AN EVALUATION OF THE REARFOOT POSTURE IN INDIVIDUALS WITH PATELLOFEMORAL PAIN SYNDROME

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ABSTRACT

Structural abnormalities of the foot may cause abnormal subtalar joint compensatory motion in order to attain normal function of the lower extremity during gait although studies have not been conclusive. Current conflict in the literature may be related to the differing measures focused on the varying protocols and also the absence of a control group in some studies. This study investigated the rearfoot posture including Subtalar Joint Neutral Position (STJN) and Relaxed Calcaneal Standing (RCS) measurements in patellofemoral pain syndrome (PFPS) and healthy subjects. The angle of STJN during non-weight bearing position and the two dimensional (2D) rearfoot RCS posture was measured using a goniometer in 14 healthy females and 13 females with PFPS. The RCS posture was also measured three dimensionally (3D) by attaching external markers to a tibia shell and the calcaneus and videoing with a four-camera three-dimensional motion analysis system. A one way ANOVA was used to assess the differences between the groups. The 2D and 3D RCS were significantly different between the groups (p ≤ 0.001) with mean -0.23° ± 1.35°, 2.52 ° ± 3.11° for the control group and 2.35° ± 1.4, 7.02° ± 3.33° for the clinical group respectively. STJN showed a slight rearfoot varus (although significant p = 0.04) in PFPS (-2.20° ± 1.51°) compared to the control group (-1.00° ± 1.36°). Negative values indicated inversion and positive values indicated eversion. The 2D and 3D RCS showed a significantly more everted posture of the rearfoot for the PFPS group. Subtalar joint varus may contribute to the increased eversion during relaxed standing in the PFPS group. Rearfoot measurements may be an important addition to other clinical measurements taken to explore the underlying aetiology of subjects with PFPS.

KEY WORDS: Subtalar joint neutral, relaxed calcaneal standing, patellofemoral pain syndrome.

INTRODUCTION

Patellofemoral pain syndrome (PFPS) is one of the most prevalent musculoskeletal injuries seen by physiotherapists and sport medicine practitioners (Clement et al., 1981; Taunton et al., 2002). The aetiology of PFPS is not fully understood and may consist of multiple factors including lower leg and foot malalignment (Austermuehle, 2001; Fredericson et al., 2002; Tiberio, 1987). Bony abnormalities of the foot may cause a compensatory motion at the subtalar joint in order to attain normal function of the lower leg and foot during the gait cycle (Root et al., 1977; Tiberio, 1987). Excessive pronation of the subtalar joint particularly is thought to lead to patellofemoral disorders (Buchbinder et al., 1979; Duffey et al., 2000; Tiberio, 1987). The excessive subtalar joint pronation may delay external rotation of the leg, and therefore will inhibit supination of the foot (Donatelli, 1987; Tiberio, 1987). Excessive rearfoot pronation therefore may lead to abnormal tibia internal rotation which could

possibly translate to greater stress on the knee structure, altering patella tracking (Buchbinder et al., 1979; Donatelli, 1987; Kaufman et al., 1999; McClay et al., 1998; Tiberio, 1987). The delay in the external rotation of the leg appears to be a compensatory reaction at the tibiofemoral joint, hence it may produce patellofemoral pain symptoms (Buchbinder et al., 1979; Jernick et al., 1979; Tiberio, 1987).

There is controversy in the literature regarding the rearfoot posture of PFPS patients and it's contribution to PFPS (Messier et al., 1991; Powers et al., 1995; Sutlive et al., 2004; Thomee et al., 1995; Witvrouw et al., 2000). Messier et al. (1991) found normal arched feet for subjects with anterior knee pain while, Witvrouw et al. (2000) indicated no significant differences in foot types between normals and subjects with patellofemoral pain. Additionally Thomee et al. (1995) reported no differences in the Relaxed Calcaneus Standing (RCS) angle relative to the lower leg or to the horizontal between controls and subjects with PFPS. Power et al. (1995) and Sutlive et al. (2004) however reported a varus rearfoot posture of subjects with PFPS when measuring subtalar joint neutral. Therefore rearfoot varus was suggested to be a factor in contributing to PFPS (Powers et al., 1995). The rearfoot angle in RCS was also shown to be in a valgus position in PFPS individuals (Sutlive et al., 2004). Differences between these studies may be related to the use of diverse population samples, the differing measures focused on the varying protocols and also the absence of a control group in some studies.

