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Kerry Mann

Suzi Edwards

Eric J. Drinkwater
Edith Cowan University, e.drinkwater@ecu.edu.au

Stephen Bird

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MANUSCRIPT – MEDICINE AND SCIENCE IN SPORT AND EXERCISE

A lower limb assessment tool for athletes at risk of developing patellar tendinopathy

[1]Kerry J. Mann, [1]Suzi Edwards, [1]Eric J. Drinkwater, and [1]Stephen P. Bird.

[1]*School of Human Movement Studies, Charles Sturt University, Bathurst, New South Wales*

Correspondence, proof reading and reprint requests to:

Dr. Suzi Edwards
School of Human Movement Studies
Charles Sturt University
Panorama Ave
Bathurst NSW 2795 Australia

FAX 61-2-6338 4065
Phone 61-2-6338-4522
E-mail suzedwards@csu.edu.au

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ABSTRACT

Purpose: Patellar tendon abnormality (PTA) on diagnostic imaging is part of the diagnostic criteria for patellar tendinopathy. A PTA in addition to altered landing strategies are primary risk factors that increase the likelihood of asymptomatic athletes developing patellar tendinopathy. Therefore, the aim of this study was to examine risk factors that are predictors of the presence and severity of a PTA in junior pre-elite athletes.

Methods: Ten junior pre-elite male basketball athletes with a PTA were matched with ten athletes with normal patellar tendons. Participants had patellar tendon morphology, Victorian Institute of Sport Assessment score (VISA), body composition, lower limb flexibility and maximum vertical jump height measured prior to performing five successful stop-jump tasks. During each landing trial, both two- and three-dimensional kinematics and ground reaction forces were recorded. Multiple regression analyses were used to identify factors for estimating PTA presence and severity, and discriminate analysis used to classify PTA presence.

Results: Sixty-eight percent of variance for presence of a PTA was accounted for by hip joint range of motion (ROM), knee joint angle at initial foot-ground contact (IC) during stop-jump and quadriceps flexibility, whereas hip joint ROM and VISA accounted for 62% of variance for PTA severity. Prediction of the presence of a PTA was achieved with 95% accuracy and 95% cross-validation.

Conclusions: An easily implemented, reliable and valid movement screening tool comprising of three criteria's enables coaches and/or clinicians to predict for the presence and severity of a PTA in asymptomatic athletes. This enables identification of asymptomatic athletes at higher risk of developing patellar tendinopathy, which allows the development of effective preventative measures to aid in the reduction of patellar tendinopathy injury prevalence.

Keywords: Knee injury, biomechanics, movement screening, prevention through prediction, landing

INTRODUCTION

Paragraph Number 1. Identified in repetitive jumping sports, overuse injuries such as patellar tendinopathy have increased (23), with a prevalence range from 10% in college athletes (39) to 32% in elite basketball athletes (23). Although the overall prevalence across different sports indicates that every fifth elite athlete will suffer patellar tendinopathy within their career, it is particularly concerning that in basketball 55% of elite basketball players have reported current or previous patellar tendinopathy symptoms (23). Classified as a degenerating overuse knee injury (33), patellar tendinopathy is diagnosed using a combination of a history of activity related pain (25), tenderness on palpation (26), Victorian Institute of Sport Assessment (VISA) score of less than 80 (38), and patellar tendon abnormality (PTA) on diagnostic imaging (9). As PTA's tend to emerge during the developmental adolescent years (9), it is imperative that risk factors associated with patellar tendinopathy within the pre-elite population be identified and understood in order to develop effective preventative measures to aid in the reduction of patellar tendinopathy injury rates (36). Prevention through prediction aims to reduce injury rates by predicting athletes at risk of developing patellar tendinopathy within the sporting population and implementing risk modification strategies to reduce the patellar tendinopathy incidence rate.

