Influence of simulated leg length discrepancy on the spinal kinematics during stance phases

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Abstract. Exploring the walking of LLD are clinically helpful in understanding which LLD level contributed to the changes at the upper limb. The aim of this work was to determine which LLD level during single leg stance and double leg stance contributed to the spinal changes. Eighteen healthy male subjects were induced with 0.5 cm to 4.0 cm height of insoles with interval 0.5 cm accordingly and their spine motion during the stance phase was captured by 5 Oqus cameras and evaluated by using Qualisys Track Manager (QTM) software. The effect of LLD height on spinal kinematics were assessed using spinal curvature parameters which are the lateral bending angle at lumbar (LBAL), the shoulder- girdle and pelvic line bending angle (SPBA) and the shoulder-girdle line and pelvic line rotation angle (SPRA).

4 cm LLD height at double stance phase created a relatively larger LBAL when compared with normal walking. The influence of LLD on SPBA and SPRA was very minimal.

1. Introduction

Leg length discrepancy (LLD) or anisomelia affected 40 to 70 percent of the human population [1-5]. According to Burke Gurney, Jan W. Raczkowski, Barbara Daniszewska and Krystian Zolynski in their review article stated that, leg length discrepancy (LLD) is defined as the pair of lower leg did not have same inequalities that lead to the difficulties in maintaining the stability of body posture during walking, running, standing and sitting [4,6,7,8]. That difficulties were causes by the changes in the segment of spine such as lumbar and pelvic during movement of the lower limb [4, 9]. Liu et al and Walsh et al stated that LLD cause the changes in the kinematic in the lower limbs and pelvis when it reaches the severity of 2 cm and above [4,10,11]. This is because higher severity of the LLD can lead to the disease related to spinal shape such as lumbar scoliosis and low back pain [12]. Not only that, the continuous pelvic tilt in LLD patients may lead to the structural changes in spine [1-6]. As we already know, spine is the important system that served to support the human body to bear the weight, to facilitate daily movement and to protect the spinal cord to carry their vital functions [12].

When the magnitude of the lateral bending exceeds the maximum, the lumbar scoliosis may become permanent disease of patient with LLD [12]. The difficulties are causes by the changes in the segment of spine such as lumbar and pelvic [1-6]. Other difficulties related to LLD are scoliosis, change in human gait, low back pain because of the inequalities of lower limb will make the weight of body been supported more toward the short legs [2,4,10,12]. During walking there are several movements of our body such as the rotation of the hip and shoulder, the lateral bending of spine and the movement of muscle at ankle joint, knee joint and hip joint [6]. Walking which compromise of eight phases become awkward in LLD patient [10]. This is because the distribution of their body weight being support more toward short leg [1-6]. Figure 1 shows the
position of normal human without LLD and with LLD during walking. This shown that there are compensating of the LLD patient compared to normal person [10].

![Figure 1: (a) Normal person (b) LLD person [4]](image)

LLD can be classified into four groups which are functional LLD, structural LLD, environmental LLD and different severity level of LLD [2]. Functional LLD (apparent LLD) is the condition of actual leg length changes which depends on the movement of the lower limb. Meanwhile, structural LLD (structural LLD) due to different level of femur head and calcaneus [6]. Environmental LLD usually found in athlete who stepped on non-smooth track for a long period of time, while the level of LLD could be classified whether it was mild, moderate and severe [2,7]. LLD with less than 3 cm is mild, 3 cm to 6 cm is moderate and more than 6 cm is severe [2]. Plus, LLD can further divide whether the persons experienced LLD since kids and generate LLD later at certain time of their age [13].

The main objective of this study was to assess the effect of LLD on the lateral bending angle of the lumbar (LBAL), shoulder-girdle and pelvic line bending angle (SPBA) and shoulder-girdle and pelvic line rotation angle (SPRA). All of these parameters were analysed during single leg stance and double leg stance. These was to know which LLD level affected the most on the LBAL, SPBA and SPRA more specifically during single leg stance and double leg stance.

2. Method

2.1 Subjects
Eighteen male subjects (age 22±2 years, mass 62 ± 8 kg, height 1.66 ± 0.05 m, BMI 22.5 ± 1.7 kgm⁻²) with no history of back pain and no gait disorders volunteered to participate in the study. Informed consent was obtained from all participants prior to participation in the study. The study was conformed to the local ethics committee guidelines.

