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Radiographic outcome after greater trochanteric epiphysiodesis in patients with Perthes disease

Ann-Carolin Osterholt, Bernd Bittersohl, and Bettina Westhoff

Abstract

Purpose: Legg–Calvé–Perthes disease often leads to greater trochanteric overgrowth, which negatively affects the biomechanics of the hip joint. This study aimed to evaluate the physiologic growth of the greater trochanter and the effectiveness of greater trochanteric epiphysiodesis radiographically.

Methods: Retrospectively, 46 children (33 male, average age at greater trochanteric epiphysiodesis 8 ± 1.3 years) with unilateral Legg–Calvé–Perthes disease undergoing greater trochanteric epiphysiodesis with screws and curettage of the epiphysis were included. On radiographs of the pelvis pre- and postoperatively (mean follow-up 3.5 years), trochanteric height, articulotrochanteric distance, and center–trochanter distance were determined and compared to the unaffected side. Reference values for the physiological development of trochanteric height, articulotrochanteric distance, and center–trochanter distance over time were established.

Results: Greater trochanteric epiphysiodesis reduced trochanteric growth by 29% measured by trochanteric height, but only statistically significant in the group "<8 years" ($p = 0.02$). Regression analysis revealed inhibition of trochanteric growth of 0.92 mm/year. Both articulotrochanteric distance and center–trochanter distance of the affected and unaffected side converged during the follow-up period: articulotrochanteric distance of the affected hip increased (preop: 11.2 ± 7 mm, maturity: 18.5 ± 10 mm; $p < 0.01$) compared to no change on the unaffected side (preop: 19.3 ± 5 mm, maturity: 18 ± 6 mm; $p = 0.69$). Center–trochanter distance of the affected hip stayed unchanged (preop: $(-7.9) \pm 7$ mm, maturity: $(-7.8) \pm 9$ mm; $p = 0.13$). On the unaffected side, center–trochanter distance became negative (preop: 0.9 ± 6 mm, maturity: $(-6.5) \pm 5$ mm; $p < 0.001$). Measured by articulotrochanteric distance and center–trochanter distance, 31.8% achieved an optimal result.

Conclusion: Greater trochanteric epiphysiodesis has a positive effect on greater trochanter growth and therefore on hip anatomy. Further studies must show whether these positive effects also result in biomechanical and functional benefits.

Level of evidence: level III.

Keywords: Greater trochanteric epiphysiodesis, trochanteric overgrowth, Perthes, greater trochanteric growth

Introduction

As a consequence of Legg–Calvé–Perthes disease (LCPD), a variety of deformities of the hip joint and the proximal femur like coxa magna and shortening and broadening of the femoral neck may occur—partially explained by a premature physeal closure.[1–5]

While the growth of the femoral neck might be impaired, the growth of the greater trochanter (GT) is not affected[6] and therefore leads to a relative GT overgrowth.

Department of Orthopaedic and Trauma Surgery, Medical Faculty, University of Düsseldorf, Düsseldorf, Germany

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Corresponding Author:
Ann-Carolin Osterholt, Department of Orthopaedic and Trauma Surgery, Medical Faculty, University of Düsseldorf, 40225 Düsseldorf, Germany.
Email: Ann-Carolin.Osterholt@med.uni-duesseldorf.de

LCPD patients with Herring type C hips are especially at risk.[7] A high-riding GT will lead to a narrowing of the origin and the insertion of the gluteal muscles and may therefore reduce muscle tension and result in gluteal muscle insufficiency; consecutively, a Trendelenburg or Duchenne gait pattern might clinically be observed. Biomechanically, it also impacts the lever arm conditions of the hip joint and thus will influence the loading of the hip joint.[8]

Several surgical options addressing GT overgrowth have been suggested. In skeletally immature patients, guided growth by greater trochanteric epiphysiodesis (GTE) is an option.[9–11] An alternative procedure, especially after skeletal maturity, is a GT-advancement procedure by osteotomy to improve the biomechanics of the hip joint. However, the effectiveness of this procedure is still uncertain.[12–15]

In contrast, GTE is a less invasive procedure. It can be performed in combination with containment-improving surgeries like a femoral varus osteotomy (FVO) that produces a relatively high-riding GT. For proper timing of the epiphysiodesis, knowledge about GT growth is necessary. It is known that the GT grows by physeal and appositional growth. But until now the growth pattern of the GT over time has hardly been studied.[16]

Various surgical techniques are described for growth modulation of the GT. Physeal growth may be stopped by curettage or by the Phemister technique.[17,18] Alternatively, growth might be impaired by temporary epiphysiodesis with a tension band plate or screws.[9,11,19,20] Until now, only a few studies have evaluated the outcome after GTE, and several questions related to optimal timing, optimal technique, and effectiveness have not been answered yet.

