BIOMECHANICAL EVALUATION OF INSOLE SUBJECTED TO SINGLE-LEG LANDING

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DEDICATION

This thesis is dedicated to my mother (SITI RUHANI BINTI MAT DERIS), my father (AB RASHID BIN OMAR), my wife (NUR FATIN KAMILA BINTI ZANALABIDIN), my siblings, my small family of Forecast 19 in UTM who endlessly supporting me in ups and downs. May Allah grant the best for your journey and bless your life.

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ABSTRACT

Badminton games are based on footwork techniques. Among badminton players, 92% of leg injuries have been recorded. In preventing the injuries, insoles are widely used in sports where insole's wall height, heel cup, arch-support height, thickness, and material properties will influence the stress, displacement, and rotation angle value of foot. Furthermore, the insoles are used to treat misalignment of foot and diabetes ulcers. However, there are still lacking in the analysis on insole during single-leg landing. This study was conducted with the main aims to establish a static analysis on three different insoles of badminton athletes during single-leg landing and to modify the material of pre-fabricated insoles for better performance in terms of shock absorption during single-leg landing. Three-dimensional (3D) finite element models of ankle-foot complex consisted of skin, talus, calcaneus, navicular, three cuneiform, cuboid, five metatarsals, and five phalanges were segmented from computed tomography (CT) data. The midsole and outsole were designed using 3-Matic software and three pre-fabricated insoles; insole 1 (Yonex Active Pro Truactive), insole 2 (Li-Ning L6200LA) and insole 3 (Victor VT-XD 8) were 3D scanned. In completing the ankle joint, a total of 21 ligaments were modelled. The single-leg landing was simulated with 2.95° of ankle plantar-flexion. On the superior surface of the skin, the load of 2.57 times bodyweight was applied, and the inferior surface of the outsole was fixed. The results showed the insole 3 is the most optimum in portraying the lowest peak stress on the metatarsals (3.807 MPa). Besides, the insole 3 recorded the least displacement value (10.81 mm) and acceptable bone rotation angle (3.29°). The insole 3 with ethylene-vinyl acetate medium density (EVA MD) material perform better compared to polyvinyl chloride (PVC) and ethylene-vinyl acetate low density (EVA LD) the lowest metatarsals' peak stress (3.554 MPa), displacement (13.08 mm), and bones rotation angle (2.93°) were recorded. Further design of the custom insole based on insole 3 and EVA MD material produced the lowest peak metatarsal stress (3.210 MPa) and displacement (8.99 mm), and bones rotation angle of 1.80°. This study contributes to the better understanding on biomechanics during single-leg landing hence lead to better insole development.

ABSTRAK

Permainan badminton adalah berdasarkan teknik gerak kaki. Dalam kalangan pemain badminton, 92% kecederaan kaki telah direkodkan. Bagi mencegah kecederaan, lapik dalam (LD) digunakan secara meluas dalam bidang sukan di mana ketinggian dinding LD, lengkungan tumit, ketinggian sokongan lengkung, ketebalan dan sifat bahan akan mempengaruhi tekanan, anjakan dan nilai sudut putaran kaki. Tambahan pula, LD digunakan untuk merawat salah jajaran kaki dan ulser kencing manis. Namun begitu, masih terdapat kekurangan dalam analisis ke atas LD semasa pendaratan satu kaki (PSK). Kajian ini dilakukan dengan tujuan utama untuk mewujudkan analisis statik pada tiga LD berbeza atlet badminton semasa PSK dan mengubah suai bahan LD pasang siap bagi menghasilkan prestasi yang lebih baik dalam menyerap hentakan semasa PSK. Model elemen terhingga tiga dimensi (3D) bagi kompleks pergelangan kaki yang terdiri daripada kulit, talus, tumit, navikular, tiga kuneiform, kuboid, lima metatarsal dan lima jari telah disegmen daripada data Tomografi Komputeran (CT). Lapik tengah dan luar direka menggunakan perisian 3-Matic dan tiga LD pasang siap; LD 1 (Yonex Active Pro Truactive), LD 2 (Li-Ning L6200LA) dan LD 3 (Victor VT-XD 8) telah diimbas secara 3D. Dalam melengkapkan sendi buku lali, sejumlah 21 ligamen telah dimodelkan. PSK disimulasikan dengan kaki dibengkokkan secara fleksi-plantar sebanyak 2.95°. Pada permukaan atas kulit, beban sebanyak 2.57 kali berat badan telah dikenakan, dan permukaan bawah lapik luar telah ditahan. Keputusan menunjukkan LD 3 adalah yang paling optimum dalam menunjukkan tekanan puncak terendah pada metatarsal (3.807 MPa). Disamping itu, LD 3 menunjukkan nilai anjakan paling sedikit (10.81 mm) dan sudut putaran tulang yang boleh diterima (3.29°). LD 3 dengan bahan EVA MD mempunyai prestasi yang lebih baik berbanding PVC dan EVA LD di mana tekanan puncak metatarsal (3.554 MPa), anjakan (13.08 mm), dan sudut putaran (2.93°) telah direkodkan. Rekaan LD seterusnya berasaskan reka bentuk LD 3 dan bahan EVA MD mengahsilkan tekanan metatarsal puncak (3.210 MPa),anjakan (8.99 mm) terendah, dan sudut putaran tulang (1.80°) terendah. Kajian ini menyumbang kepada pemahaman yang lebih baik dalam biomekanik semasa PSK justeru mengarah kepada rekaan LD yang lebih baik.

