LANDING TECHNIQUE IS RELATED TO PATELLAR TENDON LOADING DURING A VOLLEYBALL BLOCK JUMP MOVEMENT

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Patellar tendinopathy is the most common overuse injury incurred in volleyball. Although high patellar tendon loading is thought to be a causative factor of patellar tendinopathy, it remains unknown how landing technique is related to high patellar tendon loading. Landing kinematics and patellar tendon loading were quantified for 49 volleyball players who performed a lateral stop-jump block movement. Correlations identified that volleyball players who displayed high ankle dorsiflexion velocity, high ankle dorsiflexion acceleration, and high knee flexion acceleration also generated greater peak patellar tendon force and faster patellar tendon force development. These results suggest that athletes who demonstrate rapid ankle and knee flexion when landing may be predisposed to developing patellar tendinopathy.

KEY WORDS: injury prevention, patellar tendinopathy, knee

INTRODUCTION: The highest prevalence of patellar tendinopathy in sport is reported in volleyball with up to 45% of elite male volleyball players likely to sustain this injury (Lian, Engebretsen, & Bahr, 2005). Male volleyball players also report a patellar tendinopathy prevalence of more than twice that of their female counterparts (Zwerver, Bredeweg, & van den Akker-Scheek, 2011). In an attempt to identify variables likely to contribute to the development of patellar tendinopathy, researchers have previously compared the landing technique displayed by athletes with and without the injury. For example, Richards, Ajemian, Wiley, & Zernicke (1996) reported that the presence of patellar tendinopathy could be predicted by the maximum knee flexion displayed by elite male volleyball players during landing, whereby players with higher knee flexion on landing were more at risk of having the injury. In another study, participants with patellar tendinopathy displayed less ankle plantar flexion excursion accompanied by greater ankle dorsiflexion velocity compared to participants without the injury (Bisseling, Hof, Bredeweg, Zwerver, & Mulder, 2008). It remains unknown, however, whether the landing kinematics displayed by these injured athletes contributed to the development of their patellar tendinopathy, or whether these participants modified their technique in response to their injury.

Although patellar tendinopathy is an overuse injury and, therefore, challenging to isolate the exact mechanism, high loading of the patellar tendon fibres during landing is thought to be one of the main causative factors of the injury (Lian, Engebretsen, Ovrebo, & Bahr, 1996). No known studies, however, have investigated the association between landing technique and patellar tendon loading. Therefore, the purpose of this study was to investigate the relationship between landing kinematics and patellar tendon loading when players landed from a volleyball-specific jump and to ascertain whether this relationship was displayed by both elite and sub-elite players, and male and female players.

METHODS: A total of 49 volleyball players volunteered for this study including 9 elite (National team) male players (21.0 ± 2.7 yrs; 1.97 ± 0.09 m; 88.0 ± 9.9 kg), 20 sub-elite males (24.0 ± 5.6 yrs; 1.86 ± 0.06 m; 83.8 ± 13.9 kg), and 20 sub-elite females (23.0 ± 4.1 yrs; 1.73 ± 0.07 m; 69.5 ± 8.4 kg). To simulate volleyball court conditions in the laboratory, a volleyball net was set at the regulation height and a standard volleyball was positioned 0.15 m above net height and 0.15 m into the opposing court. Participants then performed five successful lateral stop-jump block movements, to block to the suspended ball, moving from the right towards the left of the court (see Figure 1). This movement was selected as the experimental task as it is the movement most commonly performed by middle blocker players, who report a high incidence of patellar tendinopathy in volleyball. The final landing was the focus of the current investigation.

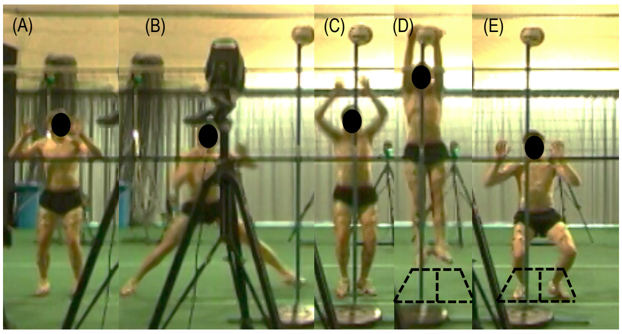

Figure 1: The lateral stop-jump block movement: It was the final landing phase (E) that was investigated in the current study.

