Biomechanical Evaluation of Insole for Badminton Players: A Preliminary Study

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Abstract. Study in sports biomechanics is a demand field for any athletes due to the fact that it can contribute a lot for the improvement of sports performance. One of them is a study on badminton games where the athletes are normally perform many movements with a combination of usage of sport shoes and insoles. It should be noted that analysis on the badminton games and insoles are very limited in the literature. Therefore, this paper is presenting an art of development process of three-dimensional model of bone and insole in order to simulate the condition of badminton games via finite element method. Computed tomography images were used to reconstruct the bones using Mimics software whereas insole was developed using Gensole®. The bones were reconstructed by setting a Hounsfield Unit (226 to 3071) to differentiate the cortical bone. Anthropometric procedure was firstly used to develop the insole of Slazenger. For the preliminary analysis, the models were used to simulate the landing phase of the badminton player where the inferior part of the insole were lifted at 2° with a total of 2.57 times of body weight was applied from the bottom of insole. From the results, it is shown that the von Misses stress were observed at the contact point between bones and insole. From the preliminary results, the stress distribution on the insole is higher at certain points, might due to a larger contacted part. Nevertheless, a detail of foot and ankle joint should be developed in the future to mimic the real condition of the landing phase of athletes.

1. Introduction

Badminton games requires player to make various manoeuvres due to rapid changes of direction that have been made during the matching games [1, 2]. It is well known that the badminton player needs to perform strokes correctly in order to execute quality of shot. The strokes can be divided into three types of manoeuvres which are, drop, clear and smash [3]. It should be noted that the badminton games is based on a basis technique which is called as a footwork [4, 5]. The correct footwork of badminton player enable them to minimize the work load hence can reduce the time to reach the shuttlecock [6]. One of lethal manoeuvres in the badminton games is a jumping smash. During a landing phase of the jumping smash, players tend to increase the time of impact by doing ankle plantar flexion [7]. The players are also will conduct this manoeuvre in numerous times in a game which is can lead to unstable posture and ankle and knee joints injury. This is due to fact that, instead of two-foot landing, the one-foot landing pattern is normally used by the players [8].

Insoles are widely used for therapeutic purposes such as for diabetic patient with neuropathic ulcers [9, 10]. A semi-rigid custom-fitted insole need to be designed for the diabetic patient [11]. Based on the fundamental of mechanical engineering, the functions of insole can be in terms of spreading the pressure over the density of materials, in order to prevent the occurrence of abnormalities of foot such as pronation, metatarsalgia, flat feet, neuroma, plantar fasciitis and arch pain [11, 12]. In addition, the insoles were also can reduce the pain by decreasing the strain in plantar fascia [11, 13]. From previous study, it is suggested that by increasing the total contact insole (TCI) will reducing the plantar pressure from rear foot to midfoot [14]. In fact, the arch support is another contribution to reduce pressure during the load bearing from human body.

In the badminton games, it was found that 92% of the injuries occur in lower extremities part of the human body [15]. This is due to fact that a lot of sudden changes of direction and braking in repetitive manoeuvres that was done by the player. Therefore, this may cause the human body to bear excessive external loads from upper part [6]. From previous study, analysis of pressure distribution upon impact phase during landing can potentially improve the reaction time, reduce injuries, and propose design of badminton insoles [16]. As shown in many literatures, a lot of researchers were conducted the analysis of pressure distribution of badminton players associated with the shoes and insoles. Nevertheless, the study is very limited in the literature regarding the pressure distribution on the foot ankle joint of human with the insoles. This may due to the fact that the foot ankle is a complex joint where some limitations and assumptions must be conducted during the experiments. Previous studies were involved in many biomechanical analyses using experiment equipment and computer resources to conduct such a study. In this paper, the authors representing the art of development process of three-dimensional model of human foot bone and athlete insole via computer resources. A preliminary analysis was done to evaluate the insole via finite element method.

