Aims
Perthes’ disease (PD) often results in femoral head deformity and leg length discrepancy (LLD). Our objective was to analyze femoral morphology in PD patients at skeletal maturity to assess where the LLD originates, and evaluate the effect of contralateral epiphysiodesis for length equalization on proximal and subtrochanteric femoral lengths.

Methods
All patients treated for PD in our institution between January 2013 and June 2020 were reviewed retrospectively. Patients with unilateral PD, LLD of ≥ 5 mm, and long-leg standing radiographs at skeletal maturity were included. Total leg length, femoral and tibial length, articulotrochanteric distance (ATD), and subtrochanteric femoral length were compared between PD side and the unaffected side. Furthermore, we compared leg length measurements between patients who did and who did not have a contralateral epiphysiodesis.

Results
Overall, 79 patients were included, of whom 21 underwent contralateral epiphysiodesis for leg length correction. In the complete cohort, the mean LLD was 1.8 cm (95% confidence interval (CI) 1.5 to 2.0), mean ATD difference was 1.8 cm (95% CI -2.1 to -1.9), and mean subtrochanteric difference was -0.2 cm (95% CI -0.4 to 0.1). In the epiphysiodesis group, the mean LLD before epiphysiodesis was 2.7 cm (95% CI 1.3 to 3.4) and 1.3 cm (95% CI -0.5 to 3.8) at skeletal maturity. In the nonepiphysiodesis group the mean LLD was 2.0 cm (95% CI 0.5 to 5.1; p = 0.016). The subtrochanteric region on the PD side was significantly longer at skeletal maturity in the epiphysiodesis group compared to the nonepiphysiodesis group (-1.0 cm (95% CI -2.4 to 0.6) vs 0.1 cm (95% CI -1.0 to 2.1); p < 0.001).

Conclusion
This study demonstrates that LLD after PD originates from the proximal segment only. In patients who had contralateral epiphysiodesis to balance leg length, this is achieved by creating a difference in subtrochanteric length. Arthroplasty surgeons need to be aware that shortening of the proximal femur segment in PD patients may be misleading, as the ipsilateral subtrochanteric length in these patients can be longer. Therefore, we strongly advise long-leg standing films for THA planning in PD patients in order to avoid inadvertently lengthening the limb.

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Introduction
Perthes’ disease (PD) is a relatively rare childhood disorder,¹ with an annual rate among children aged between 0 and 14 years in the UK of 5.7 per 100,000.² The disease is characterized by osteonecrosis of the proximal femoral epiphysis and typically affecting boys between three and ten years of age.³⁴ Despite operative and nonoperative methods of treatment aimed at preserving the anatomy of the proximal femur, PD often results in femoral head deformity and leg length discrepancy (LLD).˙⁵-⁸ LLD ≥ 1 cm is reported in 55% of patients, and is associated with the extent of femoral head involvement,⁹ but in the majority it does not exceed 2.5 cm.⁹⁺⁺

However, patients with PD are also at risk of early degenerative changes of the hip joint, and subsequently requiring a total hip arthroplasty (THA).⁴,¹⁰ THA for PD patients is less successful than in primary osteoarthritis, with higher risks of
14 For PD patients, these factors have developed from significant asymmetry in femoral length distal to the proximal femoral deformity, but can also result from the proximal femoral deformity, for example, it has been shown that LLD might not only lead to changes in the proximal and subtrochanteric femoral length.14-16 Dysplasia, for example, it has been shown that LLD might not only result from the proximal femoral deformity, but can also develop from significant asymmetry in femoral length distal to the trochanteric region.16 For PD patients, these factors have not been specifically described. To correct LLD during growth, contralateral epiphysiodesis is frequently performed, which might lead to changes in the proximal and subtrochanteric femoral proportions.

The aim of our study was to analyze proximal femoral morphology and subtrochanteric femoral length in relation to LLD in PD patients at skeletal maturity. We also evaluated the effect of contralateral epiphysiodesis for leg length equalization on LLD, and proximal and subtrochanteric femoral length.

Methods
We retrospectively reviewed the medical records of a consecutive series of patients who were under treatment for PD at the Royal National Orthopaedic Hospital from January 2013 through June 2020. The study was approved by the local medical ethical committee. Due to its retrospective nature, an informed consent procedure was not deemed necessary. Inclusion criteria were: completely healed (Waldenström IV) bilateral PD, underlying metabolic disease, and skeletal dysplasia. Despite the extensive literature available on LLD in PD, reports on the morphological changes in specific anatomical regions leading to LLD are scarce. In patients with hip dysplasia, for example, it has been shown that LLD might not only result from the proximal femoral deformity, but can also develop from significant asymmetry in femoral length distal to the trochanteric region.16 For PD patients, these factors have not been specifically described. To correct LLD during growth, contralateral epiphysiodesis is frequently performed, which might lead to changes in the proximal and subtrochanteric femoral proportions.

