EFFECTS OF SIMULATED LIMB LENGTH DISCREPANCY ON THE AMOUNT OF PELVIC MOVEMENT ACROSS DIFFERENT HEIGHT GROUPS

DR. CHUA WEI SIONG

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Dr Chua Wei Siong

MMed Orthopaedics

Department of Orthopaedics

School of Medical Sciences, Universiti Sains Malaysia

Health Campus, 16150 Kelantan, Malaysia

Introduction and objectives:

Limb length discrepancy causes pelvic tilt and excessive pelvic movement which subsequently change the biomechanics of hip and spine.

We conducted the study to determine the effects of simulated limb length discrepancies on pelvic movement throughout the gait cycle in different height groups. It also investigated the amount of longer limb knee flexion as a form of compensation to simulated limb length discrepancy

Methodology:

This is a cross sectional study of 30 normal volunteers, with 10 each in height groups of 130,150 and 170 cm. They were made to walk without shoe raise followed by 1, 2, and 3 cm shoe raise on one side to simulate leg-length discrepancy. The amount of sagittal and coronal pelvic movement throughout the gait cycle was recorded by 3D cameras via reflective markers placed on bony pelvic and lower limb landmarks. The amount of pelvic motion was taken as the difference from the peak and the trough of the pelvic angle graph. The amount of maximum knee flexion was also assessed in the similar way. The analysis within and between groups were analysed using repeated measure analysis of variance.

Results:

There were no significant differences in the mean of sagittal (P-0.67) and coronal (P-0.38) pelvic movement among the individuals with simulated limb length discrepancy between 1 cm to 3 cm . Similar findings were found on volunteers with height between 130 to 170 cm with a range of simulated limb length discrepancies between 1.9% to 7.7% of the lower limb. Mean amount of knee flexion (P-0.93) throughout the gait cycle was no different between all the studied height groups.

Conclusion:

Various simulated limb length discrepancy of 7.7% or less of the lower limb length did not cause a significant different in amount of coronal and sagittal pelvic motion in subjects between 130 to 170 cm height. Inconsistent amount of knee flexion as compensation of different simulated limb length discrepancies indicate that other parts also contribute to the compensation.

Associate Professor Abdul Razak Sulaiman: Supervisor

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

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ABSTRAK

Pengenalan dan objektif

Perbezaan panjang anggota bawah menyebabkan pergerakan berlebihan tulang pelvis semasa berjalan dan seterusnya mengakibatkan perbezaan terhadap biomekanik tulang belakang dan pelvik.

Kami menjalankan kajian ini untuk menunjukkan kesan perbezaan panjang anggota bawah terhadap pergerakan tulang pelvis semasa berjalan di kalangan kumpulan ketinggian berbeza. Dalam kajian ini juga kami menyelidik julat sudut sendi lutut anggota yang lebih panjang sebagai mekanisme pampasan untuk perbezaan panjang anggota bawah.

Metodologi :

Ini adalah satu kajian keratan rentas melibatkan 30 sukarelawan yang normal dengan 10 subjek dalam setiap kumpulan ketinggian 130, 150 dan 170 cm. Mereka mula mula berjalan tanpa perbezaan panjang anggota dan seterusnya dengan kasut tinggi sebelah sebanyak 1,2 dan 3 cm untuk mensimulasikan perbezaan panjang anggota bawah. Julat pergerakan tulang pelvis di paksi sagital dan koronal sepanjang masa berjalan dikaji menggunakan kamera 3D yang mengesan tanda-tanda pada tulang pelvis dan tanda-tanda utama lain pada anggota bawah. Julat pergerakan tulang pelvis dikenal pasti sebagai perbezaan antara sudut maxima dan minima kedudukan tulang pelvis. Julat pergerakan sendi lutut juga dikenalpasti dengan cara yang sama.

