JAPMA Online Early **DOI: 10.7547/18-043**

ORIGINAL ARTICLE

Plantar Pressure Profiles and Possible Foot Syndromes of the Taiwanese College Elite Basketball Players

Tong-Hsien Chow, PhD*
Yih-Shyuan Chen, PhD†
Wen-Cheng Tsai, PhD*
Ming-Hsien Lin, MD, PhD‡

*Department of Leisure Sport and Health Management, St. John's University, New Taipei, Taiwan.
†Department of Digital Literature and Arts, St. John's University, New Taipei, Taiwan.
‡Department of Nuclear Medicine, Cheng Hsin General Hospital, Taipei, Taiwan.

Corresponding author: Tong-Hsien Chow, PhD, Department of Leisure Sport and Health Management, St. John's University, 499, Sec. 4, Tam King Road, Tamsui District, New Taipei City, 25135 Taiwan. (E-mail: thchow1122@mail.sju.edu.tw)

Background: Plantar pressure assessment are useful for understanding the functions of the foot and lower limb and predicting injury incidence rates. Musculoskeletal fatigues are likely to affect the results of plantar pressure profiles. This study aimed at characterizing college elite basketball players' plantar pressure profiles and pain profiles during static standing and walking.

Methods: Fifty-one male elite basketball players and eighty-five male recreational basketball players participated in this study. An optical plantar pressure measurement system was used for collecting the arch index (AI), regional plantar pressure distributions (PPDs), and footprint characteristics during static and dynamic activities. Elite basketball players' pain profiles were examined for evaluating their common musculoskeletal pain areas.

Results: The AI values in recreational basketball players fell in the normal range, whereas was considerably lower in elite basketball players. Elite basketball players' static PPDs of both feet were mainly exerted on the lateral longitudinal arch and the lateral heel, and relatively lower on the medial longitudinal arch, the medial and lateral metatarsal bones. The PPDs mainly transferred to the lateral metatarsal bone and lateral longitudinal arch, and decreased at the medial heel during the midstance phase of walking. The footprint characteristics of elite basketball players illustrated the features of the calcaneal varus (supinated foot) of high arches and the dropped cuboid foot. The lateral ankle joints and anterior cruciate ligaments were the common musculoskeletal pain areas.

Conclusions: Elite basketball players' AI values was found to be high arches, and their PPDs tended to parallel the features of the high-arched supinated and dropped cuboid foot. Their pain profiles not only resonated with the common basketball injuries, but also reflected the features of the Jones fracture and cuboid syndrome. The potential links among high-arched supinated foot, Jones fracture and cuboid syndrome are worth further studies.

Keywords: elite basketball players, arch index (AI), plantar pressure distributions (PPDs), supinated foot, Jones fracture, cuboid syndrome

Basketball is an intensely physical sport involving various tactical elements. Its varied technical includes jumps, accelerations and decelerations, short sprint with sudden stops, lay-ups and cutting movements in various directions.[1,2] Basketball maneuvers are repetitive and impose specific loading demands on athletes, which usually results in a high incidence of lower extremity injuries, where key roles have amortisation in area of foot. This is particularly true in elite athletes whose bodies are trained for enduring high stresses inherent in strenuous repetitive jumping and pivoting.[3] 'Jones fracture' is one of the common podiatric diseases in basketball players[4] and usually occurs when the proximal fifth metatarsal suffers from the forces caused by the basketball-specific repetitious jumping and cutting[3] and the inherent structure of the ligamentous and capsular attachments.[5] A high rate Jones fracture was developed in basketball players because they often suffer from reinjury and regard to injury return to play and performance.[6] In addition, the cuboid syndrome is most likely to happen in people who do the particular sports such as basketball, tennis, running and ballet. These sports place large forces through the foot or in quick movement where players are quickly changing direction. This, in turn, makes muscles attached to the cuboid bone overused and tightened, and increases the stress placed upon the cuboid bone joints and attachments. Repetitive pressure on the cuboid bone could damage and tear the surrounding ligaments or joint capsule, which may cause the support around the cuboid bone to slacken, allowing the cuboid bone to dislodge and dislocate.[7] Cuboid syndrome usually results from flat foot when foot arches have fallen and in some cases when arches are too high. Abnormal foot arches may put disproportionate pressure through the cuboid bone and increase the stress through the lower leg muscles.[7]

Foot arch types can be classified as being high, normal and low arches. Foot arches provide vital shock absorption for foot to adapt people's movement during activities. One of the more important and highly variable structural characteristics of the human foot is its medial longitudinal arch (MLA).[8,9] The MLA provides adequate elastic forces and twisting forces for absorbing the ground reaction force, and is helpful for attenuating the shock from movement during walking and running.[10] Height of the MLA is generally treated as the influential and key determinant of the function of the foot and lower limbs.[11] High-arched foot are possibly at increased risk for injuries to bony structures on the lateral side of the foot (oversupinated), whereas low-arched foot seem to be at high risk for soft-tissue damage on the medial side of the foot (overpronated).[12] It is, therefore, important to have a relatively easy and reliable way to classify the foot arch. Footprint parameters such as the arch index (AI) could be considered a reliable and valid method to characterize the foot arch and MLA height.[13-15] Recently, assessment of static arch mobility, associated with lower extremity and footprint measures has been placed at the core of understanding the overall function of the foot and lower extremities during running.[16]

Plantar pressure assessment from footprints is an effective method for evaluating plantar loading characteristics during functional activities.[17] It could show foot and ankle function during gait since foot and ankle provide necessary support and flexibility for weight bearing and weight shifting while performing activities.[18-20] Parameters obtained from plantar pressure assessment could be used for understanding and evaluating people’s different foot impairments, combined with neurological and musculoskeletal disorders.[21,22] For example, greater regional plantar loadings are usually involved with forefoot rheumatoid arthritis, hallux valgus deformity,[23] medial midfoot osteoarthritis,[24] and posterior tibialis tendon dysfunction leading to flatfoot deformity.[25] In addition, a recent prospective study noted that static characteristics of flatfoot, high-arched foot, and rearfoot ranges of motion seemed to be risk factors for lower extremity overuse injuries.[26] When plantar pressures in each region of the foot are distributed evenly, sports injuries could be reduced effectively.[19]

According to previous studies, the results of plantar pressure distributions (PPDs) could demonstrate foot and lower limb functions and predict injury incidence rates. Notably however, the characteristics of individuals with specific musculoskeletal fatigues are likely to affect the results of PPDs.[27,28] Hence, profiles of the athletes’ PPDs during standing and activities are worth examination and understanding, in that frequently stressful training, exercises and competition usually make athletes' feet burdened with excessive pressures and forces. In order to gain deeper insight into basketball players' PPDs, potential pain profiles and sport injuries, there is a need to further examine plantar pressure profiles of the entire foot in both static and dynamic activities. PPDs have been predominantly investigated in the research field concerning running,[29] soccer-specific tasks,[30,31] basketball technical gestures[2,32] and specific maneuvers.[32-34] Yet, little is known about basketball players' PPDs during static standing and walking. The purpose of this study was to explore the differences between elite basketball players and recreational basketball players in terms of their PPDs during static standing and walking, and to examine elite basketball players' potential pain profiles. Parameters secured from the plantar pressure assessment including the AI values, regional PPDs of the forefoot, midfoot and rearfoot, six subregional PPDs, and footprint characteristics. Furthermore, elite basketball players' pain assessment and self-reported health status were examined for accurately evaluating their common musculoskeletal pain areas. We hypothesized that elite basketball players in the present study were more likely to be classified into high-arched foot, and their PPDs were mainly concentrated on the lateral aspect of the foot. Furthermore, the PPD profiles and pain profiles may be related to the features among high-arched foot, Jones fracture and cuboid syndrome.