Paragraph Number 2. With controversy surrounding the precise etiology of PT, a combination of internal and external risk factors is thought to play a part in the development of patellar tendinopathy (10, 33). Although the presence of a PTA is used to confirm diagnosis of patellar tendinopathy (9, 26), PTA's have also been identified as a risk factor in the development of patellar tendinopathy (8). Asymptomatic athletes with a PTA have an increased likelihood of developing patellar tendinopathy (7, 8), especially males who are twice as likely to develop a PTA compared to females (9). Regardless of this supporting evidence of PTA as a risk factor for patellar tendinopathy development, the clinical importance of PTA changes have not yet been identified as the size of the PTA varies over time and is unable to predict patellar tendinopathy symptoms (18). Nevertheless, identification of asymptomatic athletes with a PTA utilising a different landing strategy may provide a method to identify these athletes at risk of developing patellar tendinopathy.

Paragraph Number 3. With repetitive landing being identified as the primary risk factor of patellar tendinopathy (10, 33), symptomatic athletes with patellar tendinopathy (4, 34) and asymptomatic athletes with a PTA (13) have been associated with altered landing strategies. The critical characteristics associated with these altered landing strategies are knee and hip joint motion. During a dynamic landing, maximum knee joint flexion is the strongest predictor of symptomatic patellar tendinopathy (34), and asymptomatic athletes with PTA compared to athletes with normal patellar tendons displayed increased knee joint flexion at initial foot-ground contact (IC) and different hip movement strategies, whereby they extend their hip during landing as opposed to flexing their hips (13).

Paragraph Number 4. As these altered landing strategies primarily occur in the sagittal plane, it may be possible to identify athletes with these altered landing patterns utilizing a simple two-dimensional video camera as opposed to three-dimensional motion analysis. Although three-dimensional lower limb motion analysis is considered the gold standard of assessing landing technique, it is costly, and extensively time and space consuming (29). It is therefore not practical for all coaches and/or clinicians to utilize this method. A successful alternative method for validly screening athletes at risk in a cost, time and space effective method is to screen athletes using a two-dimensional video analysis, previously used in knee joint injuries (31). Nevertheless, the two-dimensional video analysis may be limited if there is a lack of validity between three- and two-dimensional measures (29). Therefore, further research is warranted to determine if this analysis method could be implemented to developing a movement screening tool for another knee joint injury, patellar tendinopathy.

Paragraph Number 5. Other risk factors associated with patellar tendinopathy that are also readily measurable and modifiable that may be included with a movement screening tool to assess injury risk include increased adiposity (10, 17), decreased lower limb flexibility (26, 39), and higher vertical jump height (25). If any of these modifiable risk factors are meaningful predictors of an increased risk of developing a PTA and therefore patellar tendinopathy, these risk factors should be used to screen athletes. Athletes identified as being at risk can then have modification strategies implemented to reduce injury risk and/or prevalence of patellar tendinopathy.

Paragraph Number 6. The present study aimed to i) determine the risk factors that are most influential in predicting the incidence and severity of PTA and ii) to develop an easily implemented, valid and reliable movement screening tool based on critical risk factors associated with patellar tendinopathy that can be utilized by coaches and/or clinicians to identify their athletes who are at higher risk of developing patellar tendinopathy. We hypothesised that a criteria of altered hip and knee motion strategies during a stop-jump task, lower limb flexibility, increased adiposity, and increased vertical jump performance will allow a prevention through prediction approach to determine the i) presence; and ii) severity of a PTA in asymptomatic individuals.

METHODS

Participants

Paragraph Number 7. Twenty-two junior pre-elite male basketball athletes (mean age = 17.7 ± 1.5 years, height = 183 ± 10 cm; mass = 78.0 ± 14.7 kg) were recruited from junior pre-elite rural representative teams. The presence of a PTA (Table 1) (7) was assessed by an experienced musculoskeletal sonographer (M.J., PRP Imaging Bathurst NSW Australia) using a 12MHz linear array ultrasound transducer (Toshiba, Aplio XG, Japan). Body composition was estimated by a dual-energy X-ray absorptiometry (DEXA; XR800, Norland, Cooper Surgical Company, USA) using a supine whole body scan performed by a qualified technician (scanning resolution = 6.5 x 13.0 mm; scanning speed = 130 mm s^{-1}). Each participant's height, body composition, anthropometric dimensions, static dorsiflexion (26), static hamstring (39) and quadriceps flexibility (14), and maximum vertical jump height (25, 36) were measured before determining their dominant lower limb on the basis of their preferred kicking leg (15). Ten participants with PTA with no current signs of patellar tendinopathy were individually matched for height, mass, and test limb to ten participants with normal patellar tendons (13). The lower limb with the larger PTA area (mm^2) (24) was selected for analysis if a participant had bilateral PTA. Written informed consent was obtained from each participant prior to data collection, with parental/guardian consent obtained for minors. All methods were approved by the institution's Human Research Ethics Committee (2011/071).