A study which includes Subtalar Joint Neutral and RCS clinical measurements and a video based methodology may assist to more fully understand the contribution of the rearfoot posture to PFPS. Functionally, measuring the Subtalar Joint Neutral Position during non-weight bearing position may provide information about leg alignment and existence of deformities (Elveru et al., 1988b; Root et al., 1977) in the rearfoot in PFPS subjects. Deformities in the rearfoot however may lead to a compensatory mechanism during weight bearing (Donatelli, 1987; Donatelli et al., 1999; Root et al., 1977). Consequently, accurate biomechanical assessment of the subtalar joint should also be done in a weight bearing position which represents the human function during walking as well as in a non weight bearing position (Lattanza et al., 1988).

As the functional structure of the foot is inherently three-dimensional (3D) the use of 3D static measurement of the rearfoot may reflect more accurately the rearfoot frontal plane position (Dahlman et al., 2002). Additionally measuring the 3D rearfoot may eliminate the possibility of bias from the examiner during relaxed standing, and

therefore may assist objectively in identifying the rearfoot posture of PFPS subjects. Since measuring the Subtalar Joint Neutral Position requires manipulation of the foot by the examiner it may be difficult to measure it three dimensionally. However measuring the RCS posture three dimensionally in addition to the clinical simple two dimensional (2D) RCS measurement may provide complete and objective information about the rearfoot posture in this population during weight bearing position. As the aetiology of PFPS is still not fully clear, this study addressed the importance of including static rearfoot measurements in a clinical practice. Evaluation of rearfoot posture may assist clinicians to better understand the effect of rearfoot posture on PFPS and may add to the limited base evidence of studies with PFPS population. Currently, rearfoot measurements are not necessary included in routine musculoskeletal assessment in PFPS. The purpose of this study was to examine the rearfoot posture of subjects with PFPS including Subtalar Joint Neutral and 2D and 3D RCS postures in comparison to healthy controls. It was hypothesised that subjects with PFPS may show altered rearfoot posture in the rearfoot clinical measurements.

METHODS

The study design was a cross sectional comparative investigation of the rearfoot measurements in a clinical group (patellofemoral pain syndrome) and a control group (asymptomatic). Prior to participation, all subjects were informed about the nature of the study and signed an informed consent, which was approved by the Human Ethics Committee of Southern Cross University (ECN-02-101).

The clinical group consisted of 13 females with unilateral PFPS diagnosed by a physiotherapist. Subjects mean age, body mass and height are presented in Table 1. PFPS subjects had symptoms on their right knee for mean of 11 years (range 1.5-30 years) and complained of pain during either ascending stairs, descending stairs, squatting or after prolonged sitting. Subjects with traumatic injury in the patellofemoral joint, patellar tendonitis (jumper's knee), previous surgery, patella plica, ligament and meniscal disorders were excluded from the study. The control group consisted of 14 asymptomatic females with no history of congenital or traumatic deformity to their lower extremity (knee or foot). Subjects' age, body mass and height are presented in Table 1. Asymptomatic subjects with severe foot deformities such as pes cavus and pes planus were excluded from the study.