Methods

Participant Selection

Research subjects within this study comprised two groups of college and university students in Taiwan. One of the groups, labelled as 'elite basketball players', included 51 male elite basketball players. Participants in elite basketball players were recruited from the National Taiwan Sport University, National Taiwan University of Sport, College of Kinesiology in University of Taipei, and three city sports centers in Taipei, Taiwan. They all had more than 4 successive years of basketball experiences, aged between 19 and 22, and registered in the University Basketball Association (UBA). Their basketball workout schedules (Monday to Friday), including physical and shooting training, were set from 8AM to 10AM. Basic movements and tactical training were set from 3PM to 5PM. Weight training and 1- to 2-hour high intensity interval sprint training were set for 3 to 5 days a week. The other group, 'recreational basketball players', was composed of 85 male recreational basketball players of the same age range as elite basketball players. Participants in recreational basketball players were recruited from five city sports centers in Taipei and had more than 4 years of recreational basketball experiences. They play basketball at least 3 days per week at the basketball court or at the stadium within 6 months before this study was initiated. Each participant's age, height, body weight and body mass index (BMI) were recorded in the research process. It has been widely accepted in many studies that people's arch shapes change when gaining weight in the process of growth and development, and there seems to be a strong link between obesity and flat feet.[13] Considering the effect of body weight on shape characteristics of the foot arch, each participant's BMI was required to range between 18.5 and 24. This particular range of BMI is defined by the World Health Organization (WHO) as healthy weight. A total of 116 subjects participated in this study, and their average age, height, weight and BMI value were shown in Table 1.

Both groups in this study were recruited from a relatively homogeneous population. Two groups were different in their training intensity, training patterns, rigid workout schedules and competition experiences. The present research aimed at exploring the effects of the different exercise behavior on the plantar pressure characteristics between both groups. Furthermore, the elite basketball players' pain and health assessments were conducted through the self-reported health describes and the diagnoses made by a professional physiotherapist at the rehabilitation department. These health assessments were essential for this research to ensure that all participants had no history of previous fracture and surgery, and that they had no injuries in their ankle joints, knee joints, hip joints, spine, and bones and muscles of their lower limbs within a year as this study was underway. Prior to the experiments, all subjects were required to sign the informed consent forms of participation in this study. All experiments within this study followed the guidelines of the Research Ethics Committee, National Taiwan University, and the recommendations of the Declaration of Helsinki.

Instruments and Equipment

'JC Mat optical plantar pressure analysis system' (View Grand International Co., Ltd., New Taipei City, Taiwan) was the main research tool for measuring plantar pressure and PPD. The measurement technology and principles of JC Mat were parallel to the operation principles of the Harris footprint measurement instrument. The following are the main features of JC Mat: (1) foot characteristics are easily and effectively recognized; (2) the PPD and footprints conform to the weight calibration data (data not shown); (3) 25 sensors are in each square centimeter for plantar pressure measurement, and thus, 13,600 sensors are on each side (32*17 cm) of JC Mat; (4) the sensitive pressure sensing with a wide working area can display and mark the delicate plantar pressure image with round dots; (5) the pressure profiles from footprints and barefoot images are captured instantly; and (6) the built-in FPDS-Pro software is qualified for analyzing the following parameters: the arch index (AI), plantar pressure distribution (PPD) values, balance of the center of gravity, toe angles and footprints.

Methods and Procedures

It took approximately six months to select research participants and conduct the experiments. Before the experiments, each participant's consent to participate in this research was gained. Time for each experiment was set from 10AM to 12PM on the same day in order to ensure consistency and trustworthiness of the present research. All participants were asked to measure their body weights and heights during the experiments for calculating the BMI values for this study. It was necessary for securing the data of the static footprints via brief trials of the static upright standing, participants were required to obey the following steps:

(1) Roll both trouser legs up to above the knees for avoiding the clothing from limiting movements of the extremities.

(2) Stand with bare feet on the sensing cushion with specific marks and measuring range of JC Mat.

(3) Relax the body. Control and balance the center of gravity by standing with feet shoulder-width apart and with body weight evenly distributed on feet.

(4) Stampede for 6-8 steps; then, stand still with a natural posture and arms hanging straight down at sides.

(5) Face the experiment instructor. Look the instructor straight in the eye. Keep the body stationary and balanced until no obvious changes in the foot pressure value measured by JC Mat.

When participants reached the condition in step 5, pressure profiles from the static footprints were recorded directly. In follow-up measurement of the dynamic footprints, participants walked at a self-selected speed over the 4-m-long and JC Mat embedded walkway. Multiple walking trials were completed until at least three steps for each limb were correctly acquired (i.e., the sensing cushion with marks of the specific measuring range of JC Mat was struck with a single foot).

Data Analysis

For exploring the PPDs in three regions and six subregions of both feet, the computer program (FPDS-Pro software) was used for managing digital images of the static and walking footprints. The software generated the first line (a perpendicular line) on the footprint image. The perpendicular line extended from the tip of the second toe to the center of the heel; then, was drawn tangential to the most anterior and posterior part of the footprint excluding the toes. The software formed four parallel lines perpendicular to the first line and divided the footprint into three equal regions (regions A, B and C) and six subregions (subregions 1, 2, 3, 4, 5 and 6). Regions A, B and C were defined, respectively, as the forefoot, midfoot and rearfoot regions. Subregions from 1 to 6 were defined, respectively, as the lateral metatarsal bone (LM), lateral longitudinal arch (LLA), lateral heel (LH), medial metatarsal bone (MM), medial longitudinal arch (MLA) and medial heel (MH). The AI ratio method proposed by Cavanagh and Rodgers assumes that the AI is calculated as the ratio of the area of the middle third of the footprint divided by the entire footprint area excluding the toes, i.e., AI=B/(A+B+C). For Cavanagh and Rodgers, an AI lower than 0.21 is a high-arched foot, between 0.21 and 0.26 is a normal arched foot, and higher than 0.26 is a flat arched foot.[35]

Pain Assessment and Self-Reported Health Status

Participants' pain assessments and self-reported health status, and skeleton arrangement were undertaken by a physiotherapist at the rehabilitation department of Tri-service General Hospital in Taipei after the plantar pressure measurement. This was essential for the participant selection criteria, physiological symptom assessment and confirming pain locations. In this study, all participants subject to individual self-reported health status survey by the physiotherapist conducting a history and physical examination. Personal data with individuals will be collected by filling out a questionnaire. In the process of the skeleton arrangement and soft tissue pain assessment, lower limb pain was defined as the musculoskeletal pain which occurred during the past month and originated from the structures of the foot, ankle, knee, lower leg and thigh. This definition excluded intermittent cramps, dermatological conditions, digital calluses and night-time paresthesia from analysis. A standardized protocol of the questioning and examination techniques was used for ensuring the precise nature of the complaint (e.g., metatarsalgia and plantar fasciitis). The following shows the steps of examining participants' frequent pain areas:

(1) The physiotherapist examined participants' self-reported health status and pain areas.

(2) Participants needed to stand with bare feet and roll both trouser legs up to above the knees.