To characterise each participant's landing technique, three-dimensional marker trajectories were sampled at 250 Hz (Vicon motion analysis system, Oxford Metrics Ltd, Oxford, UK) while the ground reaction forces generated by each participant during foot-ground contact were sampled (1,500 Hz) using two force platforms (Kistler Instrumente, Winterthur, Switzerland; 0.6 m x 0.9 m). Landing was defined from the instant the vertical ground reaction force exceeded 10 N (initial foot-ground contact) until the time of the peak patellar tendon force.

The kinematic and ground reaction force data were filtered using a fourth-order zero-lag Butterworth digital low pass filter (f_c = 16 Hz). Kinematic data were then combined with the ground reaction force data to calculate internal knee moments using standard inverse dynamics. Patellar tendon loading was characterised by two variables: (i) peak patellar tendon force normalised to body weight (BW), calculated as the knee extension moment divided by the patellar tendon moment arm, estimated by a regression equation using knee flexion angle; and (ii) patellar tendon force loading rate (BW/s), defined from initial foot-ground contact until the time of the peak patellar tendon force. To characterise landing technique, three-dimensional ankle, knee, hip, and trunk angles at the time of initial foot-ground contact and at the time of the peak patellar tendon force were calculated. In order to understand how these body positions were attained, average joint angular displacement, angular velocity, and angular acceleration were also calculated.

Descriptive statistics were calculated for the outcome variables characterising landing technique and patellar tendon loading, grouped according to the three participant groups; (i) elite male, (ii) sub-elite male; and (iii) sub-elite female players. A series of correlations (IBM SPSS Statistics 21.0.0; Somers, NY) were then conducted to determine whether there were any significant relationships between landing technique and patellar tendon loading.

RESULTS: The landing technique variables that were found to be significantly correlated with peak patellar tendon force or the patellar tendon force loading rate are shown in Table 1. Several significant ($p < 0.05$) correlations between landing kinematics and patellar tendon loading were observed across the participant groups. Interestingly, three landing variables were positively and significantly correlated for all three participant groups; ankle dorsiflexion velocity, ankle dorsiflexion acceleration, and knee flexion acceleration from the time of initial contact until the maximum patellar tendon force. The positive correlation coefficients indicated that those athletes who displayed higher ankle dorsiflexion velocity and acceleration and higher knee flexion acceleration during landing, generated higher patellar tendon force and had more rapid patellar tendon force development during landing. In addition, knee flexion velocity was significantly and positively correlated with peak patellar tendon loading, but not the loading rate, for all three participant groups.

Table 1
Variables characterising landing technique that were found to be significantly correlated ($p < 0.05$) with patellar tendon (PT) loading generated for: (A) all player groups, and (B) for one or two of the participant groups. Correlation coefficients (R) are presented for elite male (n = 9), sub-elite male (n = 20), and sub-elite female (n = 20) volleyball players.

(A)	Elite males		Sub-elite males		Sub-elite females	
	Variable	R	Variable	R	Variable	R
Peak PT Force	Ankle DF/PF veloc (°/s)	0.817	Ankle DF/PF veloc (°/s)	0.487	Ankle DF/PF veloc (°/s)	0.467
	Ankle DF/PF accel (°/s^2)	0.787	Ankle DF/PF accel (°/s^2)	0.490	Ankle DF/PF accel (°/s^2)	0.538
	Knee FL/EXT veloc (°/s)	0.687	Knee FL/EXT veloc (°/s)	0.453	Knee FL/EXT veloc (°/s)	0.517
	Knee FL/EXT accel (°/s^2)	0.753	Knee FL/EXT accel (°/s^2)	0.495	Knee FL/EXT accel (°/s^2)	0.587
PT Force Loading Rate	Ankle DF/PF veloc (°/s)	0.925	Ankle DF/PF veloc (°/s)	0.762	Ankle DF/PF veloc (°/s)	0.753
	Ankle DF/PF accel (°/s^2)	0.918	Ankle DF/PF accel (°/s^2)	0.855	Ankle DF/PF accel (°/s^2)	0.837
	Knee FL/EXT accel (°/s^2)	0.824	Knee FL/EXT accel (°/s^2)	0.837	Knee FL/EXT accel (°/s^2)	0.849

