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Reference

# **An investigation of the clinical relationship between foot posture and patellofemoral joint alignment**

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**Doctor of Philosophy**

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## Abstract

It has been suggested that abnormal foot posture is related to patellofemoral joint pain. An understanding of the relationship hinges on assessment of the relationship between the two, but whilst satisfactory (reliable and valid) clinical methods of foot posture exist, there is no consensus on the optimal technique for assessing patellofemoral joint alignment. Therefore, a series of studies were performed to examine standardisation, reliability, validity and functional significance of patellofemoral joint alignment measures (*Q*, *modified A*, *tibiofemoral joint* and *tubercle sulcus* angles). Intraclass correlation coefficients of all measures was fair-to-excellent (standard error of measurement  $<2^\circ$ ), whilst each measure showed significant differences ( $p < 0.001$ ) in selected foot positions and postures (i.e.  $10^\circ$  abduction, maximally pronated). A cross-sectional study then investigated normal values for these measures in 335 asymptomatic individuals. The Foot Posture Index<sup>®</sup> was used to categorise participants into pronated ( $n = 110$ ), neutral ( $n = 111$ ) and supinated ( $n = 114$ ) groups. All patellofemoral joint measures differed significantly between pronated and supinated foot postures, with values tending to increase with pronation. This data was used to categorise 60 asymptomatic individuals into three patellofemoral joint alignment groups (high, central and low,  $n = 20$  per group), and a group of patellofemoral joint pain patients was also included. Rearfoot and midfoot loading characteristics were obtained using the EMED<sup>®</sup>-m system. Comparisons between groups showed significant differences, with high and patellofemoral joint pain groups demonstrating slower and reduced loading at the rear and midfoot compared to central and low groups ( $p < 0.001$ ). Whilst further inquiry is required this data suggests that foot posture, functional foot loading characteristics and patellofemoral joint alignment are related. Differences in loading characteristics suggest a mechanism by which patellofemoral joint alignment and foot posture may be related to pathology. This provides a rationale for clinical interventions aimed at modifying foot and/or patellofemoral joint alignment.

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## List of Abbreviations

<b>Abbreviation</b>	<b>Meaning</b>	<b>Page of definition</b>
AH	Arch height	49
ANOVA	Analysis of Variance	67
AOG	Angle of gait	54
ASIS	Anterior superior iliac spine	36
AUC	Area under the curve	122
BOG	Base of gait	54
BW	Bodyweight	8
CI	Confidence interval (s)	67
cm	Centimetre	62
CT	Computed tomography	32
CoP	Centre of pressure	58
CoV	Coefficient of Variation	67
DCoP	Duration of centre of pressure	59
EMG	Electromyography	21
EoF	Envelope of function	11
F	Female	41
GRFv	Ground reaction force vector	6
FL	Foot length	52
FPI <sup>®</sup>	Foot Posture Index <sup>®</sup>	52
FTI	Force time integral	58
ICC	Intraclass correlation coefficient	39
kg	Kilograms	62
km	Kilometres	12
LMAI	Lateral medial area indices	58
LMFI	Lateral medial force indices	58
MRI	Magnetic Resonance Imaging	2
M	Male	41
MF	Maximum force	58
MLA	Medial longitudinal arch	14
m	Metre	12

mm	Millimetre	63
m/s	Milliseconds	59
N	Newton force	29
ND	Navicular drop	50
NH	Navicular height	50
NNH	Normalised navicular height	119
NR	Not reported	56
PFJt	Patellofemoral Joint	1
RCSP	Resting calcaneal stance position	46
RF	Rectus femoris	5
ROC	Receiver operator characteristic	122
SD	Standard Deviation	29
SEM	Standard Error of Measurement	33
SPSS™	Statistical Package for the Social Sciences™	67
STJt	Subtalar joint	13
STROBE	STrengthening the Reporting of OBservational studies in Epidemiology	182
TFJt	Tibiofemoral joint	1
TS angle	Tubercle sulcus angle	36
UWIC	University of Wales Institute, Cardiff	62
VAS	Visual analogue scale	26
VCoP	Velocity of centre of pressure	59
VIM	Vastus intermedius	5
VL	Vastus lateralis	5
VML	Vastus medialis longus	6
VMO	Vastus medialis obliquus	6