The subject lay prone with the foot and ankle (to be measured) hanging 15-20 cm over the end of the table. The opposite limb was positioned in hip

flexion, abduction and external rotation with the knee flexed and resting on the supporting surface (Elveru et al., 1988b; Wooden ,1990). With the foot perpendicular to the floor the examiner bisected the posterior lower leg and the posterior calcaneus using Sliding Calipers. The palpation method of measuring the Subtalar Joint Neutral position was based on Wooden (1990) and Elveru et al. (1988b). The foot to be measured was in dorsiflexion and the rearfoot passively pronated and supinated. When the head of the talus was felt equally between the lateral and medial sides, the subtalar joint was in neutral position (Elveru et al., 1988b; Wooden, 1990). The position of the subtalar in the neutral position was maintained and the angle formed by the longitudinal midline of the posterior calcaneus and the line drawn on the posterior lower leg was measured (Elveru et al., 1988b). One arm of the goniometer was placed on the lower leg bisection line while the other arm was placed on the calcaneal bisection line (Figure 1). The axis of the goniometer was placed between the malleoli in the frontal plane (McPoil et al., 1985).
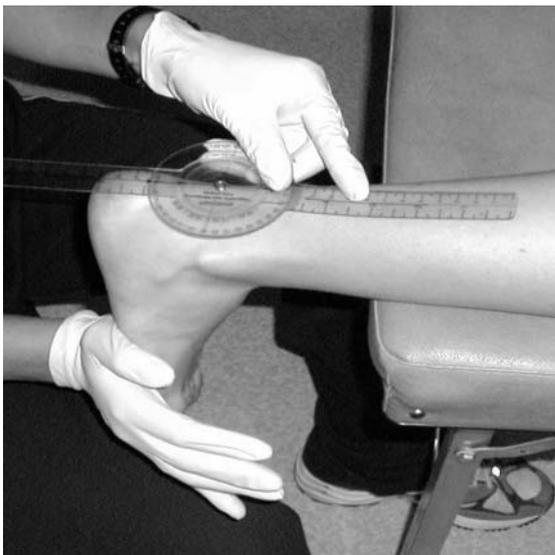

Figure 1. Subtalar Joint Neutral measurement.

The 2D Relaxed Standing position of the calcaneus was measured using a small international standard SFTR pocket joint goniometer (Baseline, overall length 15cm) while subjects were standing in full extension of the knee and relaxed on a raised platform (20 cm) with both heels on the edge of the platform (Lattanza et al., 1988; McPoil et al., 1996). The calcaneal bisection line was measured relative to the horizontal surface (Wooden, 1990). One arm of the goniometer was placed on the horizontal surface while the other arm was placed on the calcaneal bisection line (Figure 2). Subtalar Joint Neutral position and the 2D RCS were measured by the same examiner and reported for three trials. The static measurements were recorded as a deviation in

degrees into inversion (negative values) or eversion (positive values) from the vertical.
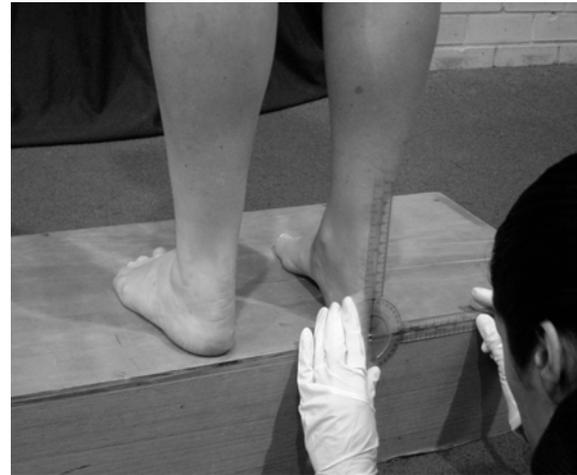
Figure 2. Relaxed Calcaneal Standing posture measurement.

The 3D RCS measurement of the rearfoot relative to the tibia was measured by attaching external retro-reflective markers to a tibia shell and the calcaneus. Four Panasonic WV-CL830/G colour CCTV cameras were used to record the external markers during the relaxed standing posture for a single trial. Peak Motus (version 7) software was used to capture and optimally filter the 3D trajectories of each marker. Filter level for smoothing was chosen for each axis using Jackson knee method and a Quintic Spline processor (Peak Performance Technologies, Peak Motus, version 7, user manual).

