Effect of Leg Length Discrepancy on Joint Contact Force during Gait Using Motion Tracking System: A Pilot Test

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***Abstract*—Leg length discrepancy (LLD) often leads to a distraction of everyday routine, especially to a person with an active lifestyle. Normally, as there is a discrepancy between leg, the kinematic (i.e. gait pattern) as well as kinetic parameters (i.e. joint stresses) throughout the lower limb will be changed. This alteration will later develop more problems if it remains untreated. However, the way of treatments depending on the level of discrepancy. This pilot study aims to examine the effect of stress distribution on the LLD. There are two subjects participate; the true LLD, and simulated LLD. The true LLD comes from the patient with a history of Total Hip Replacements acts as a control subject to verify the simulated subject (healthy subject with no history of orthopaedic surgery), meets the exacts behaviour of real LLD. Nine levels of LLD are implemented, starting from 0cm up to 4cm with 0.5cm interval each. To analyse the joint reaction force, inverse dynamic modelling software was used, Freebody v2.1. As the results obtained, it is shown that ankle gives greater peak value, following by hip, tibiofemoral, and patellofemoral joint. An implication of this study is the possibility that the subject tries to compensate the LLD posture during gait. Hence, reduce the contact within the joint, so the contact area of the ankle become smaller resulting greater stress.**

***Index Terms*—Gait; Joint Reaction Force; Joint Contact Force; Load Distribution; Leg Length Discrepancy.**

I. INTRODUCTION

LLD is a typical issue found in 40% to 70% of the population. LLD appear to be the third most typical cause of running injuries, and occur in 60% to 90% of the population[1], [2]. The presence of LLD may indicate a musculoskeletal dysfunction and has been implicated as an aetiological factor in low back pain (LBP), and in the hip, knee, ankle, and foot pain, then at worst case stress fracture[3]–[7]. According to the previously mentioned statistics, a healthy people with LLD could later develop a knee, hip or lumbar osteoarthritis (OA) at the shorter limb. This condition results from the degenerative joint disease on the shorter limb caused by thinning of the articular cartilage. Thus, pelvic tilt appears during the standing posture, resulting of the unequal stresses in the hip and the knee joints [8].

Correction of LLD is not an easy task. Many aspects need to be considered such as patient's age, mental and emotional condition as well as the risk of treatment failure. Therefore, there are several options in the selection of treatment. LLD magnitude ≤2cm, the internal or external insole, could be inserted into the patient shoes. A 3cm ≥ LLD magnitude ≥ 15cm will undergo surgery either shortening or lengthening the asymmetry lower limb if else surgeon will do both lengthen the short limb and shorten the long limb. Up to 20cm, a patient will be used the external prostheses [9].

While ago, most of the research focused on the clinically significant length discrepancies. The biomechanical effects, especially those related to alteration in kinetic parameters are less tested. The amendment of kinetics could lead to the occurrence of bone fractures since the repetitive and extreme loading disseminated within the unequal leg length. This phenomenon develops from the greatest stress distributed along the longer side of leg inequality as there are tilted on pelvis which induced more stress. The study by Pasha et al. showed that the greater stress distribution on the left side of the sacrum, as there are gravitational loading, had moved to the longer side (left side) [10]. These results were supported by the findings of Raczkowski et al., which showed that there is an increment of the mechanical loads on foot (6% of the body weight) on the side of lifted limbs [9, 11].

Hence, gait analysis combined with the musculoskeletal inversed dynamic method are such powerful tools for detailed analysis of kinematic and kinetic behaviour during gait (e.g., ground or joint reaction force, angle, moment, power) [12-15]. It can be used to further examine typical clinical issues without use on the real patient, for example, stress fracture. The purpose of this study is to examine the joint contact forces induced on the longer side of LLD.

II. SUBJECTS AND SETUP

A. Subjects

The subjects involved in this study were given detailed information regarding the procedures of the experiment with the written informed consent. The study was approved by Ethics Committee in Universiti Malaysia Perlis, Malaysia. There are two subjects involved in this pilot study, one the true LLD which represents the person with the history of orthopaedic surgery. The LLD level of the true subject is 2 cm. Meanwhile, the simulated LLD represents the healthy subject with no history of orthopaedic surgery. Data of subjects are presented in Table 1. The purpose of comparing with the real patient of LLD (refer to True LLD) is to set a benchmark for the simulated case of LLD. By doing so, a simulated LLD can demonstrate the behaviour of LLD itself.