Therefore, the aim of this study was (1) to investigate radiographically the physiologic GT growth and the development of the relation between the GT and the hip joint over time and (2) to evaluate the effectiveness of GTE by curettage and screw fixation.

Methods

Study population

Patients were retrospectively recruited from our database of LCPD patients. Inclusion criteria were (1) unilateral LCPD and (2) availability of a radiograph of the pelvis before surgery and at least 24 months postoperatively. Patients were excluded if they had bilateral LCPD (n = 3), if containment-improving surgery (varus and/or pelvic osteotomy) was performed at the time of GTE (n = 2), and if GTE was performed due to other conditions (n = 8).

The indication for GTE was a manifest or impending GT overgrowth—especially in severe LCPD—and open physes, so a significant alteration may be expected after the surgery. X-ray follow-up examinations were generally recommended depending on the LCPD stage.

The local ethics committee approved the study.

Surgical technique

GTE was performed by a lateral approach to the GT. The physeal growth plate was localized by an image intensifier and then partially disrupted by curettage. Then two cannulated cancellous screws—4.5 or 6.0 mm—with washers were implanted from the tip of the GT toward the femoral calcar capturing the medial femoral cortex under image intensifier control. Postoperatively, partial weight-bearing was recommended during wound healing.

Radiographic assessment

X-rays of the pelvis were evaluated on a diagnostic monitor in a digital medical archiving and communication system (PACS = Picture Archiving and Communication System) at our institution. The observer (A.-C.O.) assessed the radiographs twice within a 2-week interval to test the intra-observer reliability. Radiographic parameters were evaluated immediately before GTE preoperatively and on any available postoperative radiographs at defined time intervals until skeletal maturity. The unaffected hip served for assessing the physiological development and as a control (Figure 1).

The trochanteric height (TH), articulotrochanteric distance (ATD), and center–trochanter distance (CTD) were assessed on each available radiograph of the pelvis to evaluate the development of trochanteric growth and the relation between the GT and the hip joint (Figure 2).

Statistical analysis

The statistical analysis was performed with the spreadsheet program Microsoft Office Excel (Microsoft Office Professional; Version 2108, Redmond, WA, USA: Microsoft Corp.) and the statistical analysis software Python.

The intra-rater variability was assessed by the intraclass correlation coefficient (ICC) for TH, ATD, and CTD.

The analysis included a descriptive analysis of the collected data reporting means, standard deviations (SD), and ranges. The physiological trochanteric growth was assessed by analyzing the mean trochanteric parameters of the unaffected side by age.

The radiological parameters TH, ATD, and CTD of the unaffected and affected hips were analyzed at different time intervals to evaluate the effectiveness of the GTE during follow-up. Furthermore, to assess the dependence of GTE effectiveness on age, TH, ATD, and CTD were analyzed in patients younger than 8 years and 8 years and older at the time of GTE. The development of the unaffected hip served as a control. The following intervals were defined:

