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Original Research

Effect of shoes containing nanosilica particles on knee valgus in active females during landing

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Abstract

Objective(s): The effect of silica nanoparticles (SNPs) in sport shoes outsoles on the parameters related to anterior cruciate ligament (ACL) Injury has not been investigated. The aim of this study was to investigate the effect of shoes outsole containing a composite of thermoplastic elastomer based on styrene-butadiene and silica nanoparticles (TPEN shoe) on Knee Valgus Angle (KVA) as a risk factor of ACL injuries during landing
Materials and Methods: Fourteen active healthy women without knee injuries and disorders performed bilateral drop jump *(DJ)* and single leg drop landing (SLL) tasks in barefoot, wearing shoes fabricated with polyvinyl chloride outsole (PVC shoe) and TPEN shoes conditions , randomly. The knee valgus angle values of right and left legs were calculated in the landing conditions. Two factors repeated measures ANOVA were used to investigate the effect of landing and footwear conditions on KVA of right and left legs.
Results: For both left and right limbs, the KVA was at maximum and minimum values during landing with barefoot and TPEN shoes, respectively. PVC shoe significantly reduced the knee valgus by 3.84% in left and 4.18% in right knee ($P<0.05$) as compared to barefoot landing. In a similar pattern, TPEN shoe significantly reduced the knee valgus compared to barefoot by 7.82% and 9.71% in left and right limbs, respectively. Moreover, the knee valgus during DJ was significantly increased as compared to SLL condition ($P<0.05$).
Conclusion: Shod landing and specially TPEN shoe decreases KVA compared to barefoot. Our results suggested that using SNPs could produce some viscoelasticity property and a better joint movement control in shoe outsoles which can reduce KVA and consequent reduction of ACL Injury.

Keywords: Knee valgus angle, Landing, Nanoparticles, Shoe, Silica

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Introduction

Anterior cruciate ligament (ACL) injury is a common and traumatic knee joint injury in female athletes (1). Non-contact ACL injuries account for more than two-thirds of ACL injuries (2-5). The non-contact mechanism usually involves a deceleration before a change of direction, deceleration phase of landing after a jump or in preparation for a cutting maneuver that are associated with high loads on the knee joint (2, 5-8). It has been reported that landing from a jump is one of the primary non-contact mechanisms for ACL injury in female basketball and volleyball and soccer players (2, 9-13). Decreased knee flexion and increased knee valgus angle (KVA), tibial rotation, hip adduction and hip internal rotation during landing and cutting maneuvers, commonly seen during ACL injury episodes (6, 7, 14-16), can increase strain placed on the ACL (17, 18). Knee valgus has been defined as abducted position of the knee on landing or during the stance phase of gait (19). Females have been found to land in more KVA during a single leg step landing (20) as well as a double leg drop jump (19, 21) and it can be a reason for higher incidence of ACL injuries (22). In fact, increased valgus angles during landing activities are predictive of ACL injury in female athletes (19). The majority of studies in KVA focused on its gender and sport differences (19, 21, 23-25).

The choice of footwear across these studies ranges from the participant wearing their own shoes (20, 26) to testing while barefoot (27) and some studies do not report footwear condition (21). However, athletic activity usually involves wearing appropriate sports shoes.

The athletic shoes are usually composed of soft compressible support surface interfaces designed to protect against injuries occurring in sport activates (28). Chiu and Shiang (2007) demonstrated that athletic shoes can attenuate injury risk during sports through their cushioning system (29). Furthermore, Hootman et al. (2007) reported that barefoot sports such as gymnastics displayed a high incidence rate of knee injuries, like anterior cruciate ligament (ACL) injuries, as compared to shod sports including volleyball and basketball (30).

Several materials such as carbon rubber, styrene-butadiene rubber (SBR), micro-cellular rubber, ethyl vinyl acetate (EVA), polyurethane (PU), polyvinyl chloride (PVC) and Hytrel® have been used in sport shoe soles (31). However, these materials have had two primary limitations. First, to achieve appropriate cushioning with these materials, sole thicknesses must be increased (32); second, these materials have low capabilities to return energy and control joint movement (33). It is reported that thicker-soled shoes can produce more cushioning (32), but it can increase the soles height possibly leading to ankle instability and risk of foot and ankle strain and sprain (28, 34, 35).

We hypothesized that silica nanoparticles have properties that may improve biomechanical factors related to shoe sole. Tensile strength of silica nanoparticles can increase viscoelasticity property and reduce thickness of the shoe sole. Thus, it can possibly close the ankle to the ground and change the ground reaction force moment arms.

Moreover, elasticity property of the shoe sole can change energy return from shoe sole leading to better joint movement control, particularly on landing after a vertical jump.

