Effect of Surface Hardness on Joint Contact Forces During Barefoot Running: A Pilot Study

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***Abstract*—This paper presents an experimental pilot study on the effect of different surface hardness to the joint contact force during barefoot running. Peak joint contact forces during the stance phase of a male subject that running barefoot on three types of surface with different hardness level (concrete, artificial grass and rubber) were investigated experimentally. Differences in peak joint contact force at the ankle, medial tibiofemoral, lateral tibiofemoral, hip and patellofemoral due to surface effects were analysed using Freebody (Version2.1) software. The result showed that the pattern of peak joint contact force was similar for ankle with medial tibiofemoral and hip with lateral patellofemoral. The joint contact force was varied in the varying of the surface hardness. The correlation between various surface hardness and joint contact force was found at the ankle and medial tibiofemoral joint. However, the findings of this pilot study provide the insight into the method and approach selected for the experiment be suitable for an actual experiment for more subjects.**

***Index Terms*— Barefoot; Joint Contact Force; Running; Surface Hardness.**

I. INTRODUCTION

Involving no specific equipment and environment, barefoot running always considered as a natural form of exercise. Barefoot running with a kinetic adaptation that generates minimum impact peaks is believed capable of reducing injury as well as to strengthen the feet [1]. However, runners vary their running form depending on the various condition for example speed, surface texture, surface hardness and fatigue level [1]. Fast reaction to disturbance and adaptation to a wide range of running environment is required in barefoot running [2] to avoid running-related injuries and to obtain the advantages of running activity [3]. The surface characteristics and related biomechanical alterations may be an important factor related to injury frequency and severity [4-5].

Runners' biomechanical alteration in diverse running surface provide leg stability and assist in minimisation of ground reaction force (GRF) during running gait cycle [6]. The increment of GRF possibly caused a higher knee joint contact force (JCF) that might lead to soft tissue damage and continuous joint deterioration. Repetitive cyclical loading of the skeletal system that referred to JCF is reported might lead to stress fracture [7], and altered joint loading contributes to the major risk of joint degeneration [8]. Therefore, JCF that generated by joint reaction force (JRF) can be regarded as an important kinetic parameter in clinical analyses [9].

Previously, JCF generated during running has been investigated by several researchers [6-7, 10-12]. Sinclair studied the differences of patellofemoral JCF produced during barefoot running and running in barefoot-inspired footwear. Barefoot and barefoot-inspired footwear was found to be associated with a reduction of JCF at the patellofemoral joint. Furthermore, Kulmala et al. investigate the influence of foot strike pattern during running on JCF at patellofemoral. The result showed that forefoot strikers demonstrated a lower patellofemoral contact force compared with heel strikers. Rooney et al. who investigated the effect of foot strike to JCF at ankle, knee and hip also reported that JCF at ankle and knee was higher in forefoot strike running.

In general, the lower extremity JCF was commonly measured at ankle [11], knee [10-12] and hip [11]. Running strategy by biomechanical alteration can be suggested as a common issue studied in the previous study. However, there has yet to be a study investigating the influenced of the surface characteristic on JCF generated during running in adapting to the running surface. Therefore, the purpose of this study to assess the effect of surface hardness to JCF of lower extremity during barefoot running.

II. METHOD

A. Subjects

A healthy male recreational runner at the age of 26 years old with normal body mass index (BMI) category participated in this pilot study. His height and weight are 170 cm and 69 kg respectively. An individual with recently musculoskeletal injury or orthopaedic abnormality were excluded in this study due to dissimilarity in the movement and potential difficulty in performing the task. The subject was voluntarily consented to participate in the study had filled the survey form and signed the consent form before participation.

B. Instrument and Equipment

Experimental work of this pilot study was done in Biomechanics Laboratory at Universiti Malaysia Perlis. The joint contact force was obtained using five Oqus cameras in Motion Captured System at the frequency of 200 Hz with two Bertex force plates. The cameras were conducted in a position that could detect all the eighteen markers during the stance phase of running gait. The markers were a plastic sphere with 20 mm diameter covered by reflective tape. The track dimension used was 10 m long and 1 m wide and placed over the force plate. The arrangement of instruments and equipment involved is as presented in Figure 1. The joint contact force responses in this study needed to be measured using Qualysis Track Motion (QTM) and analysed using Freebody (version 2.1) software. Three different running surfaces involved in this pilot study were concrete, artificial grass, and rubber. A simple experiment according to American Society of Testing and Materials (ASTM) F2117-10 was completed to determine the cushioning properties of each surface. The protocol of the test was done referring to a previous study [13]. The rubber was found to be the softest surface followed by artificial grass and concrete.