2.2 Experimental Protocol
The subjects were instructed to wear tight sport shirt. 30 round reflective skin markers, 12.5 mm in diameters were placed on the subject’s body as shown in Figure 2. They had to wear the sandal with induced insoles inserted under the right foot started from 0.5 cm, 1.0 cm, 1.5 cm, 2.0 cm, 2.5 cm, 3.0 cm, 3.5 cm and 4.0 cm accordingly.
Three-dimensional kinematics and kinetics data were obtained using 5 cameras motion capture system (100 Hz; Qualisys AB, Gothenburg, Sweden) and two rectangular Bertec force platforms (FP4060-10-2000, Bertec Corporation, Columbus, USA) operated at 1000 Hz. The two force platforms were installed in series in the middle of 7m walkway to record the gait cycles. Participants walked three to five time on 7 m platform to familiarize with the artificially created LLD. Subject completed 5 trials and one-minute rest between trial was provided to prevent fatigue.

2.3 Data and Statistical Analysis
The data was analysed using Qualisys Track Manager (QTM) software (Gothenburg, Sweden). The LBAL, SPBA and SPRA were defined based on the study done by kakushima et al [10]. The LBAL was defined as the angle formed by markers placed at Lumbar 1, 3 and 5 and viewed in coronal plane. The SPBA was defined as an angle formed by shoulder girdle line and pelvic line and viewed from coronal plane. The SPRA was defined as an angle formed by shoulder girdle line and pelvic line and viewed from transverse plane. The LBAL, SPBA and SPRA were evaluated during single stance of right leg (SR), single stance of left leg (SL) and double stance (DS). A two-way repeated measure ANOVA were applied to test the effect of artificially created LLD heights and Stance Phases on spinal curvature parameters. Statistical analyses were completed using SPSS 16 (SPSS, Chicago, IL).

3. Result

3.1 Lateral Bending Angle of Lumbar (LBAL)
In each stance phases, comparison of LBAL created at different LLD height with normal gait (0 cm LLD) were performed. No significant differences were found for LBAL created at SL and SR when compared with normal gait. However, significantly larger LBAL value was shown when comparing 4.0 cm LLD height with normal gait at DS, $F(1,17) = 6.544$, $r = 0.52$.

In each LLD height, comparison was made between SL, SR and DS stance phases. No significant differences of LBAL values were found during normal gait in all stance phases. There was a significant main effect of LBAL values when comparing between stance phases at 4 cm LLD height, $F(2,34) = 3.887$, $p < 0.05$; however, it did represent a medium-sized effect, $r = 0.32$. Contrast revealed that value of LBAL of DS stance phase was higher than SL and SR stance phases, $F(1,17) = 6.917$, $r = 0.53$ and $F(1,17) = 5.252$, $r = 0.49$, respectively.
Table 1 Means and SD of SL, SR and DS for Lateral Bending Angle of The Lumbar with and without insoles

| Level of LLD (cm) | Lateral Bending Angle of Lumbar (°) | SL       | SR       | DS       |
|-------------------|------------------------------------|----------|----------|----------|
| 0.0               |                                    | 5.2±2.0  | 4.4±1.3  | 4.7±2.3  |
| 0.5               |                                    | 4.3±1.5  | 4.9±1.0  | 4.7±3.2  |
| 1.0               |                                    | 4.7±1.7  | 5.5±2.0  | 4.6±2.3  |
| 1.5               |                                    | 4.2±2.3  | 4.1±1.8  | 3.8±2.6  |
| 2.0               |                                    | 5.5±2.0  | 4.4±2.6  | 4.5±2.6  |
| 2.5               |                                    | 3.9±2.4  | 4.9±2.8  | 6.0±3.3  |
| 3.0               |                                    | 4.1±2.7  | 4.7±2.2  | 4.6±2.3  |
| 3.5               |                                    | 3.7±2.3  | 3.6±2.5  | 6.0±3.2  |
| 4.0               |                                    | 5.1±2.1  | 4.4±1.7  | *6.4±1.2 |

*p<0.05

3.2 Shoulder- girdle and Pelvic line Bending Angle (SPBA)
The SPBA at each LLD height was compared with the SPBA at normal gait in each stance phases. As shown in table 2, there were no significant LBAL created at SL, SR and DS when compared with normal gait. Comparison of SPBA between stance phases for each LLD height were performed. No significant differences of SPBAs between stance phases were found during normal gait and walking with 4 cm LLD height.