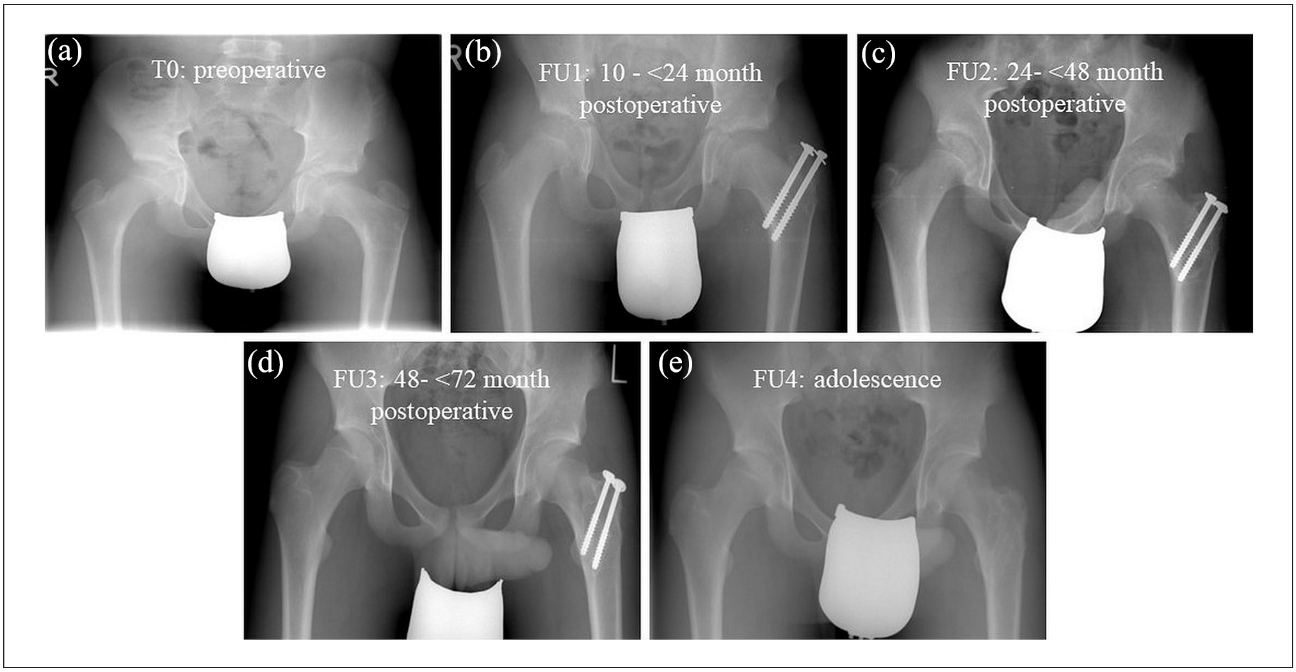

Figure 1. Radiological follow-up after greater trochanteric epiphysiodesis. This patient (male, 11 years old at the time of greater trochanteric epiphysiodesis (GTE), state after Salter osteotomy and FVO) suffered from Perthes disease on the left side and healed with a spherical head. Radiological follow-up examination showed a coxa vara with a high-riding greater trochanter (a). Therefore, GTE was performed with curettage and two screws. X-rays show the development over the follow-up periods FU1 to FU4 at the age of 12.1 years (b), 13.7 years (c), 15.8 years (d), and 16.5 years (e).

T0: preoperatively;
FU1: 10 to <24 months postoperatively;
FU2: 24 to <46 months postoperatively;
FU3: 46 to <72 months postoperatively;
FU4: >72 months postoperatively respectively, bony consolidation of the trochanteric physeal growth plate on the unaffected side indicating maturation.

The Shapiro test was used to check on normal distribution prior to running statistical tests (t-test, Wilcoxon test, and Mann–Whitney U test). The parametric analysis was tested with analysis of variance (ANOVA) and regression analysis. A two-sided p-value of less than or equal to 0.05 was considered to indicate statistical significance.

Results

Patients' characteristics

In total, 46 patients—33 males—who were undergoing GTE between 2006 and 2019 could be included. The age at surgery was 8.0 (SD, 1.3) years. In 65% of the patients, the right hip was involved; 44 patients had had containment-improving surgery previously. In total, 167 X-rays were available for analysis. The average follow-up period postoperatively was 3.5 (SD, 1.2) years (Table 1).

ICC analysis

The ICC analysis of the described parameters TH, ATD, and CTD at different time points revealed an ICC between 0.88 and 0.99 with a p-value < 0.01—indicating excellent intra-rater reliability.

Physiological development of GT growth and its relation to the hip joint

Table 2 and Figure 3 show the mean results of parameters characterizing the GT of the healthy unaffected hip during growth.

The height of the GT (TH) increases in school-age children up to the age of 11 years almost linearly by 3.0 mm (SD, 0.8) per year ($p < 0.05$). Between 11 and 12 years, a growth spurt was observed with an increase in TH of 5.6 mm ($p = 0.001$). After that, growth velocity decreased and no statistically significant differences between the age groups were detected (Figure 3).