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LIST OF ABBREVIATIONS

Three-Dimensional	-	3D
Computed Tomography	-	CT
Finite Element	-	FE
Two-Dimensional	-	2D
Left Front-Court Lunge Steps	-	LFLS
Right Front-Court Lunge Steps	-	RFLS
Rear-court Revolve to Jump	-	RRJ
Range of Motion	-	ROM
von Mises stress	-	VMS
Digital Imaging and Communications in Medicine	-	DICOM
Computer-Aided Design	-	CAD
Polyvinyl Chloride	-	PVC
EVA Low Density	-	EVA LD
EVA Medium Density		EVA MD

LIST OF SYMBOLS

mm	-	Millimetre
MPa	-	Megapascal
kPa	-	Kilopascal
F	-	Force
k	-	Spring Constant
x	-	Displacement
σ	-	Stress
E	-	Young's Modulus
ε	-	Strain

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Badminton games require a player to make various movements because of rapid changes in direction that have been made [1, 2]. The badminton games also include a fundamental of arm movement which is forehand or overhead stroke. The strokes can be divided into three types of movements which are, drop, clear and smash, and net play [3, 4]. All these movements involved jumping and landing, which had put the lower limbs of players' bodies under heavy loads [2, 5, 6]. These movements will be made within 40 m^2 court [7]. The games are based on a basic technique called footwork [8, 9]. The correct footwork of badminton player enable them to minimize the workload hence can reduce the time to reach the shuttlecock [10]. There is fundamental and critical footwork that needs to be applied by a badminton player, which is right-forward, left-forward, right-backward, and left-backward [10].

Footwear is one of the crucial accessories for athletes. Foot orthosis or insole is a device that allows the optimum functionality of a foot [11]. The insole is also a device that acts as a preventive and/or managing a wide range of lower limb injuries in sports [12, 13]. In the case of the development of calluses undersides head of second to the fourth metatarsals, insoles are expected to evenly distribute the pressure to reduce pain [14]. Insoles were also used for varus-type and valgus-type osteoarthritis treatment [15], where athletes or former athletes lower limb tend to bend towards medial or lateral from body midline. Development of wedge on the anterior and lateral or medial side of insoles provides better load distribution [16]. Bordelon et al. divided insole into three types of insoles; 1) Device to reduce cushion and impact [17], 2) Pressure-relieving device, 3) Device to correct the foot alignment [18]. Footwear consists of the upper part, insole, midsole, and outsole [19]. Insole is a part of the footwear, which have direct contact with the foot and became the first medium acting on pressure distribution.

There are previous studies that had been conducted which investigate on plantar pressure of badminton players during jumping in toe-off and touchdown phase [3, 20]. It was found that plantar pressure seems to be related to foot injuries [10, 21, 22]. In conjunction with that, Zhao and Li suggested that footwear performance in terms of resistance needs to be improved at central and lateral sides, especially at the first metatarsal and forefoot area [3]. Fu reported toe-off phase during jumping recorded the highest plantar pressure at the first metatarsal area, which supported the suggestion of developing an outsole with suitable materials [20]. A study regarding the relationship between the stiffness of the shoe sole stiffness and the kinematics of lower limb during movements in badminton game reported that changes in the stiffness of the sole of the footwear might contribute to alteration in agilities of player, game strategies, and also kinematics of lower limb joints [23].

1.2 Problem Statement

It was recorded about 92% of injuries that occurred in badminton games involving lower extremities [24]. Metatarsal fractures occurrence were recorded at 35% out of all foot fractures and 6% out of all skeletal injuries. Based on a study conducted by Fu, during touch-down movements by badminton players after conducting a stroke showed that the peak of plantar pressure was recorded at the forefoot [20]. In conjunction with that, consuming inappropriate footwear was found as one of the factors that contributed to fatigue overstress injuries [25-27]. A study had been conducted by Yong et al. [28] on the effect of different footwear on the metatarsophalangeal joint which resulting in badminton designated footwear is more beneficial for the metatarsophalangeal joint.