Table 2 Means and SD of SL, SR and DS for SPBA with and without insoles

| Level of LLD (cm) | Shoulder-girdle and Pelvic Lines Bending Angle (°) | SL       | SR       | DS       |
|-------------------|---------------------------------------------------|----------|----------|----------|
| 0.0               |                                                  | 3.8±0.9  | 3.8±1.0  | 3.4±1.3  |
| 0.5               |                                                  | 3.3±1.6  | 3.4±1.8  | 3.2±1.4  |
| 1.0               |                                                  | 3.3±1.8  | 4.6±2.2  | 3.1±1.9  |
| 1.5               |                                                  | 2.8±1.0  | 3.6±1.4  | 2.8±1.6  |
| 2.0               |                                                  | 3.5±2.6  | 4.4±1.3  | 2.7±1.0  |
| 2.5               |                                                  | 3.9±2.8  | 4.2±1.1  | 2.5±2.2  |
| 3.0               |                                                  | 2.3±0.8  | 4.4±1.6  | 2.1±1.9  |
| 3.5               |                                                  | 4.0±2.1  | 3.5±1.9  | 2.6±1.9  |
| 4.0               |                                                  | 4.7±2.5  | 4.4±0.6  | 3.8±2.3  |

3.3 Shoulder- girdle and Pelvic line Rotation Angle (SPRA)
Comparison of LBAL created at different LLD height and at different stance phases with normal gait were performed. As shown in table 3, there were no significant LBAL created at SL and DS when compared with normal gait. However, significantly larger SPRA value was shown when comparing 4.0 cm LLD with normal gait at SR, \( F(1,16) = 5.801, r = 0.52 \).

In each LLD height, comparison was made between SL, SR and DS stance phases. No significant differences of LBAL values were found between stance phases during normal gait and walking with 4 cm LLD height.
Table 3 Means and SD of SL, SR and DS for Shoulder-girdle and Pelvic Lines Bending Angle with and without insoles

| Level of LLD (cm) | Shoulder-girdle and Pelvic Lines Rotation Angle (°) |
|------------------|----------------------------------------------------|
|                  | SL        | SR        | DS        |
| 0.0              | 5.4±1.9  | 4.4±1.5  | 7.3±1.6  |
| 0.5              | 5.9±1.7  | 3.9±1.6  | 7.5±1.5  |
| 1.0              | 6.4±1.9  | 5.2±2.0  | 7.6±1.4  |
| 1.5              | 6.0±1.1  | 4.8±1.6  | 6.7±1.8  |
| 2.0              | 5.4±1.8  | 3.7±1.3  | 6.9±1.9  |
| 2.5              | 5.3±2.3  | 4.0±1.6  | 6.9±2.0  |
| 3.0              | 4.8±1.3  | 2.9±2.0  | 5.9±1.9  |
| 3.5              | 3.9±1.7  | 5.7±2.5  | 5.1±1.2  |
| 4.0              | 3.8±1.9  | 5.4±2.5  | 5.3±2.3  |

4. Discussion
In this study, the effects of LLD during gait on the spinal kinematics were evaluated in healthy male adults. Analysis were performed to identify any significant angle values created at different LLD height when compared with normal walking in each stance phases. During normal walking, there was no significant difference observed in LBAL, SPBA and SPRA value in single stance of left and right leg. However, a relatively larger LBAL value was observed at 4 cm LLD height during double stance phase. Thus, LLD at double stance phase is likely to expose the spine to a larger amount of lateral bending stresses. Kakushima et al performed similar studies using 3 cm insoles on the right foot and found that the Maximum Lateral Bending Angle of the Lumbar (MLBAL) of right side was significantly larger in LLD than in normal gait. However, it was not clear at which gait event the MLBAL was assessed. Bargenter et al investigated the effect of LLD on spinal gait kinematics in patients with structural LLD of 20-60 mm. They did not report any significant differences for Lumbar Lateral Bending Angle viewed in sagittal plane. However, patients with LLD showed larger frontal plane lumbar bending angle to the longer side (convex on the short side) during initial contact and early mid-stance. In the current study, the frontal plane lumbar bending angle was not considered for analysis. In the case of SPBA and SPRA, none of the LLD height give significant impact to the spine kinematics. Some errors in determining SPBA and SPRA could be the reasons for these insignificant results. Further investigation is necessary to find the changes of LLD on SPBA and SPRA.

5. Conclusion
4 cm LLD during double leg stance contributed to the change of the spinal kinematic. LLD patients may find difficulties during physiological and physical activities of their body. Thus, the treatment for LLD may be helpful in preventing the physical and physiological of the body from being aggravated.

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