2. Methodology

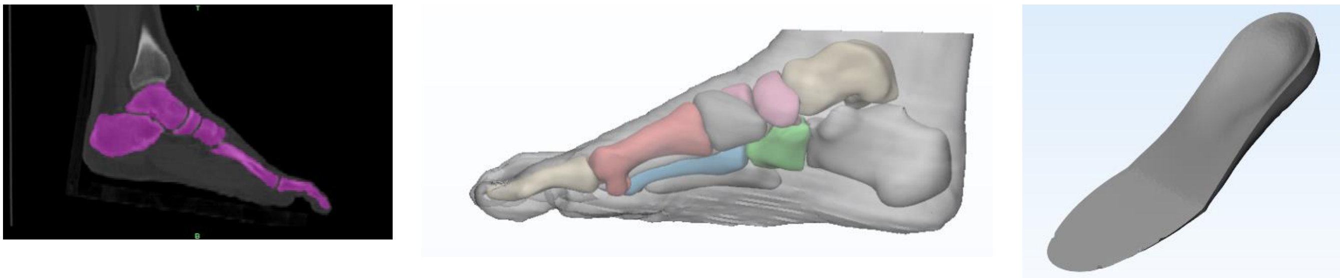
2.1. Model Development

A datasets of Computed Tomography (CT) of a healthy 27 years old man with 169 cm height and 75kg weight was used to reconstruct bones and skin. The data was obtained from Hospital Tengku Ampuan Afzan, Kuantan, Pahang, Malaysia with an ethical approval [9]. A three-dimensional (3D) software, Mimics (Materialise, Leuven, Belgium) was used to reconstruct the interested bones which are talus, calcaneus, cuboid, navicular, metatarsals and phalanges. Figure 1 showed the development process of foot joint of human where it was started with 2D images of CT data (Figure 1a) until 3D model of foot (Figure 1b). In order to differentiate the hard tissue from the images, Hounsfield Unit (HU) was used that ranging from 226 to 3071 [10, 11] while -200 to 100 was used for skin[12]. For the insole, Slazenger was chosen in this preliminary study. Sense 3D Scanner was used to produce the 3D model of insole as shown in Figure 1c. Once the 3D models were developed, all of them were converted into finite element (FE) model as shown in Figure 1d and 1e.

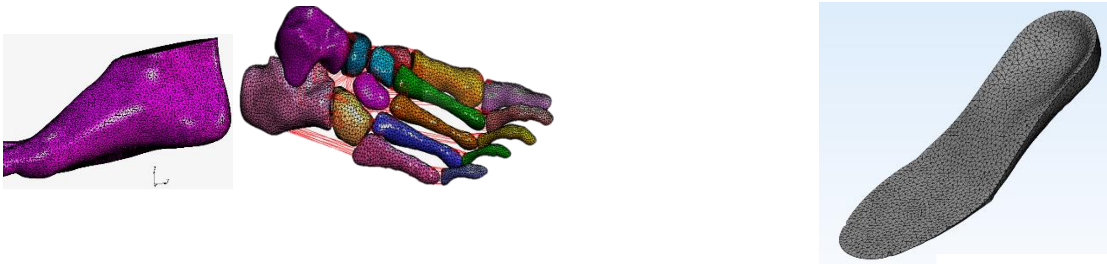
2.2. Finite Element Modelling

The meshing of insole, skin and bones were done in 3-Matic (Materialise, Leuven, Belgium). The meshing size of bones, skin and insole were set at 4.5mm[13], 3.0mm [14] and 4.3mm [15] respectively. The 3D models then were then analysed through Finite Element Method in Marc Mentat (MSC. Software, Santa Ana, CA). The Young's Modulus and Poisson ratio of the bones were set at 7300MPa and 0.3 respectively [16] while the insole's Young's Modulus and Poisson ratio were set at 11.7MPa and 0.45 respectively [17]. For skin, the Young's Modulus and Poisson Ratio were set at 1.15MPa and 0.49[18]. The plate was used in common biomechanical modelling were set at Young's

Modulus of 17000MPa and 0.1 Poisson Ratio[19]. The bonding between the bones and the insole have been set to bonded to mimic the touching between them.



(a) (b) (c)



(d) (e)

Figure 1. 3D modelling process of insole, skin and bones; a) 2D images of CT data, b) 3D model of foot, c) 3D model of insole, d) finite element model of foot bones and skin, and e) finite element model of insole

2.3. Boundary Condition

In order to simulate the landing phase of the badminton player, the inferior part of the insole were lifted at 2°[20]. The boundary condition was fixed at the superior of the skin. A total of 2.57 times of body weight of force were set on the inferior part of the plate. The boundary condition is illustrated in Figure 2.

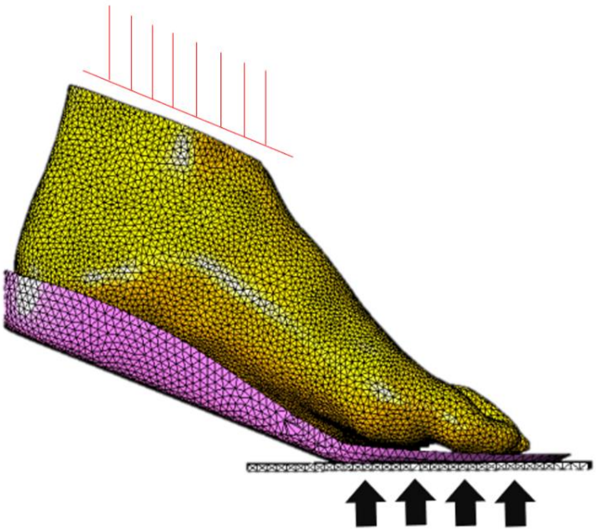


Figure 2. Boundary Condition.