Keputusan:

Tiada perbezaan yang jelas dari segi statistik dikenalpasti antara purata pergerakan tulang pelvis paksi sagital (p-0.67) dan coronal(P0.380) antara individu dengan ketidaksamaan panjang anggota bawah antara 1 hingga 3 cm. Pada masa yang sama, tidak terdapat juga perbezaan dalam sukarelawan yang tingginya di antara 130 hingga 170cm dengan ketidaksamaan panjang anggota bawah di antara 1.9% hingga 7.7% panjang anggota bawah. Purata julat sudut pergerakan sendi lutut(p-0.93) sepanjang masa berjalan adalah tidak berbeza yang jelas dari segi statistik dalam kalangan kumpulan ketinggian yang dikaji.

Kesimpulan:

Semua ketidaksamaan panjang kaki anggota bawah yang peratusnya 7.7% ke bawah dari jumlah panjang anggota bawah tidak menunjukkan perbezaan yang signifikan dalam julat sudut pergerakan tulang pelvis dalam subjek yang tingginya di antara 130 ke 170cm. Julat sudut sendi lutut yang tidak konsisten sebagai mekanisma pampasan apabila dikenakan kasut tinggi sebelah menunjukkan bahawa terdapatnya mekanisma pampasan yang lain semasa berjalan.

CHAPTER 1: INTRODUCTION

1.1 Background of Study

Clinical significance of LLD may depend on several factors, including the amount of discrepancy, and the ability of the pelvis and spine to make up for the inequality (Manello et al (1991). There has been contradicting evidences on how much LLD would cause clinical problem. McCaw et al (1991) says that the effect of a LLD of less than 30 mm on gait and posture has questionable significance. Kaufman et al (1996) which studies gait symmetry shows that a LLD of more than 20 mm resulted in a gait asymmetry greater than that of observed in the general population. Gross et al (1983) studies 35 male marathon runners and found that there is no functional detriment in LLDs up to 25 mm.

Walsh et al (2000) finds that the pelvic obliquity is the most common form of compensatory mechanism up to 22 m of limb length discrepancy. The pelvic obliquity will decrease in area of contact between femoral head and acetabulum as well as an increase in tone of the hip abductors secondary to an increased distance between origin and insertion. Based on this explaination, Morsher et al (1977) describes that a greater amount of pressure is transmitted through the hip of the longer leg. In addition to that, increase of ground reaction force on longer leg make the right hip at risk of pathology. (Gurney, et al, 2002). Gofton et al (1971) studied 67 patients with osteoarthritis of the hip, and of these, 36 of them has a superolateral type of osteoarthrtitis. These 36 subjects are found to have significant leg-length disparity. Brunet et al (1990) studies 1493 runners and found that complaint of hip pain is over twice as common in subjects with LLD as compared to those without.

Cummings et al (1993) concluded in their study that the total pelvic mobility ranged from 2 to 6 degrees with unilateral lifts ranging from 2/8 to 7/8 inches. The amount of tilt is dose related meaning with each increase in shoe raise the pelvic angular tilt will rise in tandem.

However, Walsh et al (2000) describes knee flexion as a form of compensation on the longer side of the leg when the LLD is more than 2.2 cm. This was supported by Needham et al (2012), who found the reduction in pelvic obliquity at 3 cm LLD and conclude that it was due to compensatory knee flexion.

1.2 Rationale of the Study

All these studies never mention about the height of the study population. We would like to confirm the amount of LLD that causes compensatory mechanisms such as pelvic movement and longer limb knee flexion. In order to help in making decision on treating short population, skeletal dysplasia patient or children, we create model of LLD using shoe raises on different height of population. By doing this we hope to find; (1) the amount of LLD that causes knee flexion compensation to occur in different height of population.(2) how would the given same LLD affect different height groups.

CHAPTER TWO: LITERATURE REVIEW

2.1 Longer leg knee flexion with shoe raise

The amount of literature describing knee flexion is limited to two studies so far.

One of them is Walsh et al (2000) which describes knee flexion as a form of compensation on the longer side of the leg when the LLD is more than 2.2 cm while Needham et al (2012) in their study mentions in an indirect manner that the reduction in pelvic obliquity at 3 cm LLD is due to compensatory knee flexion. However point to note is that Needham et al (2012) does not have data to back up this claim.