Table 1
Subjects Data

	Height (m)	Body mass (kg)	Body Mass Index (BMI)
Simulated LLD	1.60	58.5	22.9
True LLD	1.69	66.6	23.4

B. Experimental Setup and Data Analysis

Three-Dimensional gait analysis was performed to capture kinematic and kinetic data, by using a Qualisys Track Manager (QTM) motion capture analysis version 2.6. For data acquisition, five motion capture cameras system analysis with a sampling rate of 200 Hz (OqusQualisys 100), together with two forces-plates (Bertec) were used (Figure 1). To decrease the noise during data collection, calibration needs to run by using a T-wand and an L-shaped metal frame placed on the floor. Thirty-one reflective markers (diameter= 20mm) were attached with double-sided adhesive were tape onto the skin. The arrangement of the marker was adopted from Horsman's method (Figure 2).

During the data collection, subjects will perform the walking activity in 7 m walking the track with sandal, and the additional insole was attached to the sandal on the right leg to illustrate the LLD disorder. There are eight levels of insole used to analyse the effect of joint contact forces on mimic LLD starts from 0.5cm up to 4cm with 0.5cm interval each. Before every data collection, subjects were first asked to walk with their self-selected walking speed to make them familiar with the attached insole under their feet to ensure they walked naturally. After that, capturing data will be done in three trials each level and one best trial was picked for further analysis.

For analysis of joint stress distribution, the Freebody v2.1 software from Imperials College London, London, United Kingdoms was used. This software is the inverse kinetic modelling and analysis software of the lower limb segment that is packed with MATLAB as the interface and medium to run this software. It consists of five rigid segments-foot, shank, patella, thigh, and pelvis and articulate with four joint, such as the ankle, tibiofemoral (TF), patellofemoral (PF), and hip joint. The details interpretation of analysis is available in the literature [16-17].

