

**THE EFFECT OF MILD LEG LENGTH
DISCREPANCY ON VERTICAL GROUND REACTION
FORCE IN ADULT WITH HEIGHT 150 CM TO 170 CM**

DR. MOHAMMAD AL- HAFIZ BIN SA'ADON ZUBIR

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ABSTRAK

Pengenalan

Perbezaan panjang kaki adalah keadaan kedua-dua kaki yang tidak mempunyai panjang yang sama. Ia adalah masalah yang kerap berlaku dalam 40% hingga 70% di kalangan masyarakat. Perbezaan panjang kaki sebanyak 2 cm di anggap sebagai normal dalam sesetengah kajian. Oleh yang demikian, kajian ini dijalankan untuk mengetahui kesan perbezaan panjang kaki sebanyak 1 cm dan 2 cm kepada daya tindak balas tanah menegak. Kajian ini juga bertujuan untuk mengetahui sama ada kaki pendek atau kaki panjang lebih terjejas dalam perbezaan panjang kaki yang disimulasikan.

Metodologi

Ini adalah kajian keratan rentas melibatkan 18 orang lelaki dewasa yang sihat yang mempunyai ketinggian lingkungan 150 cm hingga 170 cm. Daya tindak balas tanah menegak diukur dengan menggunakan kajian analisis berjalan. Penanda reflektif dilekatkan pada bahagian tertentu di bahagian kedua-dua kaki dan imej diambil oleh kamera gerakan 3D. Peserta akan berjalan di atas plat daya untuk mengukur daya tindak balas tanah menegak. Ukuran pertama diukur tanpa perbezaan panjang kaki (0 cm) diambil sebagai kawalan. Ukuran seterusnya dilakukan dengan simulasi perbezaan panjang kaki menggunakan tambahan tapak kasut setinggi 1 cm dan 2 cm dan daya tindak balas tanah menegak diukur berulang kali untuk kaki yang panjang dan pendek. Daya tindak balas tanah menegak yang pertama diambil untuk dianalisa. Perbandingan dilakukan antara daya tindak balas tanah menegak di antara kaki yang tanpa perbezaan panjang dengan kaki yang dengan perbezaan panjang sebanyak 1 cm dan 2 cm dan seterusnya di analisa dengan menggunakan “repeated measures analysis of variance within factors”.

Keputusan

Daya tindak balas tanah menegak yang pertama menurun secara perlahan untuk kaki yang panjang dan menaik secara perlahan untuk kaki yang pendek selepas simulasi perbezaan panjang kaki 1 cm dan 2 cm. Terdapat perbezaan daya tindak balas tanah menegak yang ketara pada perbezaan panjang kaki 1

cm dan 2 cm berbanding dengan kawalan (0 cm). Terdapat perbezaan yang ketara antara perbandingan ukuran kaki pendek dengan perbezaan panjang kaki 1 cm dan 2 cm.

Kesimpulan

Perbezaan panjang kaki sebanyak 1 cm dan 2 cm telah menunjukkan kesan yang ketara terhadap daya tindak balas tanah menegak. Kaki pendek mengalami peningkatan daya tindak balas tanah menegak dengan peningkatan perbezaan panjang kaki. Namun, tidak ada perubahan ketara pada kaki panjang dengan perbezaan panjang kaki.

Kata kunci: *perbezaan panjang kaki, daya tindak balas tanah menegak, analisis berjalan, simulasi, tambahan tapak kasut*

ABSTRACT

Introduction

Leg length discrepancy is defined as condition in which paired legs are noticeably unequal. It is relatively common problem found as many as 40% to 70% of the population. Leg length discrepancy up to 2 cm is considered normal by some studies. Therefore, we conducted this study to determine the effects of leg length discrepancy of 1 cm and 2 cm to vertical ground reaction force. This study also aims to find out whether long leg or short leg were more affected in the simulated leg length discrepancy.

Methodology

This was a cross sectional study involving 18 healthy male subjects with height of range from 150 to 170 cm. Vertical ground reaction force was measured using gait analysis study. Reflective markers were placed on bony landmark of bilateral lower limbs to be captured by 3D motion cameras. Subjects walked on a straight walkway with a force plate to measure ground reaction force. First measurement was taken without discrepancy (0 cm) as control. Then leg length discrepancy simulated with shoe raise of 1 cm and 2 cm and vertical ground reaction force were measured repeatedly on the long and short legs. Measurement of first peak of vertical ground reaction force was taken for analysis. Vertical ground reaction force of 1 cm and 2 cm simulated leg length discrepancy was compared with control for both long and short legs and were analysed with repeated measure analysis of variance within factors.