Seeley et al (2010) studied 26 subjects and compared those with less than 10 mm LLD to those with more than 10 mm LLD. He found that there were no significant changes in the angle of the knee flexion, although he found that there was an increase in knee and ankle joint moments.

2.2 Pelvic tilt with shoe raise

There are several literatures correlating pelvic tilting with LLD. Majority of the studies show how the pelvic tilt with shoe raise during the standing .Pitkin et al (1936) found that a 1.5 inch elevation causes the pelvis on the lengthened side to rotate posteriorly and the contralateral side to rotate anteriorly. This finding is consistent with other literatures studying the effect of limb lengthening on pelvic rotation (Cummings, et al, 1993; Beaudoin, et al, 1999). Pitkin et al (1936) found that there is an average tilt of 11 degrees of the pelvis with shoe lift with 1.5 inch elevation.

Cummings et al (1993) concluded in their study that the total pelvic mobility ranged from 2 to 6 degrees with unilateral lifts ranging from 2/8 to 7/8 inches while standing. The amount of tilt is dose related meaning with each increase in shoe raise the pelvic angular tilt will rise in tandem.

Beaudoin et al (1999) utilises video cameras with reflective markers to determine the postural responses to a shoe lift of 1.5cm. In this study, it shows a tight correlation between leg elevation and pelvic innominate rotation. It is found that there is a 3 degree of posterior rotation. However there is no calculation of the different amount of pelvic rotation with differing shoe raises.

In the study of Young et al (2000), pelvic tilt was measured with an inclinometer using bubble technology. In his study, when one side was lifted with at least a 15mm lift, a corresponding pelvic tilt of 1.2 degrees is found.

Needham et al (2012)studied seven male participants and finds that in simulated limb length discrepancies during walking from being barefoot to 3 cm LLD, the pelvic obliquities are 2.67, 5.29 and 3.95 degrees respectively, attributing the decrease of pelvic tilt due to knee flexion. Each of the subjects had 17 reflective markers placed all over the pelvis and the spine and the data is captured via an eight camera motion capture system. In this study however, no reflective markers were placed over the knee, questioning the validity of the attribution of knee flexion influencing the decrease in pelvic tilt.

Walsh et al (2000) studied seven normal subjects using CODA MPX 30 analyser to analyse the gait in 3D. The subjects are fitted with lifts of varying heights and finds that the pelvic obliquity is the most common form of compensatory mechanism up to 2.2 cm of limb length discrepancy.

2.3 Effects of limb length discrepancy

2.3.1 LLD and low back pain

In the establishing of the correlation of LLD with low back pain, there appears to be conflicting findings. Fann et al (2002) compares the extent of pelvic obliquity and lateral sacral base angle between subjects with and without chronic back pain using postural radiographs and showed that the Z scores has no significant statistical differences. Levangie et al (1999) shows a weakly positive association between posterior superior iliac spine asymmetry and low back pain. Soukka et al (1991) compared symptom free patients with those with disabling low-back pain for the past 12 months and found that there is questionable significance between these two group's LLD.

In contrast, Knutson et al (2002) tried to link patients with supine leg length alignment asymmetry and the incidence of back pain. He recruited volunteers with chronic low back pain and gave assessed their pain on a visual analogue scale. An independent chiropractor who is blinded to the back pain examines for supine leg length alignment asymmetry. It is found that the pain score on the visual analogue scale was higher on the leg length asymmetry group compared to those without asymmetry ($P<0.01$). Friberg et al (1983) took 798 patients with chronic and therapy resistant low back pain and finds the proportion with leg length equality. He found in his study that up to 89%of these patients had chronic or recurrent sciatic pain on the longer side of the leg. He went on to correct the discrepancies with adequate shoe lifts and found that he was able to alleviate most symptoms of back pain in most patients.