The aim of our study was to analyze proximal femoral morphology and subtrochanteric femoral length in relation to LLD in PD patients at skeletal maturity. We also evaluated the effect of contralateral epiphysiodesis for leg length equalization on LLD, and proximal and subtrochanteric femoral length. early revision, nerve injury, and residual LLD.16 Preoperative LLD and specific changes in femoral anatomy both need to be considered to allow for optimal biomechanical reconstruction of the affected joint.11-13

In total, 224 PD patients with a LLD were identified from our institutional database. Of these, 30 patients were excluded because of bilateral involvement, seven patients were excluded because of an associated metabolic condition, 89 patients were excluded because they had not reached skeletal maturity, and 19 were excluded because they did not have full leg-length radiographs available at skeletal maturity. This left 79 patients who were suitable for analysis and their characteristics are presented in Table I.

Medical records were reviewed for information regarding age of PD onset, sex, side affected, and surgical treatment methods used during the disease course. The residual femoral head deformity in the healed stage of the disease was assessed on plain anteroposterior and lateral radiographs, and scored according to Stulberg.4,16

Leg length measurements at skeletal maturity were obtained from standardized, calibrated, AP long-leg standing radiographs with patellae facing forward (Figure 1). Both the affected and the contralateral side were evaluated. Measurements were performed using TraumaCad software (v. 2.5; Brainlab, Israel), which has been shown to be an accurate and reliable system.17 Total leg length was defined as the distance between the midpoint of the distal tibial surface and the most proximal part of the femoral head. Tibial length was defined as the distance between the midpoint of the distal tibial surface and a point between the tibial eminences. Femoral length was the distance between the intercondylar notch and the most proximal part of the femoral head. The anatomical disturbance of the proximal femur was assessed by measuring the

### Table I. Patient and treatment characteristics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total cohort</th>
<th>Epiphysiodesis group</th>
<th>Nonepiphysiodesis group</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients, n</td>
<td>79</td>
<td>21</td>
<td>58</td>
<td>0.152</td>
</tr>
<tr>
<td>Sex, M:F</td>
<td>50:29</td>
<td>16:5</td>
<td>34:24</td>
<td>0.114</td>
</tr>
<tr>
<td>Side affected, R:L</td>
<td>41:38</td>
<td>14:7</td>
<td>27:31</td>
<td></td>
</tr>
<tr>
<td>Mean age, yrs (range)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At onset</td>
<td>6.3 (2.0 to 13.0)</td>
<td>6.6 (3.0 to 12.0)</td>
<td>6.2 (2.0 to 13.0)</td>
<td>0.663†</td>
</tr>
<tr>
<td>At final follow-up</td>
<td>18.9 (14.2 to 42.7)</td>
<td>18.0 (14.3 to 41.7)</td>
<td>19.4 (14.2 to 39.2)</td>
<td>0.257‡</td>
</tr>
<tr>
<td>Residual femoral head deformity, n (%)</td>
<td></td>
<td></td>
<td></td>
<td>0.620§</td>
</tr>
<tr>
<td>Stulberg 2</td>
<td>9 (11.5)</td>
<td>3 (15.0)</td>
<td>6 (10.3)</td>
<td></td>
</tr>
<tr>
<td>Stulberg 3</td>
<td>33 (42.3)</td>
<td>8 (40.0)</td>
<td>25 (43.1)</td>
<td></td>
</tr>
<tr>
<td>Stulberg 4</td>
<td>28 (35.9)</td>
<td>8 (40.0)</td>
<td>20 (34.8)</td>
<td></td>
</tr>
<tr>
<td>Stulberg 5</td>
<td>8 (10.3)</td>
<td>1 (5.0)</td>
<td>8 (12.1)</td>
<td></td>
</tr>
<tr>
<td>Treatment received, n (%)¶</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conservative</td>
<td>32 (40.5)</td>
<td>9 (42.9)</td>
<td>23 (39.7)</td>
<td>0.797</td>
</tr>
<tr>
<td>Varus osteotomy</td>
<td>10 (12.7)</td>
<td>2 (9.5)</td>
<td>8 (13.8)</td>
<td>0.614</td>
</tr>
<tr>
<td>Valgus osteotomy</td>
<td>30 (38.0)</td>
<td>10 (47.6)</td>
<td>20 (34.5)</td>
<td>0.288</td>
</tr>
<tr>
<td>Pelvic osteotomy</td>
<td>8 (10.1)</td>
<td>1 (4.8)</td>
<td>7 (12.1)</td>
<td>0.342</td>
</tr>
<tr>
<td>Shelf acetabuloplasty</td>
<td>2 (2.5)</td>
<td>0 (0)</td>
<td>2 (4.2)</td>
<td>0.389</td>
</tr>
<tr>
<td>Contralateral epiphysiodesis, n (%)</td>
<td>21 (26.6)</td>
<td>100 (100)</td>
<td>0 (0)</td>
<td></td>
</tr>
</tbody>
</table>