3. Main Results

The results of finite element analysis conducted were shown in figure 3. It was recorded the von Misses Stress (VMS) obtained at the second metatarsal, 32.74MPa, was the highest followed by fifth phalanges, 31.20MPa and second phalanges 29.65MPa. The VMS obtained from the static analysis shows the highest VMS at the second metatarsal as similar recorded by Gu et al. [19] and Weinfeld et al.[21] . The VMS distribution on the bones shows a shifting pattern from middle bones to lateral side of the bones.

The VMS distribution on insole as shown in figure also was observed. It was recorded the peak pressure was on the area which align with second phalanges which was 2.435MPa. However, in the area of metatarsals head which was expected to be high VMS, recorded maximum pressure at the area was 0.497MPa. The contact interaction between skin and the insole was suspected as the problem and need to be revised.

For skin, as shown in figure, VMS distribution was observed on the inferior surface which in contact with the insole. The highest VMS recorded at the proximal of second phalanges which was 0.520 MPa. VMS of the skin also record high VMS distribution at the area of in contact with metatarsals which ranging from 0.1MPa up to 0.367MPa

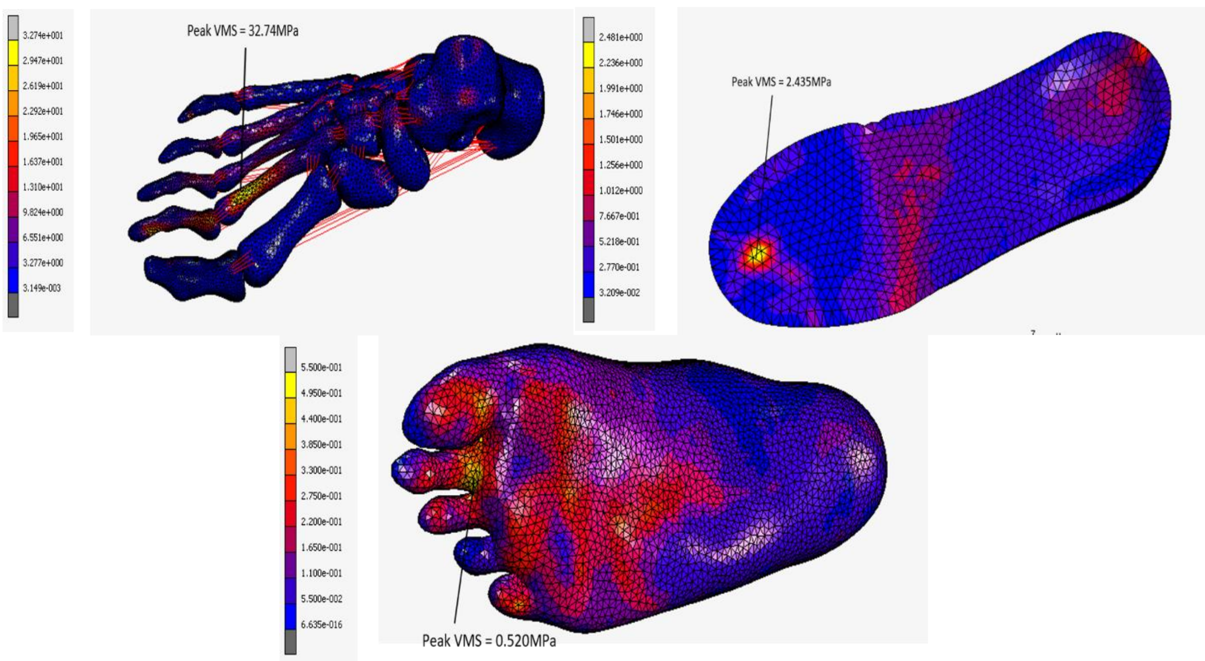


Figure 3. Von Misses Stress value for the analysis of the insole, bones and skin

4. Conclusion

The 3D model of the bones, skin and insole have been developed through a reconstruction method using CT data images. The insoles have been designed accordingly via 3D Scanning procedure. Finite element method has been used in this study to conduct static analysis to check the availability of models. However, this study is a pilot study and many improvements will be done by the authors. There are several limitations identified in this study.

The model of skin and insole supposed to be assigned with hyperelastic material properties as reported by Sarikhani et al.[22] and Cheung et al.[16] . By assigning those material properties to the respected models, it is expected for the computational time in completing the analysis is increase. For further improvement also, badminton insoles can be chosen to be used for 3D scanning of insole 3D models.

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