The ATD did not change during the follow-up period. The CTD changed from positive to negative values,

Figure 2. Radiographic measurements of trochanteric height (TH), articulotrochanteric distance (ATD), and center–trochanter distance (CTD). TH was defined as the distance in millimeters (mm) between two parallel lines—one at the tip and one at the lateral base of the bony greater trochanter (GT), perpendicular to the femoral shaft axis. ATD was measured as the distance in mm between two lines perpendicular to the axis of the femoral shaft—one through the tip of the GT and the other as a tangent through the superior portion of the femoral head. CTD was defined as the distance in mm between two parallel lines perpendicular to the axis of the femoral shaft—one through the center of the femoral head and the other through the tip of the GT.

Table 1. Demographics of the study population.

Patients (n)	46
Age at surgery (mean ± SD, range), years	8.0 ± 1.3 (5.3–11.8)
Age of diagnosis (mean ± SD, range), years	5.9 ± 1.5 (3.0–10.4)
Classification of Catterall	
2	1
3	18
4	27
Classification of Herring	
A	2
B	20
B/C	5
C	19
Affected side	
Right	65.2% (30)
Left	34.8% (16)
Male	71.7% (33)
Female	28.3% (13)
Containment surgery	95.6% (44)
Pelvic osteotomy	17.4% (8)
Femoral varus osteotomy	17.4% (8)
Combined pelvic and femoral osteotomy	60.9% (28)
None	4.3% (2)

SD: standard deviation.

indicating that the tip of the GT is finally more proximal than the center of the femoral head.

Development of GT growth and its relation to the hip joint after GTE

During the follow-up period, the GT grew as measured by TH between T0 and FU4 on the affected side by 14.5 (SD, 6.4) mm while on the unaffected side TH increased by 20.4 (SD, 6.9) mm. This difference corresponds to a significant growth reduction of 28.9% ($p=0.005$) (Figure 4(a)). The regression analysis revealed inhibition of trochanteric growth of 0.92 mm per year.

The ATD of the affected hip increased statistically significantly from 11.2 (SD, 6.6) mm at T0 up to 18.5 (SD, 10.0) mm at the time of maturity (FU4) ($p<0.01$), while in the unaffected hip no significant changes occurred (T0 19.3 (SD, 5.0) mm, FU4 18.0 (SD, 5.7) mm, $p=0.69$). At the final follow-up (FU3 and FU4), no statistically significant differences were observed between the affected and unaffected sides (Figure 4(b)).

The CTD on the affected side constantly stayed negative during the follow-up period while on the unaffected side the value was positive at the time of surgery and became negative. At the final follow-up (FU3 and FU4), no statistically significant differences were observed between the affected and unaffected sides (Figure 4(c)).

The detailed results are shown in Table 3.

Influence of age

The patients were divided into two groups to analyze the influence of age at the time of surgery: Group 1: <8 years ($n=20$, 70% male, age at surgery 7.0 (SD, 0.7) years, range = 5.3–7.9 years) and Group 2: ≥8 years ($n=26$, 73% male, age at surgery 8.9 (SD, 1.0) years, range = 8.0–11.8 years).

In Group 1, TH on the unaffected increased by 23.2 (SD, 5.6) mm and on the affected side increased by 16.3 (SD, 6.2) mm, resulting in growth inhibition of 29.7% ($p=0.02$). In contrast, in Group 2, no significant growth inhibition ($p=0.07$) could be observed (TH growth on unaffected side 18.0 (SD, 7.1) mm, on affected side 13.0 (SD, 6.4) mm).

Table 2. Development of radiological parameters characterizing the greater trochanter of the healthy hip during follow-up.

