EFFECTS OF DIFFERENT AMOUNT OF LIMB LENGTH DISCREPANCY TO VERTICAL GROUND REACTION FORCE AMONG THE POPULATION WITH HEIGHT OF I50 AND 170 CM

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ABSTRAK

Pengenalan: Perbezaan panjang anggota bawah boleh menyebabkan cara berjalan yang tidak simetri dan menyebabkan perubahan biomekanik. Terdapat banyak kajian mencari jumlah perbezaan panjang yang signifikan untuk menyebabkan perubahan biomekanik pada anggota kaki, tetapi tiada kajian melihat sama ada jumlah perbezaan ini dipengaruhi oleh ketinggian pesakit. Kajian ini dijalankan untuk melihat kesan simulasi perbezaan panjang kaki terhadap tekanan balas vertikal dikalangan sukarelawan dengan ketinggian berbeza.

Metodologi: Ini adalah sebuah kajian keratan rentas melibatkan 28 sukarelawan dengan ketinggian 150cm dan 28 sukarelawan dengan ketinggian 170cm. Tekanan balas vertikal diukur menggunakan kajian analasis cara berjalan. Penanda reflektif dilekatkan pada bahagian tertentu anggota bawah dan imej diambil oleh kamera gerakan 3D. Sukarelawan berjalan di atas plat tekanan dan tekanan balas vertikal diukur. Ukuran pertama dilakukan tanpa perbezaan panjang kaki. Ukuran seterusnya dilakukan dengan penambahan tapak kasut setinggi 2, 3 dan 4 cm secara berturutan dan tekanan pada kaki yang dipanjangkan diambil setiap kali. Tekanan balas vertikal puncak pertama dan kedua dianalisa secara berasingan. Perbandingan dibuat di antara tekanan kaki tanpa perbezaan kepanjangan dan kaki dengan perbezaan kepanjangan dan dianalisa menggunakan ‘repeated measures analysis of variance (ANOVA)’.

Keputusan: Untuk ketinggian 150 dan 170 cm, nilai tekanan balas vertikal puncak kedua pada kaki yang dipanjangkan menurun secara berperingkat semasa ketebalan tapak kasut ditambah secara berturutan dari 2 ke 3 cm dan seterusnya ke 4 cm. Perbezaan 3 cm didapati signifikan secara statistik untuk menyebabkan penurunan tekanan balas vertikal pada kaki yang dipanjangkan (nilai p sama dan kurang dari 0.001) untuk kedua-dua kumpulan ketinggian (150 dan 170 cm).

Kesimpulan: Perbezaan panjang kaki sebanyak 3 cm dan ke atas menyebabkan penurunan yang signifikan pada tekanan balas vertikal puncak kedua. Penyataan ini benar untuk kumpulan ketinggian 150 dan 170 cm. Penurunan tekanan balas vertikal pada kaki yang dipanjangkan disertai dengan peningkatan tekanan balas vertikal pada kaki yang pendek dan boleh menyebabkan gangguan pada sendi kaki yang pendek.

Kata kunci; *Perbezaan panjang kaki, tekanan balas vertikal, tinggi.*

ABSTRACT

Introduction: Leg length discrepancy is a known cause of gait asymmetry and can lead to subsequent changes in biomechanics of the lower limb. Although many studies have look into the significant amount of leg length discrepancy that causes problem to the limb biomechanics, none of them specified whether the amount is influenced by height of patients. We conducted this study to determine the effects of simulated leg length discrepancy on vertical ground reaction force in volunteers with different height.

Methodology: This was a cross sectional study involving 14 volunteers with 150 cm height and 14 volunteers with 170 cm height. Vertical ground reaction force were measured using gait analysis study. Reflective markers were placed on bony landmarks of bilateral lower limbs to be captured by 3D motion cameras. Volunteers walked on a straight walkway with a force plate to measure ground reaction force. First measurement was taken without discrepancy as control. Subsequently leg length discrepancy simulated with shoe raise of 2, 3 and 4 cm and vertical ground reaction force were measured repeatedly on the longer leg. Measurement of first and second peak of vertical ground reaction force were taken for analysis separately. Vertical ground reaction force of simulated leg length discrepancy was compared with control. Repeated measures analysis of variance (ANOVA) within each groups' height were done.

Results: In both 150 and 170 cm height volunteers, the second peak of vertical ground reaction force in the longer leg reduced gradually when the shoe raise increased sequentially from 2 to 3 cm and then to 4 cm. Three cm discrepancy was statistically significant to cause reduction in vertical ground reaction force on the longer limb with p-value of 0.001 and less in both group of volunteers (150 and 170cm height).

