Scand J Med Sci Sports 2013: ••: ••–••
doi: 10.1111/sms.12130

SCANDINAVIAN JOURNAL OF MEDICINE & SCIENCE IN SPORTS

The effect of ankle bracing on knee kinetics and kinematics during volleyball-specific tasks

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Accepted for publication 21 August 2013

The purpose of this study was to examine the effects of ankle bracing on knee kinetics and kinematics during volleyball tasks. Fifteen healthy, elite, female volleyball players performed a series of straight-line and lateral volleyball tasks with no brace and when wearing an ankle brace. A 14-camera Vicon motion analysis system and AMTI force plate were used to capture the kinetic and kinematic data. Knee range of motion, peak knee anterior–posterior and medial–lateral shear forces, and peak ground reaction forces that occurred between initial contact with the force plate and toe off were compared using paired sample *t*-tests between the braced and non-braced conditions ($P < 0.05$). The results revealed no significant effect of bracing on knee kinematics or ground reaction forces during any task or on knee kinetics during the straight-line movement volleyball tasks. However, ankle bracing was demonstrated to reduce knee lateral shear forces during all of the lateral movement volleyball tasks. Wearing the Active Ankle T2 brace will not impact knee joint range of motion and may in fact reduce shear loading to the knee joint in volleyball players.

Volleyball is the second most participated sport in the world, second only to soccer in terms of global participation rates (Bahr & Bahr, 1997; Reeser et al., 2006). Volleyball players are susceptible to a broad range of injuries including acute ankle sprains, acute knee injuries and overuse conditions of the knee and shoulder (Reeser et al., 2006; Agel et al., 2007). Acute ankle sprains are the most common injury reported by volleyball players, accounting for up to half of all volleyball-related injuries (Bahr & Bahr, 1997; Agel et al., 2007). Consequently, many players wear ankle braces (Rosenbaum et al., 2005), with evidence supporting ankle bracing as a successful ankle sprain prevention strategy (Sitler et al., 1994; Surve et al., 1994; Stasinopoulos, 2004; Pedowitz et al., 2008). Semi-rigid "stirrup" orthoses, like the Active Ankle T2 brace (Cramer Products, Inc., Gardner, Kansas, USA), are designed to restrict inversion and eversion while allowing full movement of the ankle into plantarflexion and dorsiflexion (MacKean et al. 1995). The Active Ankle T2 brace has been demonstrated to effectively reduce the incidence of ankle sprains in athletes (Pedowitz et al., 2008) and is therefore a popular choice among volleyball players.

In addition to ankle injuries, volleyball players are also at significant risk of knee injuries (Schafle et al., 1990), with a higher incidence reported in females than in males (Ferretti et al., 1990, 1992). These injuries are typically overuse in nature (Schafle et al., 1990). Patellar tendinopathy is the most common knee injury reported (Reeser et al., 2006) and can have a significant impact on volleyball players, shortening or ending their participation in the sport (Richards et al., 1996). Patellar tendinopathy is thought to result from tendon overload (Lian et al., 2003; Cook & Purdham, 2009), with repeated eccentric loading such as landing from a block or spike, considered to be a major risk factor (Richards et al., 1996; Lian et al., 2003). More specifically, the vertical magnitude of a jump, the range of movement of the knee, the valgus strain about the knee during the eccentric loading phase of the spike approach, and the flexibility of the hamstrings and quadriceps muscles have all been identified as mechanical risk factors to patellar tendon injuries (Richards et al., 1996; Lian et al., 2003; Malliaras et al., 2006). In addition to patellar tendinopathy, volleyball players are also at risk of knee osteoarthritis, with research suggesting that women participating in weight-bearing sports are 2–3 times more likely to develop the condition than their age-matched controls (Spector et al., 1996). The development of knee osteoarthritis is thought to be a result of the repetitive joint stress, torsional loading, and high-impact forces associated with volleyball (Buckwalter & Lane, 1997; Wolf & Amendola, 2005; Arden & Nevitt, 2006). More specifically, recent studies have linked the development and progression of osteoarthritis with knee lateral–medial shear forces (Lynn et al., 2007). Shear forces are known to be detrimental to joint health with repetitive shear stress resulting in microtrauma to articular cartilage over time (Buckwalter & Lane, 1997; Wolf & Amendola, 2005).