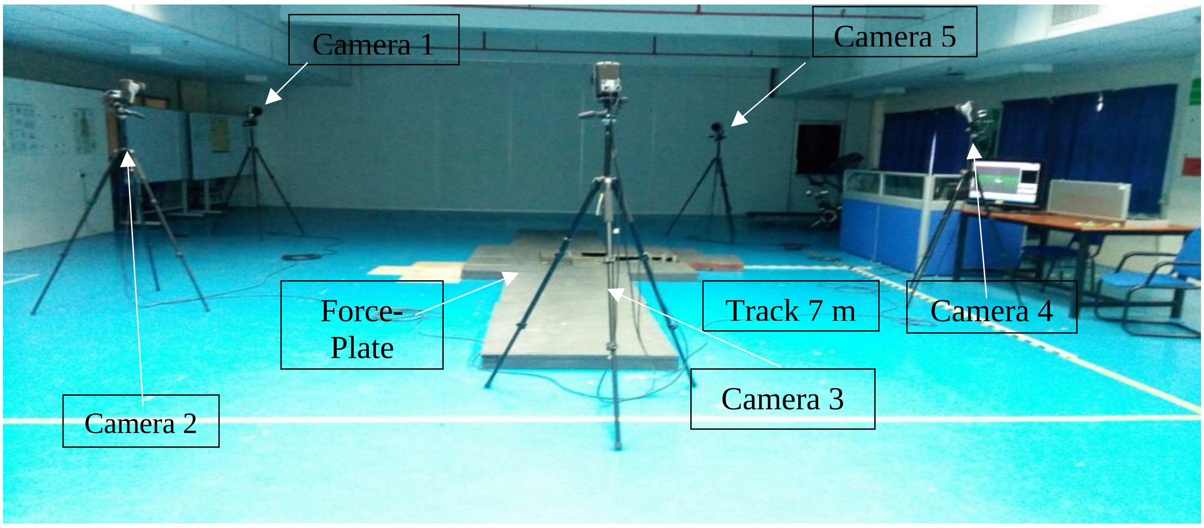

Figure 1: Laboratory set up

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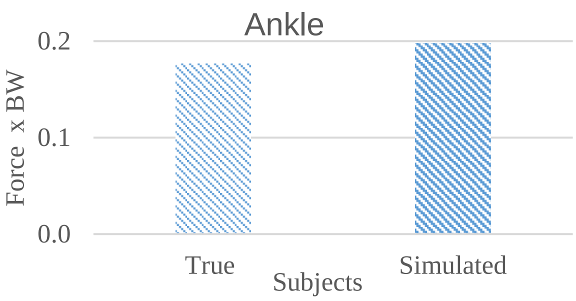
Before further analyses, the data are compared with the true-LLD to verify either the materials used in the simulated subject can illustrate LLD or not. Then, it can be considered as the length increment on the normal subject. The true-LLD subject wore a sandal on both legs without any insole attached to it, while the simulated-LLD subject wore a sandal with 2cm insole fix onto it, on the right leg. This study only limits to the longer side (right side) leg.

III. RESULTS AND DISCUSSIONS

Results for peak joint forces on four articular joint (ankle, TF, hip, and PF joint) were computed in Figure 3 and Figure 4. This result presents from the stance phase of gait cycle on the right leg. Figure 3 presents the results obtained from the analysis of the true-LLD and simulated-LLD subjects. Ankle shows the highest magnitude of peak joint contact force (true-LLD=0.176 while simulated-LLD=0.198). Whereas, the lowest magnitude of peak contact forces shows at PF joint (true-LLD=0.046, simulated-LLD=0.037). The overall peak joint contact force value of true LLD was less than simulated LLD except for TF both for lateral and medial joint part. TF-medial part shows that true -LLD (0.059) was greater peak magnitude compared to simulated -LLD(0.042) meanwhile TF-lateral part shows that True-LLD is 0.085 and Simulated-LLD is 0.038. These results are due to the difference in subjects BMI. Throte et al. said that greater BMI would induce more forces as compared to lesser BMI [12]. As compared to the maximum ground reaction force along overall stance phase between these subjects, the greater BMI (true-LLD=688N) shows a greater value of ground reaction force compared to lesser BMI (simulated-LLD=596N). However, the contact force induced on the subjects shows a contradict results. Therefore, the dissimilar in the findings uncertainty on the ability of simulated-LLD's subject to adapt on the insole increment.

Figure 2: Marker placement of the subject



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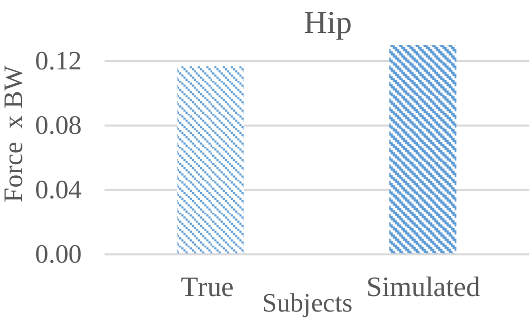

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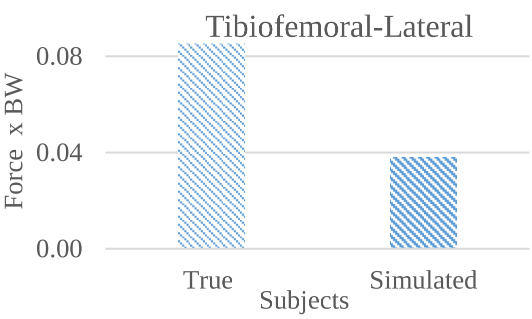

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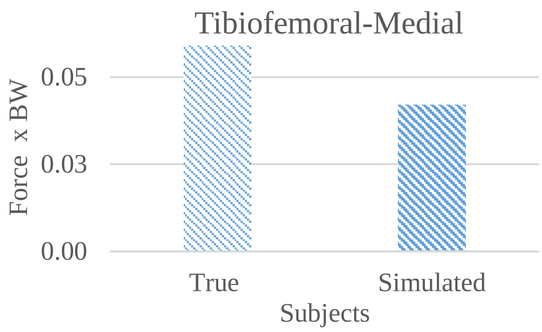

