ORIGINAL ARTICLE

Correlation Analysis between Leg-length Discrepancy and Lumbar Scoliosis Using Full-length Standing Radiographs

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Abstract

Aim: When a leg-length discrepancy (LLD) is severe enough, it can result in lumbar scoliosis and other postural defects. To our knowledge, no study has demonstrated associations between LLD and lumbar curvature using full-length standing radiographs of the lower limbs and lumbar spine. This study aimed to examine the correlations between LLD and lateral curvature of the lumbar spine using standing radiographs.

Materials and methods: Full-length standing radiographs of the lower limbs and spinal column of 113 participants (age range: 10–65 years) obtained between November 2006 and September 2019 were reviewed. Leg length was measured as the linear distance from the centre of the femoral head to the centre of the tibial plafond and converted to millimetres using a radiographic ruler captured in the images. Leg-length discrepancy was analysed as the absolute difference (mm) between the left and right leg lengths. Inequality was also evaluated as leg-length discrepancy ratio (LLDR), calculated as leg-length discrepancy/length of the unaffected (longer) leg × 100 (%). Lateral lumbar curvature was evaluated with the Cobb angle (°). The association between LLD or LLDR and lumbar Cobb angle was analysed by correlation analysis. Statistical analysis was performed by simple regression in SPSS.

Results: Both LLD and LLDR exhibited a robust and positive correlation with lumbar Cobb angle ($\gamma = 0.53$, $\gamma = 0.62$), as illustrated by the following regression equations: lumbar Cobb angle (°) = 0.316 × leg-length discrepancy (mm) + 2.83 and lumbar Cobb angle (°) = 2.19 × leg-length discrepancy ratio (%) + 3.0.

Conclusion: Using objective imaging data, we found that the lumbar Cobb angle tends to be >10° if the difference in leg lengths is >20 mm.

Keywords: Deformity correction, Leg-length discrepancy, Limb deformity, Radiography.

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Introduction

Severe LLD, a condition in which the left and right lower limbs are different in length, can result in various problems. Research has been conducted to investigate the effect of LLD on a variety of conditions, such as lower back pain,[1] hip osteoarthritis,[2] stress fracture,[3] and standing[4] and running balance.[5,6] Existing evidence suggests that a long-term severe LLD may permanently change the biomechanics of the lumbar spine, potentially increasing susceptibility to irremediable scoliosis.[7,8] Leg lengthening or other surgical procedures are recommended to correct large discrepancies for this reason. However, there is no consensus on how large the differential must be for surgery to be indicated.[3,9–12] When recommending orthopaedic surgery, it is essential to quantify the difference in leg lengths using a reliable diagnostic modality and to inform the patient of the sequelae of LLD.[13]

Despite the many studies detailing its associations with the lumbar spine, few studies measured LLD directly using lower-limb radiographs. Nearly all studies calculated the LLD based on pelvic tilt angle or femoral head position(s) or derived it using measurements taken from the body surface.[1,14–18] We agree with the ideas of Machen and Stevens[13] and Sabharwal,[19] who contend that full X-ray scans of the lower limbs taken while a patient is in the standing position are a superior diagnostic screening tool for the condition. Both LLD and scoliosis are caused by bone-length differences and abnormal angles in the bone. Standing radiographs allow clinicians to observe the patient's bones directly in the standing position, the posture in which such irregularities are most prominent. However, to the best of our knowledge, no study has quantified this difference in full-length standing radiographs and examined its relationship with lumbar scoliosis. Thus, this study aimed to examine the association between LLD and lumbar scoliosis measured with full-length radiographs of the lower limbs and lumbar spine in the standing position.

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Materials and Methods

Study Design

We identified 113 participants who underwent full-length radiography of the lower limbs and lumbar spine in the standing position between November 2006 and September 2019. Participants with any of the following conditions were excluded: osteoarthrosis of the lumbar spine or lower limb, lumbar or lower-limb symptoms such as pain or numbness, deformity of the region between the ankle and sole (for example, equinus foot deformity or flatfoot), inability of the heel to touch the ground or severe obesity [body mass index (BMI) ≥35 kg/m^2]. Body mass index was calculated as weight in kilograms divided by the square of height in metres (kg/m^2).