Ankle braces are designed to prevent ankle injuries through restricting ankle frontal plane movement; however, a number of studies have shown ankle bracing to also limit ankle dorsiflexion and plantarflexion range (Cordova et al., 2000, 2010). One study in particular demonstrated that wearing the ASO Ankle Brace (Medical Specialties, Inc., Charlotte, North Carolina, USA) during a drop landing task limited ankle dorsiflexion range of motion and increased knee flexion angle at initial ground contact (DiStefano et al., 2008). The greater degree of knee flexion was thought to compensate for the restricted ankle dorsiflexion, thereby allowing ground reaction forces to remain consistent (DiStefano et al., 2008). Given that landing with increased knee flexion is a risk factor for patellar tendinopathy (Richards et al., 1996; Lian et al., 2003; Malliaras et al., 2006), it was concluded that ankle bracing may have detrimental implications for the knee joint.

The effect of ankle bracing on knee shear forces in volleyball players has not been reported to date. Therefore, this study aimed to quantify the effect of ankle bracing on the knee kinetics and kinematics of elite female volleyball players during volleyball-specific functional tasks. Secondarily, in order to assist in the interpretation of results relating to knee forces, peak ground reaction forces, and time to peak ground reaction forces will be analyzed. The results of this study might have clinical implications, given that repetitive knee shear forces have been linked with the development of knee osteoarthritis and patellar tendinopathy, both of which volleyball players are known to be at heightened risk (Spector et al., 1996; Reeser et al., 2006).

Specifically, it was hypothesized that:

1 Ankle bracing would increase the shear forces acting at the knee joint during volleyball-specific tasks,
2 Ankle bracing would increase the range of movement at the knee joint during volleyball-specific tasks.

Materials and methods

Participants

Fifteen female volleyball players [mean and standard deviation (SD) age 22.7 (3.30) years, height 1.80 (0.07) m, mass 72.1 (7.90) kg] participated in this study. All players were current state- or national-level indoor volleyball players and aged 18 years or above. Players were excluded if they had any illness or musculoskeletal injury affecting performance at the time of data collection, any lower limb musculoskeletal injuries resulting in treatment and missed or modified training in the six weeks prior to testing, or any history of knee or ankle surgery. Relevant institutional ethical approval was gained (PT0168) and all participants provided signed informed consent prior to participation.

Data collection

Each participant attended a single data collection at the Curtin University Motion Analysis Laboratory. Data were collected using a 14-camera Vicon MX motion analysis system (Oxford Metrics, Inc., Oxford, UK) at a capture rate of 250 Hz, and an AMTI force plate (Advanced Mechanical Technology Inc., Watertown, Massachusetts, USA) operated at 1000 Hz.

Following arrival to the laboratory, each participant's height and mass were measured using a standardized stadiometer and electronic scale, respectively. Retro-reflective markers (necessary for motion tracking) were then placed on anatomical landmarks on the participants' pelvis, thighs, legs and their own volleyball shoes in accordance with a cluster based marker set and International Society of Biomechanics recommendations (Wu et al., 2002; Besier et al., 2003). Ankle and knee joint centers were calculated prior to the application of the ankle brace during a single static trial. Ankle joint center locations were referenced to the lower leg cluster of markers, in order to ensure no error following the application of the brace. Participants then completed a standardized, typical pre-match warm up. Following this, each participant's maximum jump reach height was determined from the best of three attempts. The distance between each participant's standing reach and their maximum jump reach height was then utilized as their jump height. This measure was then used to calculate the optimal ball height for the spiking and blocking tasks (ball height = standing reach height + 65% maximum jump height), as previously described (Mitchinson et al., 2013). A standard volleyball ball (Mikasa) was secured to rope "levers" via Velcro, and the ball was suspended at the predetermined height for each player (Fig. 1).

The participants then performed a series of volleyball tasks with no brace and when wearing the Active Ankle T2 brace (Fig. 2). This ankle brace (semi-rigid, sport-stirrup orthosis consisting of two molded plastic sides, connected to a heel piece by a hinge joint) was selected for this study as it is popular among Australian female volleyball players, and has been used in previous research (Santos et al., 2004; Venesky et al., 2006; Pedowitz et al., 2008). The braced and non-braced conditions were completed in a randomized order, and the order that each task was performed within each condition was similarly randomized using Microsoft Excel (Microsoft, Redmond, Washington, USA) random number generator.

The series of tasks included a set of straight-line tasks (running, blocking and spiking) which included movements in only one direction, and a set of lateral tasks (cutting, block and push off, and spike and cover) which included movements involving a change of direction. These tasks were selected in consultation with the Australian Volleyball Team physiotherapist and Australian

Fig. 1. Data collection setup, including spike ball position.

Women's Team captain as tasks that were prominent features of volleyball trainings and matches.

