearly demarcate the metaphyseal border in the radiographs of our patient population between 1944 and 1998, which consisted of 69 patients who had surgery at a mean age of 9 years (range, 6.0–14.1 years). From these measurements, we formulated an index termed "growth plate involvement." Radiographic results were classified as described by Stulberg et al A growth plate involvement index less than 0.25 resulted in a good radiographic outcome. We found 93.2% sensitivity and 100% specificity in predicting Stulberg's outcomes. The growth plate involvement index is a reliable and reproducible measurement method and may be used prospectively as a useful prognostic factor to predict radiographic outcomes after containment acetabuloplasty.

Level of Evidence: Level II, prognostic study (retrospective study). See the Guidelines for Authors for a complete description of levels of evidence.

Received: June 28, 2006
Revised: November 28, 2006
Accepted: January 16, 2007
From the [*]Department of Orthopedics, Alfred I. duPont Hospital for Children, Nemours Children's Clinic, Wilmington, DE; the [†]Orthopedics and Traumatology Center, Malatya, Turkey; and the [‡]Department of Orthopedics, Shriners Hospital for Children, Philadelphia, PA.
Each author certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.
Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.
Correspondence to: S. Jay Kumar, MD, Department of Orthopedics, Alfred I. duPont Hospital for Children, 1600 Rockland Road, Wilmington, DE 19803. Phone: 302-651-5911; Fax: 302-651-5951; E-mail: sjayakum@nemours.org.
DOI: 10.1097/BLO.0b013e3180380ef2

The goal for treatment of Legg-Calve-Perthes disease is to achieve a congruous hip, which is likely to delay the development of late arthritic changes and pain. However, the natural history of Legg-Calve-Perthes disease is variable and depends on many clinical and radiographic factors.[5] If left untreated, the femoral head may deform and extrude, resulting in hinge abduction and subluxation. Different risk factors and classification systems have been proposed to predict the final outcome.[5,13,28]

Containment of the deformed femoral head in the acetabulum should improve the sphericity,[9,10,12,18,27] although some believe "there is no indication that surgical containment alters stresses or prevents collapse of an extensively necrotic femoral head."[25] Containment is achieved by performing a proximal femoral derotation osteotomy to redirect the femoral head into the acetabulum, a Salter innominate osteotomy to redirect the acetabulum to contain the femoral head anteriorly and laterally, or by a buttressing procedure called shelf acetabuloplasty.[2,10,13,18,27] In 1996, Yasuda and Tamura described a simple radiographic measurement involving the growth plate of the proximal femur in Legg-Calve-Perthes disease and found good correlation between their measurement and the final outcome.[35] We attempted to use this method but found it difficult to interpret the metaphyseal border of the growth plate on some radiographs; therefore, we modified this method by using only the epiphyseal border, which is clearly visible as a thin white line (Fig 1).

The primary research question of this study is: Does this new method of measurement of growth plate involvement have a higher diagnostic use than the lateral pillar classification of Herring et al[13] in predicting the outcome after surgical containment in Perthes disease as assessed by the classification of Stulberg et al?[32] To answer this question, we first assessed interobserver and intraobserver reliability and reproducibility of measuring growth plate involvement using intraclass correlation coefficients. This hypothesis also was tested by answering the following questions: (1) Does the period of delay from the onset of the disease and surgery correlate with changes in growth

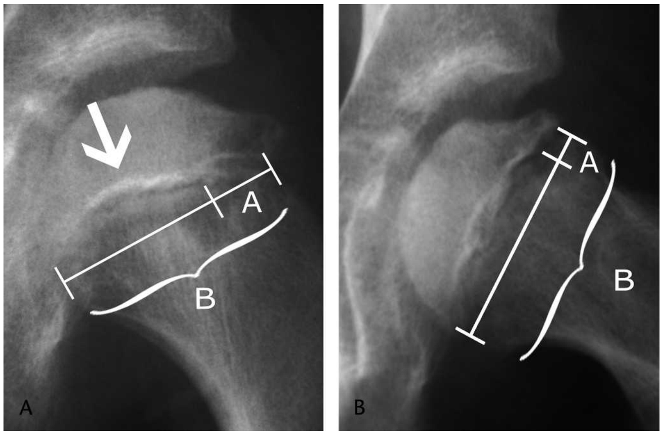

Fig 1A–B. (A) Measurement of growth plate involvement is shown on (A) AP and (B) frog leg radiographs. Distance A is the involved part of the growth plate and distance B is the width of the physis. The arrow points to the margin of the growth plate (growth plate involvement = A/B [AP] × A/B [frog leg]) (growth plate involvement = 0.037).

plate involvement?; (2) Does the amount of time the proximal femoral growth plate remains open after surgery influence the Stulberg class at skeletal maturity?; and (3) Does growth plate involvement at the time of surgery correlate with the amount of time the proximal femoral growth plate remains open after surgery?