Age (years)	Number of patients	TH Mean ± SD (mm)	ATD Mean ± SD (mm)	CTD Mean ± SD (mm)
5 to <6	2	11.7 ± 5.7	17.5 ± 0.6	1.9 ± 0.8
6 to <7	6	16.3 ± 3.8	19.2 ± 3.5	2.3 ± 3.4
7 to <8	18	19.2 ± 3.7	19.7 ± 3.5	2.1 ± 4.1
8 to <9	33	23.3 ± 3.4	20.4 ± 4.5	1.4 ± 4.6
9 to <10	24	25.5 ± 4.0	18.3 ± 4.7	−1.0 ± 5.8
10 to <11	23	28.3 ± 4.2	21.4 ± 5.3	0,5 ± 5.1
11 to <12	14	33.9 ± 5.0	15.8 ± 6.3	−6.4 ± 6.3
12 to <13	12	36.7 ± 5.7	17.7 ± 4.1	−4.4 ± 4.3
13 to <14	10	37.7 ± 5.4	15.5 ± 7.2	−7.7 ± 7.7
14 to <15	7	41.5 ± 1.8	20.1 ± 3.0	−3.9 ± 2.3
15 to <16	11	42.4 ± 4.7	16.5 ± 5.8	−8.1 ± 6.1
≥16	7	44.0 ± 3.4	19.4 ± 7.9	−6.4 ± 7.9

TH: trochanteric height; SD: standard deviation; ATD: articulotrochanteric distance; CTD: center–trochanter distance.

For ATD and CTD, no significant differences could be found depending on the age group.

Over- and under-correction

Based on the ATD and CTD, the over- and under-correction rates at final follow-up (FU4) were determined. The results for the unaffected side served as a control and a value of 18.0 (SD, 5.7) mm for the ATD and of −6.5 (SD, 5.3) mm for the CTD was rated as normal. On the affected side, 7 (31.8%) of the 22 patients, who reached skeletal maturity, showed an optimal result at FU4, with a value within ±1 SD of the controls (Table 4). In comparison, four patients (18.2%) showed an over- or under-correction (> or <2 SD) regarding the ATD and seven (31.8%) regarding the CTD, respectively, with heterogeneous age and gender distribution.

Two patients (9.1%)—both male, one had GTE performed before the age of 8 years—showed an overcorrection with ATD and CTD values above the 2 SD range (patient 1: ATD affected side: 33.1 mm, CTD affected side: 6.6 mm; patient 2: ATD affected side: 35.5 mm, CTD affected side: 7.4 mm).

Discussion

LCPD may cause deformities of the proximal femur, including coxa vara, coxa magna, and trochanteric overgrowth. Therapeutic concepts are still the subject of controversy. In general, therapy focuses on preserving joint mobility and containment.[21,22] The development of a high-riding GT is due to impairment of the physeal growth of the femoral head while the growth of the GT is not impaired. FVO for improving containment also leads to a high-riding GT.[9,11,23] Therefore, the inhibition of GT growth by epiphysiodesis is a viable treatment option in the growing child. Even though this method has been studied, there is still no consensus regarding the indication, the optimal technique, or the effectiveness or the timing of the surgery.[6,9,11,18–20]

Therefore, the aim of this study was to evaluate normal GT growth (TH) and its development relative to the hip joint (ATD, CTD) as a base for timing epiphysiodesis, and to analyze the effectiveness of GTE by curettage of the GT physis and fixation with two screws.

Until now, the characteristics of normal GT growth and its relation to the hip joint have hardly been studied, and normative data are missing. The results of the present study may serve as a reference for other studies in the future. But the data only reflect the bony conditions of the GT, and it may be debatable whether data on the healthy side of LCPD patients may serve for defining physiological growth.

Knapik et al.[16] measured the bony TH on radiographs from the Bolton–Brush database—the same historical collection used to compose the Greulich and Pyle bone age atlas; the database consists of longitudinally collected radiographs of healthy children from 1929 to 1942 growing up in Cleveland, Ohio. Forty-five children were included. They found that bony growth continued to age 12 in female and age 13 in male individuals. In the present study, TH increased yearly significantly up to the age of 12 years. After that the annual increase was no longer significant. Knapik et al. also analyzed the bony trochanter height and its overlying cartilage cap in 55 individuals, with a mean age of 9.9 (SD, 2.7) years by magnetic resonance imaging (MRI) in a cross-sectional study. They showed that the cartilage cap decreased with growth, becoming minimal by the age of 10 years in females and 11 years in male individuals. The combined bony and cartilaginous height was largely completed by the age of 7 years in female and 8 years in male individuals. This observation suggests that the bony trochanteric growth after 7 years is likely ossification of the existing cartilage