Straight-line movement tasks

For the running task, the participants were asked to run through the center of the laboratory (10 m from start to finish). After each trial, the speed of the thorax was utilized to verify trials were completed at 5 m/s (± 1 m/s). The block jump task involved the participants performing a maximal effort jump while raising their arms in order to "block" the suspended volleyball with their hands, and then land with their preferred foot on the force plate. The spike approach task required the participants to perform a maximum effort spike approach and arm swing, spike the suspended volleyball, and land on the force plate with their preferred foot.

Lateral movement tasks

The cutting task required participants to run in a straight line for 5 m then plant their preferred foot on the force plate and push off at a 90° angle. The block and push off task required the participants to perform a stationary maximum block jump (as described above), land on the force plate with their preferred foot, and then push off at a 90° angle, as they would during a typical volleyball rally. The spike and cover task required the participants to perform a maximum effort spike action (as described above), land with their preferred foot on the force plate, and push off at a 90° angle, again in order to replicate a movement that would occur during a typical volleyball rally.

For each task, the participants were required to perform a minimum of three successful trials. Trials were deemed successful if the participants landed with their preferred foot within the boundaries of the force plate, although participants were unaware of this requirement in order to ensure that their typical technique was not altered, and following verbal confirmation that they executed the task at competition intensity. Further, the lateral movement tasks' angle of push off was monitored by the attending researchers, and if participants appeared to deviate from this angle, the trial was repeated.

Fig. 2. The Active Ankle T2 brace.

Data analysis

The Vicon data were checked for breaks in the trajectories that can result from occlusion of the markers during the trial using Vicon motion analysis software (Nexus; Oxford Metrics, Inc.). Breaks were filled using standard biomechanical procedures, including algorithmic interpolation between trajectory end points, with no break greater than 20 frames in duration. The data was filtered using a quintic spline filter using a mean square error of 3, as determined by a residual analysis (Woltring, 1986). A valid lower limb three-dimensional mathematical model (Besier et al., 2003) that utilized previously published lower limb segment parameters (de Leva, 1996) and followed recommended biomechanical procedures was applied in order to calculate lower limb kinematics and kinetics (Wu et al., 2002).

A custom LabVIEW program (v2011, National Instruments, Austin, Texas, USA) was used to output knee flexion range of motion, peak knee shear forces (anterior–posterior and medial–lateral), peak ground reaction forces, and time to peak ground reaction forces between the instant of foot contact with the force plate, until the instance of foot take off from the force plate. The means of each participant's three trials were then input into statistical software SPSS (v19.0 for Windows, SPSS Inc., Chicago, Illinois, USA). Normality was investigated using the Shapiro-Wilk test for normality, and paired sample t-tests were utilized to compare between the braced and non-braced conditions. Variables were considered statistically significant with a P-value < 0.05.

Results

The results of the knee kinetic data revealed no significant difference in peak anterior–posterior forces between braced and non-braced trials in any of the volleyball tasks. In addition, no differences were detected in lateral or medial forces between the braced and non-braced trials in any of the straight-line movement tasks (Table 1).

The results revealed a significant effect of ankle bracing on medial–lateral knee forces during all of the lateral movement tasks (Table 2). The averaged peak

Table 1. Mean (standard deviation) of knee lateral and medial shear forces in braced and non-braced trials during the landing of the straight-line movement tasks

	Mean (SD) Braced	Mean (SD) Non-braced	Mean difference (SE)	95% CI	P-value
Lateral shear forces (N/kg)					
Running	0.41 (0.42)	0.38 (0.31)	0.03 (0.09)	−0.15, 0.22	0.711
Blocking	0.33 (0.27)	0.37 (0.24)	−0.04 (0.06)	−0.16, 0.08	0.473
Spiking	1.37 (1.42)	1.48 (1.35)	−0.11 (0.13)	−0.40, 0.17	0.415
Medial shear forces (N/kg)					
Running	3.47 (0.52)	3.50 (0.70)	−0.03 (0.10)	−0.24, 0.18	0.737
Blocking	2.29 (0.47)	2.39 (0.55)	−0.10 (0.08)	−0.27, 0.08	0.262
Spiking	3.98 (1.04)	4.15 (1.09)	−0.17 (0.20)	−0.59, 0.25	0.392

Table 2. Mean (standard deviation) of knee lateral and medial shear forces in braced and non-braced trials during the landing of the lateral movement tasks