(3) Inspecting participants' lower extremities by pressing their feet (including phalanges, metatarsal bones, navicular bone, cuboid bone and calcaneus), ankle joints, knee joints, hip joints, tibias, fibulas and femur. Assessing participants' skeleton arrangement of their lower extremities.

Two key steps of examining the soft tissue pains were:

(1) The physiotherapist pressed participants' self-reported pain areas and re-checked the corresponding locations on the opposite side of pain areas.

(2) According to their clinical experiences, the physiotherapist checked the specific points in participants' common pains areas, including plantar metatarsal heads, plantar fascia, the inferior margin of navicular bones, the Achilles tendon, the medial and lateral sides of ankle joints, the medial and lateral fossas of knee joints, gastrocnemius, tibialis anterior and posterior, biceps and quadriceps femoris. This was beneficial for confirming participants' pain areas.

Statistical Analysis

Descriptive statistics was used for outlining all participants' ages, heights, weights and BMI values. Numerical data within this study was presented as mean and standard deviation (e.g. mean ± SD). Parameters gained from the plantar pressure measurement regarding the AI values, three regional PPDs of the forefoot, midfoot and rearfoot, six distinct subregional PPDs were compared between groups using independent sample *t* test. Statistical significance was defined as $P < .05$ (marked as *) and $P < .01$ (marked as **). The statistical software (SPSS version18; SPSS Inc, Chicago, Illinois) was used for managing statistical analysis.

Results

Arch Index

The mean AI values of recreational basketball players was 0.22 (Table 2). Yet, the AI of both feet in elite basketball players was significantly smaller than that in recreational basketball players ($P < .01$), suggesting that the arch type was higher in elite basketball players than in recreational basketball players.

PPDs of the Forefoot, Midfoot, and Rearfoot Regions

The PPDs were presented as percentages of the relative load. During static standing, the relative load in the forefoot region of both feet was lower in elite basketball players than in recreational basketball players ($P < .01$) (Table 3). The relative load in the midfoot region of both feet was found to be significantly higher in elite basketball players than in recreational basketball players ($P < .01$). In addition, the relative load in the rearfoot region of both feet was higher in elite basketball players than in recreational basketball players ($P < .01$). Yet, in the midstance phase of walking, the relative load of both feet was higher in the forefoot and midfoot regions ($P < .01$) but lower in the rearfoot region in elite basketball players than in recreational basketball players ($P < .05$) (Table 4).

PPDs of the Six Subregions

The relative loads at the six distinct subregions were derived from the data from the three equal regions. During static standing, the relative load in the forefoot region of both feet in elite basketball players was significantly lower at the lateral and medial metatarsal bones than in recreational basketball players (*P* < .01). In the midfoot region, the relative load at the lateral longitudinal arch of both feet was significantly higher in elite basketball players (left foot: 22.24% ± 3.25%; right foot: 22.77% ± 3.21%) compared with recreational basketball players (left foot: 19.10% ± 4.18%; right foot: 20.58% ± 4.49%) (*P* < .01). The mean ± SD relative load at the medial longitudinal arch of both feet was found to be significantly lower in elite basketball players than in recreational basketball players (*P* < .01). In the rearfoot region, the mean ± SD relative load at the lateral heel of both feet was higher in elite basketball players (left foot: 23.82% ± 2.69%; right foot: 24.24% ± 2.45%) than in recreational basketball players (left foot: 19.69% ± 3.63%; right foot: 23.11% ± 3.71%) (*P* < .05) (Fig. 1). The results from the midstance phase of walking showed that the mean ± SD relative load in the forefoot region of both feet was exerted more on the lateral metatarsal bone in elite basketball players (left foot: 33.19% ± 3.31%; right foot: 34.46% ± 3.69%) compared with recreational basketball players (left foot: 26.29% ± 3.74%; right foot: 25.95% ± 3.19%) (*P* < .05). Nonetheless, the relative load at the lateral longitudinal arch of both feet was higher in elite basketball players (left foot: 19.95% ± 2.78%; right foot: 19.91% ± 3.18%) compared with recreational basketball players (left foot:15.58% ± 3.05%; right foot: 14.22% ± 3.87%) (*P* < .05). In the rearfoot region, the mean ± SD relative load at the medial heel of both feet was lower in elite basketball players than in recreational basketball players (*P* < .05) (Fig. 2).

Footprint Characteristics

The static footprints of elite basketball players showed lower pressure profiles in the forefoot region of both feet and higher pressure profiles in the lateral midfoot and rearfoot regions of both feet compared with recreational basketball players (Fig. 3). To a certain extent, these findings indicate that the arch type was higher and displayed an oversupinated foot in elite basketball players than in recreational runners.

Pain Assessment and Self-reported Health Status of the Participants

According to findings from the elite basketball players' pain assessment and self-reported health status, the eleven most common pain areas are the lateral ankle joint (51.0%); the lateral knee joint (51.0%); the medial knee joint (45.1%); the plantar metatarsal bone (43.1%); the calcaneus (41.2%); the tibia (39.2%); the femur (35.3%); the patella (35.3%); the hip joint (33.3); the fibula (29.4%) and the medial ankle joint (17.6%) (Table 5). The twelve most common sites of soft-tissue pain were the anterior cruciate ligament (64.7%); the lateral ankle ligament (60.8%); the medial collateral ligament (58.8%); the patellar tendon (58.8%); the quadriceps femoris (51.0%); the biceps femoris (41.2%); the gastrocnemius (37.3%); the tibialis anterior (37.3%); the lower back (37.3%); the Achilles tendon (33.3%); the plantar fascia (29.4%); and the neck and shoulder (17.6%).

Discussion

The present research aimed at examining the differences in plantar pressure characteristics between elite basketball players and recreational basketball players during static standing and walking. Static AI of both feet was considerably close to each other within the respective groups. The AI of both feet was lower in elite basketball players than in recreational basketball players. Previous studies concluded that the AI from footprints could act as a predictor of arch height,[8,13-15,35] and that normal AI ranged between 0.21 and 0.26.[35] In this view, recreational basketball players appeared to fall into normal foot arches, and elite basketball players may be categorized into high-arched foot. High-arched individuals with increased height of the MLA often suffered from supinated foot and decreased pronation during the stance phase.[36] An oversupinated foot was viewed as increased calcaneal inversion and tended to be helpful for reducing contact time when running.[37] Hasegawa et al noted that runners with a greater degree of heel inversion at foot strike had shorter contact time, and that shorter contact time and higher frequency inversion at foot contact usually resulted in higher running economy.[37] Therefore, deformation of foot arches seemed to be crucial for force transfer and shock absorption, particularly in impact sports, such as jump and sprint.[38]

During static standing, results from three regional PPDs revealed that relative load of elite basketball players' both feet mainly focused on the midfoot and rearfoot regions, but was significantly lower in the forefoot region compared with recreational basketball players. The opposite situation was found during the midstance phase of walking. Relative load of elite basketball players' both feet was generally concentrated more in the forefoot and midfoot regions, but less in the rearfoot region. The results showed high homogeneity on the forefoot and rearfoot regions of both feet within and between groups. This is possibly because most Taiwanese college basketball players' PPDs were homogeneously distributed on both regions. High heterogeneity on the midfoot region of both feet within and between groups may be related to the features of the basketball players' high arches or/and dropped cuboid feet, since these features could cause either a lack of PPDs on the midfoot region or a higher PPDs at the lateral longitudinal arch of feet. The results seemed to be consistent with previous studies that high arches usually experience oversupination, and this results not only in a decrease in pronation throughout the stance phase but also in an increase in supination in the forefoot and rearfoot regions of the foot during exercise.[36] Previous studies concerning the basketball-specific maneuvers noted that male basketball players increased total foot and lateral midfoot peak pressures while decreasing contact area and lateral midfoot force-time integral during the side-cut task. During the crossover-cut task, the footplate increased total foot and lateral midfoot peak pressure and lateral forefoot force-time integral while decreasing total and lateral forefoot contact area.[32] Pau and Ciuti profiled female basketball players' barefoot PPDs and found that high pressures tended to happened in forefoot when performing technical gestures, including free throw, jump stop shot, three-point shot and lay-up.[39] Studies by Chua et al went further, arguing that high plantar loadings often happened not only to heels during the take-off steps but also to heels and forefoot regions when landing.[33]