MATERIALS AND METHODS

We retrospectively reviewed the medical records and radiographs of all 97 consecutive children with unilateral Legg-Calve-Perthes disease treated with shelf acetabuloplasty of the hip from 1944–1998 at the Alfred I. duPont Hospital for Children in Wilmington, DE. Records were included if we had complete clinical and radiographic data from the time of onset, preoperative and final followups, an open growth plate of the proximal femur at the time of surgery, closed triradiate cartilage of the acetabulum at the last followup, and a minimum followup of 2 years. The radiographs included anteroposterior (AP) and frog leg lateral radiographs of the hips. Of the 97 children we excluded, 12 (12%) were because of incomplete radiographic data. Eleven of the 97 (11%) were not available for followup. We also excluded five patients who had a closed growth plate at the time of the shelf procedure. The remaining 69 patients (69 hips) formed the study group, reflecting 71% of the total. There were 59 boys and 10 girls. The left hip was affected in 29 patients and the right hip in 40 patients. The mean age at the time of onset of symptoms was 7.5 years (range, 5–13 years). The mean age at the time of surgery was 9.1 years (range, 6–14.1 years). The mean delay between the onset of symptoms and the shelf procedure was 17 months (range, 1–77 months). The mean age at the last followup was 17 years (range, 15–58 years). The minimum followup was 2 years (mean, 15 years; range, 2–44 years). We obtained Institutional Review Board approval before performing the study. In our institution, the shelf acetabuloplasty is the only method of containment for Legg-Calve-Perthes disease. The surgical procedure was performed as described by Gill[8] and Kumar and MacEwen.[19]

Thirty hips were classified as Catterall Group IV, 33 as Group III, and six as Group II.[5] According to the modified lateral pillar classification of Herring et al,[12,13] 41 hips were Group C, 20 Group B, and eight Group B/C. At the time of surgery, 13 hips were in the necrotic stage, 22 in the fragmentation stage, 21 in the reossification stage, and 13 in the remodeling stage. The last radiograph without irregularity and fragmentation in the bony structure of the epiphysis was considered the end of the necrotic stage.[3,33]

The growth plate index is a modified version of the method described by Yasuda and Tamura.[35] They described the involved growth plate as the portion of the growth plate with ill-defined borders at the metaphyseal and epiphyseal sides. We were unable to define the metaphyseal border because it could not be clearly demarcated on the radiographs. Additionally, the presence of metaphyseal cysts made this border indistinct. Therefore, we limited measurements strictly to the epiphyseal border because it was clearly visible as a thin white line on the AP and frog leg radiographs. Measurements started from the lateral edge of the growth plate on the AP radiograph and the superior edge in the frog leg radiograph. We followed the white line until it was not traceable. The point from where the line was not traceable was the border between the healthy and unhealthy parts of the growth plate. We measured the distance from this point to the lateral edge of the growth plate on the AP view and to the superior edge in the frog leg view (Fig 1). The growth plate index is calculated by dividing the width of the involved portion of the growth plate ($W_{involved}$) by the total width of the growth plate (W_{total}). These measurements are made on the AP and frog leg views. The values of both calculations are multiplied to obtain the growth plate involvement:

$$\text{Growth plate involvement} = (W_{involved}/W_{total})_{AP} \times (W_{involved}/W_{total})_{Frog\ Leg} \quad \text{(Fig 1)}$$

Three authors (MD, MI, SKJ) analyzed the extent of growth plate involvement of the proximal femur on all radiographs from disease onset to the time of surgery (Fig 2; Table 1). Radiographs taken within 2 months before surgery were considered preoperative radiographs. If multiple radiographs were taken in a short time, we only included radiographs that clearly showed the growth plate. Three authors assessed the growth plate independently. They also graded the Catterall, Herring, and Stulberg groups independently. We defined the growth plate as open when an unbroken white line was visible between the epiphysis and metaphysis at the level of the growth plate on AP and frog leg view radiographs (Fig 1). The radiographic results were assessed after closure of the triradiate cartilage of the acetabulum and were classified using the criteria of Stulberg et al[32] Stulberg Classes I and II were considered good results and Classes III, IV, and V were considered poor outcomes.[32] Because we had only one hip rated as Stulberg Class I, for further analysis, this hip was included with Stulberg Class II (good results). Clinically,

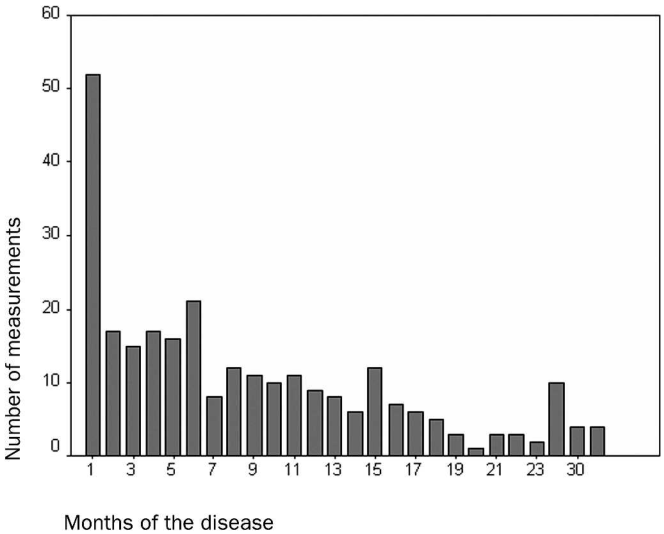

Fig 2. The total number of measurements of growth plate involvement after disease onset is shown.

hips rated Stulberg Class II had full abduction, full flexion, less than 10° limitation of internal rotation, no limp, and no pain.