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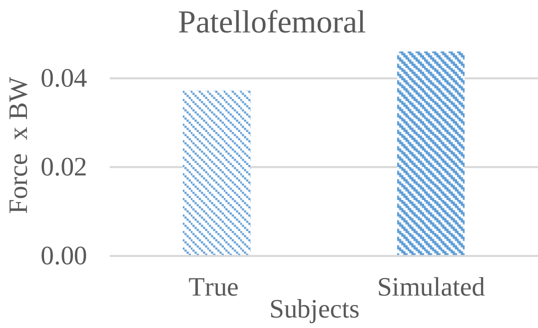

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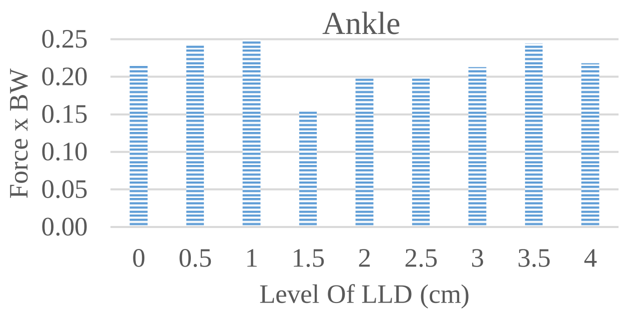
Figure 3: Result of joint contact force on true LLD versus simulated LLD; (a) the magnitude of peak ankle joint contact force, (b) the magnitude of peak hip joint contact force, (c) the magnitude of peak TF joint-Lateral contact force, (d) the magnitude of peak TF joint-Medial contact force, and (e) the magnitude of peak PF joint contact force

Meanwhile, Figure 4 illustrates the results of the magnitude of joint contact forces as the increments of insole were implemented. As can be seen from the figure 4, a magnitude of ankle reports significantly higher in peak value (0.25 at level of 3.5cm), following by hip (0.18 at level of 4cm). TF-lateral recorded almost constant (starting from level of 1cm up to 4cm), and PF joint (0.05 starting from 3.5cm and 4cm). Comprehensively, the magnitude of peak joint contact forces shows an increasing value along the level of LLD except for TJ joint in medial part (lowest value was at level 3cm up to 4cm which is 0.05). For ankle, there are fluctuated in peak value. Ankle and foot act as a main function to support the body during stance still, to dissipate the forces with acceleration as well as become a lever arm to prevent instability during gait [18]. Therefore, during a normal walking posture, the joint contact area within the ankle is greater compared to hip and knee. This condition makes the load spread easily throughout the space so that the stress distribution is lower. However, in this study, ankle joint induced greater contact force uncertainty in the kinematic pattern of gaits such as speed and steps cadence does affect the result obtained [19].

Next is hip joint force peak value presents a gradual increase in level 0.5cm up to 2.5cm yet decline in 3cm until 3.5cm then increase during 4cm.The declining value of 3cm and 3.5cm shows in line with the study of Brand et al. which explained there is a pelvic tilt event which moves the centre of mass to the contralateral sides as the propulsion of foot during the stance phase[20]. Also, the increasing value of hip joint contact force during 0.5cm to 2.5cm and 4cm are consistent with those of works reviewed by Burke Gurney. In his findings, since the subject move with discrepancy leg length, much of pressure would be transmitted toward the longer side of LLD because of the small area of contact between the acetabulum and femoral head as the influences of the hip abductors muscle tone increase[7].

TF joint is engaged and weight bearing during the stance phase of gait, while PF joint is non-weight bearing with ambulation. Typically, patella does not in contact on trochlea while walking until knee flexion minimum at 20˚[21]. Hence PF joint should have less peak value compared to TF joint. There are two parts of TF joint being analysed which are TF-Lateral joint and TF-Medial joint. The TF-joint is compartmentalised into two compartments so that the effect of this two-part can distinguish regarding contact stresses. As the level is increased, the value of peak TF joint for medial part shows declining trends. While peak value of TF joint for lateral part show almost a constant trend along the level up to 4cm of LLD's level. The declined trends indicate that medial part does not seem to be affected by the level of LLD. The PF joint peak value shows an increment at the beginning but slightly decrease at the end level of LLD. This inconsistency may be due to the speed used in the subject was a bit slower compared to the initial level of LLD and he might flex more on his knee, as subject try to compensate with LLD posture.