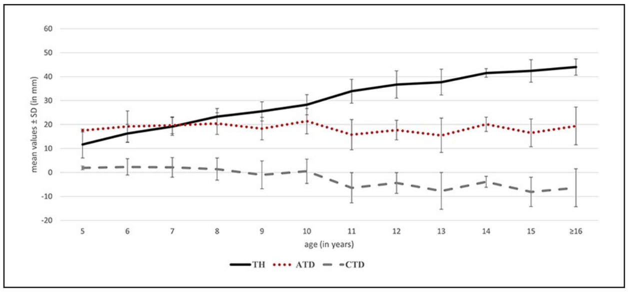

Figure 3. Development of parameters characterizing the greater trochanter during physiologic growth. Line chart of the mean values with standard deviations of trochanteric height (TH), articulotrochanteric distance (ATD), and center–trochanter distance (CTD) of the unaffected hip dependent on age.

scaffold. This knowledge is expected to be of relevance for the timing of the GTE.

In the present study, GTE by curettage of the GT physis and fixation with two screws resulted in significant inhibition of the TH by 28.9% after a mean follow-up of 3.5 years. The parameters characterizing the relation and therefore the biomechanics between the GT and the hip joint—ATD and CTD—also improved significantly. Therefore, GTE in the described technique seems to be an effective option for preventing/treating a high-riding GT in LCPD.

TH was only significantly influenced by GTE in patients younger than 8 years at the time of surgery, while there was no significant difference for ATD and CTD between the age groups. This difference might be due to changes in the femoral head which recovers and regains height during the reparation stage of LCPD.

The observation that TH was only positively influenced by GTE in patients younger than 8 years is in accordance with the results by Knapik et al.[16] that trochanteric growth might be completed by the age of 7–8 years. Kwon et al.[11] and Shah et al.[9] confirmed that GTE is most effective before the age of 8 years. Furthermore, Shah et al. found that GTE is effective in 52% of patients aged between 8.5 and 10 years. This might be explained by the fact that in LCPD patients skeletal age is often significantly behind the chronological age.[24–27] Van Tongel and Fabry[18] (mean age at GTE 10.6 years) and Schneidmueller et al.[12] (mean age at GTE 11.2 years, range = 8–14) found no positive effect radiographically. Surprisingly, McCarthy and Weiner[20] found GTE to be more effective in the age group over 8 years (mean age, 9.7 years) than in those under 8 years. Therefore, further studies on physiologic trochanteric growth and especially on GTE in LCPD patients should consider skeletal age for analysis.

The indication for GTE in LCPD patients is still under discussion. Studies by Kwon et al., Matan et al., and Shah et al. recommended GTE in patients who underwent a FVO.[9,11,28] It should be further considered in manifest