2.3.2 LLD association with knee and hip osteoarthritis

Golightly et al (2007) isolated subjects with knee and hip osteoarthritis and found that participants with LLD are more likely than those without LLD to have radiographic knee osteoarthritis(45% vs 28.3%, P<0.01) and hip osteoarthritis (35.2% vs. 28.7%, P.0.063), with the latter being less significant. This is done after controlling other variable including gender, race, age and BMI. The amount of LLD was not specified.

Gofton et al (1971) studied 67 patients with osteoarthritis of the hip, and of these, 36 of them has a superolateral type of osteoarthrtitis. These 36 subjects are found to have significant leg-length disparity.

Brunet et al (1990) studies 1493 runners and found that complaint of hip pain is over twice as common in subjects with LLD as compared to those without.

2.3.3 Increment in joint forces with LLD

Based on a study by Morsher et al (1977), he describes that a greater amount of pressure is transmitted through the hip of the longer leg due to both decreased in area of contact between femoral head and acetabulum as well as an increase in tone of the hip abductors secondary to an increased distance between origin and insertion. Similarly findings of reduced femoral acetabular head contact surface area coupled with an increase of ground reaction force suggest the longer lower limb to be at risk of hip pathology. (Gurney, et al, 2002)

Williams et al (1987) in his study says that a larger ground reaction force was consistently found in the longer leg. Based on a study on subjects with an artificially induced LLD of 23, 35 and 65 mm, Brand et al(1996) found that 35 and 65mm lifts increased mean peak intersegmental resultant hip forces of the short leg by 2% and 12% respectively.

Bhave et al (1999) took 18 patients with true LLD and compared the ground reaction force between the longer and shorter leg. The mean LLD of this group was 4.9 cm. Before any intervention is done to correct the LLD, he measured the ground reaction force using a force plate and found a significant increase in ground reaction force of subjects with a true LLD. The increase of ground reaction force is found on the longer side. After leg lengths were corrected with surgical intervention within 10 mm, the gait analysis was repeated and it was found that there is no significant ground reaction force between legs.

2.4 Clinically significant LLD

Based on a study on leg length inequality and its biomechanical significance, Manello et al (1991) highlights that clinical significance of LLD was maybe dependant on several factors, including the amount of discrepancy, and the ability of the pelvis and spine to make up for the inequality. Most literature will examine the existence of LLD and show the absence of clinical significance when the discrepancy is under a certain magnitude. To begin with McCaw et al (1991) says that the effect of a LLD of less than 3 cm on gait and posture has questionable significance while Kaufman et al (1996) which studies gait symmetry shows that a LLD of more than 20 mm resulted in a gait asymmetry greater than that of observed in the general population. Gross et al (1983) took 35 marathon runners and looked for the existence of leg length discrepancy. He found that there is no 18 runners had a LLD of less than 5mm, 10 had a difference of 5-9mm and 7 had more than 1cm leg length discrepancy. He concluded that up to 25 mm leg length discrepancy is not necessarily a functional detriment to marathon runners and cannot conclude on the benefits of a use of a shoe lift.

Amongst the correlations studies is the link of LLD induced post operatively with a clinical outcome. Gibson et al (1983) followed up 15 patients with previous femoral fracture up to ten years. These group had a mean LLD of 3cm (1.5 to 5.5cm, and it was found that there was no presence of significant discomfort, degenerative changes or structural abnormalities. Edeen et al (1995) followed up 68 patients post operatively for hip surgery for up to 6 years and were not able to show a correlation between LLD and low back pain. These groups had a mean LLD of 9.7mm. Parvizi et al (2003) did a retrospective study of 6954 total hip arthroplasties over a 7 year period and found only 21(0.3%) of patients with severe symptoms such as back and hip pain that require a second surgery to equalize the leg length. The mean LLD in this group is 3.6cm.

In limited literature of LLD in children, of those is described by Yrjonen et al (1992) is regarding LLD in children with Perthes disease. 81 patients with a mean LLD of 12 mm were followed up for an average of 35 years. It is found that most patients had no back pain, and the conclusion that there was no correlation between LLD due to Perthes and low back pain. In Papaioannou et al (1982), a follow up of adults since childhood with a mean LLD of 29.1mm, shows there was no complaints of back pain or degenerative changes.