< Insert Table 1 about here >

Experimental Task

Paragraph Number 8. Since a substantial component of basketball play is rapid acceleration, deceleration (28), and repetitive landing (27), the stop-jump task was chosen as the experimental task. The stop-jump task involved five phases, which included a horizontal preparation, horizontal landing, horizontal take-off, vertical preparation and vertical landing phase (12). Each participant was required to perform the horizontal preparation phase accelerating forwards for 10 m towards a force platform (mean approach speed = 5.1 ± 0.3 $m \cdot s^{-1}$), which was measured using infrared timing lights

(Speed Light, Swift Sports Equipment, Lismore, Australia). Then each participant performed the horizontal landing phase by jumping off one lower limb then stopping abruptly using a simultaneous two-foot landing with one foot wholly contacting a force platform, and then immediately jump vertically upwards (horizontal takeoff phase) off the ground to strike a ball suspended from the ceiling (vertical preparation phase), with both hands (vertical jump height = 52 ± 7 cm). Finally, participants performed the vertical landing phase by landing on both feet a second time (vertical landing phase). Participants performed five successful stop-jump movements for each lower limb. A successful stop-jump was defined as a participant obtaining an adequate approach speed of between 4.5 and 5.5 $m \cdot s^{-1}$ during the horizontal preparation phase, placing a foot wholly on the force platform during the horizontal landing phase, and contacting ball suspended from the ceiling with both hands. The approach speed was based on the 10 m sprint time (3) and average sprint duration of 2.1 s (1) as these are typical values in junior elite male basketball. During task familiarisation, jump height effort was standardised among the participants by positioning the ball at the maximum height each participant could touch the ball with both hands after performing the horizontal landing phase of the stop-jump task.

Experimental Procedure

Paragraph Number 9. Prior to completing a 5- to 10-min warm-up on a cycle ergometer (Monark 828E, Varburg, Sweden), a static trial was performed. Each participant was then familiarised with the stop-jump task before performing at least five successful stop-jump trials. During each trial, the ground reaction forces generated at landing were recorded (2400 Hz) using a multichannel force platform with built-in charge amplifier (Type 9281CA, Kistler, Winterthur, Switzerland) embedded in the floor and connected to a control unit (Type 5233A, Kistler, Winterthur, Switzerland). The participant’s three-dimensional lower limb and trunk motion was recorded (240 Hz) using a Qualisys Oqus 300 camera system (Qualisys AB, Göteborg, Sweden) and two-dimensional lower limb and trunk motion was recorded (30 Hz) using a digital video camera (GZ-MG465, JVC, Yokohama, Japan). Passive reflective markers were placed on each participant’s lower limbs, pelvis and torso, on the shoe at the first and fifth metatarsal head, mid anterior foot and calcaneous, lateral and medial malleolus, lateral and medial femoral epicondyle, four-marker cluster placed on the leg and thigh, greater trochanter, anterior superior iliac spine, posterior superior iliac spine, iliac crest, sternal notch, xiphoid process, acromion, lumbo-sacral (L5-S1) intervertebral joint space, thoraco-lumbar (T12-L1) intervertebral joint space, bilaterally on the ribcage at the level of the T12-L1 intervertebral joint space and immediately superior to the iliac crest marker, and five tracking markers placed on the lumbar region. To avoid losing view of the passive reflective markers, the participant's wore minimal clothing (shorts), and their own socks and athletic running shoes.