We used Student's t test to compare data on the interval level between two groups. Student's t tests were used to compare growth plate involvement at the time of surgery between boys and girls and also to compare left- and right-sided involvement. We found no difference in growth plate involvement at the time of surgery between age-matched boys and girls or between left and right side of involvement.

We used Pearson's correlation coefficient to determine the correlation between variables. We assessed the correlation between (1) the period of delay from the onset of the disease and surgery to the growth plate involvement at surgery; and (2) the time that the growth plate remained open after surgery to the growth plate involvement at surgery. The relationship of the period of delay from the onset of the disease to surgery to the growth plate involvement at surgery was significant (Pearson's correlation coefficient 0.66, $p < 0.01$). Because the period of delay from the onset of the disease and surgery had a relationship with growth plate involvement, we compared average values of growth plate involvement in different stages of the disease at the time of surgery.

When performing a comparison between three or more groups, an analysis of variance (ANOVA) with Tukey's post hoc analysis for variables showing a normal distribution was used. An ANOVA was performed to compare the independent variable growth plate involvement with the dependent variable of stage of the disease. Analysis of variance also was used to compare the independent variable of growth plate involvement at the time of surgery with the dependent variable of Stulberg classification at

TABLE 1. Total Number of Measurements of Growth Plate Involvement after Disease Onset (includes all patients)

Months	Number of Measurements	Mean Growth Plate Involvement	Minimum	Maximum	Standard Deviation
1	52	0.0212	0.01	0.05	0.01422
2	17	0.0348	0.01	0.08	0.02258
3	15	0.0707	0.01	0.11	0.03166
4	17	0.0951	0.02	0.21	0.06517
5	16	0.0757	0.01	0.13	0.05036
6	21	0.1141	0.02	0.27	0.07248
7	8	0.1147	0.01	0.22	0.06588
8	12	0.1405	0.04	0.24	0.06221
9	11	0.1649	0.07	0.3	0.07467
10	10	0.2437	0.04	0.36	0.10567
11	11	0.2291	0.07	0.4	0.11894
12	9	0.1888	0.09	0.42	0.11040
13	8	0.3543	0.17	0.62	0.16227
14	6	0.3664	0.16	0.57	0.14640
15	12	0.3323	0.06	0.82	0.18570
16	7	0.3555	0.14	0.7	0.20242
17	6	0.3738	0.1	0.53	0.16952
18	5	0.3705	0.15	0.47	0.12938
19	3	0.3833	0.25	0.6	0.18930
20	1	0.15	0.15	0.15	N/A
21	3	0.4281	0.32	0.54	0.15822
22	3	0.34	0.2	0.51	0.15716
23	2	0.3	0.24	0.36	0.08485
24	10	0.491	0.3	0.83	0.15914
30	4	0.56	0.4	0.73	0.14213
36	4	0.5	0.39	0.61	0.11605

N/A = not available

skeletal maturity. A third ANOVA was run to compare the average growth plate involvement (based on lateral pillar group) with Stulberg classification at skeletal maturity; the purpose of this third analysis was to confirm Herring's lateral pillar groups correlated with Stulberg radiographic outcome and it was valid to compare this scoring system with the growth plate involvement. For all statistical analyses, a significance level of $p \leq 0.05$ was used.

We assessed interobserver agreement using intraclass correlation coefficients. The consistency rule was more lenient than complete agreement. The intraclass correlation coefficients were computed for both rates using a two-way random effects model (rater and subject) as specified by McGraw and Wong.[22] According to Landis and Koch,[20] we generally considered intraclass correlations between 0.61 and 0.8 substantial agreement and correlations between 0.81 and 1 almost perfect agreement. In our study, all intraclass correlations were above the 0.81 level showing the reliability and reproducibility of the measure. Readers must exercise caution when interpreting the Landis and Koch criteria. We are not recommending surgical intervention based on is necessary to provide clinicians with the data to assess the gravity of an error in classification or choice of treatment. The intraclass correlation coefficient results showed high agreement for agreement and consistency rules. The intraclass correlation coefficient values for complete agreement were 0.9 for growth plate involvement, 0.88 for total growth plate width, and 0.89 for the index of involvement. The intraclass correlation coefficient for all three variables using the consistency rule showed the same value (0.95). Because we found no differences in measurements between observers, we used the original measurements of growth plate involvement made by the first observer (MD).