Six subregional PPDs were found to be parallel to three regional PPDs. Findings from six subregional PPDs were summarized as follows: during static standing, elite basketball players' plantar loadings were mainly exerted on the lateral longitudinal arch and the lateral heel of both feet. Yet, they were found to be relatively low on the medial longitudinal arch, the medial and lateral metatarsal bones of both feet. During the midstance phase of walking, elite basketball players' plantar loadings were mainly transferred to the lateral metatarsal bone and the lateral longitudinal arch of both feet, whilst decreased at the medial heel of both feet. These findings seemed to support the studies of dynamic plantar loadings. As can be seen in the studies by Teyhen et al and Wong et al, the center of pressure was more lateral in high-arched foot during gait stance.[40,41] Queen et al found that for sports (e.g., soccer) similar to basketball in terms of crossover-cut tasks, most players' plantar loads were beneath the lateral column of the foot.[42] In Guettler et al's research, most college basketball players' plantar loads were exerted on the fifth metatarsal during simulated basketball lay-up, one-footed landing, side-to-side shuffle and maximal-effort sprinting.[43] Yu et al maintained that high peak force and plantar loading were usually concentrated at the fifth metatarsal during basketball lay-up landing and the stance of the shuttle run.[44] Increased lateral forefoot loads were observed in highly repetitive movements (e.g. running and sprinting) in basketball games.[44] However, for people suffering from the Jones fracture (a stress fracture occurring at the proximal fifth metatarsal diaphysis), their maximal loading was usually exerted on the lateral aspect of foot.[6] Wright et al reported that patients with Jones fracture had a twofold increase in peak pressures at the base of the fifth metatarsal head compared with normals, and that athletes who undertake running and cutting maneuvers may be predisposed to these fractures.[5] Lee et al went further, arguing that under weight-bearing conditions athletes with a history of the fifth metatarsal stress fracture tended to have inverted rearfoot alignmen.[45] An increased inversion of the rearfoot in basketball players is a common accident during cutting maneuvers.[46] Baumhauer et al found that 85% of the ankle injuries were caused by excessive rearfoot inversion.[47] Excessive rearfoot inversion resulted from sudden lateral forces which were sufficient to compromise the joint integrity.[47] Other studies presented that people with a pes cavus foot and an anterior equines deformity with a plantar flexed lateral column may make them walk in a more supinated position, which could place excess lateral pressures on the midfoot. This may increase the incidence of cuboid syndrome.[48] Despite many proposed etiologies that may result in cuboid syndrome, plantar flexion and inversion ankle sprains have been widely accepted as the main cause throughout the literature.[49]

Plantar pressure and impact forces on the foot have been widely accepted as one of the main causes of lower extremity injuries in sports.[50] In the present study, elite basketball players' common bony pains were mainly at the lateral ankle joint, the lateral knee joint, the medial knee joint, the plantar metatarsal bone, and calcaneus. Their soft-tissue pain occurred most frequently in the anterior cruciate ligament (ACL), the lateral ankle ligament, the medial collateral ligament (MCL), the patellar tendon, and the quadriceps femoris. The results seemed to supported the studies by Williams et al. who noted that high-arched runners were more likely to experience bone injuries on the lateral portion of the lower extremity and injuries at the foot.[50] Molgaard et al maintained that high-arched people had a high probability of ankle injuries, heel pains, and stress fractures.[51] In terms of basketball injuries, basketball players usually landed on another competitor's foot, which caused a plantar-flexed inversion and stretched the lateral ankle ligaments beyond their capacity. This, in turn, may result in an ankle sprain.[52] Highly repetitive cutting maneuvers in basketball competition can lead to soft tissue injuries such as ACL injuries,[53] ankle sprains,[54] Jones fracture[6] and foot problems.[55] Ankle injuries are one of the most common sports injuries in contact sports (e.g. basketball, soccer and volleyball). Most ankle sprains are inversion injuries which damage the lateral ligaments of the ankle.[56] Most common mechanism of the lateral ankle sprain is a distinct incidence involving the rearfoot's supination and the lower leg's external rotation. This mechanism is often described as a plantar flexion-inversion which frequently involves internal rotation (adduction) of the foot.[57] In addition, extensive stop-and-go movements and cutting maneuvers in basketball games seem to be at the core in putting the ligaments and menisci of the knee at risk.[58] The related studies observed that male college basketball and soccer athletes had a high rate of ACL injuries which were the most commonly disrupted ligaments in the knee. Non-contact ACL injuries were common in basketball competition with movements of rapid decelerations and pivoting.[59] ACL injuries usually result from an abrupt change in direction and landing for the jump. MCL injuries may be attributed to a blow to the outside of the knee in basketball competition.[59] Furthermore, lateral ankle and foot pains may be due to cuboid syndrome.[49] Ankle inversion sprain is the most common injury which can possibly result in cuboid syndrome. More specifically, pathomechanics of the cuboid syndrome may stem from an eversion of the cuboid from an inverted foot position, such as the mechanism of injury for a lateral ankle sprain and produce pain over the lateral column of the foot.[60] As evidenced in many studies, cuboid syndrome to a certain degree is related to other injuries presenting with signs and symptoms on the lateral aspect of the foot. The injuries including Jones fracture, fracture of the anterior calcaneal process, stress fractures of the cuboid, meniscoid of the ankle, malalignment of the lateral ankle and subtalar joints.[60-62] Basketball players' stress fractures usually occur in the foot and tibia.[58] Basketball players have an increased prevalence of sustaining the fifth metatarsal stress fractures compared with other athletes.[4,63] The fifth metatarsal fractures commonly occur in basketball games and practices in which the shuttle run and cutting tasks were frequently performed.[5]

The present research was limited by its particular highlights of plantar pressure characteristics of 51 elite and 85 recreational basketball players who were 19 to 22 years college or university students in Taiwan. It is inevitable that results from the present research may limit the possibilities for generalization. Notably, however, little research is currently being conducted for exploring recreational and elite basketball players' plantar loading characteristics by focusing exclusively on static standing. It is anticipated that findings from this study may shed light on college and university elite basketball players' static and dynamic pressure profiles and pain profiles. It is expected that the results and literature on dynamic states discussed in this study may contribute to illuminating the issues of the possible correlation between pressure profiles and pain profiles.