Conclusions: Leg length discrepancy of 3 cm and above caused significant reduction in second peak ground reaction force. It was true for was both 150 and 170 cm height population. Reduction of ground reaction force in the longer leg can be inferred as increment of ground reaction force in the shorter leg, thus may indirectly cause problem in the joints of shorter leg.

Keyword; *Limb length discrepancy, ground reaction force, height.*

Chapter 1

INTRODUCTION

1.1 INTRODUCTION

Limb length discrepancy or leg length discrepancy for lower limb (LLD) is a common problem, found in 45 to 70 percent of general population (1). It can be further classified into structural and functional. Structural LLD is when the difference in leg length is caused by the inequalities in bony structure from head of femur to the ankle. It can be a congenital cause such as in developmental dysplasia of hip or acquired due to trauma or infection. Functional LLD is a physiological response to altered mechanics along kinetic chain from foot to lumbar spine (2).

Clinical significance of LLD depends on amount of discrepancy and the ability of pelvis and spine to compensate the inequality (3). There are various opinions regarding the acceptable amount of discrepancy needed to warrant treatment. Many studies trying to quantify significant LLD and accept as much as 20 to 30 mm discrepancy as compensable by body. Some studies define significant discrepancy based on functional outcomes (2). However, most studies agree on discrepancy of more than 2 cm is considered significant as it caused gait asymmetry between the shorter and longer leg. Biomechanical effect of LLD less than 3 cm has questionable significance as it can be compensated by postural adjustment (4). Apart from that, children can tolerate LLD better than adult with different compensatory mechanism. Smaller LLD is more significant in athlete as compared to non atheletic group due to the difference in biomechanical effect of certain sports activities such as running (5).

Complications of LLD can be divided into two groups. The first group is functional limitations including gait asymmetry and balance problem and the second group is associated musculoskeletal disorders such as stress fractures, low back pain and chronic hip pain due to arthrosis (2).

Gait asymmetry in subjects with LLD was found manifested throughout the kinetic chain. LLD will result in increased vertical displacement of center of mass that lead to increase in energy consumption. LLD may reduce walking velocity, increase cadence, reduce stance time and step length on the shorter leg. Various compensatory mechanism for LLD were used to reduce energy consumption by minimizing the displacement of body center mass during walking.

Two different groups of compensatory mechanisms were described which are to lengthen the shorter limb or to shorten the longer limb. In order to lengthen a shorter limb, body may increase downward pelvic obliquity, increase knee extension, tip toe or vault. The mechanisms to shorten the longer leg, body may increase pelvic obliquity, circumduction, increase hip and knee extension and ankle dorsiflexion (2). However, there is limit to the compensatory mechanisms, beyond which gait asymmetry is still present.

One of the objective way to measure gait asymmetry is by doing biomechanical analysis via gait analysis study. Gait parameters that had been studied include difference in stance time, rate of loading and vertical ground reaction force (GRF) (6). Vertical GRF is the force exerted by the ground on a body in contact with it. In normal gait, the GRF for both lower limbs should be equal. However, the opinion varies in how much differences in limb length that is significant to cause GRF asymmetry and which limb; the shorter or longer limb will sustain greater load.

Using the GRF vector analysis, Kaufman (7) found that LLD more than 2cm caused gait asymmetry. Bhave (6) reported that LLD can cause asymmetry in GRF with larger GRF found on the longer limb. After correction of LLD to within 10mm, there were no significant difference in GRF for both limb. In contrast to that, Liu (8) found that acceptable gait symmetries were evidence with mean LLD up to 23.3mm. Brand and Yack (9) demonstrated that artificially induced LLD of 35 and 65mm increased mean intersegmental hip force of the shorter leg.

Apart from gait asymmetry, another important associated musculoskeletal disorders with LLD is low back pain. LLD cause pelvic obliquity in frontal plane and scoliosis with lumbar convexity toward the short leg. These lead to asymmetrical forces on the spine causing early degeneration of the intervertebral disc and facet joint (2). Effect of LLD to hip joint is also well described in the literature. Incidence of hip arthritis is higher in the longer leg due to reduction of weight bearing area of the femoral head (2) . Due to the pelvic tilting, there will be decrease in contact area between the femoral head and acetabulum and increase tone of the hip abductors in the longer leg. These changes lead to increase in the amount of pressure transmitted to the hip of the longer leg (10). Relationship between LLD and reduction of weight bearing area on femoral head was mentioned by Krakovits (11) every 10 mm increase in leg length, there will be 5 percent reduce in the hip contact area.

Although many studies have look into various complications of LLD, none of them specified the sample population height. Whether height can influence the effect of LLD to our body is a relevant question. We wonder whether differences in the available evidence is related to the height of the patient.