The aim of the last set of analyses was to determine diagnostic accuracy (ie, sensitivity and specificity) of the growth plate involvement versus Herring's pillar classification in predicting Stulberg classification. The diagnostic accuracy was determined by creating receiver operating characteristic curves. Visually, the procedure entails using graph paper and plotting the sensitivity (y axis) and false-positive rate (x axis) of a test while systematically moving the test's cut score across its full range of values. Specifically, sensitivity (all true-positives are found) and specificity (no false-positives are found) were calculated for every possible growth plate involvement cut point value. The purpose of varying the cut point is to determine the value of growth plate involvement that has the highest accuracy in predicting Stulberg class. An assessment used to calculate the performance of the test, or the diagnostic accuracy, is provided by the area under the receiver operating characteristic curve. This area is equivalent to the probability that when two patients are randomly drawn from the population (one with a Stulberg classification of II and the other with a Stulberg classification of III), the test used to predict the final result will provide an accurate classification.

Because we found a difference in growth plate involvement between the groups with good and poor radiographic outcomes, we determined the optimal cut point for the growth plate involvement in predicting Stulberg results by calculating sensitivity and specificity levels for each growth plate involvement value. The comparison revealed the optimal growth plate involvement cut point was 0.25. This cut point produced sensitivity levels of 93.2% and specificity levels of 100%. All hips with a good radiographic outcome (Stulberg Classes I and II) had growth plate involvement less than 0.25. We called this group growth plate involvement Type I (Fig 3). All hips with growth plate involvement greater than 0.25 were classified as growth plate involvement Type II, which resulted in Stulberg Classes III and IV hips. In growth plate involvement Type II, ½ or more than ½ of the growth plate was involved on the AP and frog leg lateral radiographs (Fig 4).

RESULTS

The growth plate of the proximal femur was open for an average of 29 months postoperatively (range, 0–70

Fig 3A–D. Before shelf acetabuloplasty, an (A) AP radiograph shows disruption of the epiphyseal border of the growth plate in a 7-year-old boy, which is limited to the lateral portion of the growth plate. (B) A frog leg radiograph shows disruption of the growth plate in the superior (anterior) portion. Disruption of the epiphyseal border (white line) of the growth plate is clearly visible in this area (growth plate involvement = 0.064). Two-thirds of the growth plate was preserved on the (C) AP and (D) frog leg views (growth plate involvement Type I at the time of the surgery).

Fig 4A–D. Marked disruption of the growth plate is visible preoperatively on the (A) AP and (B) frog leg radiographs. Despite shelf acetabuloplasty, the result was poor as seen on (C) AP and (D) frog leg radiographs at skeletal maturity.

months). In the group with a good radiographic outcome (Stulberg Classes I and II), this period averaged 57 months (range, 38–70 months; standard deviation, 9.3). In the group with an unfavorable outcome, this period averaged

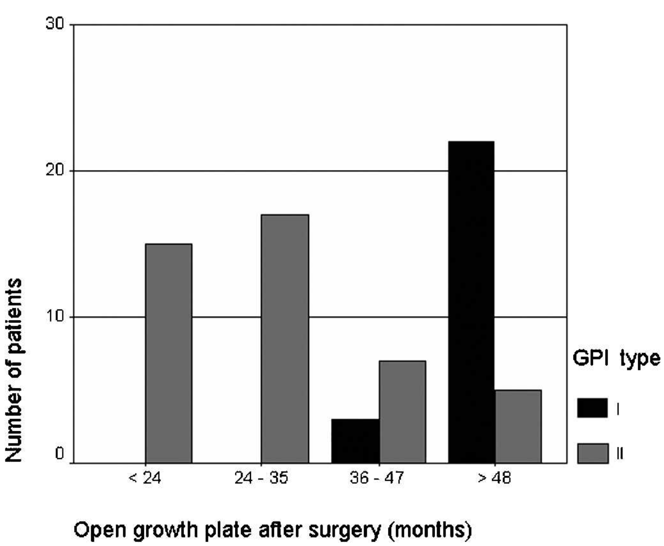

Fig 5. The time the growth plate remained open after surgery was based on growth plate involvement (GPI) type. The majority of patients in growth plate involvement Group I had an open growth plate for more than 48 months after surgery.

TABLE 2. The Proximal Femoral Growth Plate in Perthes' Disease

Stage of the Disease	Number of Patients	Mean Growth Plate Involvement	Standard Deviation
Necrosis	13	0.09	0.06*
Fragmentation	22	0.25	0.13*
Reossification	21	0.38	0.14*
Remodeling	13	0.54	0.14*

*Results from ANOVA were significant (F = 30.5, df [3.65], p = 0.001); all comparisons between groups were significant at p < 0.01

32 months (range, 12–66 months; standard deviation, 15) for Stulberg Class III and 23 months (range, 10–48 months; standard deviation, 11) for Class IV. The growth plate of the proximal femur was open for a longer ($f = 36.98$; $p = 0.001$) time in the group with a good outcome (Stulberg Classes I and II) when compared with the group with a poor radiographic outcome (Stulberg Classes III and IV). There was no difference in the outcome between Classes III and IV regarding how long the growth plate remained open. We found a correlation ($r = 0.642$, $p < 0.05$) between the extent of involvement of the growth plate at the time of surgery and the period of time the growth plate remained open after surgery. Hips with higher growth plate involvement at the time of surgery had earlier growth plate closure (Fig 5).