To conclude, elite basketball players in the present study were generally classified as high-arched foot, and their PPDs were categorized into the features of calcaneal varus (supinated foot) of high arches and dropped cuboid foot. Patterns of the elite basketball players' pressure profiles indicated possibilities for Jones fracture and cuboid syndrome. Results from the elite basketball players' pain profiles revealed that the lateral ankle joint and the anterior cruciate ligament were the most common musculoskeletal pains. The results could reinforce the findings from previous studies regarding basketball players' commonly observed injuries.[64] Many studies have noted the relationships among basketball players, pressure profiles and pain profiles. Nevertheless, limited research has been undertaken for understanding potential link between high-arched supinated foot and incidence of the cuboid syndrome and Jones fracture. Findings from the present research confirmed that high-arched supinated patterns tended to occur in elite basketball players. The results stressed the possible links among high-arched supinated foot, cuboid syndrome and Jones fracture, and the correlations are worth further study.

Acknowledgements: The authors report no conflict of interest. This work was supported by the Ministry of Science and Technology, Taipei, Taiwan under Grant MOST 104-2622-H-129-001-CC3.

Financial Disclosure: None reported.

Conflict of Interest: None reported.

References

1. Ben Abdelkrim N, El Fazaa S, El Ati J: Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. Br J Sports Med **41:** 69, 2007.
2. Lam WK, Ng WX, Kong PW: Influence of shoe midsole hardness on plantar pressure distribution in four basketball-related movements. Res Sports Med **25:** 37, 2017.
3. Smith TO, Clark A, Hing CB: Interventions for treating proximal fifth metatarsal fractures in adults: a meta-analysis of the current evidence-base. Foot Ankle Surg **17:** 300, 2011.
4. Iwamoto J, Takeda T: Stress fractures in athletes: review of 196 cases. J Orthop Sci **8:** 273, 2003.
5. Wright RW, Fischer DA, Shively RA, et al: Refracture of proximal fifth metatarsal (Jones) fracture after intramedullary screw fixation in athletes. Am J Sports Med **28:** 732, 2000.
6. Kavanaugh JH, Brower TD, Mann RV: The Jones fracture revisited. J Bone Joint Surg Am **60:** 776, 1978.
7. Marshall P, Hamilton WG: Cuboid subluxation in ballet dancers. Am J Sports Med **20:** 169, 1992.

8. Chu WC, Lee SH, Chu W, et al: The use of arch index to characterize arch height: a digital image processing approach. IEEE Trans Biomed Eng **42:** 1088, 1995.
9. Shiang TY, Lee SH, Lee SJ, et al: Evaluating different footprint parameters as a predictor of arch height. IEEE Eng Med Biol Mag **17:** 62, 1998.
10. Kaye RA, Jahss MH: Tibialis posterior: a review of anatomy and biomechanics in relation to support of the medial longitudinal arch. Foot Ankle **11:** 244, 1991.
11. Razeghi M, Batt ME: Foot type classification: a critical review of current methods. Gait Posture **15:** 282, 2002.
12. Xiong S, Goonetilleke RS, Witana CP, et al: Foot arch characterization: a review, a new metric, and a comparison. J Am Podiatr Med Assoc **100:** 14, 2010.
13. Mickle KJ, Steele JR, Munro BJ: The feet of overweight and obese young children: are they flat or fat? Obesity (Silver Spring) **14:** 1949, 2006.
14. Williams DS, McClay IS: Measurements used to characterize the foot and the medial longitudinal arch: reliability and validity. Phys Ther **80:** 864, 2000.
15. Wearing SC, Hills AP, Byrne NM, et al: The arch index: a measure of flat or fat feet? Foot Ankle Int **25:** 575, 2004.
16. Williams DS 3rd, Tierney RN, Butler RJ: Increased medial longitudinal arch mobility, lower extremity kinematics, and ground reaction forces in high-arched runners. J Athl Train **49:** 290, 2014.
17. Cousins SD, Morrison SC, Drechsler WI: The reliability of plantar pressure assessment during barefoot level walking in children aged 7-11 years. J Foot Ankle Res **5:** 8, 2012.
18. Soames RW. Foot pressure patterns during gait. J Biomed Eng **7:** 120, 1985.
19. Sneyers CJ, Lysens R, Feys H, et al: Influence of malalignment of feet on the plantar

pressure pattern in running. Foot Ankle Int **16:** 624, 1995.

20. Duckworth T, Betts RP, Franks CI, et al: The measurement of pressures under the foot. Foot Ankle **3:** 130, 1982.
21. Masson EA, Hay EM, Stockley I, et al: Abnormal foot pressures alone may not cause ulceration. Diabet Med **6:** 426, 1989.
22. Veves A, Murray HJ, Young MJ, et al: The risk of foot ulceration in diabetic patients with high foot pressure: a prospective study. Diabetologia **35:** 660, 1992.
23. Minns RJ, Craxford AD: Pressure under the forefoot in rheumatoid arthritis. A comparison of static and dynamic methods of assessment. Clin Orthop Relat Res **187:** 235, 1984.
24. Menz HB, Munteanu SE, Zammit GV, et al: Foot structure and function in older people with radiographic osteoarthritis of the medial midfoot. Osteoarthritis Cartilage **18:** 317, 2010.
25. Imhauser CW, Siegler S, Abidi NA, et al: The effect of posterior tibialis tendon dysfunction on the plantar pressure characteristics and the kinematics of the arch and hindfoot. Clin. Biomech **19:** 161, 2004.
26. Kaufman KR, Brodine SK, Shaffer RA, et al: The effect of foot structure and range of motion on musculoskeletal overuse injuries. Am J Sports Med **27:** 585, 1999.
27. Bisiaux M, Moretto P: The effects of fatigue on plantar pressure distribution in walking. Gait Posture **28:** 693, 2008.
28. Escamilla-Martínez E, Martínez-Nova A, Gómez-Martín B, et al: The effect of moderate running on foot posture index and plantar pressure distribution in male recreational runners. J Am Podiatr Med Assoc **103:**121, 2013.

29. Verdejo R, Mills NJ: Heel-shoe interactions and the durability of EVA foam running-shoe midsoles. J Biomech **37:** 1379, 2004.
30. Orendurff MS, Rohr ES, Segal AD, et al: Regional foot pressure during running, cutting, jumping, and landing. Am J Sports Med **36:** 566, 2008.
31. Wong PL, Chamari K, Mao DW, et al: Higher plantar pressure on the medial side in four soccer-related movements. Br J Sports Med **41:** 93, 2007.
32. Queen RM, Abbey AN, Verma R, et al: Plantar loading during cutting while wearing a rigid carbon fiber insert. J Athl Train **49:** 297, 2014.
33. Chua YK, Quek RK, Kong PW: Basketball lay-up - foot loading characteristics and the number of trials necessary to obtain stable plantar pressure variables. Sports Biomech **16:** 13, 2017.
34. Cong Y, Lam WK, Cheung JT, et al: In-shoe plantar tri-axial stress profiles during maximum-effort cutting maneuvers. J Biomech **47:** 3799, 2014.
35. Cavanagh PR, Rodgers MM: The arch index: a useful measure from footprints. J Biomech **20:** 547, 1987.
36. Nigg BM, Cole GK, Nachbauer W: Effects of arch height of the foot on angular motion of the lower extremities in running. J Biomech **26:** 909, 1993.
37. Hasegawa H, Yamauchi T, Kraemer WJ: Foot strike patterns of runners at the 15-km point during an elite-level half marathon. J Strength Cond Res **21:** 888, 2007.
38. Chang YW, Hung W, Wu HW, et al: Measurements of Foot Arch in Standing, Level Walking, Vertical Jump and Sprint Start. Int J Sports Med **2:** 35, 2010.
39. Pau M, Ciuti C: Stresses in the plantar region for long- and short-range throws in women basketball players. Eur J Sport Sci **13:** 575, 2013.