We conducted this study to find out the significant LLD that can cause gait asymmetry and the influence of difference in population's height to the effect of LLD. The initial part of this study, we were planning to measure the effect of LLD specifically to hip joint reaction force (JRF) in different height population. However, due to certain problem in the method to calculate hip JRF and time constraint, we decided to focus on the effect of LLD to vertical GRF that can be measured directly from the gait analysis 3D Qualysis® motion camera.

Knowing the significant LLD that can cause gait asymmetry is important as it determine the threshold to treat patients. Method of available treatment varies from shoe insert to operative lengthening of the shorter limb or shortening of the longer limb depending on the patient's age and severity of discrepancy.

Chapter 2

OBJECTIVES OF THE STUDY

2.1. General Objectives

1. To find the effect of limb length discrepancy (LLD) on the gait of volunteers with 170 and 150 cm height.

2.2. Specific Objectives

1. To measure longer leg vertical GRF in 150 and 170 cm height volunteers with different LLD as below

    - without LLD

    -2cm simulated LLD

    - 3cm simulated LLD

    - 4cm simulated LLD

2. To compare the difference of vertical GRF in longer leg of 150 cm height volunteers without LLD with vertical GRF on the longer leg of the following simulated LLD

    - 2cm simulated LLD

    - 3cm simulated LLD

    - 4cm simulated LLD

3. To compare the difference of vertical GRF in longer leg of 170 cm height volunteers without LLD with vertical GRF on the longer leg of the following simulated LLD

    - 2cm simulated LLD

    - 3cm simulated LLD

    - 4cm simulated LLD

4. To find out whether height of volunteers has influence on the effect of LLD over GRF.

Chapter 3

MANUSCRIPT

3.1. TITLE: EFFECTS OF DIFFERENT AMOUNT OF LEG LENGTH DISCREPANCY ON VERTICAL GROUND REACTION FORCE AMONG THE POPULATION WITH HEIGHT OF I50 AND 170 CM

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3.2 ABSTRACT

Introduction: Leg length discrepancy is a known cause of gait asymmetry and can lead to subsequent changes in biomechanics of the lower limb. Although many studies have look into the significant amount of leg length discrepancy that causes problem to the limb biomechanics, none of them specified whether the amount is influenced by height of patients. We conducted this study to determine the effects of simulated leg length discrepancy on vertical ground reaction force in volunteers with different height.

Methodology: This was a cross sectional study involving 14 volunteers with 150 cm height and 14 volunteers with 170 cm height. Vertical ground reaction force were measured using gait analysis study. Reflective markers were placed on bony landmarks of bilateral lower limbs to be captured by 3D motion cameras. Volunteers walked on a straight walkway with a force plate to measure ground reaction force. First measurement was taken without discrepancy as control. Subsequently leg length discrepancy simulated with shoe raise of 2, 3 and 4 cm and vertical ground reaction force were measured repeatedly on the longer leg. Measurement of first and second peak of vertical ground reaction force were taken for analysis separately. Vertical ground reaction force of simulated leg length discrepancy was compared with control. Repeated measures analysis of variance (ANOVA) within each groups' height were done.

Results: In both 150 and 170 cm height volunteers**,** the second peak of vertical ground reaction force in the longer leg reduced gradually when the shoe raise increased sequentially from 2 to 3 cm and then to 4 cm. Three cm discrepancy was statistically significant to cause reduction in vertical ground reaction force on the longer limb with p-value of 0.001 and less in both group of volunteers (150 and 170cm height).

Conclusions: Leg length discrepancy of 3 cm and above caused significant reduction in second peak ground reaction force. It was true for was both 150 and 170 cm height population. Reduction of ground reaction force in the longer leg can be inferred as increment of ground reaction force in the shorter leg, thus it may indirectly cause problem in the joints of shorter leg.

Keyword; *Limb length discrepancy, ground reaction force, height.*

3.3 INTRODUCTION

Limb length discrepancy or leg length discrepancy for lower limb (LLD) is a common problem, found in 45 to 70 percent of general population (1). It can be further classified into structural and functional. Structural LLD is when the difference in leg length is caused by the inequalities in bony structure from head of femur to the ankle. It can be a congenital cause such as in developmental dysplasia of hip or acquired due to trauma or infection. Functional LLD is a physiological response to altered mechanics along kinetic chain from foot to lumbar spine (2). Complications of LLD can be divided into two groups. The first group is functional limitations including gait asymmetry and balance problem and the second group is associated musculoskeletal disorders such as stress fractures, low back pain and chronic hip pain due to arthrosis(2).