However Friberg et al(1983) finds that the within the population in the military hospital, there was at least 5mm LLD in 75% of subjects with chronic low back pain, as opposed to 43.5% of controls. This was statistically significant ($p<0.01$) with a chi square test.

2.5 Physiological changes and adaptations in leg length discrepancy

The effects of LLD on physiological function have also been numerously studied due to the postulation that it affects, structure, coordination, asymmetry and hyper tonicity. (Travell,et al, 1999). Mincer et al (1997) compared 15 patients with LLD to another 15 as the control group. In this study, the author tested muscle fatigue by repetitive flexion and extension of the trunk. It is found that no difference was detected in variance of excursion into rotation, lateral flexion or in the number of repetitions.

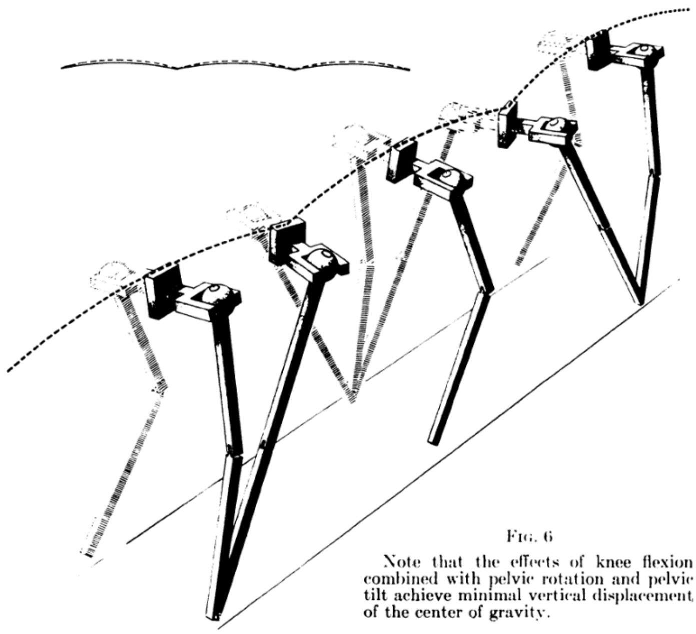
A study tested muscular performance on trunk extension by subjecting a group of young men with up to 1.5 cm of shoe lifts. The result shows there was no statistical significant difference between the two tested groups. (Yen et al, 1998)

Murell et al examined standing balance between groups with LLD of at least 9.5 mm with those without LLD and found that there is no difference. They concluded that this is probably due to long term adaptation by the patient's neuromuscular system.

When there is an artificial discrepancy that is greater than 20mm, Gurney et al (2001) found that there is greater energy consumption, significantly greater heart rate, significantly greater minute ventilation and a reported a higher rate of perceived exertion particularly in those with artificial LLD of 30 and 40 mm compared to no LLD.

2.6 Major determinants of gait in reduction of energy consumption

As early as 1953, Sanders et al showed that there are 6 major determinants that aid in the reduction of energy consumption during gait, aka increasing gait efficiency. They are pelvic rotation, pelvic tilt, knee flexion, foot and ankle motion, knee motion and lateral displacement of pelvis. These move in tandem during walking to reduce the centre of gravity of an able-bodied person.



Adapted from Saunders et al(1953): The major determinants in normal and pathological gait.
Figure 1: Knee flexion with pelvic movement to minimise vertical displacement of the centre of gravity

The act of knee flexion combined with pelvic rotation and pelvic tilt work together to achieve minimal displacement of the centre of gravity (Saunders et al, 1953).

2.7 Gait analysis

There exist numerous research starting as early as 1936 where Pitkin et al(1936) used calipers and a pendulum to detect the amount of pelvic tilt (Figure 2). As technology advances, more modalities could be measured. In 1993, Cummings et al (1993) when studying the effects of simulated LLD on pelvic movement, used waterloo spatial motion recording technique to capture infrared markers placed on our bodies (Figure 3).