The rearfoot segment was defined by three 6-mm diameter external markers on the calcaneus: two markers on a line on the posterior aspect of the calcaneus, which bisected the heel in the frontal plane, one on the upper ridge and second on the lower ridge. A third marker was positioned on the lateral aspect of the calcaneus, approximately mid point in the vertical direction between markers one and two (McClay and Manal, 1998; Rattanaprasert et al., 1999). All the foot markers were attached to the calcaneus during weight bearing (resting standing) to decrease the error between skin marker and skeletal location (Maslen et al., 1994). Four 1.2-cm diameter reflective markers were attached to a tibia shell similar in position to Manal and McClay (2000). An individual tibia shell (20.5cm x 9 cm, 0.08kg), made of heated polyform material, (Rolyan), similar to Manal et al. (2000), was located at the lateral distal one third of the shank length while the subject was sitting with the tibia perpendicular to the floor. Sports tape was placed around the shank over the shell in order to maintain the position of the tibia shell. The first marker

Table 1. Subjects profile and static rearfoot measurements. Data are presented in means (±SD).

	Control	PFPS	F value	P value
Age (years)	25.1 (8.7)	38.4 (10.1)	13.54	.001
Body mass (kg)	61.3 (7.5)	70.6 (18.2)	3.046	.109
Height (m)	1.66 (.06)	1.66 (.06)	.00	.997
Subtalar joint neutral position (°)	-1.00 (1.36)	-2.20 (1.51)	4.716	.04
2D RCS (°)	-.23 (1.35)	2.35 (1.41)	23.802	.001
3D RCS(°)	2.52 (3.11)	7.02 (3.33)	13.137	.001

Negative values indicated inversion and positive values indicated eversion.

was located 30% of the shank length proximal to the lateral malleolus (Figure 3). Then the three markers remaining were positioned with a 20% of the shank length being the vertical and horizontal spacing between the four markers in lateral and anterior positions (Figure 3) (Manal et al., 2000). The angle of the rearfoot relative to the tibia was calculated according to Grood and Suntay (1983).

Figure 3. Three-dimensional Relaxed Calcaneal Standing measurement.

A one way ANOVA was used to investigate the differences between the groups in the rearfoot clinical measurements including Subtalar Joint Neutral and 2D and 3D RCS measurements. All variables were assessed for normal distribution (Shapiro- Wilk) prior to the statistical analyses and were conducted at the 95% level of significance. Intraclass Correlation Coefficient (ICC (3, 1)) and Percent Close Agreement (PCA) were used to assess reliability between trials for the Subtalar Joint Neutral and 2D RCS measurements for both groups.

RESULTS

The reliability trial to trial of the Subtalar Joint Neutral and 2D RCS for the control group was ICC (3, 1) = 0.76 and 0.82 respectively. For the clinical group the trial to trial showed ICC (3, 1) = 0.91 for subtalar joint neutral and ICC (3, 1) = 0.86 for RCS. The PCA between trial reliability showed 85% -

95% values were within one degree of agreement for the control group and 94% - 98% for the clinical group.

Significant (p < 0.001) difference was found for the mean age between the groups with no significant differences for body weight or height (Table 1). The 2D RCS was significantly different between the groups (p < 0.001, Table 1).

The 3D RCS showed significant differences between the groups (p = 0.001, Table 1). Also, Subtalar Joint Neutral position during non-weight bearing position showed a significant different between the groups (p = 0.04, Table 1).