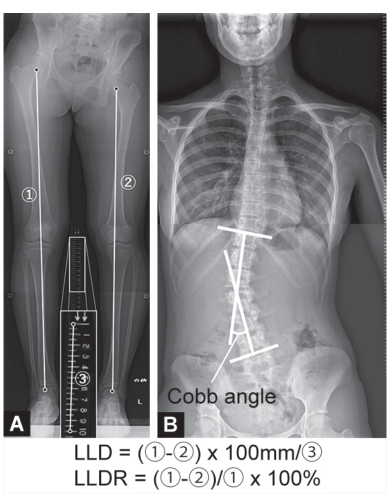
Imaging Studies and Data Analysis

Initially, each participant was scanned as they stood on a level platform to obtain X-ray images of the entire lengths of the lower limbs and lumbar spine. Full-length standing anteroposterior radiographs were taken after turning the participant to face the X-ray scanner with the patellae facing straight ahead. They were instructed to support their full body weight using their legs, distributing it equally between left and right, without relying on any assistive device. The participant could not use a lift or other prostheses under the foot of the shorter leg. A radiographic scale was also captured in each scan.

Leg length was measured on each side as the linear distance from the centre of the femoral head to the centre of the tibial plafond and converted to millimetres using the inset scale. Leg-length discrepancy was analysed as the absolute difference between the lengths of the left and right legs (mm; Fig. 1A). However, the same LLD could affect people quite differently depending on the length of their legs. Hence, the inequality was also evaluated in relative terms as LLD ratio (LLDR) calculated as the LLD divided by the length of the unaffected (longer) leg × 100 (%) (%; Fig. 1A). Lumbar scoliosis was evaluated with the lumbar Cobb angle (°) (Fig. 1B).[20]

Statistical Analysis

Computation of sample size, using G*Power, revealed that for a *correlation ρ* H1 of 0.3, power of 0.8, and α level of 0.05, a total of 84 individuals were required; hence, the sample size of our study was sufficient to achieve statistical significance and the number of participants was justified. All results are presented as mean ± standard deviation. Neither variable was normally distributed. Therefore, we analysed the correlation between LLD and lumbar Cobb angle using Spearman's rank-correlation coefficients. The regression equation was determined using univariable linear regression analysis. The coefficient and equation for the correlation between LLDR and lumbar Cobb angle were determined in the same manner. All statistical analyses were performed using Social Sciences Statistical Package Version 23.0 (SPSS, Inc., Chicago, IL, USA). *P*-values of <0.05 were considered indicative of statistical significance. Correlations were classified as weak (0.10–0.29), moderate (0.30–0.49), strong (0.5–0.99), or complete (1.0) based on the absolute value of the corresponding coefficient (|*r*|).[21,22]



Figs 1A and B: Radiographic measurements. (A) Leg-length discrepancy (LLD) and leg-length discrepancy ratio (LLDR); (B) Lumbar Cobb angle

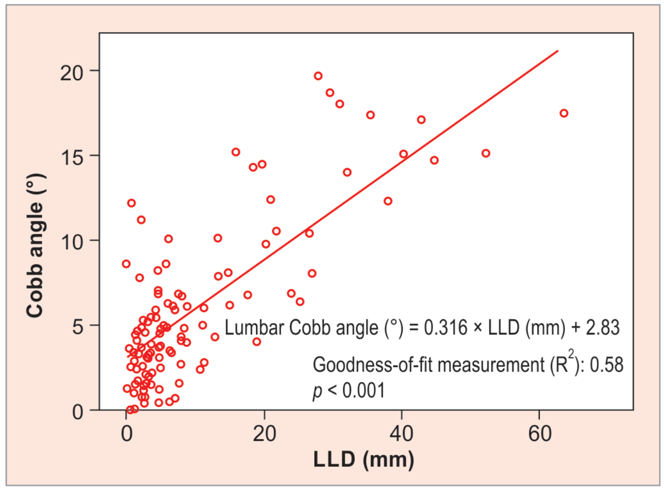


Fig. 2: Leg-length discrepancy (LLD) vs lumbar Cobb angle: correlation and regression equation