(B)	Elite males		Sub-elite males		Sub-elite females	
	Variable	R	Variable	R	Variable	R
Peak PT Force	Ankle DF/PF PT$_{time}$ (°)	0.783	Tibial rotation accel (°/s^2)	0.447	Foot AB/ADD veloc (°/s)	-0.474
	Ankle DF/PF excurs (°)	0.702	Trunk lateral FL PT$_{time}$ (°)	0.452	Foot AB/ADD accel (°/s^2)	-0.564
	Trunk FL accel (°/s^2)	0.721			Knee AB/ADD accel (°/s^2)	-0.551
					Trunk lat FL accel (°/s^2)	-0.464
PT Force Loading Rate	Ankle DF/PF PT (°)	0.735	Foot AB/ADD accel (°/s^2)	-0.494	Foot AB/ADD accel (°/s^2)	-0.569
	Ankle DF/PF excurs (°)	0.702	Knee FL/EXT PT (°)	-0.460	Knee FL/EXT veloc (°/s)	0.707
			Knee FL/EXT excurs (°)	-0.571	Knee AB/ADD veloc (°/s)	-0.497
			Knee FL/EXT veloc (°/s)	0.624	Knee AB/ADD accel (°/s^2)	-0.707
			Knee AB/ADD veloc (°/s)	-0.472	Hip FL/EXT accel (°/s^2)	0.630
			Knee AB/ADD accel (°/s^2)	-0.727	Trunk FL excursion (°)	-0.580
			Tibial rotation accel (°/s^2)	0.513		
			Hip FL/EXT accel (°/s^2)	0.639		

DF/PF = dorsiflexion/plantar flexion; FL/EXT = flexion/extension; AB/ADD = abduction/adduction; veloc = velocity; accel = acceleration; PT$_{time}$ = at time of peak patellar tendon force; lat = lateral

DISCUSSION: Although patellar tendinopathy is very prevalent in volleyball and high patellar tendon loading is thought to lead to this injury, it remains unknown which variables characterising landing technique are related to high patellar tendon loading generated during a volleyball-specific landing. This study is the first study to report specific technique features that were significantly correlated with high patellar tendon loading. How these results provide insight into the relationship between landing technique and patellar tendon loading, and the implication of these results in an applied sports setting, is discussed below.

Ankle dorsiflexion velocity, ankle dorsiflexion acceleration, and knee flexion acceleration from the time of initial contact to the time of the maximum patellar tendon force were found to be positively correlated with both peak patellar tendon force and the patellar tendon force loading rate for all three participant groups. That is, the faster the participants flexed their ankle and knee during landing, the greater was the patellar tendon force generated at landing; and this patellar tendon force was generated faster than athletes who displayed slower ankle and knee flexion. Why these variables are likely to be associated with generating higher patellar tendon forces during landings is explained below.

During landing, patellar tendon loading is influenced by several variables, including the patellar tendon moment arm, the knee flexion angle, and the knee extensor moment generated during the landing action. The patellar tendon moment arm is typically determined by sagittal plane tibial and femoral movements, with the peak patellar tendon moment arm occurring between 45° and 60° of knee flexion. In volleyball, the high volume of jumps and landings require substantial eccentric quadriceps activation to control the knee flexion during landing. A high knee flexion acceleration may imply that there is less time to control knee flexion and dissipate the forces generated during landing, possibly increasing the loading rate of the patellar tendon force compared with athletes who utilise a slower knee flexion acceleration. High knee flexion acceleration may therefore potentially predispose volleyball players to a greater risk of developing patellar tendinopathy, because of the higher patellar tendon loading they incur.

To our knowledge, this is the first study to report a significant relationship between landing technique and patellar tendon loading during landing in a volleyball-specific lateral stop-jump block movement performed by uninjured volleyball players. In previous studies, volleyball players who suffered from patellar tendinopathy displayed higher knee flexion and faster ankle dorsiflexion velocity than those who did not (Bisseling et al., 2008). When combined with the results from this study, it is suggested that uninjured volleyball players who display higher knee flexion and faster ankle dorsiflexion velocity during landing movements may be susceptible to developing patellar tendinopathy.

The three technique variables found to be positively and significantly correlated with patellar tendon loading for each group occur in the sagittal plane and can be quantified using standard biomechanical procedures. It is therefore plausible to use biomechanical techniques to screen athletes who are likely to generate high patellar tendon loading, although further research is warranted to determine the thresholds at which these variables contribute to excessive patellar tendon loading.

CONCLUSION: Male, female, and elite male volleyball players all demonstrated a significant and positive relationship between patellar tendon loading and the variables of ankle dorsiflexion velocity, ankle dorsiflexion acceleration, and knee flexion acceleration during landing. These results suggest that volleyball players who flexed their ankle and knee faster during landing may be predisposed to developing patellar tendinopathy. Evidence-based strategies to reduce patellar-tendon loading, based on modifying the landing technique of players, warrant investigation.

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