40. Teyhen DS, Stoltenberg BE, Eckard TG, et al: Static foot posture associated with dynamic plantar pressure parameters. J Orthop Sports Phys Ther **41:** 100, 2011.
41. Wong L, Hunt A, Burns J, et al: Effect of foot morphology on center-of-pressure excursion during barefoot walking. J Am Podiatr Med Assoc **98:** 112, 2008.
42. Queen RM, Haynes BB, Hardaker WM, et al: Forefoot loading during 3 athletic tasks. Am J Sports Med **35:** 630, 2007.
43. Guettler JH, Ruskan GJ, Bytomski JR, et al: Fifth metatarsal stress fractures in elite basketball players: evaluation of forces acting on the fifth metatarsal. Am J Orthop **35:** 532, 2006.
44. Yu B, Preston JJ, Queen RM, et al: Effects of wearing foot orthosis with medial arch support on the fifth metatarsal loading and ankle inversion angle in selected basketball tasks. J Orthop Sports Phys Ther **37:** 186, 2007.
45. Lee KT, Kim KC, Park YU, et al: Radiographic evaluation of foot structure following fifth metatarsal stress fracture. Foot Ankle Int **32:** 796, 2011.
46. Stacoff A, Steger J, Stüssi E, et al: Lateral stability in sideward cutting movements. Med Sci Sports Exerc **28:** 350, 1996.
47. Baumhauer JF, Alosa DM, Renström AF, et al: A prospective study of ankle injury risk factors. Am J Sports Med **23:** 564, 1995.
48. Subotnick SI: Peroneal cuboid syndrome. J Am Podiatr Med Assoc **79:** 413, 1989.
49. Patterson SM: Cuboid syndrome: a review of the literature. J Sports Sci Med **5:** 597, 2006.
50. Williams DS 3rd, McClay IS, Hamill J: Arch structure and injury patterns in runners. Clin Biomech **16:** 341, 2001.

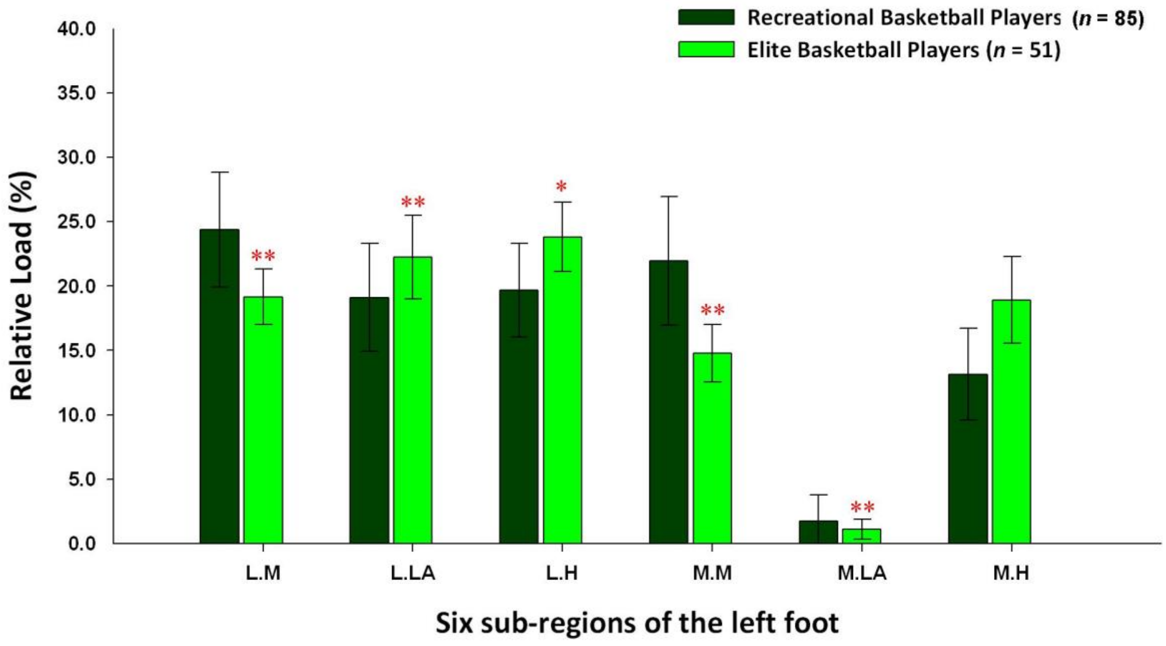
51. Mølgaard C, Lundbye-Christensen S, Simonsen O: High prevalence of foot problems in the Danish population: a survey of causes and associations. Foot **20:** 7, 2010.
52. Wright IC, Neptune RR, van den Bogert AJ, et al: The influence of foot positioning on ankle sprains. J Biomech **33:** 513, 2000.
53. Yu B, Garrett WE: Mechanisms of non-contact ACL injuries. Br J Sports Med **1:** i47, 2007.
54. Fong DT, Hong Y, Shima Y, et al: Biomechanics of supination ankle sprain: a case report of an accidental injury event in the laboratory. Am J Sports Med **37:** 822, 2009.
55. Yavuz M, Davis BL: Plantar shear stress distribution in athletic individuals with frictional foot blisters. J Am Podiatr Med Assoc **100:** 116, 2010.
56. Willems T, Witvrouw E, Verstuyft J, et al: Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. J Athl Train **37:** 487, 2002.
57. Kaminski TW, Hertel J, Amendola N, et al: National Athletic Trainers' Association. National Athletic Trainers' Association position statement: conservative management and prevention of ankle sprains in athletes. J Athl Train **48:** 528, 2013.
58. Miyasaka KC, DM Daniel, ML Stone: The incidence of knee ligament injuries in the general population. Am J Knee Surg **4:** 43, 1991.
59. Schilaty ND, Bates NA, Krych AJ, et al: How anterior cruciate ligament injury was averted during knee collapse in a NBA point guard. Ann Musculoskelet Med **1:** 8, 2017.
60. Jennings J, Davies GJ: Treatment of cuboid syndrome secondary to lateral ankle sprains: a case series. J Orthop Sports Phys Ther **35:** 409, 2005.
61. Caselli MA, Pantelaras N: How to treat cuboid syndrome in an athlete. Podiatry Today **17:** 76, 2004.

62. Leerar PJ: Differential diagnosis of tarsal coalition versus cuboid syndrome in an adolescent athlete. J Orthop Sports Phys Ther **31:** 702, 2001.

63. Fernández Fairen M, Guillen J, Busto JM, et al: Fractures of the fifth metatarsal in basketball players. Knee Surg Sports Traumatol Arthrosc **7:** 373, 1999.

64. Taylor JB, Ford KR, Nguyen AD, et al: Prevention of lower extremity injuries in basketball: A systematic review and meta-analysis. Sports Health **7:** 392, 2015.

Figure 1. Plantar pressure distributions of the six subregions of the left (A) and right (B) feet in static standing. **P* < .05 and ***P* < .01 are significantly different between elite basketball players and recreational basketball players by the independent-samples *t* test. LH, lateral heel; LLA, lateral longitudinal arch; LM lateral metatarsal bone; MH, medial heel; MLA, medial longitudinal arch; and MM, medial metatarsal bone.