*Comparison of nonepiphysiodesis group with epiphysiodesis group.
†Chi-squared test.
‡Independent-samples t-test.
§Mann-Whitney U test.
¶Percentages add up to more than 100% as patients may have received more than one treatment option, except for patients in the conservative group.
articulotrochanteric distance (ATD), defined as the distance between the tip of the trochanter and the highest part of the femoral head, in the mechanical axis of the femur. Subtrochanteric femoral length was calculated as \( \text{femoral length} - \text{ATD} \).

In our institution, patients who had over 2 cm LLD and sufficient growth remaining were considered for length correction with epiphysiodesis. The aim was not to completely equalize the leg length, but to reduce the difference to under 2 cm. For the group treated with guided growth, age at epiphysiodesis, type of epiphysiodesis (distal femur or distal femur and proximal tibia), and preoperative LLD on long-leg standing radiographs were measured.

**Statistical analysis.** For descriptive statistics of continuous variables, means with range were reported, depending on normality of data distribution. For discrete variables, counts and percentages are presented. Characteristics of patients who had an epiphysiodesis for leg length correction and patients who did not have an epiphysiodesis were compared using chi-squared test, Mann-Whitney U test, or independent-samples \( t \)-test as appropriate.

Mean LLDs between the PD affected and the unaffected leg were calculated for each of the leg segments measured (total leg length, tibial length, total femoral length, ATD, and subtrochanteric femoral length) and reported as mean differences with 95% confidence intervals (CIs). Difference in leg length for each segment with the contralateral side was calculated using either a parametric (paired \( t \)-test) or non-parametric test (Mann-Whitney U test) depending on normality of data distribution, and reported accordingly.

To assess factors affecting the LLD at skeletal maturity, a multiple linear regression analysis was performed with patient characteristics and the surgical treatment performed as candidate predictors. All candidate predictors were entered into the multivariate model. Goodness-of-fit is reported using adjusted \( R^2 \).

To analyze the effect of guided growth on the relationship between the proximal femur and subtrochanteric segment, we compared the length difference in each leg segment between patients who did and patients who did not have guided growth. This was analyzed using independent-samples \( t \)-test, and presented as means with 95% confidence intervals. For all analyses the significance level was set at \( p < 0.05 \). Calculations were made using SPSS software v. 24.0 (IBM, USA).

**Results**

Measurements of total leg length, length of each segment, and mean between side differences at skeletal maturity are presented in Table II. Results of the linear regression analysis exploring factors affecting the LLD at skeletal maturity are presented in Table III. A history of valgus osteotomy (\( p = 0.042 \), multiple linear regression analysis), as well as Stulberg grade (\( p = 0.006 \), multiple linear regression analysis), were significant independent predictors of LLD, with an \( R^2 \) of 0.187. A higher Stulberg grade was shown to be associated with a greater LLD, resulting in a relatively shorter LCPD leg, and history of valgus osteotomy was associated with less LLD.
During the course of their treatment, 21/79 patients (26.6%) were treated with a contralateral epiphysiodesis for leg length correction. Of these, 12 patients had a distal femoral epiphysiodesis only and nine patients had distal femoral and proximal tibial epiphysiodeses; none of the patients had a greater trochanter epiphysiodesis. Mean age at the time of the epiphysiodesis was 11.6 years (10.1 to 13.0) for females and 13.5 years (10.9 to 15.1) for males. Mean total LLD at the time of epiphysiodesis was 2.7 cm (1.3 to 3.4), mean femoral length difference was 2.5 cm (1.4 to 4.3), and mean tibial length difference was 0.2 cm (-0.7 to 1.2). A comparison of LLDs (presented for each segment) in the epiphysiodesis group compared to the LLDs in the nonepiphysiodesis group is shown in Table IV.