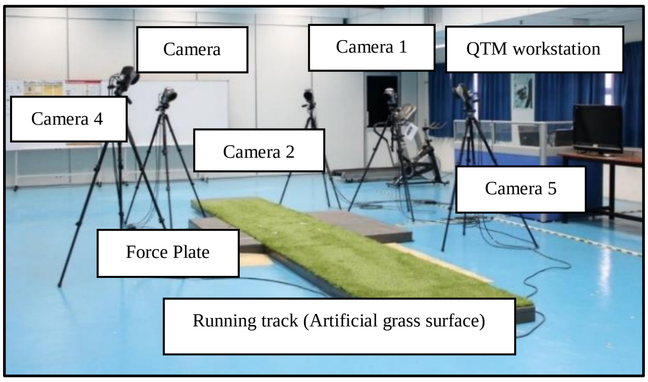

Figure 1: Equipment set up

C. *Experiment protocol*

The joint contact forces were analysed based on the marker placement that was introduced by Cleather et al. 2015 [13]. Eighteen reflective markers were placed on the right leg and both right and left of anterior and posterior superior iliac spine of the subject as shown in Figure 2. The anatomical landmark involved is head of the second metatarsal, calcaneus, tuberosity of the fifth metatarsal, foot, malleolus, calf, femoral epicondyle, thigh and superior iliac spine.

The markers were attached to the anatomical landmark using double-sided adhesive tape. The subject first ran on the runway prior data collection to familiarise with each condition of the experiment before was asked to run over 10 m indoor running surfaces (rubber, concrete and artificial grass). The subject ran at his comfortable speed that reflects recreational run. A static trial was also recorded with the subject stand upright in double-leg support posture. Data of the subject running on all surfaces were then collected. Trials were accepted if all markers position were well captured and the right foot contacted with the force plate without obvious alterations to the run stride.

Figure 2: Markers placement on the subject

D. *Data analysis*

Joint contact force response at the ankle, lateral tibiofemoral, medial tibiofemoral, hip and knee were investigated in this study. The joint contact forces were processed and analysed using Freebody (Version 2.1). The details of software and algorithm of the software can be found in previous studies [13], [14]. The joint contact forces were particularly investigating in each time frame and analysed into X, Y and Z components of forces. Only the Y component of the force was analysed in this pilot study.

III. Result and Discussion

The purpose of this pilot study was to investigate the joint contact force produced by an individual during barefoot running on different surface hardness. Figure 3 shows the result obtained from the analysis of peak JCF at ankle. It appears from the bar chart, the highest peak value of JCF at the ankle is during running on the rubber with a value of 22.8kN followed by artificial grass and concrete with a value of 19.6kN and 18.3kN respectively.

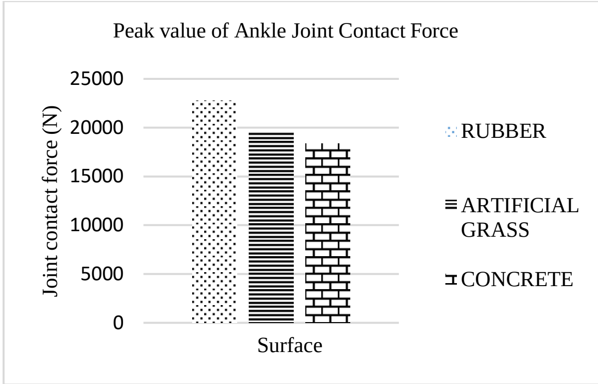

Figure 3: Peak contact force at ankle joint

Similar to the peak JCF at the ankle, the peak JCF at medial tibia-femoral also is the highest during running on rubber surface followed by artificial grass and concrete as shown in Figure 4. Both peak JCF at the ankle and medial tibiofemoral seems to be correlated to the surface hardness. From the bar chart, it can be seen that the peak joint contact force was increasing as the surface hardness decreased. These results may be explained by the relationship between surface hardness and stance time behaviour. It is possible to hypothesise that, the longer the foot on the surface, the higher the joint contact force. These results are also in agreement with other research which found the highest stance time is during running on rubber surface followed by artificial grass and concrete [15].

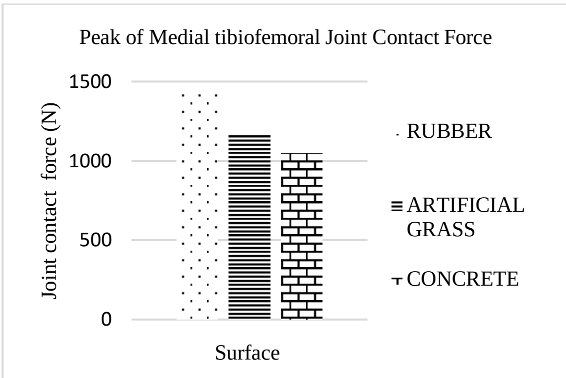

Figure 4: Peak contact force at medial tibiofemoral joint

Instead of that, Figure 5 and Figure 6 provide the result of peak JCF at lateral tibia-femoral and hip respectively. As shown in both figures, the highest value is during running on rubber followed by concrete and artificial grass. The difference between peak values during running on each surface was approximately in the range from 100N to 1000N. A similar trend of peak JCF at lateral tibia-femoral and hip but different with ankle and medial tibia-femoral was observed.