The average growth plate involvement measured on preoperative radiographs was 0.31 (range, 0.01–0.83; standard deviation, 0.19). The growth plate involvement was higher ($p < 0.01$) in each stage of the disease as it progressed (Table 2). At the last followup, we rated the radiographic result in one hip (1.4%) as Stulberg Class I, 24 hips (34.8%) as Stulberg Class II, 26 (37.7%) as Stulberg Class III, and 18 (26.2%) as Stulberg Class IV. Patients in Stulberg Classes I and II had lower ($p = 0.001$) growth plate involvement when compared with those in Classes III and IV (Table 3). Hips with a deformed femoral head at the final radiographic evaluation (Classes III and IV) showed no difference in growth plate involvement measured at the time of surgery. The average values of growth

TABLE 3. Comparison of Growth Plate Involvement Based on Stulberg Group

Stulberg Classification	Number of Patients	Mean Growth Plate Involvement	Standard Deviation
Group I and II	25	0.11	0.06*
Group III	26	0.41	0.13
Group IV	18	0.45	0.14

*Results from ANOVA were significant (F = 57.27, df [2.66], p = 0.001); growth plate involvement was lower in Groups I and II than in Groups III (p < 0.001) and IV (p < 0.001); the difference between Groups III and IV was not significant

TABLE 4. Growth Plate Involvement in Herring's Lateral Pillar Groups and Correlation with Radiographic Outcome

Lateral Pillar Group	Growth Plate Involvement	Standard Deviation	Stulberg Classes I and II	Stulberg Class III	Stulberg Class IV	Total
B	0.1674*	0.16	13	6	1	20
B/C	0.2600†	0.13	5	1	2	8
C	0.4053*,†	0.16	7	19	15	31

Analysis of variance (F = 5.38, p = 0.007); *Significant difference between group B and C (p = 0.001); †Significant difference between Group B/C and C (p = 0.004); chi square analysis (chi square = 17.866, p = 0.001, phi 0.36)

plate involvement at the time of surgery based on Herring lateral pillar groups were lower (F = 5.38; p = 0.007) in group B and increased as the groups progressed (Table 4).

On average, the growth plate from radiographs made from the time of onset of Legg-Calve-Perthes disease until surgical containment reached a value of 0.25 at approximately 12 months after the onset of the disease. In one hip, growth plate involvement greater than 0.25 occurred 6 months after the onset of the disease (Fig 6).

The receiver operating characteristic curves for growth plate involvement and Herring's pillar classification were located markedly above and to the left of the diagonal (Fig 7). Consequently, the curves showed strong association to outcomes from the Stulberg classification. The overall p values (significance levels) for the receiver operating characteristic analysis were highly significant (Table 5). The area under the curve also gives information regarding the applied use of each measure. The growth plate involvement and Stulberg systems showed high accuracy (ie, both areas under the curve exceed the 0.66 criterion recommended by Rice and Harris[26]). For instance, the area under the curve for growth plate involvement was 0.97. This value indicates when two patients are randomly drawn from the population (one with a Stulberg classification of II and the other with a Stulberg classification of III), 97% of the time the growth plate involvement will provide an accurate classification. Likewise, 75% of the time the Herring's pillar classification will provide an accurate classification. The areas under the curve of the two systems were compared. The comparison reveals the growth plate involvement was diagnostically superior (p = 0.001) to the lateral pillar classification (Table 5).

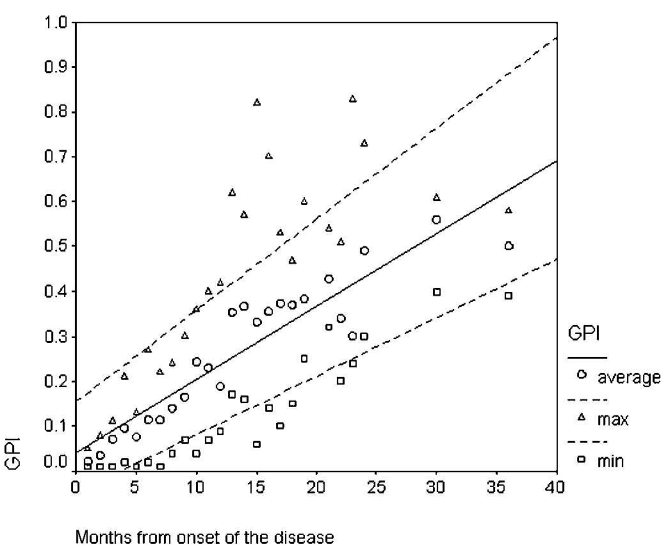

Fig 6. Changes in the growth plate involvement (GPI) index during disease progression are shown. One patient had growth plate involvement exceeding 0.25, which appeared 6 months after disease onset. On average, growth plate involvement reached 0.25 approximately 12 months after disease onset.