Gait asymmetry in subjects with LLD was found to be manifested throughout the kinetic chain. LLD will result in increased vertical displacement of center of mass that lead to increase in energy consumption. LLD may reduce walking velocity, increase cadence, reduce stance time and step length on the shorter leg.

Various compensatory mechanism for LLD were used to reduce energy consumption by minimizing the displacement of body center mass during walking. Two different groups of compensatory mechanisms were described which are to lengthen the shorter limb or to shorten the longer limb. In order to lengthen a shorter limb, body may increase downward pelvic obliquity, increase knee extension, tip toe or vault. The mechanisms to shorten the longer leg are increase of pelvic obliquity, circumduction, increase hip and knee extension and ankle dorsiflexion (2). Thus, clinical significance of LLD depends on amount of discrepancy and the ability of pelvis and spine to make up the inequality (3). Many studies have been conducted in trying to quantify significant LLD and accept as much as 20 to 30 mm discrepancy as compensable by body. Biomechanical effect of LLD less than 3 cm has questionable significance as it can be compensated by postural adjustment (4).

One of the objective way to measure gait asymmetry is by measuring vertical GRF. Vertical GRF is the force exerted by the ground on a body in contact with it. In normal gait, the GRF for both lower limbs should be equal. Increased in GRF may be associated with higher risk of injury to subchondral bone, cartilage and soft tissue (12). During stance phase of gait, there are 2 peaks of vertical GRF observed, the first and second peak. First peak force represent maximum load during heel contact and second peak force represent maximum load during push off.

Based on the GRF vector analysis, a few studies found that LLD between 20mm to 23.3mm caused gait asymmetry (7). Brand and Yack (9) demonstrated that artificially induced LLD of 35 and 65mm increased mean intersegmental hip force of the shorter leg. Although many studies have look into various complications of LLD, none of them specified the sample population height. Whether height can influence the effect of LLD to our body is a relevant question.

We conducted this study to find out the amount of LLD that caused significant vertical GRF changes–in different population's height. The information may guide clinicians in deciding the treatment of LLD especially in short stature patients.

3.4 METHODOLOGY

This was a cross-sectional study carried out at Hospital Universiti Sains Malaysia from a period of 12 months from June 2015 to June 2016. Male volunteers with the height of 150 cm (range of 148 to 152 cm) and 170 cm (range of 168 to 172 cm) with normal BMI (within 18.5 to 24.9) were selected from undergraduate students in Universiti Sains Malaysia and primary school students in Kota Bharu via simple random sampling method. All volunteers had normal gait, normal range of motion of the lower limb joints and no limb length discrepancy. Volunteers with neuromuscular disease such as cerebral palsy, scoliosis or any abnormal joint were excluded from the study.

Sample size was calculated using G*Power version 3.9.1.2 (Faul, Erdfelder, Buchner and Lang, 2009) for planned repeated measures ANOVA within factors. Effect size was set at 0.7 with type 1 error of 5%. Minimum sample size required is 24. This study was approved by the Human Ethical Committee of the School of Medical Sciences, Universiti Sains Malaysia. Fourteen volunteers with 150 cm height and 14 volunteers with 170 cm height were involved in the study. For each volunteers, LLD were simulated for right and left limb. Therefore, 28 limbs studied for 150 cm height volunteers and 28 limbs studied for 170 cm height volunteers.

This study was done in Sport Science Laboratory, Universiti Sains Malaysia for one day to do gait analysis study using 3D Qualisys® motion camera and Qualisys® software. Informed consent were taken. All volunteers wore tight non reflective black pants with canvas shoes that was provided in the laboratory. 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. Only volunteers with no LLD or with LLD less than 1 cm were chosen to continue the study.

Fifteen reflective markers were applied at anatomical bony landmarks: fifth metatarsal head, heel, most prominent part of lateral malleolus, lateral side mid shaft tibia, lateral femoral epicondyle, lateral side mid shaft femur, anterior superior iliac spine and sacrum to be captured by camera. All the markers were applied bilaterally except for the sacrum.

Before the measurements, all volunteers performed walking trials for 15 meters on a straight walkway to familiarize with the procedure and the shoe raise to establish their natural gait. The 400 x 600 mm force plate was calibrated before measurement started. Immediately after familiarization, volunteers walked along 6 meters length straight walkway with single force plate at their self-selected walking speed. The walkway located approximately equidistance from the six cameras placed around the laboratory (figure 2). Camera captured the reflective markers when the longer legs stepped on the force plate. Longer legs were chosen to be analyzed as they were considered as the abnormal leg.