DISCUSSION

The trial to trial reliability of the 2D RCS and Subtalar Joint Neutral position was good to excellent similar to previous reports (Diamond et al., 1989; Elveru et al., 1988a; Ogilvie et al., 1997; Sobel et al., 1999). Root et al. (1977) suggested that the "ideal foot" should be when the Subtalar Joint Neutral position is aligned or parallel with the bisection line of the distal lower leg. However some investigators reported varus position of the calcaneus with values of 2°-8° to be normal, and therefore do not conform to the theoretical concept of the "ideal foot" (Astrom et al., 1995; McPoil et al., 1988). For both the control and the clinical groups the mean of the Subtalar Joint Neutral was within the reported normal range (Astrom and Arvidson, 1995; McPoil et al., 1988). However, the clinical group demonstrated significantly more inverted position in Subtalar Joint Neutral measurement similar to Powers et al. (1995) and Sutlive et al. (2004). Rearfoot varus was found to be one of the most common bony deformities of the foot (Tiberio, 1988) which is present in 83% of a normal population (McPoil et al., 1988). It was suggested however that subjects with PFPS had higher incidence of rearfoot varus deformity (Powers et al., 1995). Although PFPS subjects were found to have some degree of rearfoot varus in the present study, the approximate 1° difference between the group means can be debated despite the statistical significance. Thus, rearfoot varus may be

a factor in contributing to PFPS, however caution must be taken when generalising this finding to the entire PFPS population as only a small difference existed between the groups. Subtalar Joint Neutral position measurement provides information about the leg and foot alignment (Elveru et al., 1988b; Root et al., 1977) as well as adequate assessment of bony deformities (Powers et al., 1995). Therefore this measurement may be important to include in the evaluation process of PFPS individuals.

The 2D calcaneus angle values were lower compared to the 3D RCS angle. We measured the 2D calcaneus angle in standing relative to the laboratory axis and the 3D calcaneus angle in standing relative to the tibia. By reporting the calcaneal angle relative to the vertical laboratory axis, the tibia deviation was not included, hence smaller values of the RCS angle were observed as also reported by Astrom and Arvidson (1995).

The control group exhibited a relaxed standing posture angle similar to the normal range reported for healthy subjects with no foot or leg injuries (Astrom and Arvidson, 1995; McPoil and Cornwall, 1996). The literature however is equivocal in reported normal range. Sobel et al. (1999) reported higher values. Foot types however were not stated and the inclusion of subjects with severe foot valgus or varus although asymptomatic may have influenced the results of Sobel et al. (1999).

According to Dahle et a.l (1991) and McPoil and Brocato, (1985) one of the criteria for classification as excessively pronated was 3° eversion relative to the vertical. Furthermore a value of more than 6° in relaxed calcaneal posture relative to the lower leg was suggested to represent a moderately pronated foot (Subotnick, 1975). Therefore, the results of the current study for 2D and 3D RCS angle indicated a slight to moderately pronated foot for PFPS similar to Sutlive et al. (2004).

The 2D and 3D RCS angle were significantly different between the current groups indicating a slight valgus position of the calcaneus relative to the vertical and relative to the lower leg for subjects with PFPS. Previous studies however reported no differences in RCS angle between controls and PFPS subjects using a goniometer measurement (Thomee et al., 1995; Witvrouw et al., 2000). However, similar values of the rearfoot 3D RCS angle were reported in Sutlive et al., (2004) although there was no comparison to a control group. The conflicting results between studies may be due to differing sample population and also protocol. The use of a three dimensional video method has eliminated examiner bias which maybe possibly inherent in the use of a goniometer. Different sample population may occur as the aetiology of PFPS may consist of multiple factors, and hence sampling populations as occurs for research purposes, does not necessarily result in similar samples. Differences in samples may affect the research outcomes, and therefore may explain the conflicting results between these studies. RCS measurement therefore may be an important addition to other clinical measurements taken to explore the underlying aetiology of subjects with PFPS, as this population may demonstrate an increased pronation of the rearfoot during weight bearing position.

Although differences in the mean age were found between the groups, it is unlikely that the changes found would be a result of age difference or degenerative process in the knee joint related to aging in the PFPS group. Changes due to age are suggested to occur above 55 years (Yanagida et al., 1997). Age–related diseases process, such as osteoarthritis, affect females mainly over 50 years of age (Hart et al., 1999; Hudelmaier et al., 2001; Kee, 2000; Lanyon et al., 2003; Lethbridge-Cejku et al., 1994; Oliveria et al., 1995), thereby it is unlikely that the differences found between the groups in the rearfoot posture would be related to the age difference.