Moreover, landing from doing jumping smash will exert more load on the body as the landing is conducted using single-leg landing [29]. Insoles, part of the shoe, are widely used in sports to increase athlete's performance and stabilization and to reduce the risk of injury [30, 31]. Since single-leg landing is a stiffer landing technique compared to double-leg landing, the angle of ankle plantarflexion and hip flexion had reduced causing the decrease of the lower extremity's capability to attenuate shock [32]. Furthermore, it was reported that off-the-shelf insoles equipped with medial-arch support tend to increase the peak inversion angle of the ankle during landing. It had caused the elevation of the pressure on the fifth metatarsal which is the most common fractures experienced by young athletes [33]. Thus, a better insole design needs to be introduced in preventing metatarsals fracture occurrence among athletes.

Many studies have been conducted on jumping movements in various activities such as basketball, walking, and running [9, 10, 34-36]. However, there are still lacking FE studies that involve jumping movements in badminton [9, 10]. Badminton also had received minimal attention in developing sports medical equipment for players [10, 37]. Jumping smash is one of lethal movements in badminton as it will help players to obtain points and playing with offensive gameplay. Jumping smash is also a very popular technique in badminton [38]. Hence, there is a need to conduct FE studies for badminton players to identify the localization of pressure exerted on the foot.

Insoles with different material and density can also affect the shock absorption characteristics [39, 40]. Footwear with an additional cushion is also used to reduce shock [40]. Lam et al. [41] conducted a study on the effect of shoe design on badminton players. The study focused on the design of heel parts of the footwear since the manoeuvre conducted by the subject is the forward lunge, which involves a heel strike. However, the studies on insole design for single-leg landing movements in badminton athletes are still limited. In short, the problem statement of this study could be summarized as below:

1. How does different types of insoles from different manufacturers affect pressure distribution on the insole, bones and skin?

2. How does custom-fit insole and different insole material affect the pressure distribution on the insole, bones and skin?

1.3 Objectives

1) To compute a static analysis on three different insoles of badminton athletes during single-leg landing.

2) To modify the prefabricated insoles for better performance in terms of shock absorption during single-leg landing.

1.4 Scope of the Study

A dataset of Computed Tomography (CT) of a healthy 27-year-old man with 169 cm height and 75kg weight was used to reconstruct bones. Three-Dimensional (3D) bones were developed from CT Scan data using the segmentation method through Mimics software. The first part of the project involved only three types of market-ready insoles from three different models and brands: 1) Yonex Active Pro Truactive, 2) Li-Ning L6200LA, 3) Victor VT-XD 8. The badminton insoles were 3D scanned using the Sense 3D Scanner. The 3-Matic (Materialise, Leuven, Belgium) software was used to conduct the post-processing of the insole. The region of interest involving 17-foot bones which are, 5 phalanges, 5 metatarsals, 3 cuneiforms, cuboid, navicular, talus, and calcaneus. This study focused on analysing the pressure distribution on the insoles, skin, and bones during ground contact in the landing phase after a badminton player doing a stroke. Static finite element (FE) analysis using Marc. Mentat (MSC. Software, Santa Ana, CA) will be conducted on the insoles involving insoles, skin, and bones and von Misses Stress, displacement and rotation angle will be observed on the insoles and bones.

1.5 Significance of the Study

In badminton, most of the movements had been done using forefoot as reported by previous research [20]. Hence, developing a feature that can reduce the plantar pressure in the forefoot area especially metatarsals heads is crucial. As reported by Lorentson, better badminton footwear in terms of shock absorption can be a medium in injury prevention [42]. An insole is crucial for sports footwear as it can increase the time of impact [43], hence reducing the impact force [44]. As badminton involves many braking and sudden changes of direction during the game [43], alternatives for reducing the risk of injury need to be developed [31]. The output of this study also can help further the development of sports medical equipment, especially in badminton. Shoes comfort is another level of important characteristics of badminton shoes.

Since insole is part of badminton footwear, the development of better insole can also provide a higher level of comfort to the user [45, 46]. FE analysis is a common approach in determining the yield strength and pressure distribution of a structure. Through the FE analysis approach, local pressure distribution on bones, insole, and skin can also be beneficial for further biomechanical alteration [47]. Localization of pressure on the insole and the skin will contribute mainly to modification stages of insoles. FE analysis also benefits in providing internal stress of the ankle-foot complex [48].

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LIST OF PUBLICATIONS

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