Three different simulated LLD (shoe raised of 2, 3 and 4 cm) were created for each volunteers using rubber foam (figure 1). Measurements without shoe raised were taken as control. Mean of vertical GRF of 28 limbs for each LLD (2, 3 and 4cm) were compared for each group of volunteers height (150 and 170 cm).

Data were gathered from the force plate and camera at a frequency of 200 Hertz. The force plate was connected by a charge amplifier to a computer for data collection. Using the Qualisys Software, vertical GRF graph were plotted. It had ‘M’ curve shape. During the initial phase of heel contact, the force was zero and then rapidly increased forming the first peak of vertical GRF (first peak force) when the body supported by foot. When the gait cycle progressed, at the mid stance phase, the force reduced as evident by deceleration in the graph. Towards the end of stance phase, the push off phase, the force rapidly increased again forming the second peak of vertical GRF (second peak force). When the cycle reached toe off, the force reduced to zero. These first and second peak force from the vertical GRF graph for were taken for analysis (Figure 3).

Statistical Packages for Social Science [SPSS]® version 20.0 were used for data analysis. All data were checked and cleaned. Repeated measures analysis of variance (ANOVA) within factors were used to compare mean between these four groups of shoe raise; control group (no shoe raised), 2cm, 3cm and 4cm for each 150 cm height group and 170 cm height group. If significant, post hoc test is performed for detailed analysis. Confidence interval was set at 95% with p-value of less than 0.05 considered significant.

3.5 RESULTS

Volunteers in 150 cm height group aged between 9 to 11 years old and volunteers in 170 cm height group aged between 20 to 27 years old. All volunteers had normal body mass index (BMI) from 18.5 to 24, normal joints of the lower limbs, normal gait and no limb length discrepancy of more than 1 cm.

In 150 cm height group, mean first peak force were 426.69 N for control group (no shoe raise), 433.27 N during 2 cm shoe raise, 425.99 N during 3 cm shoe raise and 430.22 N for 4 cm shoe raise on the longer leg. It was found that the differences of force were not statistically significant when the shoe raise increased gradually from 2 to 4cm (Table 1).

The highest second peak force of the longer leg occurred in the control group (no shoe raise) (411.60 N). The force on the longer leg then reduced progressively when the shoe raise increased to 2 cm (398.61 N), followed by 3 cm (390.02 N) and further down during 4 cm shoe raise (381.04 N). Mauchly's test of sphericity showed significant result with p-value of 0.03. Multivariate analysis showed significant difference of mean second peak force of vertical GRF between these four groups of shoe raise with p-value of less than 0.001 (Table 2). Pairwise comparison was done to find significant relationship between groups with confidence interval 95% adjusted by Bonferroni. It was found that, there were significant reduction in the force on the longer leg between control and 3 cm shoe raise, control and 4 cm shoe raise and 2 and 4 cm shoe raise with p value of 0.001 and less. The difference however not significant between control and 2 cm, 2 and 3 cm and 3 and 4 cm of shoe raise with p value more than 0.05 (Table 3).

In 170 cm height group, for the first peak force, it was found that, the highest force of longer leg occurred in the control group (670.62 N) and declined progressively during 2 cm (664.58 N) followed by 3 cm (657.84 N) of shoe raise. However, it showed slight increment in

4 cm (661.57 N) shoe raise as compared to 3 cm. Mauchly's test of sphericity showed significant result with p-value of 0.01. However, the multivariate analysis showed no significant difference in the first peak force between control, 2 cm, 3 cm and 4 cm shoe raise group with p-value of more than 0.05 (Table 1).

The highest second peak force of longer leg occurred in the control group (689.64 N) and declined progressively following order from 2 cm (680.54 N) to 3 cm (661.44 N) and further down in 4 cm (656.86 N) shoe raise in the longer limb. Mauchly's test of sphericity showed significant result with p-value of 0.007. Multivariate analysis showed highly significant difference of second peak force between these four groups of shoe raise with p-value of less than 0.001 (Table 2). Pairwise comparison showed significant reduction in force between control and 3 cm shoe raise, control and 4 cm shoe raise, 2 and 3 cm shoe raise and 2 and 4 cm shoe raise, all with p-value of less than 0.001. However, there was no significant difference in force between control and 2 cm shoe raise with p-value of 0.089 (Table 4).

Comparing between these 2 groups height, it was found that the mean first and second peak force of vertical GRF in the longer leg in 150 cm group were lower as compared to the force in 170 cm group. Mean first peak force for 150 cm height were 429.04 N and mean second peak force were 395.32 N. In 170 cm height group, mean first peak force were 663.65 N and mean second peak force were 672.12 N (Table 5). However, for the second peak force, for both height groups, there were consistent progressive reduction of force in the longer leg when shoe raise increase sequentially from 2 cm to 3 cm and 4 cm. Similarly, the differences were statistically significant between control and 3 cm, control and 4 cm and between 2 and 4 cm of shoe raise in both 150 cm and 170 cm height volunteers.