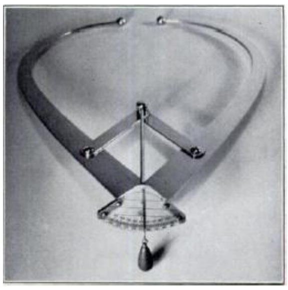


Illustration adapted from Pitkin et al(1936)

Figure 2: Calipers and Pendulum to measure pelvic tilt

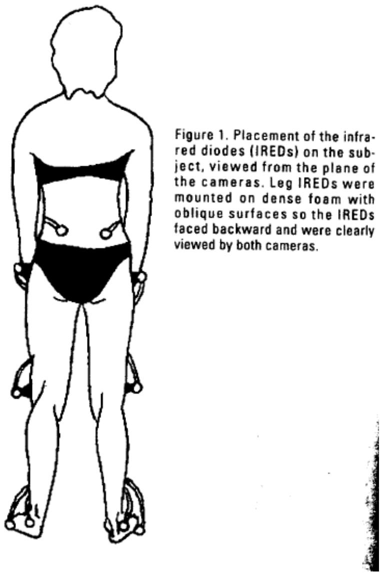


Illustration adapted from Cummings et al(1993)

Figure 3: Infrared diodes attached to body landmarks

Kaufman and colleagues in 1996 uses force plates to measure the contact time, first and second vertical force, peak loading/unloading as mean to detect asymmetry in subjects with true LLD.

Walsh et al (2000) measured the outcomes of pelvic tilt and knee flexion in a rather indirect way. When subjected to shoe lifts, they used a CODA MPX 30 system to do a static analysis on the body and derive the knee flexion and pelvic movements using mathematical models.

In studying the effect of simulating leg length inequality on pelvic torsion, Young et al (2000) used an inclinometer with a bubble level to measure the amount of pelvic torsion when subjected to a shoe raise (Figure 4). Krawiec et al (2003) used a similar device called the Palpation Meter (PALM) to detect static innominate rotation.

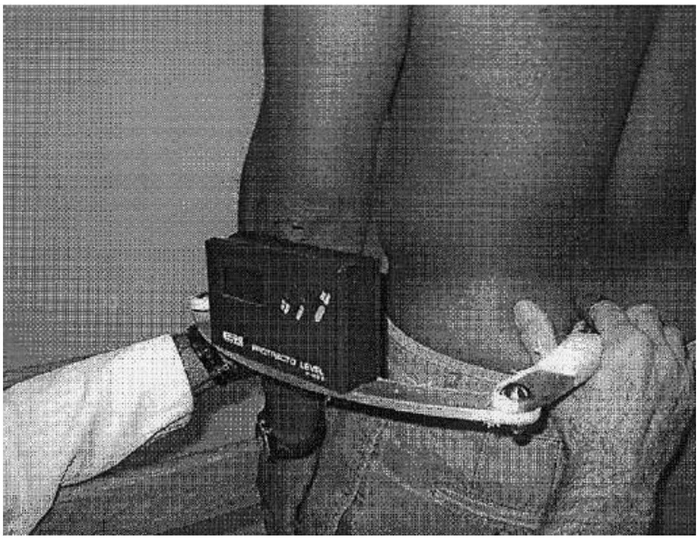


Illustration adapted from Young et al (2000)

Figure 4: Inclinometer with bubble level to measure pelvic tilt

Pertunnen et al (2002) in studying asymmetrical gait patterns in moderate LLDs, they used force platforms with photocells. The insoles of the shoes are also fitted with 16 transducers on each side. For measuring the amount of skeletal muscle contraction, EMGs were applied to the lateral side of the gastrocnemius, vastus medialis, and rectus femoris. In more recent studies, the force over the limbs when walking were detected using pressure sensitive gait carpet(GaitRite Inc)((Cole et al 2014)

In a study to to examine the effects of artificial LLD, Betch et al (2011) used rastersterography to study the effects of LLD on pelvic torsion and spine deviation.