	Mean (SD) Braced	Mean (SD) Non-braced	Mean Difference (SE)	95% CI	*P*-value
Lateral shear forces (N/kg)					
Cutting	0.35 (0.27)	0.60 (0.34)	−0.26 (0.10)	−0.48, −0.04	0.025*
Block and push off	0.46 (0.28)	0.68 (0.33)	−0.21 (0.06)	−0.35, −0.08	0.004*
Spike and cover	1.21 (0.49)	1.55 (0.51)	−0.33 (0.12)	−0.59, −0.07	0.016*
Medial shear forces (N/kg)					
Cutting	3.00 (0.61)	3.32 (1.02)	−0.33 (0.16)	−0.67, 0.01	0.057
Block and push off	3.03 (0.71)	3.28 (0.63)	−0.26 (0.11)	−0.49, −0.02	0.033*
Spike and cover	4.44 (1.19)	4.50 (1.16)	−0.06 (0.17)	−0.43, 0.30	0.707

*significant difference between braced and non-braced trials ($P < 0.05$).

Table 3. Mean (standard deviation) of peak ground reaction forces and time to peak ground reaction force in braced and non-braced trials during the landing of each movement task

	Mean (SD) Braced	Mean (SD) Non-braced	Mean Difference (SE)	95% CI	*P*-value
Peak ground reaction force (N/kg)					
Straight line movement tasks					
Running	2.32 (0.19)	2.32 (0.22)	−0.00 (0.07)	−0.16, 0.14	0.937
Blocking	1.89 (0.35)	1.90 (0.43)	−0.02 (0.14)	−0.32, 0.28	0.900
Spiking	3.62 (1.15)	3.85 (1.05)	−0.22 (0.39)	−1.10, 0.59	0.576
Lateral movement tasks					
Cutting	2.34 (0.36)	2.51 (0.37)	−0.16 (0.13)	−0.43, 0.11	0.234
Block and push off	3.51 (0.56)	3.71 (0.50)	−0.19 (0.19)	−0.59, 0.21	0.333
Spike and cover	4.73 (1.14)	4.55 (1.08)	0.17 (0.41)	−0.66, 1.00	0.678
Time to peak ground reaction force (sec)					
Straight line movement tasks					
Running	0.10 (0.01)	0.10 (0.01)	−0.00 (−0.01)	−0.01, 0.01	0.893
Blocking	0.07 (0.02)	0.08 (0.02)	−0.01 (0.01)	−0.2, 0.01	0.431
Spiking	0.03 (0.01)	0.03 (0.01)	−0.00 (0.03)	−0.01, 0.00	0.433
Lateral movement tasks					
Cutting	0.10 (0.05)	0.09 (0.04)	0.01 (0.02)	−0.02, 0.04	0.486
Block and push off	0.07 (0.02)	0.08 (0.02)	−0.00 (0.00)	−0.01, 0.01	0.931
Spike and cover	0.04 (0.01)	0.04 (0.01)	−0.00 (0.00)	−0.01, 0.01	0.426

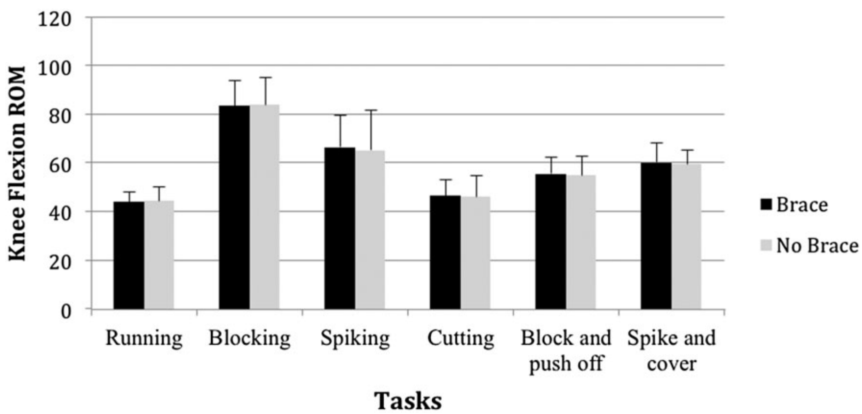

Fig. 3. Mean knee flexion range of motion (ROM; standard deviation) in braced and non-braced trials during volleyball tasks.

knee lateral shear forces were significantly smaller when the participants wore ankle braces during the cutting, block and push off, and spike and cover tasks than without ankle braces.

The analysis revealed no significant difference in peak ground reaction forces or time to peak ground reaction forces between braced and non-braced trials in all tasks with $P > 0.05$ (Table 3).