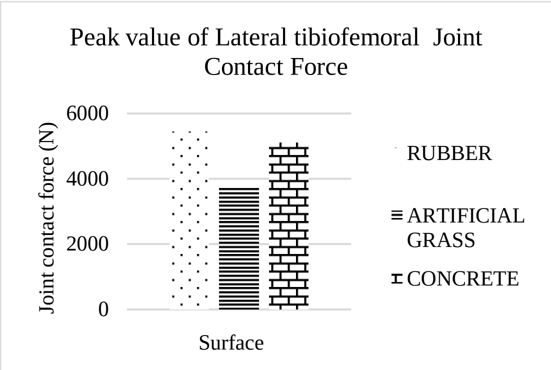

Figure 5: Peak contact force at lateral tibiofemoral joint

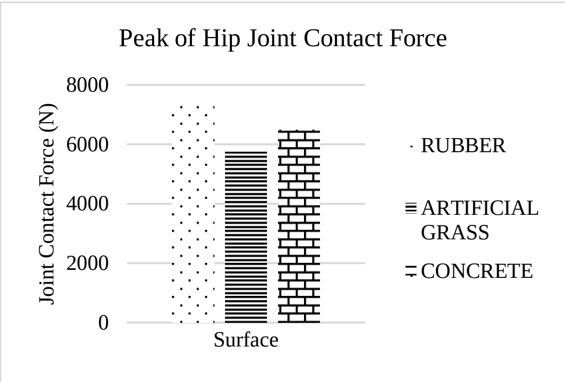

Figure 6: Peak contact force at the hip joint

Figure 7 shows the peak JCF at patellofemoral during running on each surface. Interestingly, the highest peak value is during running on artificial grass with the obvious difference compared to rubber and concrete surface. It can be seen from the data in Figure 5, the sequence of peak JCF value at the knee is dissimilar to other four joints.

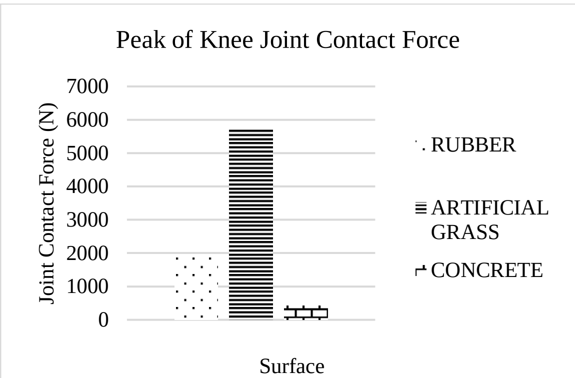

Figure 7: Peak contact force at patellofemoral joint

The result of this pilot study shows that ankle and lateral tibiofemoral joints shared similar trend of peak joint contact during running on the different surfaces. A possible explanation for this might be that the influenced of foot alteration in adapting to the running surface. Foot motion in adapting to the running surface that involving ankle joint may alter the load on the medial tibiofemoral joint [16].

Instead of that, hip and lateral tibiofemoral joints have same sequence of peak contact force value during running on the various running surfaces. These results are likely to be related to findings reported by Weidow et al. 2005 [17] who found that lateral of the knee joint was more commonly associated to hip or pelvis joint that observed in medial of the knee joint. Also, the differences of peak joint contact force of medial and lateral tibiofemoral trend observed in this pilot study might explain by the fact that loads generated in the medial compartment of the knee are greater compared to lateral compartment of the knee in most daily activities [18].

Furthermore, based on data collected in this pilot study, the highest peak contact force generated is mostly during running on rubber which is the softest surface. The peak contact force in each joint analysed is not correlated to surface hardness. Since the data collection conducted was involved only a subject, the findings obtained in this experiment cannot be used as the general conclusion. Some subjects should be employed in a future experiment conducted to generalise the conclusion for the whole population.

IV. Conclusion

This pilot study was set out to assess the effective surface hardness on joint contact force during running. It was found that, generally, contact force produced on each joint is different during running on various surface hardness.

As a conclusion, it can be suggested that the ankle was associated with medial tibiofemoral joint contact force, while, the hip was associated with the lateral tibiofemoral joint. The findings of this pilot study also provide the insight of the method and approach selected in the experiment be suitable for an actual experiment for more subjects.

Acknowledgement

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