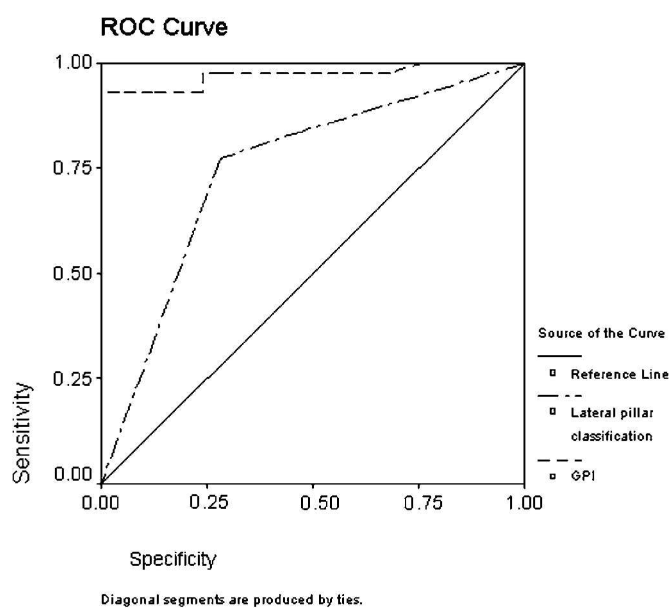

Fig 7. The receiver operating characteristic (ROC) curves for growth plate involvement (GPI) and lateral pillar classification are shown. The area under the curve is the area below and to the right of each line.

TABLE 5. Accuracy of Growth Plate Involvement versus Herring's Lateral Pillar Classification

Variable	Overall p Values	Area Under the Curve	Score Comparison
Growth plate involvement (1)	0.001	0.97	1 > 2, p = 0.001
Herring's pillar classification (2)	0.001	0.75	

The score comparison is a test of the two areas under the curve to determine which is more accurate. In this case, growth plate involvement is significantly more accurate than the lateral pillar classification.

DISCUSSION

The main goal in the treatment of Perthes disease is to prevent deformation of the hip and to delay development of arthritic changes. However, the natural history of Perthes disease is variable and depends on many clinical factors. To predict the final outcome and establish a treatment protocol, different classification systems and risk factors were described.[5,13,28] Commonly used classification systems are those of Catterall,[5] Salter and Thompson,[28] and Herring et al[13] The groups can be determined at the fragmentation stage of the disease; however, the fragmentation stage in Legg-Calve-Perthes disease is indicative of advanced destruction.[15] Histologic analysis of the femoral head during different stages of the disease reveals the stage of necrosis is already the culminating point of the disease.[15] In late-presentation Perthes disease, femoral head collapse is rapid and is associated with subluxation and extrusion, which often leads to an unsatisfactory outcome.[14,34] The Salter-Thompson classification may be useful when subchondral fractures are visible.[28] The purpose of developing and analyzing growth plate involvement is to provide the clinician with a useful adjunct to the Herring's lateral pillar classification system. The main focus of this article is to compare the new classification system of growth plate involvement with the lateral pillar classification of Herring et al in predicting the radiographic outcome after surgical containment of Perthes disease as assessed by the criteria of Stulberg et al We believe that the GPI can be a useful adjunct to the Herring's pillar classification system, while not necessarily replacing it. If the Herring's pillar classification is unclear, the clinician can use the GPI to assist in predicting outcome.

One of the main limitations of our study is the fact that all patients were treated with a shelf acetabuloplasty. We cannot say whether and to what extent this altered the natural history of the disease and whether the data apply to other procedures. However, this is a relatively large consecutive series of patients treated at one institution with the same procedure. To ascertain generalizability other studies of patients with differing procedures would be required using the same methods. Although this study is retrospective, we do not believe this a major limitation. While we did not randomize patients to different treatments or use the growth plate involvement in a prospective manner, to determine prognosis we used the same Stulberg rating for each patient to compare growth plate involvement and lateral pillar classifications. We believe that if the patients were enrolled in a prospective study and followed until skeletal maturity without altering our classification and method of treatment of Perthes disease, each patient would have had the same radiographic outcome as seen in the current study.

We used only the epiphyseal line as the reference line for distinguishing growth plate involvement. This is reflected as a thin white line on the epiphyseal side of the growth plate (Fig 1). We noticed the involvement of the growth plate increased as the disease progressed (Fig 6). Also, comparison of growth plate involvement in different stages of the disease at the time of surgery showed statistically significant differences (Table 2). Although the mean growth plate involvement in the necrotic stage was 0.09, it increased to 0.25 in the fragmentation stage and to 0.38 in the reossification stage.