Data Reduction and Analysis

Paragraph Number 10. Analysis of the three-dimensional kinematic and kinetic data was performed using Visual 3D software (Version 4, C-Motion, Germantown, MD). The raw kinematic coordinates, ground reaction forces, free moments and centre of pressure data were initially filtered using a fourth-order zero-phase-shift Butterworth digital low pass filter (f_c = 18 Hz) before calculating individual ground reaction forces and joint kinematics. Segment masses were defined from Zatsiorsky et al. (40) for the foot, shank and thigh segments, and Pearsall et al. (32) for the pelvis, lumbar, thorax and trunk segments. Segmental inertial properties of each segment were modelled using geometric primitives (20), with the foot, shank and thigh defined as a frusta of a right cone (16), and the pelvis, lumbar, thorax and trunk defined as elliptical cylinders (35). With respect to the Cardanic axes of the local joint coordinate system, intersegmental joint angles were expressed for knee and hip joint angles as flexion-extension, adduction-abduction and internal-external rotation, and trunk angles as extension-flexion, right-left lateral flexion, and left-right rotation. Using the 18 Hz filtered kinetic data, the landing phase was defined from IC when the vertical ground reaction force exceeded 10 N to the first local minimum, to peak knee joint flexion angle ($\mathrm{Knee}_{\mathrm{max}}$). For each trial, the maximum vertical jump height (11), knee and hip joints and trunk segment kinematics at IC and at the time of the $\mathrm{Knee}_{\mathrm{Max}}$ were calculated.

Paragraph Number 11. The two-dimensional video data of the lower limb and trunk motion was analysed using Silicon Coach Pro (Version 6; Silicon Coach Ltd., Dunedin, New Zealand) software. Based on the passive reflective markers, knee and hip joint, and trunk segment angles were calculated in the sagittal plane at IC and at the time of the $\mathrm{Knee}_{\mathrm{Max}}$. The DEXA scan was analysed (IlluminatusDXA, ver. 4.2.0, USA), and total body fat mass (TB-FM) (22) quantities were calculated.

Statistical Analysis

Paragraph Number 12. Multiple regression analysis (forward method) was used to determine substantial factors in estimating PTA (i) presence and (ii) severity (area of the PTA within the patellar tendon (24); dependent variables). All independent variables were continuous and included seven different three-dimensional variables during the landing phase (knee and hip joint angle, and trunk segment angle at IC and at the time of the Knee_{Max}, and hip joint angle range of motion (hip joint angle at Knee_{max} minus hip joint angle at IC)) and five other variables (dorsiflexion, hamstring and quadriceps flexibility, maximum vertical jump height, and adiposity). Independent variables identified as substantial predictors of PTA presence (0 = no evidence of PTA, 1 = evidence of any degree of PTA) from the respective regression analysis were included in a discriminate analysis to correctly classify PTA presence using a leave-one-out classification. The validity of two-dimensional data collection was determined using a linear regression equation to calculate the magnitude of the standard error of the estimate (SEE) between two- (independent variable) and three-dimensional (dependent variable) kinematic data. All regressions and discriminate analyses were performed using PASW statistical package (Version 17.0.1, SPSS Inc, Chicago, IL). Intra-rater reliability of the lower limb and trunk segment two-dimensional kinematic data analysis was assessed for six participants on three separate occasions using consecutive trial pairs of the two-dimensional kinematic data (Analysis Session 1 and 2; Analysis Session 2 and 3) using the typical error of measurement (TEM; calculated as a coefficient of variation), percent change in the mean, and intra-class correlation using Microsoft Excel (21).

RESULTS

Paragraph Number 13. Means (±SD) of the variables used within the multiple regression analyses to predict PTA (i) presence and (ii) severity are illustrated in Table 2. The multiple regression model indicated that the substantial predictors of (i) presence (Equation 1) were hip joint ROM (R^2=0.474), knee flexion at IC (R^2=0.112) and quadriceps flexibility (R^2=0.090) and, (ii) severity (Equation 2) of PTA were VISA (R^2=0.392) and hip ROM (R^2=0.124), with the standard error of each equation 0.30 and 12.33 respectively. Discriminate analysis indicated that the respective predictors were able to classify the presence of PTA with 95% accuracy and 95% cross-validation.