Results

The first peak of vertical ground reaction force reduced gradually on long leg and increased gradually on short leg when simulated leg length discrepancy of 1 cm and 2 cm. There was significant difference of vertical ground force reaction in both 1 cm and 2 cm leg length discrepancy compare to control (0 cm). There were significant differences between comparison of measurements in short leg with 1 cm and 2 cm leg length discrepancy.

Conclusion

Leg length discrepancy of 1 cm and 2 cm has shown significant effect to vertical ground reaction force. Short leg had increased vertical ground reaction force with increased leg length discrepancy. However, there was no significant changes in long leg with leg length discrepancy.

Keywords: *leg length discrepancy, vertical ground reaction force, gait analysis, simulated, shoe raise*

Chapter 1

INTRODUCTION

INTRODUCTION

Limb length discrepancy is defined as condition in which paired legs are unequal. When the discrepancy is in the lower extremities, it is known as leg length discrepancy (LLD) (1). LLD is relatively common problem found as many as 40% (2) to 70% (3) of the population.

LLD are usually classified into structural LLD and functional LLD. Structural LLD also known as anatomical LLD or true LLD is a result of actual difference of bone structures length from the head of femur to the ankle which can be congenital or acquired causes. Congenital causes include developmental limb abnormalities at birth or childhood, whereas acquired causes include trauma and degenerative. Functional LLD also known as apparent LLD is a physiological response of altered mechanics along the kinetic chain from foot to lumbar spine without true osseous deficiency. The most common causes are joint contracture, muscle weakness, ligamentum laxity and mechanical axis malalignment (4). McCaw and Bates (5) classified LLD according to the magnitude of the inequality and described as mild, moderate and severe. Mild LLD defined as LLD less than 3 cm, moderate LLD defined as LLD between 3 cm to 6 cm, and severe LLD defined as more than 6 cm. LLD of greater than 2 cm is rare and occurs in at least 1 in every 1,000 individuals (6). Some authors hold the view that LLD of less than 2 cm is clinically insignificant (7, 8) and they have tried to quantify a significant LLD accepting as much as 2 cm (7) and 3 cm (8). However, many studies suggest that LLD of less than 2 cm is of clinical significance (9, 10, 11, 15).

LLD has been associated with many lower limb and lumbar biomechanical conditions including osteoarthritis in the knee and hip joints (10, 11, 12, 13, 14), low back pain (15, 16, 17), scoliosis (18) and stress fracture (19). Meanwhile, mild LLD has primarily been associated with three common orthopaedic disorders which are osteoarthritis, low back pain, and stress fracture.

Management of LLD depends on the magnitude of discrepancy. LLD from 0 cm to 2 cm does not require treatment, LLD from 2 cm to 6 cm requiring a shoe lift, epiphysiodesis, or shortening, LLD from 6 cm to 20 cm requiring lengthening which may or may not be combined with other procedures, and LLD more than 20 cm requiring prosthetic fitting (20). The question of whether to treat individuals with LLD should be taken on a case-by-case basis, although the breakpoint of 2 cm is often used, this

number could be considerably higher for younger persons who are inactive and have had LLD their entire life and considerably lower for older persons who are active and have acquired LLD later in life (1). In the context of surgical treatment, most surgeons have advocated that LLD of less than 2 cm is clinically insignificant, as no surgery is indicated (26).

In order to measure effect of LLD to lower limbs, gait analysis can be done. Parameter that can be measured is ground reaction force (GRF). GRF is a force exerted by support surface due to body mass that passing through from the foot to the ground surface. Through the same action, the force is passing back from the ground up into the feet with the similar magnitude. Whenever the foot is in contact with the ground surface, there will be vertical forces, anterior-posterior forces and medial-lateral forces acting between the foot and the ground (28). GRF is measured by force plate and reported in bodyweight (BW) units (29). GRF are important quantities in biomechanical analyses to investigate injury risk and musculoskeletal impairments (30). Increased in GRF was associated with risk of injury to subchondral bone, cartilage and soft tissue around the joint.

Vertical ground reaction force (VGRF) is an important force component that thrusts the joints upward during walking. VGRF is directly proportional to the body weight as it counters the overall body weight. The measurement of gait parameters and VGRF has been widely used to analyse abnormal lower limb loading because such measurements provide objective information for analysis of joint loading during normal gait (31). In normal gait is symmetrical as shown by equal VGRF vectors for both limbs. During stance phase gait, there are two peaks of VGRF observed, which the first and second peak. First peak force represents maximum load during heel contact and second peak force represents maximum load during push off. The net effect of LLD is an asymmetrical gait as a difference in the VGRF vector for short and long legs.