The relaxed standing posture in the present study in combination with the subtalar joint neutral may indicate a subtalar joint eversion excursion of more than 4° during standing for the clinical group. According to Wooden (1990), in order to evaluate the total amount of eversion, Subtalar Joint Neutral (if inversion) should be added to the calculation of eversion. The mean STJN of the clinical group was 2.20±1.51° inversion while the mean relaxed standing was 2.35°±1.41° eversion; therefore the subtalar joint was in 4.55° eversion. In contrast, the control group demonstrated inversion position in both measurements, suggesting less than 1° of subtalar joint eversion excursion. The larger excursion for the clinical group may indicate an increased subtalar joint eversion during weight bearing position. As subtalar joint varus has been suggested to be compensated by excessive subtalar joint eversion during motion (McPoil and Brocato, 1985; Root et al., 1977; Subotnick, 1981; Tiberio, 1988; Vogelbach et al., 1987), this compensation may partly explain the increased eversion during relaxed standing in the clinical group.

CONCLUSIONS

The rearfoot posture of PFPS subjects in the current study showed a small varus position of Subtalar Joint Neutral and a rearfoot valgus in relaxed standing posture when measured relative to the vertical and relative to the tibia. Subtalar joint varus may contribute to the increased eversion during

relaxed standing in the PFPS group. As such, RCS and Subtalar Joint Neutral Position measurements may be an important addition to other clinical measurements taken to explore the underlying aetiology of subjects with PFPS.

REFERENCES

Astrom, M. and Arvidson, T. (1995) Alignment and joint motion in the normal foot. *Journal of Orthopaedic and Sports Physical Therapy* **22**, 216-222.

Austermuehle, P.D. (2001) Common knee injuries in primary care. *The Nurse Practitioner* **26**, 26-45.

Buchbinder, M.R., Napora, N.J. and Biggs E.W. (1979) The relationship of abnormal pronation to chondromalacia of the patella in distance runners. *Journal of the American Podiatry Association* **69**, 159-162.

Clement, D.B., Taunton, J.E., Smart, G.W. and McNicol, K.L. (1981) A survey of overuse running injuries. *The Physician and Sports Medicine* **9**, 47-58.

Dahlman, B.G., Kernozek, T.W., Palmer-McLean, K. and Davies, G.J. (2002) The role of static measurements of the lower extremity in predicting dynamic rearfoot motion and subsequent injury. *Critical Reviews in Physical and Rehabilitation Medicine* **14**, 235-246.

Diamond, J.E., Mueller, M.J., Delitto, A. and Sinacore, D.R. (1989) Reliability of a diabetic foot evaluation. *Physical Therapy* **69**, 797-802.

Donatelli, R. (1987) Abnormal biomechanics of the foot and ankle. *Journal of Orthopaedic and Sports Physical Therapy* **9**, 11-16.

Donatelli, R., Wooden, M., Ekedahl, S.R., Wilks, J.S., Cooper, J. and Bush, A.J. (1999) Relationship between static and dynamic foot postures in professional players. *Journal of Orthopaedic and Sports Physical Therapy* **29**, 316-330.

Duffey, M.J., Martin, D., Cannon, W., Craven, T. and Messier, S.P. (2000) Etiology factors associated with anterior knee pain in distance runners. *Medicine and Science in Sports and Exercise* **32**, 1825-1832.

Elveru, R.A., Rothstein, J.M. and Lamb, R.L. (1988a) Goniometric reliability in a clinical setting: subtalar and ankle joint measurements. *Physical Therapy* **68**, 672-677.

Elveru, R.A., Rothstein, J.M., Lamb, R.L. and Riddle, D.L. (1988b) Methods for taking subtalar joint measurements: a clinical report. *Physical therapy* **68**, 678-682.