< Insert Table 2 about here >

Equation 1: Presence of PTA

$$y' = -0.965 + (0.024 \times hip\ ROM) + (0.013 \times quadriceps\ flexibility) + (0.024 \times knee\ flexion\ at\ IC)$$

Note: a result that exceeds 1 indicates the predicted presence of PTA. A result of >1 indicates no predicted presence of PTA.

Equation 2: Severity of PTA

$$y' = 120.742 + (-1.139 \times VISA) + (0.979 \times hip\ ROM)$$

Note: a result indicates the area, in mm^2, of PTA.

Paragraph Number 14. The two-dimensional kinematic variables showed excellent reliability between Analysis Session 2 and 3 and Analysis Sessions 1 and 2, regarding percent change in the mean, TEM and test-retest correlation (Table 3). The equation of the two-dimensional kinematic data to predict three-dimensional kinematic data is shown in Table 4.

< Insert Table 3 and 4 about here >

DISCUSSION

Paragraph Number 15. Injuries in sport can substantially affect an athlete’s career, which is why many sporting teams have recently adopted a prevention through prediction approach that involves movement screening tools (30). In planning and implementing movement screening assessment tools, it is critical that the influence of injury specific risk factors be identified to enable appropriate modification strategies to be developed and implemented to reduce the risk of patellar tendinopathy. The results of this present study identify substantial variables that enable the prediction of PTA presence and severity in pre-elite basketball athletes, which will allow risk factor modification strategies to be implemented, and therefore enable a prevention through prediction approach to reduce the risk of patellar tendinopathy in athletes.

Paragraph Number 16. In identifying variables to predict PTA in asymptomatic athletes, the importance of lumbopelvic control within rehabilitation programs for patellar tendinopathy was confirmed within this present study as the primary risk factor that predicted both the presence and severity of a PTA was hip joint ROM. That is, asymptomatic athletes with a PTA compared to athletes with normal patellar tendons utilized a different hip movement strategy, whereby they displayed a negative hip joint ROM, indicating that they extended their hip joint while landing as opposed to flexing, which was consistent with our previously findings (13). Furthermore, the larger magnitude of this negative hip joint ROM predicted an increase PTA area in participants with a PTA. By utilising this different hip movement strategy, the PTA athletes require greater forward translation of the center of mass in relation to the base of support as the center of mass is at a greater posterior location at IC, which in turn, may increase the tensile and compressive loads on the proximal part of the patellar tendon and contribute to the development of a PTA (13).

Paragraph Number 17. Asymptomatic athletes with a PTA also landed with greater knee flexion at IC compared to athletes with normal patellar tendons, which may further contribute to greater tensile loading of the superficial fibers of the patellar tendon on the anterior surface and contribute to higher compression of the patellar tendon (2), and also via a greater ratio of the quadriceps tendon force-to-patellar tendon force (5). As histological adaptations occur as a result of increased patellar tendon tension and compressive loads (19), this present study provides further evidence that the direction of the load that the patellar tendon sustains is more critical than the magnitude of this load in the development of a PTA (13), and the role compressive loads play within patellar tendinopathy development.

Paragraph Number 18. Reduced quadriceps flexibility was the only other substantial predictor of the presence of a PTA in asymptomatic athletes. This supports previous research that has associated this variable as a risk factor in the development of patellar tendinopathy (6, 39). Although the relationship between patellar tendinopathy and flexibility is not conclusive, it has been suggested that reduce flexibility may lead to greater load exerted on the tendon (39). However, asymptomatic athletes with a PTA have been shown to dissipate similar patellar tendon loads during landing stop-jump compared to athletes with normal patellar tendons (13), suggesting that quadriceps flexibility may not affect the magnitude of the load sustained by the patellar tendon during landing. Such a finding further suggests that quadriceps flexibility may influence the direction of this load, which is more critical in the development of patellar tendinopathy.