There were few literatures regarding the effect LLD on VGRF. White et al (32) reported that LLD less than 3 cm showed greater peak VGRF on shorter limb than the longer limb. Pereira et al (33) found that LLD more than 0.3 cm in asymptomatic group showed highest peak VGRF at longer limb compared to symptomatic group with same LLD and group with LLD less than 0.3 cm. Pereira and Sacco (34) also found that mild LLD of 0.5 cm to 2 cm presented higher values of minimum VGRF at the shorter limb compared to longer limb. Per Wretenberg et al (35) reported that LLD of 2 cm or more

create biomechanical changes of hip joint GRF both on long and short limb and that effect are larger on short limb. Azizan et al (36) found that LLD of 2 cm presented the highest VGRF at the shorter limb. Zabri et al (37) found that LLD at 4 cm presented highest peak of VGRF compared to LLD of 1 cm, 2 cm and 3 cm for both limb and overall result of this study showed higher mean peak VGRF at the shorter leg than longer limb.

Therefore, we conducted this study to find out the effects of mild LLD on VGRF changes in adult with height of 150 cm to 170 cm.

It is very important to understand the significant of mild LLD that can cause gait asymmetry and help to determine the threshold to treat patients.

Chapter 2

OBJECTIVES OF THE STUDY

OBJECTIVES

General objectives

1. To determine the effect of 1 cm and 2 cm simulated leg length discrepancy to vertical ground reaction force for long leg and short leg.
2. To determine whether long leg or short leg has significant changes in vertical ground reaction force with 1 cm and 2 cm simulated leg length discrepancy.

Specific objectives

1. To compare mean vertical ground reaction force for long leg and short leg in 1 cm and 2 cm simulated leg length discrepancy.
2. To identify either increase or decrease vertical ground reaction force in long leg or short leg in 1 cm and 2 cm simulated leg length discrepancy.

Chapter 3

MANUSCRIPT

**THE EFFECT OF MILD LEG LENGTH DISCREPANCY ON VERTICAL GROUND
REACTION FORCE IN ADULT WITH HEIGHT 150 CM TO 170 CM**

Author: Dr. Mohammad Al-Hafiz Bin Sa'adon Zubir

Department of Orthopaedics,
School of Medical Sciences, Universiti Sains Malaysia,
16150 Kubang Kerian, Kelantan Darul Naim, MALAYSIA.
Email: dr_alha82@yahoo.com

Corresponding Author:

Dr. Emil Fazliq Bin Mohd,
Senior Lecturer and Orthopaedic Surgeon,
Department of Orthopaedics, School of Medical Sciences, Universiti Sains Malaysia,
16150 Kubang Kerian, Kelantan Darul Naim, MALAYSIA.
Email: emil@usm.my; Tel: +609-7676389; Fax: +609-7653370

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ABSTRACT

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Conclusion

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Therefore, we conducted this study to find out the effects of mild LLD on VGRF changes in adult with height of 150 cm to 170 cm.

It is very important to understand the significant of mild LLD that can cause gait asymmetry and help to determine the threshold to treat patients.

METHODOLOGY

This was a cross sectional study done in Hospital Universiti Sains Malaysia. Eighteen male subjects that met inclusion criteria were recruited among university personnel in Universiti Sains Malaysia Health Campus. Inclusion criteria include age range from 20 years to 40 years with height 150 cm to 170 cm that has normal body mass index (BMI), normal gait, normal range of motion for both lower limbs and LLD less than 1 cm.

Sample size was calculated using G Power software version 3.1.9.2 with minimal sample size required are eighteen participants. This study was approved by the Human Research Ethics Committee of the School of Medical Sciences, Universiti Sains Malaysia (USM/JPEM).

Subject's height and weight was measured, and BMI was calculated. True length of both lower limbs measured using tape measure method (TMM) from anterior superior iliac spine (ASIS) to the tip of medial malleolus in supine position. Subjects with LLD less than 1 cm were chosen to continue this study. Informed consent was taken from all subjects. For each subject, LLD were simulated for right lower limb with shoe raise of 1 cm and 2 cm thickness (Figure 1, 2 and 3).

This study was performed in Sport Science Laboratory, Universiti Sains Malaysia using gait analysis study with Qualisys Motion Capture System which operates with three-dimensional (3D) Qualisys Motion Camera (Figure 4), Qualisys Track Manager (QTM) and Visual 3D softwares on computer (Figure 5). This gait analysis using six camera and single force plate in the laboratory.