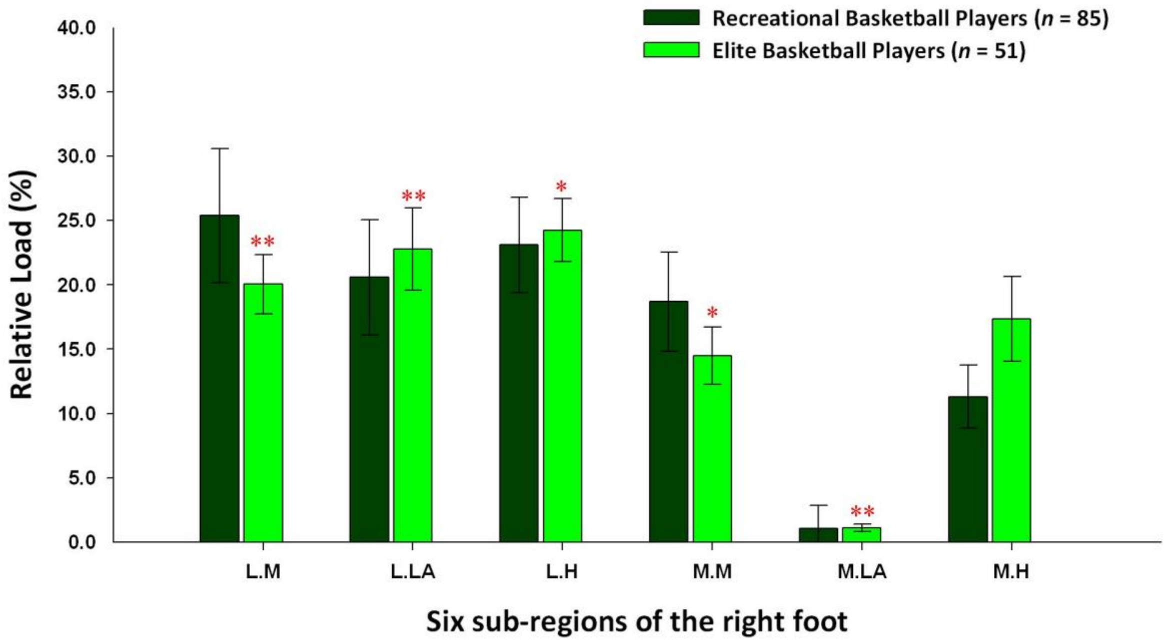


Figure 2. Plantar pressure distributions of the six subregions of the left (A) and right (B) feet during the midstance phase of walking. *$P < .05$ and **$P < .01$ are significantly different between elite basketball players and recreational basketball players by the independent-samples *t* test. LH, lateral heel; LLA, lateral longitudinal arch; LM lateral metatarsal bone; MH, medial heel; MLA, medial longitudinal arch; and MM, medial metatarsal bone.

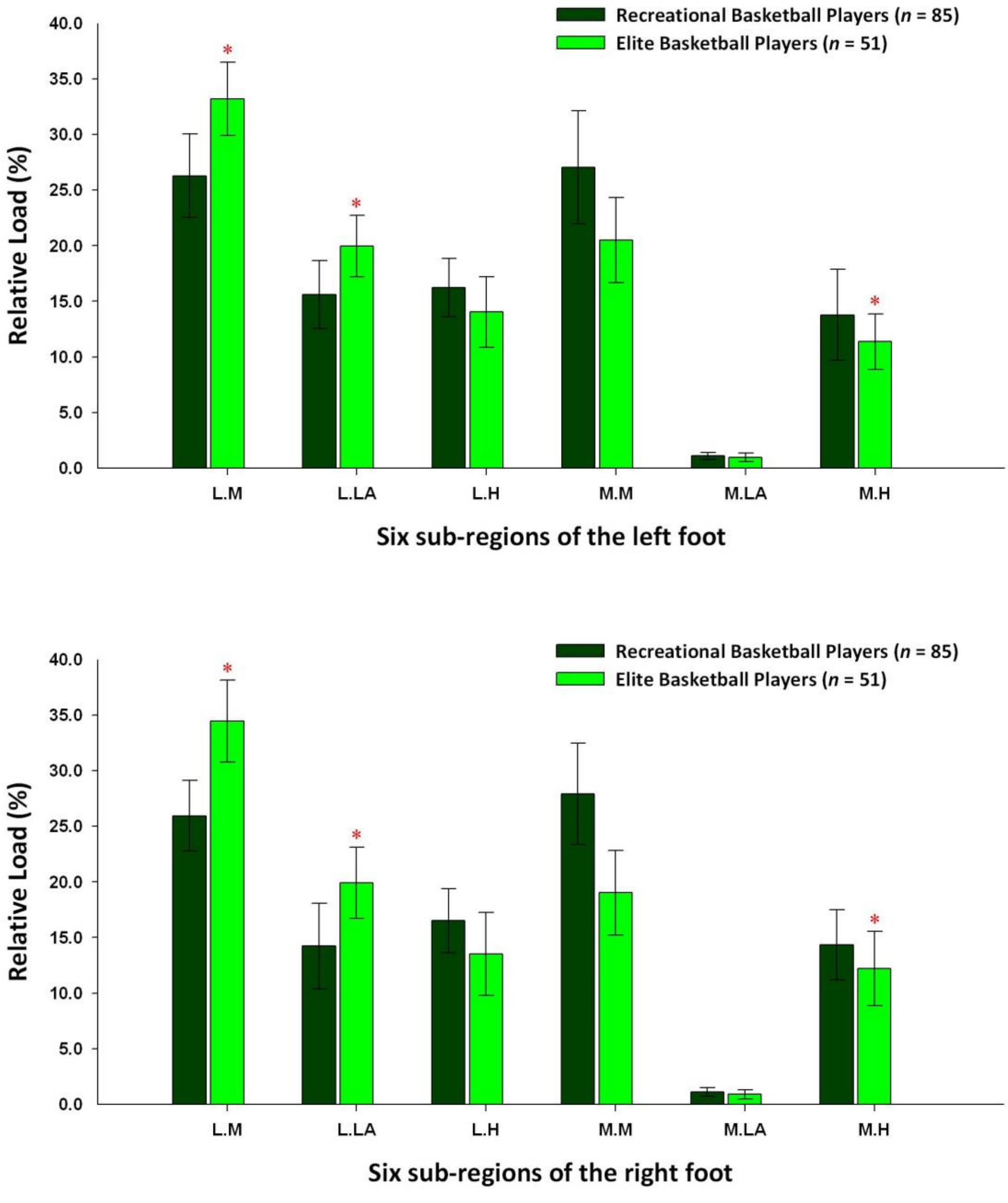


Figure 3. Static footprints of both feet from a male recreational basketball players (A), and a male elite basketball players (B). White arrows indicate higher pressure areas.