To our knowledge, the effect of using silica nanoparticles in sport shoes outsoles has not been investigated on knee joint angle changes during landing. The aim of this study was to investigate the effect of a composite of TPEN shoe on KVA of active women during landing.

Materials and Methods

Subjects

Fourteen healthy women having an average age of 24.2±1.9 year, weight of 58.1±3.4 kg, height of 170.4±2.4 cm, foot size of 41-42 volunteered. They were free of any lower extremity injuries and disorders participate in volleyball activities (4 h/week) for the past four years. The dominant leg of the all subjects was right. They were informed about the procedures and signed an informed consent.

Experimental set-up

Two-dimensional frontal projection planes were captured by a camera (JVC-9X00; 200 HZ) that was placed at a height of 50 cm, 3 m anterior to the subjects landing target, and aligned perpendicular to the frontal plane. Video data were collected using the SIMI motion software.

Six markers were placed on the lower extremity of each subject as employed by Willson et al. (36).Markers were placed at the midpoint of the ankle malleoli for the center of the ankle joint, midpoint of the femoral condyles to approximate the center of the knee joint and on the proximal thigh at the midpoint along a line from the anterior superior iliac spine to the knee marker. All markers were placed by the same experimenter.

Two pairs of shoe were used in this study. They were the same in shape and properties (weight, size and outsole design) but different in outsole materials. One of them was a PVC shoe (polyvinyl chloride) with hardness of 65 shore A and another was a TPEN shoe (composite of thermoplastic elastomer based on styrene-butadiene and silica nanoparticles) with hardness of 70 shore A.

Testing procedure

In order to simulate the landings encountered during athletic participation, subjects were asked to perform bilateral drop jump (DJ) and single leg drop landing (SLL) tasks. Each subject was given enough time to warm up and was asked to perform 3–5 practice trials of both tasks with both shoes and barefoot to become familiar with the specific conditions.

Three successful trials were performed for each task in each condition. The sequence of step landing (left or right leg first) or drop jump task and condition (barefoot, PVC shoe and TPEN shoe) was assigned in block order.

Drop jump task (DJ)

Subjects stood on a 30-cm-high bench with feet shoulder width apart and were asked to drop as vertically as possible, in an attempt to standardize landing height, landing on both feet at a mark 30 cm from the bench. They were required to perform a maximal vertical jump immediately after landing, finally landing back on the mark. There were no set instructions regarding arm movement, only for the subjects to perform the jump naturally (Fig. 1a).

Single leg landing (SLL)

Subjects dropped from a 30-cm-high bench dropping as vertically as possible. They were asked to land with the opposite leg onto a marked point 30 cm from the bench with the test limb ensuring the contralateral leg makes no contact with any other surface and balance is held for a minimum three seconds (Fig. 1b).

Analysis

All parameters were calculated using Microsoft Excel 2010 from the two-dimensional coordinates previously filtered at 12 Hz with a low-pass fourth order Butterworth filter (37).

The maximum values of angle subtended between the lines formed through the markers at the Anterior Superior Iliac spine and middle of the knee joint and that formed from the markers on the knee joint to the middle of the ankle joint was recorded as the valgus angle of the knee. The average KVA value from three trials was used for analysis from this group means and standard deviations were calculated for all KVA measures.

Statistical analysis

3 Footwear × 2 landing two factor repeated measures ANOVA were used to investigate the effect of landing and

footwear conditions on KVA of right and left legs. The Bonferroni multiple comparison procedures were used to make all post-hoc comparisons. SPSS-v20 software was used to perform all statistical analyses. The level of significance was set at $p<0.05$.

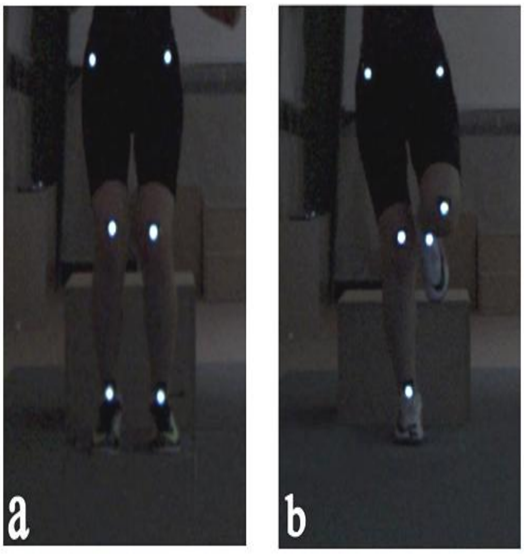

Figure 1. Example of knee valgus during drop jump task (a) and single leg landing (b).