Fredericson, M. and Powers, C.M. (2002) Practical management of patellofemoral pain. *Clinical Journal of Sport Medicine* **12**, 36-38.

Grood, E.S. and Suntay, W.J. (1983) Joint coordinate system for the clinical description of three-dimensional motions, application to the knee. *Journal of Biomechanical Engineering.* **105**, 136-144.

Hart, D.J., Doyle D.V. and Spector, T.D. (1999) Incidence and risk factors for radiographic knee osteoarthritis in middle-aged women: the chingford study. *Arthritis and Rheumatism* **42**, 17-24.

Hudelmaier, M., Glaser, C., Hohe, J., Englmeier K.H., Reiser, M., Putz, R. and Eckstein, F. (2001) Age-related changes in the morphology and deformational behavior of knee joint cartilage. *Arthritis and Rheumatism* **44**, 2556-61.

Jernick, S. and Heifitz, N.M. (1979) An investigation into the relationship of foot pronation to chondromalacia patellae. *Archives of Podiatrics Medicine and Foot Surgery* **1**, 1-31.

Kaufman, K.R., Brodine, S.K., Shaffer, R.A., Johnson, C.W. and Cullison, T.R. (1999) The effect of foot structure and range of motion on musculoskeletal overuse injuries. *The American Journal of Sports Medicine* **27**, 585-606.

Kee, C.C. (2000) Osteoarthritis: manageable scourge of aging. *Rheumatology* **35**, 199-208.

Lanyon, P., Muir, K., Doherty, S. and Doherty, M. (2003) Age and sex differences in hip joint space among asymptomatic subjects without structural change: implications for epidemiological studies. *Arthritis and Rheumatism* **48,** 1041-1046.

Lattanza, L., Gray, G.W. and Kantner, R.M. (1988) Closed versus open kinematic chain measurements of subtalar joint eversion: implication for clinical practice. *Journal of Orthopaedic and Sports Physical Therapy* **9**, 310-314.

Lethbridge-Cejku, M., Tobin, J.D., Scott, Jr. W.W., Reichle, R., Plato, C.C. and Hochberg, M.C. (1994) The relationship of age and gender to prevalence and pattern of radiographic changes of osteoarthritis of the knee: data from Caucasian participants in the Baltimore longitudinal study of aging. *Aging Clinical and Experimental Research* **6**, 353-357.

Manal, K., McClay, I., Stanhope, S., Richards, J. and Galinat, B. (2000) Comparison of surface mounted markers and attachments methods in estimating tibial rotations during walking: an in vivo study. *Gait and Posture* **11**, 38-45.

Maslen, B.A. and Ackland, T.R. (1994) Radiographic study of skin displacement errors in the foot and ankle during standing. *Clinical Biomechanics* **9**, 291-296.

McClay, I. and Manal, K. (1998) A comparison of three-dimensional lower extremity kinematics during running between excessive pronators and normals. *Clinical Biomechanics* **13**, 195-203.

McPoil, T.G. and Brocato, R.S. (1985) The foot and ankle: biomechanical evaluation and treatment. In: *Orthopaedic and Sports Physical Therapy*. Eds: Gould III, J.A. and Davies, G.J. St. Louis, Missouri: The C.V Mosby Company. 313-341.

McPoil, T.G. and Cornwall, M.W. (1996) The relationship between static lower extremity measurements and rearfoot motion during walking. *Journal of Orthopaedic and Sports Physical Therapy* **24**, 309-314.

McPoil, T.G., Knecht, H.G. and Schuit, D. (1988) A survey of foot types in normal females between the ages of 10 and 30 years. *Journal of Orthopaedic and Sports Physical Therapy* **9**, 406-9.

Messier, S.P., Davis, S.E., Curl, W.W., Lowery, R.B., Pack, R.J. (1991) Etiologic factors associated with patellofemoral pain in runners. *Medicine and Science in Sports and Exercise* **23**, 1008-1015.

Ogilvie, S.W., Rendall, G.C. and Abboud, R.J. (1997) Reliability of open kinetic chain subtalar joint measurement. *The Foot* **7**, 128-134.