3.6 DISCUSSION

The knowledge on the amount of significant discrepancy that causes gait asymmetry and biomechanical changes to body is therefore critical. Previous studies on determination of the minimum discrepancy that can cause problems such as gait asymmetry, effect on facet joint arthritis or energy consumption did not mention-height of their study population. In our study we specified the sample population into the 150 cm height group and 170 cm height groups, to find whether the significant amount of LLD is different in different height of patient. We focused on the effect of LLD to vertical GRF, using simulated LLD. The first and second peak of vertical GRF, were proven to be predictive for quantification of gait asymmetry (7). Ground reaction force (GRF) is the force exerted by the ground on a body in contact with it (13). For example, a person standing motionless on the ground exerts a contact force on it (equal to the person's weight) and at the same time an equal and opposite ground reaction force is exerted by the ground on the person. The first peak occur during the heel strike while the second peak occur during push off with action of calf muscle. Simulated LLD causes changes in the gait pattern similar to patients with real discrepancy (14). In this study, vertical GRF were measured three times for every shoe raise for both limbs to get the mean force to strengthen the accuracy of the finding. The GRF were measured and compared in different persons and different limbs in order to address different ability of persons in adapting LLD.

This study did not show any significant difference of first peak vertical GRF between control group (no shoe raise) and the longer leg. During the first peak, double foot support occurred during heel strike that caused wider distribution of body weight. Therefore we did not find the effect of LLD to the first peak force of vertical GRF.

We have found the second peak of GRF on the longer leg were gradually reduced when the shoe raise increased. The different started to be statistically significant between control and

3 cm shoe raise for both height groups. It can be concluded that, the minimum discrepancy that caused significant changes in vertical GRF in the longer leg among normal BMI population of adult patients with height of 170 cm height was 3 cm. This findings is comparable with a few other studies. Kaufman et al (7) studied magnitude of discrepancies that can cause gait abnormalities had found significant changes of GRF when LLD more than 2 cm. Bhave et al (6), who studied improvement in gait parameters including GRF after lengthening, found that there was no significant difference in GRF between legs after equalization of limb length within 1cm. Liu et al (8), after performed analysis on symmetry index with GRF and a few other parameters, concluded that acceptable gait symmetry could be observed with discrepancy of 23.3mm. Study on hip joint reaction forces also found that 35mm discrepancy altered hip forces but 23 mm discrepancy did not alter it (9). These similar findings suggested that discrepancy as small as 2 cm can be compensated by body.

Our study showed that in second peak force for both groups height, there were progressive reduction of vertical GRF in the longer leg from 2, 3 to 4 cm of shoe raise. The reduction was statistically significant from control to 3 cm and from control to 4 cm shoe raise. The reduction were however not significant between control and 2 cm shoe raise. It can be concluded that the higher the LLD, the lower the vertical GRF in the longer leg. Whether progressive reduction in vertical GRF in the longer leg with increase amount of discrepancy can be inferred as progressive increment of vertical GRF in the contralateral shorter leg with increment of discrepancy is to be proven. We assumed that there will be progressive increment of vertical GRF in the shorter leg when discrepancy increased. This was supported by White et al (15) and Pereira et al (16), who compared GRF directly in shorter and longer leg using 2 force plates. The reduction of force in the longer leg will be accompanied by increment of force in the shorter leg.

There have been many studies stated that longer leg has less GRF. Brand and Yack (9) simulated LLD of 2.3, 3.5 and 6.5 cm in normal subject, found that mean peak intersegmental hip force decreased significantly in longer leg after 3.5 and 6.5 cm lifts. White et al (15) who compared asymmetry in limb loading with LLD subjects using GRF parameters, found that the shorter limb sustained higher proportion of load and loading rate. Pereira et al (16) documented that there were significantly higher second peak force of GRF at the shorter leg among runners with LLD. In term of biomechanic, greater loading of the short limb should be expected. This is because during transition of stance from longer limb to shorter limb, the step down difference is more than the opposite. Therefore, weight acceptance forces in the shorter limb become higher due to the transfer of body weight from a greater vertical height (17). The other possible explanation of these findings is related to the stance time. It is reported that in the presence of LLD, the longer leg will have greater stance time as compared to the shorter leg. Greater stance time contributes to smaller vertical GRF(18).

Increment of vertical GRF in the shorter leg may produce problem to the joints of the shorter leg much earlier than the longer leg. There is high risk of injury to the subchondral bone, articular cartilage and soft tissue of the joints with higher GRF (12).