Results

The study population had a mean age of 41.3 ± 18.4 years, male/female ratio of 66/47, mean weight of 66.0 ± 17.5 kg, mean height of 163.2 ± 9.5 cm, and mean BMI of 24.6 ± 5.6 kg/cm^2. The mean unaffected (longer) leg length was 785.4 ± 64.3 mm (max: 785.4 mm, min: 571.8 mm). Participants had been scanned for a variety of reasons. Eighty-six participants with no symptoms or complaints of the lumbar spine or lower limbs had been imaged as part of a clinical trial for locomotive syndrome at our hospital (Hospital Ethics Committee Approval No. 1947-2). Standing radiographs were taken of the remaining 27 participants in connection to shortening or deformities of the lower extremities: 12 for post-traumatic deformity, 3 after treatment for osteosarcoma, 3 for hemihyperplasia, 2 for Ollier disease (lower-limb tumours only), 2 for Blount's disease, and 5 for idiopathic conditions.

The mean LLD and lumbar Cobb angle were 9.9 ± 12.0 mm and 5.9 ± 4.7°, respectively. Figure 2 depicts the relationship between LLD in absolute terms and lateral lumbar curvature. A strong correlation can be observed between LLD and lumbar Cobb angle [Spearman's rank correlation (γ) = 0.53, *p* <0.01]. The corresponding regression equation is as follows:

$$\text{Lumbar Cobb angle (°)} = 0.316 \times \text{LLD (mm)} + 2.83.$$

Figure 3 depicts the relationship between LLDR and the lumbar Cobb angle. This correlation was found to be even stronger than that between LLD and lumbar Cobb angle (γ = 0.62, $p < 0.01$). The corresponding regression equation is as follows:

$$\text{Lumbar Cobb angle (°)} = 2.19 \times \text{LLDR (\%)} + 3.0.$$

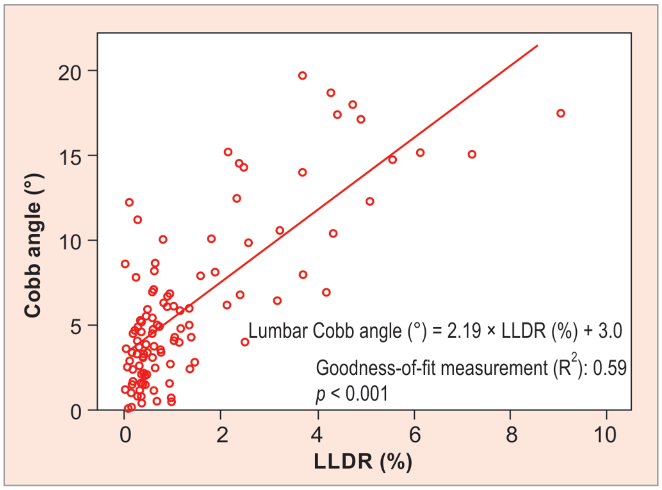


Fig. 3: Leg-length discrepancy ratio (LLDR) vs lumbar Cobb angle: correlation and regression equation

Discussion

Our investigation reveals a strong, positive correlation between the degree of LLD and the lumbar Cobb angle. Several previous studies have identified connections between LLD and lumbar scoliosis. While some of these studies[14,15] calculated the degrees of LLD and lumbar scoliosis based on the body's outer-surface measurements, they did not confirm the degree of direct deformity. Since LLD and scoliosis are ultimately attributable to bone deformities, deriving bone lengths or angles based on body-surface data can introduce errors. Numerous other studies have defined LLD in terms of differences in femoral head position on pelvic radiographs.[1,16–18] One advantage of this approach is that it allows the lower limbs to be evaluated together with the lumbar spine on a single radiograph. However, since pelvic radiographs do not capture the entire length of the legs, estimates could quickly diverge from true lengths. Further, if the hips were slightly abducted at the time of the scan, the ipsilateral leg would appear shorter than its actual length in the image. Our evidence of a strong positive correlation between LLD and lumbar Cobb angle comes from measurements obtained using standing anteroposterior radiographs of the full-length lower extremities and lumbar spine, which are the most objective and accurate imaging modalities.