As a result of the wide range of growth plate involvement values (0.01–0.89), we determined the cut point for growth plate involvement measurements based on sensitivity and specificity for predicting radiographic outcome. All hips with growth plate involvement less than 0.25 at the time of the surgery had favorable outcomes, whereas hips that exceeded the growth plate involvement value of 0.25 showed residual deformation at the last followup. Other studies suggest the disturbance in the growth of the proximal femur in Perthes disease leads to unsatisfactory results.[1,7,17,21,29,35] Growth plate involvement was a strong and accurate predictor of the course of future development of the hip. Growth plate involvement during the first months after the onset of the disease was small (0.02 on average) and equal in groups regardless of the age of onset, gender, or side. Growth plate involvement showed a linear increase with disease progression (Fig 6). All hips within the first 5 months after symptom onset showed Type I growth plate involvement (< 0.25). In one hip, growth plate involvement exceeding this value appeared 6 months after the disease onset, which corresponded with the end of the necrotic stage. Nine months after the onset, some hips showed increasing growth plate involvement greater than 0.25 (growth plate involvement Type II). These hips had unsatisfactory outcomes. Based on the growth plate involvement, we recommended containment treatment in the early months of the fragmentation stage while the growth plate involvement is small. A similar time frame for containment is proposed in other retrospective studies.[6,16,34] This recommendation is also supported by Jonsater,[15] who considered the necrotic stage as the culminating phase of Legg-Calve-Perthes disease and found the regeneration process at the histologic level starts from the beginning of the fragmentation stage.[15] Because our patients were treated with a shelf acetabuloplasty, it is difficult to predict if it altered the natural history of the disease.

Our finding that the extent of growth plate involvement at the time of the surgery correlated with final radiographic outcome is supported by other studies.[1,7,35] de Sanctis et al used MRI to observe the proximal femur and reported the amount of physeal involvement as the strongest predictor of the final radiographic outcome.[7] They suggest the extent of physeal involvement is the main risk factor in Legg-Calve-Perthes disease.[7] They described lesions of the growth plate of the proximal femur, which varied in extent and always were associated with metaphyseal cysts.

Ponseti[24] suggested that in Legg-Calve-Perthes disease, the faulty epiphyseal cartilage is the primary lesion and interruption of the blood supply to the epiphysis occurs when the retinacular vessels cross the affected layer of cartilage at the edge of the disrupted growth plate.

Slocum[30] and Snyder[31] established the importance of an open growth plate for remodeling a deformed femoral head and presumed the better results obtained in younger patients were related to a longer time to remodel. However, this potential for improvement only exists when the epiphyseal growth plate remains open. The same relationship was noted in our study; all hips with good final outcomes had open growth plates for at least 3 years after surgical containment (Fig 3). In our study, the average time of remaining growth in Stulberg Classes I and II was 57 months and only 32 months for Class III and 23 months for Class IV. We also found hips with greater involvement of the growth plate at the time of surgery had a much shorter time of open growth remaining after containment and, therefore, had a shorter time available for remodeling (Fig 5). This correlation was also described by several authors who found severely involved growth plates had a tendency to prematurely close, which leads to deformation of the proximal femur.[1,4,11,23]

Growth plate involvement is a reliable and reproducible type of measurement of the extent of the growth plate involvement in Perthes disease. The growth plate involvement showed good correlation with radiographic outcome and may be used as a prognostic factor in the early stages of the disease. Hips with growth plate involvement less than 0.25 had a favorable outcome, whereas hips with growth plate involvement greater than 0.25 developed deformity despite containment. The optimal timing for containment based on growth plate measurements is when growth plate involvement remains less than 0.25, which usually occurs within 6 months after the onset of symptoms. Growth plate involvement is an accurate predictor of the course of future development of the hip.

Acknowledgment

We thank Aaron G. Littleton for invaluable contributions to this study.