**Discussion**

This study confirms that the LLD after PD originates from the proximal segment only. In patients who had a contralateral epiphysiodesis only and nine patients had distal femoral and proximal tibial epiphysiodeses; none of the patients had a greater trochanter epiphysiodesis. Mean age at the time of the epiphysiodesis was 11.6 years (10.1 to 13.0) for females and 13.5 years (10.9 to 15.1) for males. Mean total LLD at the time of epiphysiodesis was 2.7 cm (1.3 to 3.4), mean femoral length difference was 2.5 cm (1.4 to 4.3), and mean tibial length difference was 0.2 cm (-0.7 to 1.2). A comparison of LLDs (presented for each segment) in the epiphysiodesis group compared to the LLDs in the nonepiphysiodesis group is shown in Table IV.

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<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean PD side, cm (range)</th>
<th>Mean contralateral side, cm (range)</th>
<th>Mean difference, cm (95% CI)*</th>
<th>p-value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total leg length</td>
<td>83.7 (71.2 to 106.8)</td>
<td>85.5 (71.7 to 108.1)</td>
<td>1.8 (1.5 to 2.0)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Tibial length</td>
<td>38.2 (32.4 to 48.2)</td>
<td>38.3 (32.5 to 48.6)</td>
<td>0.1 (0.02 to 0.2)</td>
<td>0.019</td>
</tr>
<tr>
<td>Total femur length</td>
<td>44.9 (37.8 to 58.3)</td>
<td>46.5 (38.3 to 59.3)</td>
<td>1.6 (1.4 to 1.8)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>ATD</td>
<td>0.5 (-1.2 to 2.7)</td>
<td>2.2 (0.7 to 4.0)</td>
<td>1.8 (1.6 to 1.9)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Subtrochanteric length</td>
<td>44.4 (36.2 to 55.6)</td>
<td>44.3 (36.3 to 55.3)</td>
<td>-0.2 (-0.4 to 0.1)</td>
<td>0.071</td>
</tr>
</tbody>
</table>

*Positive values represent a longer contralateral side.  
†Paired t-test.

ATD, articulotrochanteric distance; CI, confidence interval; PD, Perthes' disease.

**Table III.** Regression analysis analyzing factors determining leg length discrepancy at skeletal maturity.

<table>
<thead>
<tr>
<th>Factor</th>
<th>β (95% CI)*</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (male)</td>
<td>0.1 (-0.4 to 0.6)</td>
<td>0.698</td>
</tr>
<tr>
<td>Side affected (right)</td>
<td>0.2 (-0.3 to 0.7)</td>
<td>0.458</td>
</tr>
<tr>
<td>Age of onset (yrs)</td>
<td>0.04 (-0.1 to 0.2)</td>
<td>0.460</td>
</tr>
<tr>
<td>Varus osteotomy</td>
<td>-0.3 (-1.0 to 0.5)</td>
<td>0.456</td>
</tr>
<tr>
<td>Valgus osteotomy</td>
<td>-0.6 (-1.1 to -0.1)</td>
<td>0.042</td>
</tr>
<tr>
<td>Pelvic osteotomy</td>
<td>0.3 (-0.5 to 1.1)</td>
<td>0.531</td>
</tr>
<tr>
<td>Shelf acetabuloplasty</td>
<td>0.2 (-1.4 to 1.7)</td>
<td>0.838</td>
</tr>
<tr>
<td>Residual femoral head deformity (Stulberg)</td>
<td>0.5 (0.1 to 0.8)</td>
<td>0.006</td>
</tr>
</tbody>
</table>

*Prediction of leg length discrepancy, with positive values correlating with a longer contralateral leg and negative values with a longer Perthes’ disease affected leg.

CI, confidence interval.

Therefore, we strongly advise the use of long-leg films in preoperative planning for THA in patients with a history of PD to allow analysis of the complete femoral anatomy. 11,13 The arthroplasty surgeon needs also to be aware of the history of a contralateral epiphysiodesis and the possibility of resulting subtrochanteric length difference in PD patients.