Finally, the statistical analysis indicated no significant difference in knee range of motion between braced and non-braced trials in all tasks with $P > 0.05$ (Fig. 3).

Discussion

The results of this study revealed that wearing an ankle brace reduced the magnitude of medial and lateral forces transmitted through the knee during volleyball tasks requiring lateral movements. This is a novel and significant finding, with the relationship between ankle bracing and knee shear forces not previously explored. The direct mechanism for this reduced knee force is unclear from the results of this study, given that no differences were detected in the magnitude or time to peak ground reaction force between braced and non-braced trials, and that ankle movement and electromyographic data were not recorded. However, as the Active Ankle T2 brace has been previously demonstrated to reduce the magnitude of ankle inversion/eversion range of motion (Garrick & Requa, 1973; Wiley & Nigg, 1996; Cordova et al., 2000, 2010), it may be that this increased frontal plane ankle control resulted in reduced knee medial–lateral forces through a direct link in the lower limb kinetic chain. Future research is necessary to confirm this theory. This finding is in contrast with the study hypothesis and previous research demonstrating that ankle braces were associated with increased knee kinetics (Venesky et al., 2006).

The results relating to reduced knee shear forces have several clinical implications. Previous research has demonstrated that repeated medial–lateral stress may be detrimental to joint health, resulting in microdamage to the articular cartilage over time (Radin et al., 1991). In particular, repetitive knee lateral shear forces have been linked to the development and progression of knee osteoarthritis (Lynn et al., 2007), and valgus forces acting on the knee joint during the volleyball spike approach have been linked with an increased likelihood of patellar tendinopathy (Richards et al., 1996; Lian et al., 2003; Malliaras et al., 2006). Given that both knee osteoarthritis and patellar tendinopathy are common injuries in female volleyball players, it is possible that the Active Ankle T2 brace may reduce the risk of these knee injuries in this population through a reduction in shear forces at the knee joint during particular volleyball maneuvers. Future prospective and between-group studies that include populations with knee overuse injuries are required to confirm this hypothesis.

Contrary to the study hypothesis, the results demonstrate that the Active Ankle T2 brace did not alter knee flexion range of motion during any of the volleyball tasks. These findings differ from those of previous research where bracing reduced ankle dorsiflexion and subsequently increased knee flexion angle during a drop landing (DiStefano et al., 2008). It is important to note that these researchers utilized the ASO lace-up brace rather than the Active Ankle T2 sport-stirrup brace, and focused on a passive drop landing task rather than a functional volleyball movement task (DiStefano et al., 2008). Landing in positions of increased knee flexion has been linked with an increased likelihood of an overuse injury to the patellar tendon (Richards et al., 1996; Lian et al., 2003). Specifically, Richards et al. (1996) reported that greater knee flexion angle during landing was a strong predictor of patellar tendinopathy, and Lian et al. (2003) reported an increased incidence of patellar tendinopathy among volleyball players who landed from a spike approach with the deepest knee flexion angle. Given that the Active Ankle T2 brace had no effect on knee flexion angle during any landing, including from a simulated spike, it may not be associated with heightened risk of knee overuse injuries, particularly patellar tendinopathy, in volleyball players as previously suggested (DiStefano et al., 2008).

Limitations

This study was limited to the 15 elite female volleyball players. Therefore, further investigations on a larger, more diverse population may be required. In addition, future research, including prospective studies, should include analysis of the effect of ankle bracing on ankle inversion/eversion and abduction/adduction range of motion, and hip joint kinetics. These studies should also include electromyographic data in order to understand the direct mechanism for the findings of this study (i.e., reduced knee shear forces with ankle brace use). Finally, in all trials other than running, speed was only controlled by the participants' subjective performance assessment as "equivalent to competition intensity."

Perspectives

The Active Ankle T2 brace has no impact on knee flexion range of motion during volleyball movement tasks as initially hypothesized, and thus is unlikely to increase the risk of patellar tendinopathy or other knee overuse injuries in volleyball players. In contrast, the results of this study suggest that the Active Ankle T2 brace may minimize the likelihood of knee injury through a reduction in medial and lateral forces at the knee joint during volleyball-specific functional tasks. In summary, the Active Ankle T2 brace appears to be a safe method of preventing ankle sprains in the volleyball population, with no impact on knee kinematics and a potentially beneficial impact on knee kinetics.

Key words: patellar tendinopathy, osteoarthritis, shear forces, sport.

Acknowledgements

The authors would like to thank all of the Western Australian volleyball players who participated in the study, and Paul Davey (Senior Research Officer, Curtin University) for programming assistance.

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