In order to answer our final and most important objective, whether volunteers' height has influence on the effect of LLD over GRF, we compared volunteers with the height of 150 and 170 cm, with normal BMI and found that the changes in the second peak force of vertical GRF on the longer leg were similar. In both groups, 3 cm discrepancy and above were significant to alter vertical GRF in the longer leg, therefore the threshold for treatment is the same for both group. However, whether similar result can be found in younger age group with shorter height is still a question. We feel in the shorter height group, smaller amount of LLD may cause significant changes in vertical GRF due to higher percentage of LLD from height. Thus we propose further study to be conducted on shorter group of patients.

Relationship between GRF and hip and knee joint reaction force had been studied. Randall L.J studied the relationship between GRF and knee joint reaction force during jump landing, found that the value of GRF were significantly higher than knee joint reaction force. Regression analysis showed a linear relationship between GRF and knee joint reaction force in which GRF data can be used as viable alternative to assess knee joint reaction force (19). However for hip, relationship between GRF and hip joint reaction force is more complex. Due to pelvic tilting in LLD, contact area between the femoral head and acetabulum will decrease and the tone of the hip abductors will increase in the longer leg. These changes lead to increase in the amount of pressure transmitted to the hip of the longer leg (10). Relationship between LLD and reduction of weight bearing area on femoral head was mentioned by Krakovits (11) every 10 mm increase in leg length, there will be 5 percent reduction in the hip contact area. Therefore, linear relationship between GRF and hip joint reaction force in LLD cannot be concluded.

Limitations of this study is that the comparison between the shorter and longer limb were made indirectly by using the leg without LLD as control, using one force plate that available in our laboratory. It would be ideal if the comparison is done directly between shorter and longer legs by using 2 force plates. Even though GRF has been shown to correspond the most to gait deviation, it is very sensitive to any action or reaction that can alter the GRF vector such as arm lifting that can reduce the peak force (17).

Finally, it is recommended that another study conducted to measure vertical GRF in LLD for population with shorter height and the difference in simulated LLD and comparison can be made with the current findings. Effects of LLD to specific joint reaction force to hip, knee and ankle are also another scope of study and the result can be compared to specific height group.

3.7 REFERENCES

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3.8 TABLES AND FIGURES

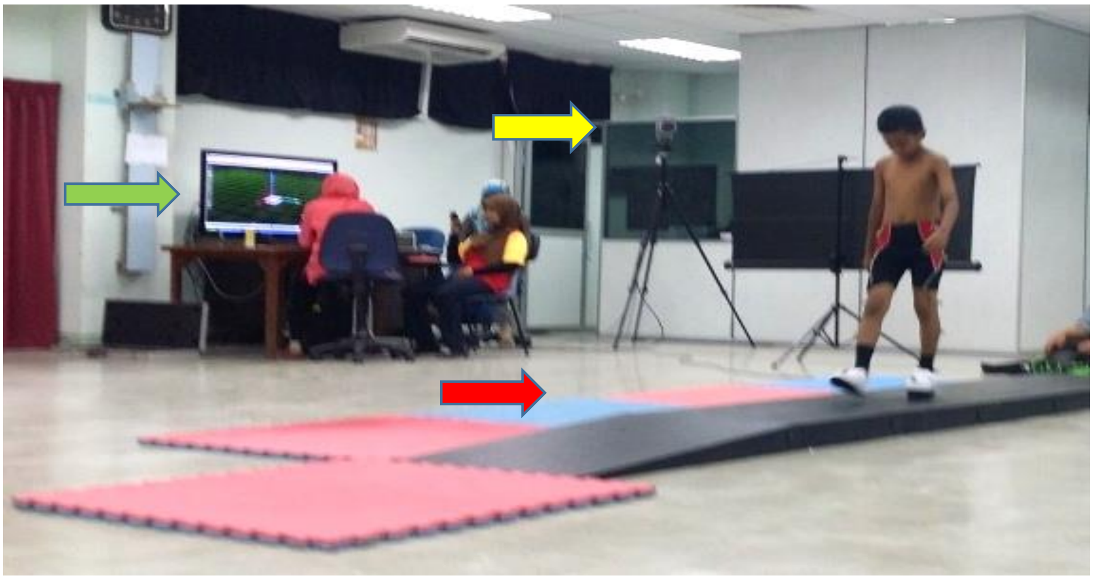

Figure 1- Volunteer walk along 6 meters platform in laboratory. Red arrow: six meters platform with force plate at the center. Yellow arrow: One of the 6 3D motion camera used to capture images. Green arrow: Image showed in the Qualisys software.