Results

The results of the present study show that footwear condition (Table 1) and landing pattern (Table 2) did affect the KVA. These finding provide evidence that the KVA differed across footwear conditions over SLL and DJ landing patterns. Specifically, statistical analysis showed that the KVA was at its maximum during landing barefoot and at its minimum values when landing in TPEN shoe values for both left and right limbs. PVC shoe significantly decreased the KVA compared to barefoot about 3.8% in left ($P<0.001$) and 4.1% in right ($P<0.001$) limbs. Also, landing in TPEN shoe caused a significant reduction of the KVA compared to barefoot by 7.8% in left ($P<0.001$) and 9.7% in right ($P<0.001$) limbs. Furthermore, significant differences were observed in KVA between DJ and SLL for both limbs ($P<0.001$). The KVA during DJ was significantly more than SLL.

Discussion

To the best of our knowledge, this is the first study aimed to investigate the effect of a composite of TPEN shoe on KVA compared to barefoot condition in active women during SLL and DJ. Generally, the results of the present study indicate that landing in TPEN shoe decreased the KVA during SLL and DJ. More detailed, our finding suggest that a) shod landing reduce KVA compared to barefoot b) landing in TPEN shoe reduce KVA compared barefoot and PVC and c) DJ landing cause greater KVA than SLL. These finding suggest that footwear change the kinematics of knee during landing. These results are consistence with Webster et al. (2004) who reported that wearing sport shoes increase peak knee flexion angles and with Pollard et al. (2010) who demonstrated wearing Brooks Maximus II shoes increase knee flexion range of motion (37, 38).

Prior studies on KVA reported that slight alternations in KVA could change knee valgus load, considerably. McLean et al. (2004) reported that 2° alternation in KVA leads to 40 N.m increase in knee valgus moment (39).

Excessive KVA cause excessive knee abduction moment that is associated with medial knee pain and tears of ACL (40). Moreover, Andriacchi et al. (1983) and Li et al. (1998) reported that the addition of valgus load to the knee increase electrical activity of pes anserinus muscles (41, 42).

With respect to results reported in the literature, our findings suggest that landing in TPEN shoe could decrease the valgus load to the knee thought increasing KVA. This decreased tendency mainly facilitates the work of gluteus medius and pes anserinus muscles that limite knee valgus motion (20). Our finding implied that landing on TPEN shoe causes these muscles work easier than landing on barefoot and PVC shoe. It may be due to the tensile strength and elasticity of TPEN shoe that caused by SNPs.

Table 1. Mean (standard deviation) of KVA for footwear conditions in left and right limbs.

Limb	Condition					
	Barefoot	PVC		TPEN		
	Mean (SD)	Mean (SD)	P-value barefoot	Mean (SD)	P-value barefoot	P-value PVC
Left	15.2°±2.8	14.6°±2.8	**0.001**	14.1°±2.7	**0.001**	**0.007**
Right	14.8°±2.8	14.1°±2.7	**0.001**	13.5°±2.7	**0.001**	**0.012**

Significant results are printed in bold (P<0.05)

Table 2. Mean and SD for landing patterns.

Limb	Pattern		
	Drop Jump	Single Leg	P-value
Left	15.0°±2.9	14.2°±2.6	**0.001**
Right	14.5°±2.8	13.8°±2.7	**0.001**

Significant results are printed in bold (P<0.05)

Furthertmore , it has been suggested that harder outsoles provide more dynamic balance during some movement such as gait (43-47). As TPEN shoe is more viscoelastic than PVC shoe, it could be suggested that higher viscoelasticity of TPEN shoe provides a more stable landing compared to PVC shoe which exert less KVA.

The greater KVA in barefoot could be a compensatory strategy. Pollard et al. proposed a theory that females who limit motion in the sagittal plane employ a strategy of reliance on passive restraints in the frontal plane to control the deceleration of the body center of mass (37). Furthermore, prior studies on shod landing reported that knee flexion in shod landing was greater than that of barefoot and that increasing in knee flexion caused KVA reduction (37, 48). Thus, this great value of valgus in barefoot landing could be as a result of less knee flexion.

In our study, KVA increased in DJ compared to SLL which was consistent with those reported previously (23, 24). The difference between DJ and SLL might be related to the nature of the sport skills of the subjects. There may be a familiarity with single leg stance tasks for the subject which may have resulted in better performances in this task. We suggest that the differences observed are due to the demands of the sport.

Conclusion

Increased KVA increased the risk of ACL injury during athletic tasks such as landing. Our study showed that shod and also TPEN decreases KVA. It seems that using SNPs caused some viscoelasticity property and joint movement control in shoe outsoles that can affect KVA as a risk factor of ACL Injury. But further studies are required to investigate the effect of other materials containing nanoparticles on KVA and another kinematic and kinetics variable related to ACL injury.

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