All subjects wore tight non reflective black pants with sandals that was provided in the laboratory (Figure 6). Thirty-three reflective markers were applied at anatomical bony landmarks of both lower limb and sacrum with double sided tape at second metatarsal head, heel, lateral malleolus, medial malleolus, tibia, distal femoral condyle, femur, ASIS and sacrum based on Helen Hayes (Davis) Marker Replacement Protocol (Figure 7).

All subjects performed walking trials for 6 metres on straight walkway to familiarize the procedure (Figure 8). The single 400 x 600 force plate was calibrated before measurement started. For this study, subjects were walked along 6 metres length walkway located equal distance from six cameras

placed around laboratory. Camera captured reflective markers when long leg stepped on the force plate followed by short leg separately. Right leg was set as long leg and left leg was set as short leg.

Two different simulated LLD with shoe raise 1 cm and 2 cm were used for each subject. VGRF were measured three times for every shoe raise for both limbs to get mean force to improve the accuracy of the finding. Measurements without shoe raise (0 cm) were taken as control. Mean VGRF of 36 legs in 18 subjects for each LLD (1 cm and 2 cm) was measured for long leg and short leg (Table 1).

Data were collected from the force plate and camera at a frequency of 200 Hertz. The force plate was connected by a charger amplifier to a computer for data collection. Using the QTM Software, VGRF graph were plotted. The 'M' curve shape graph was shown on the screen. For this study, only first peak force from VGRF graph were taken for analysis (Figure 9).

Repeated measures ANOVA within factors were used to compare mean VGRF of long leg and short leg within the subjects when subjected to different shoe raise, which was 1 cm and 2 cm simulated LLD. If significant, post hoc analysis is performed for detailed analysis. Data will be entered and analysed using SPSS version 24. Confidence interval is set at 95% with statistical significance p-value will be taken less than 0.05 ($p < 0.05$).

RESULTS

A total of eighteen participants were recruited for this study. The result of the data showed that the mean age of the participants is 22.94 (0.80). Meanwhile, for the mean BMI for the total of eighteen participants were 23.86 (SD=0.41) (Table 2).

The maximum mean first peak of VGRF demonstrated in 2 cm simulated LLD (714.17 N). The lowest mean first peak of VGRF demonstrated in 2 cm long leg (687.66N). The mean first peak VGRF on the short leg was increased progressively when the shoe raise increased to 1 cm (703.42 N), followed by 2 cm (714.17 N). The graph has shown that the mean VGRF for short leg group was higher compared to in long leg for all measurement except for the control (0 cm). Short leg had significant higher VGRF compared to long leg in 1 cm and 2 cm LLD (Figure 10).

Comparison of mean VGRF between 1 cm and 2 cm LLD to control (0 cm) in long leg and short leg were done with independent samples t-test. The mean difference of VGRF in short leg was higher than long leg, with significant increased trend. In contrast, the mean difference of VGRF in long leg from 0 cm to 1 cm or 2 cm was minimum but in decreasing trend. There was significant difference of mean VGRF in both 1 cm and 2 cm LLD compared to control (0 cm) with p-value 0.016 and 0.001 respectively (Table 3).

Comparison of percentage for mean VGRF between long leg and short leg in control (0 cm), 1 cm and 2 cm leg length discrepancy were done. From test of between subject effect in repeated measure ANOVA, there was a marginal significant difference of mean VGRF between long leg and short leg (F= 4.12, p-value=0.050) regardless of time (Table 4).

Comparison of mean VGRF for long leg and short leg during 1 cm and 2 cm simulated LLD were done with paired sample t-test. There was no significant difference of mean VGRF within long leg and short leg in repeated measure ANOVA (F=2.23, p=0.123). However, multiple analysis was performed with adjusted α based on Bonferroni correction. The results have shown that there were significant differences between comparison of measurements in short leg with 1 cm and 2 cm LLD with p-value<0.001 for both discrepancies. There was significant among the short leg in all comparisons

with highest mean difference in the group 0 cm versus 2 cm and lowest in the group 1 cm versus 2 cm. There was no significant among the long leg in all comparisons (Table 5).

Comparison of mean VGRF between long leg and short leg based on shoe raise size were done. For time-shoe raise interaction results in repeated measure ANOVA analysis, there was a significant difference of mean VGRF between long leg and short leg based on shoe raise height ($F= 9.57$, $p\text{-value} < 0.001$). Then, we proceed to multiple comparisons to determine if there was a significant difference for each time. From the results, there was a significant difference of mean VGRF for 2 cm LLD between long leg and short leg (mean difference (95% CI): -26.51 ($41.26, -11.75$), $p\text{-value}=0.001$). However, there was no significant difference of mean VGRF with $p\text{-value} 0.067$ in 1 cm LLD (Table 6).