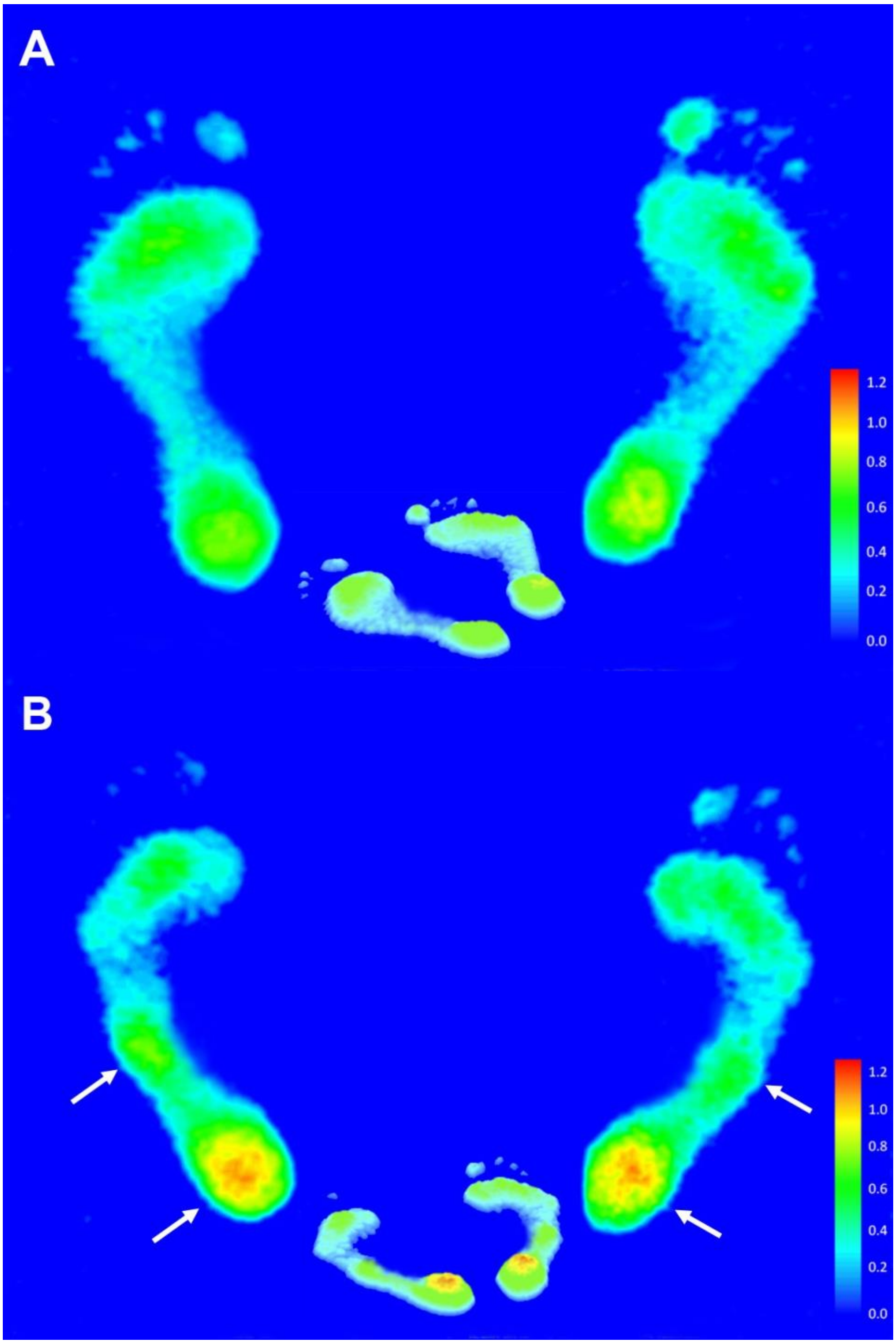

A
1.2
1.0
0.8
0.6
0.4
0.2
0.0
B
1.2
1.0
0.8
0.6
0.4
0.2
0.0

Table 1. Demographic Characteristics of the 116 Study Participants

Characteristic	Recreational Basketball Players [a] (n=85)	Elite Basketball Players [b] (n=51)
Age (years)	21.0 ± 0.8	20.2 ± 1.0
Height (cm)	171.2 ± 6.3	180.4 ± 7.9
Mass (kg)	68.3 ± 6.4	77.6 ± 7.0
BMI	23.2 ± 0.1	23.8 ± 0.2
Experience (years)	3.5 ± 1.0	5.0 ± 0.8

Abbreviation: BMI, body mass index (calculated as the weight in kilograms divided by the square of the height in meters).

Note: Data are given as mean ± SD.

[a] Recreational basketball players are college and university students who play basketball at least 3 days per week at the typical basketball court or at the stadium within the 6 months before study initiation.

[b] Elite basketball players are college and university students. They had to have more than four successive years of basketball experience and registered in the University Basketball Association (UBA) to be considered elite.

Table 2. Arch Index of the Foot in Static Standing

	Recreational Basketball Players	Elite Basketball Players	*P* Value [a]
Left foot	0.22 ± 0.03	0.18 ± 0.02	< .01
Right foot	0.22 ± 0.03	0.18 ± 0.02	< .01

Note: Data are given as mean ± SD.

[a] *P* values were determined by the independent-samples *t* test between recreational basketball players (n=85) and elite basketball players (n=51).

Table 3. Relative Load of the Forefoot, Midfoot, and Rearfoot Regions During Static Standing

Region	Recreational Basketball Players	Elite Basketball Players	*P* Value [a]
Left foot			
Forefoot（%）	23.16 ± 4.88	16.96 ± 3.09	< .01
Midfoot（%）	10.42 ± 9.29	11.68 ± 10.86	< .01
Rearfoot（%）	16.42 ± 4.87	21.37 ± 3.91	< .01
Right foot			
Forefoot（%）	22.03 ± 5.67	17.26 ± 3.59	< .01
Midfoot（%）	10.82 ± 10.36	11.94 ± 11.12	< .01
Rearfoot（%）	17.21 ± 6.70	20.80 ± 4.52	< .01

Note: Data are given as mean ± SD.

[a] *P* values were determined by the independent-samples *t* test between recreational basketball players (n=85) and elite basketball players (n=51).

Table 4. Relative Load of the Forefoot, Midfoot, and Rearfoot Regions During the Midstance Phase of Walking

Region	Recreational Basketball Players	Elite Basketball Players	*P* Value[a]
Left foot			
Forefoot（%）	26.66 ± 4.46	26.85 ± 7.30	< .01
Midfoot（%）	8.34 ± 7.58	10.46 ± 9.74	< .01
Rearfoot（%）	15.00 ± 3.65	12.69 ± 3.14	0.041
Right foot			
Forefoot（%）	26.92 ± 4.04	26.74 ± 8.60	< .01
Midfoot（%）	7.66 ± 7.13	10.40 ± 9.82	< .01
Rearfoot（%）	15.42 ± 3.20	12.86 ± 3.59	0.039

Note: Data are given as mean ± SD.

[a] *P* values were determined by the independent-samples *t* test between recreational basketball players (n=85) and elite basketball players (n=51).

Table 5. Pain Assessment and Self-reported Health Status in the 51 Elite Basketball Players

Pain Area	Elite Basketball Players (No. [%])	Pain Area	Elite Basketball Players (No. [%])
Bone pain		Soft-tissue pain	
Lateral ankle joint	26 (51.0)	Anterior cruciate ligament	33 (64.7)
Lateral knee joint	26 (51.0)	Lateral ankle ligament	31 (60.8)
Medial knee joint	23 (45.1)	Medial collateral ligament	30 (58.8)
Foot (Plantar metatarsal bone)	22 (43.1)	Patellar tendon	30 (58.8)
Foot (Calcaneus)	21 (41.2)	Quadriceps femoris	26 (51.0)
Tibia	20 (39.2)	Biceps femoris	21 (41.2)
Femur	18 (35.3)	Gastrocnemius	19 (37.3)
Patella	18 (35.3)	Tibialis anterior	19 (37.3)
Hip joint	17 (33.3)	Lower back	19 (37.3)
Fibula	15 (29.4)	Achilles tendon	17 (33.3)
Medial ankle joint	9 (17.6)	Plantar fascia	15 (29.4)
Others	7 (13.7)	Neck and shoulder	9 (17.6)