Beaudoin and colleagues in 199 were one of the earliest to use reflective markers placed over the body to detect postural changes from head to toe when these subjects were introduced shoe lifts. The changes in marker movements are detected by 8 3D cameras. Other researchers who adapted this method of gait analysis include Seeley et al (2010), and Needham et al(2012)

2.8 Management of Leg Length Discrepancy

The management of LLD differs in children compared to that of an adult. In children, often they are picked in the midst of their growth and its current LLD does not reflect the true LLD. The three factors that need to be addressed individually include the current LLD, chronological age and skeletal age. Using these three factors, one can roughly deduce the predicted LLD at skeletal maturity, and hence formulate a feasible plan to provide optimal outcome to the patient (Moseley, 2006).

The modalities of management of LLD include shoe inserts, limb lengthening, epiphysiodesis and/or shortening (Table 2). However there still exists disagreement regarding the appropriate treatment.

Reid et al (1984) suggested the following management after dividing them to certain groups:

Mild LLD	0-30mm	Non-surgical
Moderate LLD	30-60mm	Case by case basis
Severe LLD	>60mm	Surgical intervention

Table 1: Severity of LLD

Moseley (2006) went on to elaborate further on the definitive management of LLD and it is summarized in the table below:

0-20mm LLD	No treatment
20-60mm LLD	Shoe lift/epiphysiodesis
60-200mm LLD	Lengthening with or without other procedures
>200mm LLD	Prosthetic fitting

Table 2: Recommendations of management for LLD

Among all these studies, the outcome to show gait asymmetry include change in force, knee flexion, pelvic obliquity and spine kinematics in the adult population. However there does not exist literature showing how LLD affects different height groups.

CHAPTER THREE: OBJECTIVES AND HYPOTHESIS

3.1 General Objectives

To determine the effect of different amount of LLD on the pelvic movement and longer limb knee flexion among simulated LLD across different height groups

3.2 Specific objectives

1) To determine the changes in the amount of sagittal and coronal pelvic movement throughout gait cycle with 0, 1, 2 and 3cm shoe raise in the 128-132 cm height group

2) To determine the changes in the amount of sagittal and coronal pelvic movement throughout gait cycle with 0, 1, 2 and 3cm shoe raise in the 148-152 cm height group

3) To determine the changes in the amount of sagittal and coronal pelvic movement throughout gait cycle with 0, 1, 2 and 3cm shoe raise in the 168-172 cm height group

4) To determine the changes in the amount of longer limb knee flexion throughout gait cycle with 0, 1, 2 and 3cm shoe raise in the 128-132 cm height group

5) To determine the changes in the amount of longer limb knee flexion throughout gait cycle with 0, 1, 2 and 3cm shoe raise in the 148-152 cm height group

6) To determine the changes in the amount of longer limb knee flexion throughout gait cycle with 0, 1, 2 and 3cm shoe raise in the 168-172 cm height group

7) To determine the changes in the amount of sagittal and coronal pelvic movement throughout gait cycle with no LLD between 128-132cm, 148-152cm and 168-172 height groups

8) To determine the changes in the amount of sagittal and coronal pelvic movement throughout gait cycle with 1cm LLD between 128-132cm, 148-152cm and 168-172 height groups

9) To determine the changes in the amount of sagittal and coronal pelvic movement throughout gait cycle with 2 cm LLD between 128-132cm, 148-152cm and 168-172 height groups

10) To determine the changes in the amount of sagittal and coronal pelvic movement throughout gait cycle with 3 cm LLD between 128-132cm, 148-152cm and 168-172 height groups

11) To determine the changes in the amount of longer limb knee flexion throughout gait cycle with no LLD between 128-132cm, 148-152cm and 168-172 height groups

12) To determine the changes in the amount of longer limb knee flexion throughout gait cycle with 1cm LLD between 128-132cm, 148-152cm and 168-172 height groups

13) To determine the changes in the amount of longer limb knee flexion throughout gait cycle with 2 cm LLD between 128-132cm, 148-152cm and 168-172 height groups