The main factors that have been previously identified as influencing LLD at skeletal maturity after PD are the extent of femoral head deformity and premature closure of the proximal femoral physis. 6,20 It is postulated that this leads to development of LLD with a Shapiro type IV pattern (upward slope/plateau/upward slope). 5,21 With the femoral head collapse during the Waldenström 2 phase of the disease responsible for the initial
upward slope, and the premature physeal closure resulting in the second upward slope. Both these factors in theory influence only the length of the proximal head/neck region of the femur, which is in line with our results; in PD patients with a LLD, the ATD is significantly smaller compared to the contralateral side, and the average ATD difference coincides largely with the total LLD. The subtrochanteric length on the other hand was found to be generally unchanged compared to the unaffected side. Therefore, it is advisable to assess LLD and include long-leg radiographs in the routine follow-up of PD patients until skeletal maturity.

The literature suggests that another factor influencing leg length in PD patients is hyperaemia after surgical treatment leading to femoral overgrowth. In the present study we found that patients that had a proximal femoral valgus osteotomy had significantly smaller LLDs. Although growth stimulation due to hyperaemia after surgery might play a role here, it is likely that the lengthening primarily originates from mechanical lengthening via the femoral osteotomy. We cannot differentiate between these factors, as we did not analyze the progression of LLD longitudinally. In line with previous reports, no lengthening effect was observed with other surgical treatment groups. Other factors related to LLD in PD patients are limb-shortening on the affected side due to disuse atrophy, and relative tibial overgrowth on the PD side. These effects were not observed in our population.

Epiphysiodesis of the contralateral distal femur and/or proximal tibia is a potential treatment option to reduce the LLD before skeletal maturity. When timed correctly it is a relatively safe surgical option, with low risk of complications and potential to correct large leg-length differences. This is reflected by our results with a mean difference from 2.7 cm at time of epiphysiodesis to 1.3 cm at skeletal maturity. Nevertheless, it should be recognized that in these patients, the intervention altered the proportions of the subtrochanteric segment.

The proximal deformity resulting from a decreased ATD due to PD, responsible for the LLD, is corrected by creating a deformity in the subtrochanteric region of the contralateral limb. As a result, the subtrochanteric region will become relatively longer on the PD-affected side compared to the contralateral side (Figure 1). In our series, this difference averages at 1 cm, but if complete leg length equalization by epiphysiodesis was pursued, this difference would be even larger. By itself, this may not be a problem, but when further surgery such as arthroplasty is anticipated, especially in higher Stulberg grade patients, this change in anatomy should be taken into account (Figure 2). Therefore, when discussing epiphysiodesis for correction of LLD, patients should be counselled on the potential implications this might have should a THA be required in the future. Furthermore, paediatric orthopaedic surgeons should consider not striving for correction of relatively small LLDs in PD patients and consider incompletely correcting larger LLD in selected patients, especially for those who are at high risk for hip arthroplasty in the future.

A potential limitation of this study is that due to variation in landmark positioning as well as patient positioning, radiological measurement errors are inherently present. Nevertheless, for the radiological imaging and measurement method used in the present study, excellent intra- and interobserver reliability are reported. To further limit influence positioning errors all radiographs were assessed for adequate patient positioning, calibrated, and analyzed using automated measurement software. Considering these precautions and the relatively large differences reported, in our opinion the measurement methods used can be considered sufficiently reliable to support our conclusions.

Another limitation of our paper is that we focus solely on radiological outcome. Due to the retrospective nature of this study, we did not have the opportunity to collect data on important issues such as patient-reported outcomes or potential changes in gait pattern. For patients with childhood-onset leg-length inequality, in general a difference exceeding 20 mm, is regarded as clinically significant. This cut-off value is largely based on gait analysis studies and occurrence of low back pain. It might well be that smaller differences, especially those arising from an event later on in childhood, have some impact on the patients physical function and quality of movement. In further research, it would be interesting to obtain patient-reported measures in addition to the radiological measurements reported in this study, to quantify LLD after PD from a patient’s perspective.

However, arthroplasty surgeons should be aware that shortening of the proximal femur segment in PD patients may be misleading. Although residual LLD after PD originates from the proximal segment, in patients who have undergone contralateral epiphysiodesis in order to balance leg length, this has only been achieved by creating a difference in the subtrochanteric length. Therefore, we strongly advise long-leg standing films for THA planning in PD patients to avoid inadvertently lengthening the limb.
Take home message
- Leg length discrepancy after Perthes’ disease (PD) originates from a reduced articulotrochanteric distance.
- In patients who have had a contralateral epiphysiodesis for leg length correction, the subtrochanteric femoral region was significantly longer on the PD side.
- These anatomical changes need to be considered by both paediatric orthopaedic and arthroplasty surgeons when considering patients for epiphysiodesis or hip arthroplasty surgery.

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