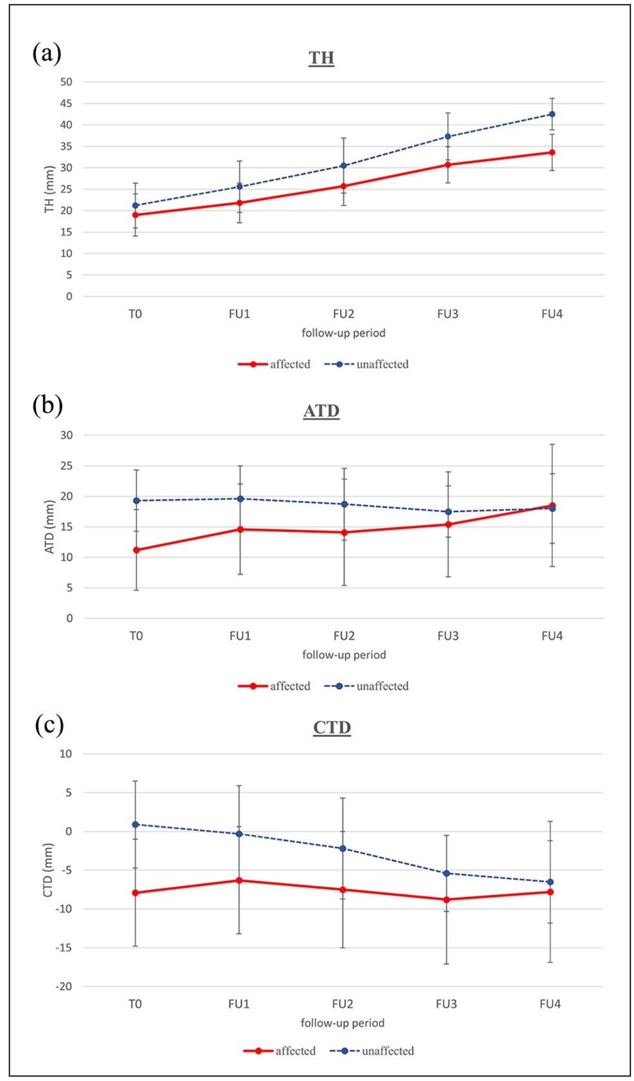

Figure 4. Development of parameters characterizing the greater trochanter after GTE on the affected and unaffected side. Line chart of the mean values with standard deviations of (a) trochanteric height (TH), (b) articulotrochanteric distance (ATD), and (c) center–trochanter distance (CTD) of the affected and unaffected hip dependent on age.

trochanteric overgrowth, when there is still a significant growth potential and in Herring-C patients as they are at special risk for a high-riding GT.[7] In the present study, GTE was performed in case of manifest or impending GT overgrowth—especially in severe LCPD and after varus osteotomy. Based on our results, the procedure should predominantly be conducted under the age of 8 years, but further investigations based on skeletal age might result in more precise recommendations.

Different techniques of GTE are described: trochanteric growth might be inhibited by the Phemister technique with a bony peg; alternatively, the physis might be destroyed by curettage or drilling or growth might be inhibited by

Table 3. Development of parameters characterizing the greater trochanter during follow-up after GTE on the affected and unaffected side.

	T0	FU1	FU2	FU3	FU4	p2	p3	p4	p5
Number of patients	46	43	36	23	22				
Mean age (years)	8.0 ± 1.3	9.4 ± 1.4	11.0 ± 1.5	13.0 ± 1.8	15.4 ± 1.5				
TH									
TH unaffected	21.2 ± 5.2	25.6 ± 6.0	30.5 ± 6.4	37.3 ± 5.5	42.5 ± 3.7	**<0.01**	**<0.01**	**<0.01**	**<0.01**
TH affected	19.0 ± 4.9	21.8 ± 4.6	25.7 ± 4.5	30.7 ± 4.2	33.6 ± 4.2	**<0.01**	**<0.01**	**<0.01**	**<0.01**
p1	**0.04**	**0.001**	**<0.001**	**<0.001**	**<0.001**				
ATD									
ATD unaffected	19.3 ± 5.0	19.6 ± 5.4	18.7 ± 5.9	17.5 ± 4.2	18.0 ± 5.7	0.59	0.42	0.06	0.58
ATD affected	11.2 ± 6.6	14.6 ± 7.4	14.1 ± 8.7	15.4 ± 8.6	18.5 ± 10.0	**<0.01**	0.43	0.47	**0.03**
p1	**<0.01**	**<0.01**	**0.01**	0.3	0.84				
CTD									
CTD unaffected	0.9 ± 5.6	−0.3 ± 6.2	−2.2 ± 6.5	−5.4 ± 4.9	−6.5 ± 5.3	**<0.01**	**0.025**	**<0.01**	0.48
CTD affected	−7.9 ± 6.9	−6.3 ± 6.9	−7.5 ± 7.5	−8.8 ± 8.3	−7.8 ± 9.1	**0.02**	0.35	0.71	0.29
p1	**<0.01**	**<0.01**	**<0.01**	0.1	0.58				

GTE: greater trochanteric epiphysiodesis; T0–FU4: defined follow-up periods; TH: trochanteric height; ATD: articulotrochanteric distance; CTD: center–trochanter distance; p: p-values; p1: comparison of affected and unaffected side; p2: comparison of T0 versus FU1; p3: FU1 versus FU2; p4: FU2 versus FU3; p5: FU3 versus FU4.
Values are mean ± standard deviation; units are millimeters (mm). P-values less than or equal to the defined significance level ($p \leq 0.05$), indicating that the result is statistically significant, are highlighted bold.

Table 4. Over- and under-correction rates at final follow-up (FU4).