14) To determine the changes in the amount of longer limb knee flexion throughout gait cycle with 3 cm LLD between 128-132cm, 148-152cm and 168-172 height groups

3.3 Hypothesis Statements

1) There are no significant differences in the changes of the amount of pelvic movement throughout gait cycle with 0, 1, 2 and 3cm shoe raise in the 128-132 cm height group

2) There are no significant differences in the changes of the amount of pelvic movement throughout gait cycle with 0, 1, 2 and 3cm shoe raise in the 148-152 cm height group

3) There are no significant differences in the changes of the amount of pelvic movement throughout gait cycle with 0, 1, 2 and 3cm shoe raise in the 168-172 cm height group

4) There are no significant differences in the changes of the amount of knee flexion throughout gait cycle with 0, 1, 2 and 3cm shoe raise in the 128-132 cm height group

5) There are no significant differences in the changes of the amount of knee flexion throughout gait cycle with 0, 1, 2 and 3cm shoe raise in the 148-152 cm height group

6) There are no significant differences in the changes of the amount of knee flexion throughout gait cycle with 0, 1, 2 and 3cm shoe raise in the 168-172 cm height group

7) There are no significant differences in the changes of the amount of pelvic movement throughout gait cycle at no shoe raise between all three groups

8) There are no significant differences in the changes of the amount of pelvic movement throughout gait cycle at 1 cm shoe raise between all three groups

9) There are no significant differences in the changes of the amount of pelvic movement throughout gait cycle at 2cm shoe raise between all three groups

10) There are no significant differences in the changes of the amount of pelvic movement throughout gait cycle at 3 cm shoe raise between all three groups

11) There are no significant differences in the changes of the amount of knee flexion throughout gait cycle at no shoe raise between all three groups

12) There are no significant differences in the changes of the amount of knee flexion throughout gait cycle at 1 cm shoe raise between all three groups

13) There are no significant differences in the changes of the amount of knee flexion throughout gait cycle at 2cm shoe raise between all three groups

14) There are no significant differences in the changes of the amount of knee flexion throughout gait cycle at 3 cm shoe raise between all three groups

CHAPTER 4: METHODOLOGY

Research Strategy

4.1 Study design

Cross sectional study

4.2 Study area

Sports Science lab, School of Health Sciences, Health Campus, Hospital Universiti Sains Malaysia

4.3 Reference population

Subjects with heights of 128-132cm, 148-152cm and 168-172 cm with no limb length discrepancy. Subjects above the age of 7(mature gait pattern)

4.4 Source population

All subjects with no limb length discrepancy with height of 128-132cm, 148-152cm and from SK Mekasar, Pasir Mas

All subjects with no limb length discrepancy with height of 168-172 cm from School of Health Sciences, Universiti Sains Malaysia

4.5 Sampling frame

All subjects with no limb length discrepancy with height of 128-132cm, 148-152cm and 168-172 cm within June 2013 to June 2014

4.6 Sampling method

Purposive sampling-all patients with the above mentioned height range that fulfilled the inclusion and exclusion criteria were included in this study

4.7 Sample size estimation

Probability of Type 1 Error (α)	= 0.05
Power (1-β)	= 0.8
Number of Groups in the analysis	= 3
Largest Difference between any two means	= 3
Expected Background Standard Deviation	= 2
Calculated Parameters	
Beta (β)	= 0.2
Between group df (μ)	= 2
effect size(Diff/SD)	= 1.5
effect size(cohen f)	= 0.7071
sample size required(per group)	=**8**

4.8 Selection Criteria

4.8.1 Inclusion criteria

- Normal walking gait
- Normal range of movement of lower limb joints
- Limb length discrepancy of less than 1 cm
- Heights within 128-132cm, 148-152cm, 168-172cm
- Able to squat fully
- BMI range 20-24

4.8.2 Exclusion criteria

- Any form of neuromuscular disabilities(muscular dystrophy, cerebral palsy)
- Abnormal gait
- Non-mobile/supple joints
- Lower limb length discrepancy of more than 1 cm
- Female