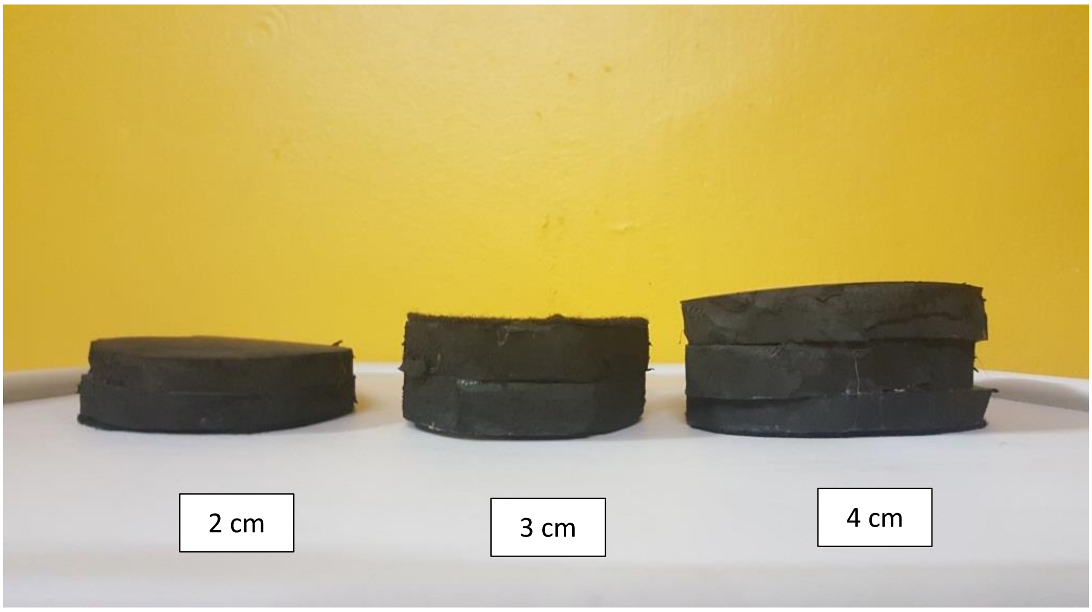

Figure 2- Shoe raise made of rubber foam with different thickness. The above surface glued to Velcro, to allow attachment to shoes.

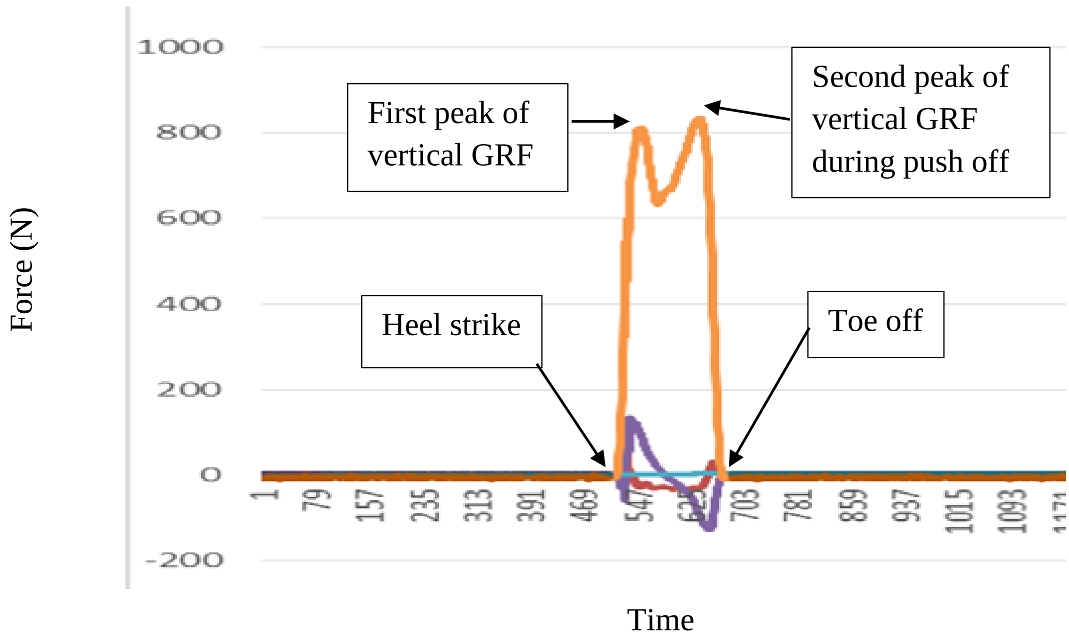

Figure 3. Ground reaction force graph of longer limb plotted in one limb had typical ‘M’ shape curve.