	Under-corrections		Optimal		Over-corrections
	<−2 SD	−2 to −1 SD	±1 SD	1–2 SD	>2 SD
ATD, n (%)	2 (9.1)	4 (18.2)	7 (31.8)	7 (31.8)	2 (9.1)
f:m	1:1		1:6		0:2
<8:≥8 years	1:1		3:4		1:1
CTD, n (%)	5 (22.7)	4 (18.2)	7 (31.8)	4 (18.2)	2 (9.1)
f:m	1:4		2:5		0:2
<8:≥8 years	1:4		3:4		1:1

SD: standard deviation; ATD: articulotrochanteric distance; n: number of patients; f: female; m: male; <8:≥8 years: age at surgery in years; CTD: center–trochanter distance.

implantation of one or two transphyseal screws or a tension band plate; a combination of the techniques is also an option.[6,9–11,20] It is desirable to inhibit not only physeal growth but also appositional growth. Whether this is possible by a screw or screw plus washer is unclear.

To our knowledge, only two studies have compared different techniques: Akpinar et al.[19] compared the effect of GTE by transphyseal screw, transphyseal screw plus washer or eight-plate in 32 patients with a mean age at surgery of 10 (SD, 2.3) years. After a mean follow-up of 50.0 (SD, 16.7) months, the difference of the greater to minor trochanter distance (TTD) increased significantly less in the screw group as well as in the screw plus washer group, indicating that those techniques are more effective than epiphysiodesis by an eight-plate. An additional advantage of applying a washer might be that implant embedding was more seldom seen than in the screw-only group, making implant removal less challenging. McCarthy and Weiner[20] compared the effect of bone peg epiphysiodesis (n = 5) versus screw epiphysiodesis plus 5 to 6 holes across the GT physis (n = 30). Although the bone peg group was very small, it showed a greater inhibition effect (1.8 mm/year) than in the screw group (0.7 mm/year)—but the effect was not statistically significant. Overall, the inhibition was 0.9 mm/year, which is the same as in the present study.

This study had some limitations. First, there was a follow-up to maturity only for 22 out of 46 patients. Although a follow-up to maturity would be desirable for all included patients, it has to be accomplished that all the patients had a minimum follow-up of 24 months, indicating that all the patients had a follow-up during the period of highest trochanteric growth. Therefore, a mean follow-up of 3.5 years already allows conclusions concerning the effectiveness of GTE. Second, due to the low number of females, a gender-dependent outcome evaluation was not possible. Third, analysis of the age-dependent outcome was based on chronological age; an outcome evaluation based on skeletal age might be more meaningful because in LCPD patients, growth retardation is often significant. Fourth, due to the relatively small number of patients, neither the influence of the severity of the LCPD nor the stage of the disease was considered. Fifth, the effectiveness of GTE was only evaluated radiographically. Clinical and especially functional outcome investigations and patient-related parameters are still missing and will be considered in future studies. Finally, only the bony conditions were investigated.

Future studies should consider MRI investigations preoperatively to know precisely the total height of the GT at the time of GTE; so, the inhibiting effect of GTE on both the bony and the cartilaginous part of the GT can be analyzed.

In conclusion, this study may serve as a reference database for normal bony GT growth and the relation between the GT and the hip joint. It could be demonstrated that GTE by curettage of the physis and implantation of two screws with washers reduce GT growth significantly in patients younger than 8 years and improves the relation between the GT and the hip joint.

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Author contributions

B.W.: principal investigator; A.-C.O., B.B., and B.W.: conceptualization; A.-C.O. and B.W.: patient selection; A.-C.O. and B.W.: data acquisition; A.-C.O., B.B., and B.W.: data analysis and interpretation; A.-C.O., B.B., and B.W.: draft preparation, reviewing, and editing. All authors have read and agreed to the published version of the manuscript.

Data availability statement

The deidentified participant data collected and analyzed during the current study are provided by the corresponding author A.-C.O. by email on request for data meta-analysis by researchers, who provide a methodologically sound proposal, beginning immediately and ending 24 months following article publication.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical approval

This study was approved by the Institutional Review Board of Heinrich-Heine-University (HHU) Düsseldorf (approval number: 2019-753) and all participants more specifically the legal guardians signed informed consent. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

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ORCID iD

Ann-Carolin Osterholt https://orcid.org/0000-0003-0616-8915

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