Paragraph Number 19. Identification of hip joint ROM, quadriceps flexibility and knee joint angle at IC as meaningful predictors of the presence of a PTA, allows these variables to be used as the movement screening criteria to predict asymptomatic athletes at risk of developing a PTA. If an athlete is identified at higher risk of developing PTA (i.e. a result score of >1.0 in Equation 2) risk modification strategies such as landing retraining can be implemented to potentially reduce further progression of the asymptomatic PTA into patellar tendinopathy. With an SEE of 0.30 in Equation 2, a score as low as 0.7 indicates that referral for further biomechanical screening with diagnostic imaging is warranted. This movement screening criteria is therefore a functional and valid tool that can be easily implemented at a community sporting level to allow coaches and/or clinicians to screen their asymptomatic athletes to predict PTA presence, and thereby allowing risk factor modification strategies to be employed by these athletes at increased risk of developing patellar tendinopathy.

Paragraph Number 20. In relation to severity of the PTA within asymptomatic athletes, the VISA score was the second strongest predictor after hip joint ROM. As VISA score is used to aid in the diagnosis of patellar tendinopathy, with a score less than 80 indicating patellar tendinopathy (38), the lower VISA predicts a larger PTA area within asymptomatic athletes. While the VISA is a highly reliable test (37), and is sensitive to changes in severity allowing it to be used to monitor rehabilitation progress of athletes recovering from patellar tendinopathy (37), the clinical importance of area of a PTA and VISA in athletes with patellar tendinopathy remains unclear.

Paragraph Number 21. Although the predictors of the presence and severity of a PTA during landing were assessed with the criterion of three-dimensional analysis, using a two-dimensional video analysis to screen athletes at risk would not be valid if there was a lack of consistency between three- and two-dimensional (29). Nevertheless, within this current study there is consistent relationship between three- and two-dimensional data indicated by the low SEE, which shows that two-dimensional data may be used to estimate three-dimensional data with a low amount of error (between 1.6 – 5.3°, Table 4). Furthermore, the intra-tester reliability of performing the two-dimensional analysis indicates that there is an excellent reliability for the lower limb and trunk segments (TEM ~1-2%, Table 3). Therefore, based on the results of this study, it is suggested that two-dimensional motion analysis is a reliable and valid alternative for coaches and clinicians relative to the costly criterion three-dimensional motion analysis to predict three-dimensional data values.

Paragraph Number 22. The authors acknowledge potential limitations within this study. Firstly, the etiology of diverse types of patellar tendinopathy are suggested to be different (10, 17), and as the asymptomatic participants with PTA incorporated in this study included both bi- and uni-lateral PTA athletes. This is suggested to potentially have an influence on the results, although further research is required. Further limitations of this study include the age and skill level of the target population included for participation. As participants were limited to junior pre-elite athletes, it is unknown if the results observed in this study could be replicated in other age groups and/or competition levels such as elite athletes. Therefore, we recommended that future research investigate an additional independent sample of athletes to confirm this current study’s findings, and based on the three criterion, development of effective preventative measures are developed to aid in the reduction of patellar tendinopathy injury.

CONCLUSIONS

Paragraph Number 23. With hip joint ROM and knee joint angle at IC during stop-jump landing, and quadriceps flexibility as significant predictors of the presence of a PTA, and are easily measured and identified, a simple and reliable movement screening tool incorporating only these risk factors during the landing phase of a stop-jump has been developed to allow coaches and/or clinicians to screen and determine the presence and severity of a PTA, and thereby enabling risk factor modification strategies to be developed and implemented, reducing the risk of developing patellar tendinopathy.

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CAPTIONS

TABLE 1. PTA Measurements.

TABLE 2. Means (±SD) of independent and dependent variables included in multiple regression analysis to predict PTA presence and severity.

TABLE 3. Intra-rater reliability of the two-dimensional kinematic data for 6 participants: analysis sessions 1 v 2 and analysis sessions 2 v 3.

TABLE 4. Equations to convert two-dimensional (2D) joint angles to their three-dimensional equivalent (y’) during the landing phase of the stop-jump task.