Using the derived regression equation, an LLD of 20 mm estimates a lumbar Cobb angle of 9.15°. To the best of our knowledge, our investigation using objective imaging data is the first to demonstrate that an LLD of approximately 20 mm is predictive of a lumbar Cobb angle of approximately 10°, which is the pathological cut-off for lumbar scoliosis adopted by several reports.[16,23] Several studies to date have used an LLD of 20 mm as the threshold for recommending treatment,[24,25] and our radiographic evidence supports the findings of previous reports recommending corrective surgery in cases with an LLD degree of ≥20 mm. However, the degree of LLD that is sufficient to warrant surgical correction remains undetermined. There are diverse reports by various studies on how LLD can affect other parts of the body. While some claim that even small differences of ≤10 mm[18,26] may have implications, others argue that only differences of ≥30 mm[14,27] are potentially harmful. According to one review of LLD, such inconsistencies could be attributable to differences in loading between these study populations.[28] Furthermore, we hypothesised that such inconsistencies could be attributable to differences in the ratio of LLD to leg lengths between study populations. The same absolute LLD could affect the lumbar spine in entirely different ways in children versus adults or between other demographic groups whose members have very different body types, leg lengths, or both. Paediatric cases are the focus of most studies that employ the 20-mm threshold,[24,25] whereas studies that utilise 30 mm primarily involve adults.[14,27] We adopted LLDR, a new assessment index, to eliminate the effects of differences in absolute leg length among participants. Indeed, LLDR was observed to be more strongly correlated with the lumbar Cobb angle than LLD. We believe that LLDR has the potential to be a superior criterion for determining the degree of discrepancy that should be indicated for surgical intervention. Based on the regression equation derived above, a lumbar Cobb angle of ~10° corresponds to an LLDR of 3.2%. This ratio was equivalent to an LLD of 25.1 mm in the longest unaffected leg (785.4 mm) and an LLD of 18.3 mm in the shortest unaffected leg (571.8 mm), a range relatively similar to the variation observed in previous studies.

One of this study's limitations was the wide age range, as we included participants aged 10–65 years. Some authors have reported that lumbar spinal posture changes induced by LLD are unaffected by participant age.[29] However, such compensations could occur quite differently in growing children compared with that in adults, in terms of mechanism and magnitude. In lumbar scoliosis, the presence or absence of plasticity, or the possibility that it originally existed regardless of LLD, has not been evaluated. Moreover, while lumbar scoliosis is ultimately a three-dimensional deformity, we only evaluated spinal posture in the coronal plane using anteroposterior radiographs. We plan to analyse the spinal posture in the coronal and sagittal planes using radiographs in both adults and children in subsequent studies.

Conclusion and Clinical Significance

It may be challenging to settle on a single, 'one-size-fits-all' threshold for deciding how severe LLD should be for surgery to be indicated because the condition's clinical importance is perhaps dependent on several factors, including the degree of LLD, the ability of the pelvis and spine to compensate for the discrepancy and associated conditions or problems. However, our investigation found that disparities above the specific thresholds, LLD of >20 mm and LLDR of >3%, tended to co-occur with marked lateral curvature in the lumbar spine (lumbar Cobb angle >10°). These values should prove useful in determining surgical-intervention criteria based on the degree of LLD.

Ethical Considerations

Our study protocol was approved by the Medical Ethics Committee at our institution (Approval no. 3285-1). The committee waived the requirement for obtaining informed consent from the participants owing to the retrospective nature of the study. This study conformed to relevant guidelines and regulations, including the Helsinki Declaration of 1975, as revised in 2000.

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