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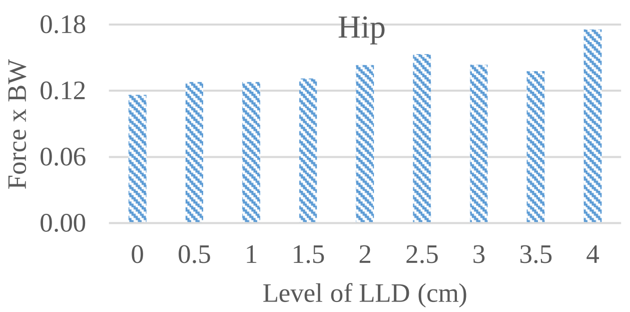

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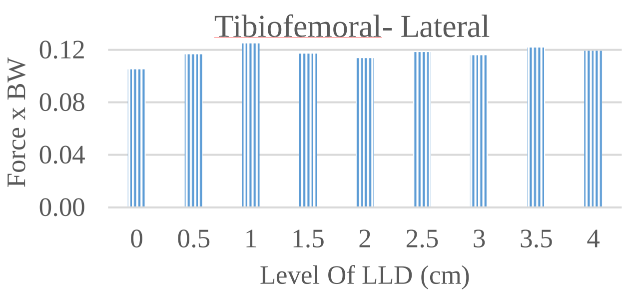

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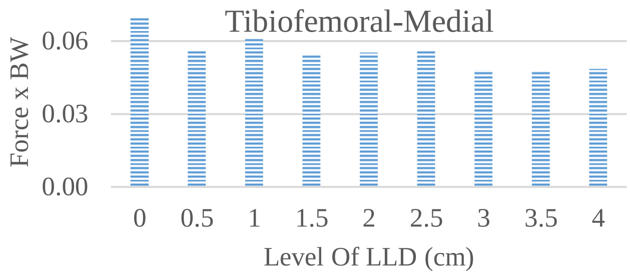

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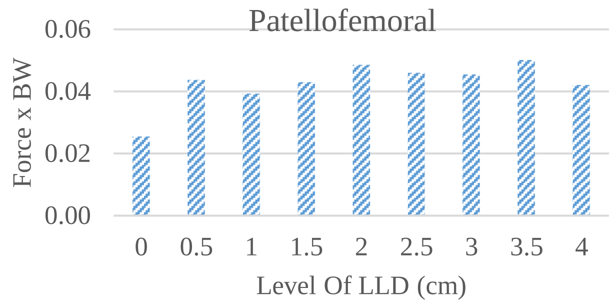

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Figure 4: The joint contact force across four articulation joint of lower limb along level of LLD; (a) the magnitude of peak ankle joint contact force, (b) the magnitude of peak hip joint contact force, (c) the magnitude of peak TF joint-Lateral contact force, (d) the magnitude of peak TF joint-Medial contact force, and (e) the magnitude of peak PFl joint contact force

IV. CONCLUSION

The purpose of the current pilot study was to determine the effect of joint contact forces on LLD during gait. This pilot study set out to examine the occurrence of joint stresses at the longer leg and to verify the suitable method used to analyse the effect of LLD. This study has identified ankle shows greater peak joint contact force compared to other three joint. Following by hip, PF joint, and TF joint lateral part. Nonetheless, TF joint at medial part shows the decreases in peak magnitude along the level of LLD. An implication of this study is the possibility that subject try to compensate the LLD posture during gait. Hence, reduce the contact within the joint, so the contact area on the ankle become smaller resulting greater stress. As the results obtained in this pilot study shows uncertainty, either every lower segment could give significant results regarding increasing of discrepancy's level would induce more or less contact forces. Therefore, improvement in the further research is to encourage such as add more subjects to identify the real pattern of joint contact within lower limb segments.

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