References

1. Allen BL Jr. Graphic analysis of femoral growth in young children with Perthes' disease. *J Pediatr Orthop*. 1997;17:255–263.
2. Axer A, Gershuni DH, Hendel D, Mirovski Y. Indications for femoral osteotomy in Legg-Calve-Perthes disease. *Clin Orthop Relat Res*. 1980;150:78–87.
3. Bohr HH. On the development and course of Legg-Calve-Perthes disease (LCPD). *Clin Orthop Relat Res*. 1980;150:30–35.
4. Bowen JR, Schreiber FC, Foster BK, Wein BK. Premature femoral neck physeal closure in Perthes' disease. *Clin Orthop Relat Res*. 1982;171:24–29.
5. Catterall A. The natural history of Perthes' disease. *J Bone Joint Surg Br*. 1971;53:37–53.
6. Daly K, Bruce C, Catterall A. Lateral shelf acetabuloplasty in Perthes' disease: a review of the end of growth. *J Bone Joint Surg Br*. 1999;81:380–384.
7. de Sanctis N, Rega AN, Rondinella F. Prognostic evaluation of Legg-Calve-Perthes disease by MRI. Part I: the role of physeal involvement. *J Pediatr Orthop*. 2000;20:455–462.
8. Gill A. Plastic construction of an acetabulum in congenital dislocation of the hip-the shelf operation. *J Bone Joint Surg Am*. 1935;17:48–59.
9. Green NE, Beauchamp RD, Griffin PP. Epiphyseal extrusion as a prognostic index in Legg-Calve-Perthes disease. *J Bone Joint Surg Am*. 1981;63:900–905.
10. Grzegorzewski A, Bowen JR, Guille JT, Glutting J. Treatment of the collapsed femoral head by containment in Legg-Calve-Perthes disease. *J Pediatr Orthop*. 2003;23:15–19.
11. Grzegorzewski A, Synder M, Szymczak W, Domzalski M, Kozlowski P. Premature femoral head growth plate closure in Perthes' disease [in Polish]. *Chir Narzadow Ruchu Ortop Pol*. 2004;69:189–195.
12. 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.
13. Herring JA, Neustadt JB, Williams JJ, Early JS, Browne RH. The lateral pillar classification of Legg-Calve-Perthes disease. *J Pediatr Orthop*. 1992;12:143–150.
14. Ippolito E, Tudisco C, Farsetti P. The long-term prognosis of unilateral Perthes' disease. *J Bone Joint Surg Br*. 1987;69:243–250.
15. Jonsater S. Coxa plana: a histo-pathologic and arthrografic study. *Acta Orthop Scand Suppl*. 1953;6:5–98.
16. Joseph B, Nair NS, Narasimha Rao KL, Mulpuri K, Varghese G. Optimal timing for containment surgery for Perthes disease. *J Pediatr Orthop*. 2003;23:601–606.
17. Katz JF. Late modelling changes in Legg-Calve-Perthes disease (LCPD) with continuing growth to maturity. *Clin Orthop Relat Res*. 1980;150:115–124.
18. Kitakoji T, Hattori T, Kitoh H, Katoh M, Ishiguro N. Which is a better method for Perthes' disease: femoral varus or Salter osteotomy? *Clin Orthop Relat Res*. 2005;430:163–170.
19. Kumar SJ, MacEwen G. Shelf operation. In: Tachdjian MO, ed. *Congenital Dislocation of the Hip*. 1st ed. New York, NY: Churchill Livingstone; 1982:695–704.
20. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33:159–174.

21. Langenskiold A. Changes in the capital growth plate and the proximal femoral metaphysis in Legg-Calve-Perthes disease. *Clin Orthop Relat Res*. 1980;150:110–114.
22. McGraw K, Wong S. Forming interferences about some intraclass correlation coefficients. *Psychol Methods*. 1996;1:30–46.
23. Phemister D. Operation for epiphysitis of the head of the femur. (In Perthes Disease). *Arch Surg*. 1921;II:221–230.
24. Ponseti IV. Legg-Perthes disease: observations on pathological changes in two cases. *J Bone Joint Surg Am*. 1956;38:739–750.
25. Rab GT, DeNatale JS, Herrmann LR. Three-dimensional finite element analysis of Legg-Calve-Perthes disease. *J Pediatr Orthop*. 1982;2:39–44.
26. Rice ME, Harris GT. Violent recidivism: assessing predictive validity. *J Consult Clin Psychol*. 1995;63:737–748.
27. Salter RB. The present status of surgical treatment for Legg-Perthes disease. *J Bone Joint Surg Am*. 1984;66:961–966.
28. Salter RB, Thompson GH. Legg-Calve-Perthes disease. The prognostic significance of the subchondral fracture and a two-group classification of the femoral head involvement. *J Bone Joint Surg Am*. 1984;66:479–489.
29. Siffert RS. Patterns of deformity of the developing hip. *Clin Orthop Relat Res*. 1981;160:14–29.
30. Slocum D. Coxa plana. *Northwest Med*. 1941;40:233–238.
31. Snyder CR. Legg-Perthes disease in the young hip: does it necessarily do well? *J Bone Joint Surg Am*. 1975;57:751–759.
32. Stulberg SD, Cooperman DR, Wallensten R. The natural history of Legg-Calve-Perthes disease. *J Bone Joint Surg Am*. 1981;63:1095–1108.
33. Waldenstrom H. Der obere tuberkulose Collumherd. *Z Orthop Chir*. 1909;24:81–92.
34. Willett K, Hudson I, Catterall A. Lateral shelf acetabuloplasty: an operation for older children with Perthes' disease. *J Pediatr Orthop*. 1992;12:563–568.
35. Yasuda T, Tamura K. Prognostication of proximal femoral growth disturbance after Perthes' disease. *Clin Orthop Relat Res*. 1996;329:244–254.