Oliveria, S.A., Felson, D.T., Reed, J.I., Cirillo, P.A., Walker, A.M. (1995) Incidence of symptomatic hand, hip and knee osteoarthritis among patients in a healthy maintenance organization. *Arthritis and Rheumatism* **38**, 1134-1141.

Powers, C.M., Maffucci, R. and Hampton, S. (1995) Rearfoot posture in subjects with patellofemoral pain. *Journal of Orthopaedic and Sports Physical Therapy* **22**, 155-160.

Rattanaprasert, U., Smith, R., Sullivan, M. and Gilleard, W. (1999) Three-dimensional kinematics of the forefoot, rearfoot and leg without the function of tibialis posterior in comparison with normals during stance phase of walking. *Clinical Biomechanics* **14**, 14-23.

Root, M.L., Orien, W.P. and Weed, J.H. (1977) *Normal and abnormal function of foot: Clinical biomechanics* Los Angeles: Clinical Biomechanics Corporation.

Sobel, E., Levitz, S.J., Caselli, M.A., Tran, M., Lepore, F., Lilja, E., Sinaie, M. and Wain, E. (1999) Reevaluation of the relaxed calcaneal stance position. *Journal of the American Podiatric Medical Association* **89**, 258-264.

Subotnick, S.I. (1975) *Podiatric Sport Medicine.* New York: Futura Publishing Company.

Subotnick, S.I. (1981) The flat foot. *The Physician and Sports medicine* **9**, 85-91.

Sutlive, T.G., Mitchell, S.D., Maxfield, S.N., McLean, C.L., Neumann, J.C., Swiecki, C.R., Hall, R.C., Bare, A.C. and Flynn, T.W. (2004) Identification of individuals with patellofemoral pain whose symptoms improved after a combined program of foot orthosis use and modified activity: a preliminary investigation. *Physical Therapy* **84**, 49-61.

Taunton, J.E., Byan, M.B., Clement, D.B., McKenzie, D.C., Lloyd-Smith, D.R. and Zumbo, B.D. (2002) A retrospective case-control analysis of 2002 running injuries. *British Journal of Sports Medicine* **32**, 95-101.

Thomee, R., Renstrom, P., Karlsson, J. and Grimby, G. (1995) Patellofemoral pain syndrome in young women. *Scandinavian Journal of Medicine and Science in Sports* **5**, 237-244.

Tiberio, D. (1987) The effect of excessive subtalar joint pronation on patellofemoral mechanics: a theoretical model. *Journal of Orthopaedic and Sports Physical Therapy* **9**, 160-165.

Tiberio, D. (1988) Pathomechanics of structural foot deformities. *Physical Therapy* **68**, 1840-1849.

Vogelbach, W.D. and Combs, L.C. (1987) A biomechanical approach to the management of chronic lower extremity pathologies as they relate to excessive pronation. *Athletic Training* **22**, 6-16.

Witvrouw, E., Lysens, R., Bellemans, J., Cambier, D. and Vanderstraeten, G, (2000) Intrinsic risk factors for the development of anterior knee pain in an athletic population. *The American Journal of Sports Medicine* **28**, 480-489.

Wooden, M.J. (1990) Biomechanical evaluation for functional orthotics. In: *The biomechanics of the foot and ankle. Ed:* Donatelli, R. Philadelphia: F.A David Company. 131-147.

Yanagida, T. and Asami, T. (1997) Age-related changes in distribution of body weight on soles of feet for selected actions and postures. *Perceptual and Motor Skills* **85**, 1263-1271.

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KEY POINTS

- Rearfoot posture of PFPS subjects showed a small varus position of Subtalar Joint Neutral and a rearfoot valgus in relaxed standing posture.
- Relaxed Calcaneal Standing and Subtalar Joint Neutral Position measurements may be an important addition to other clinical measurements taken to explore the underlying aetiology of subjects with PFPS.

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