# Chapter 1

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## Introduction

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### 1.1 The problem

The knee is a complex weightbearing joint that provides stability and mobility to the lower extremity. It is made up of two articulations: the tibiofemoral joint (TFJt) and the patellofemoral joint (PFJt). The TFJt is the articulation between the distal femur and proximal tibia whilst the PFJt is the articulation between the posterior patella and the anterior distal femur. The patella is recognised as the structure that is most vulnerable to direct and indirect mechanisms of injury (Ficat *et al.*, 1996). These injuries contribute to the condition '*patellofemoral pain syndrome*', an umbrella term used to describe pain from various origins associated with the anterior aspect of the knee. It is one of the most common and complex musculoskeletal complaints worldwide (Callaghan and Selfe, 2007; Thomee *et al.*, 1999) and is a frequent clinical finding among children, young adults and sporting individuals (Owings and Grabiner, 2002; Brody and Thein, 1998). The condition is often referred to as the '*Black Hole of Orthopaedics*' (Dye, 1997 cited in Wilk *et al.*, 1998) with treatment principles and guidelines remaining unclear and controversial (Wilson, 2007). An important factor influencing this may be the diagnostic and aetiologic complexity of PFJt pathology (Powers, 2003).

Controversy surrounds the aetiologies of PFJt pain with suspected important factors including acute trauma, muscle weakness and malalignment of the patella. Of particular interest to those clinically managing the problem is malalignment of the lower limb and the effects on PFJt function. It has been suggested that abnormal foot posture and excessive pronation in particular, is related to PFJt malalignment and pain. This is supported by reports show a reduction in symptoms associated with PFJt malalignment induced pain with the use of foot orthoses designed to address abnormal foot posture (Johnston and Gross, 2004; Saxena and Haddad, 2003). Whilst it appears that PFJt pain and biomechanical abnormalities are related this information originates from observation of patients who are symptomatic. PFJt alignment and the role of foot posture have yet to be established as a marker for PFJt pain in a prospective manner. In addition, whilst theories have been proposed to explain the

biomechanical relationship for abnormal foot posture and PFJt malalignment induced pain they have yet to be proven (Tiberio, 1987; Buchbinder *et al.*, 1979).

There are number of different techniques used to measure PFJt alignment and foot posture (i.e. clinical, radiographic, magnetic resonance imaging [MRI]) but few attempts have been made to directly associate the two. Those who have however have provided confusing and inconsistent results (Gross and Foxworth, 2003). One of the reasons for this is the variation in the methods used to obtain these measures which include non-weightbearing and weightbearing approaches. Method variations are also noted when a weightbearing approach is used and relates to a standardised or self-selected foot position (Livingston and Spaulding, 2002). Perhaps more important is the fact that many reports fail to document foot posture making it difficult to compare data and establish the link between PFJt alignment and foot posture. What is clear however is the need to consider and record a standardised foot position.

## **1.2 Aim and outline of the thesis**

The overall aim of the thesis was to investigate the relationship between foot posture and PFJt alignment. It begins with an overview of the literature relating to the functional anatomy of the PFJt and its link with foot posture (chapter 2). It also considers how measures can be used for observational inquiry and how their functional significance can be examined (chapter 3). Chapter four presents three important preliminary studies which influenced the choices and decisions made for the cross-sectional study presented in chapter five. In chapter six data produced from the preceding chapter was used to investigate the functional significance of the PFJt alignment values in normal individuals and patients with PFJt pain. Finally, chapter seven summarises the key findings of each preceding chapter and provides recommendations for further research.

## **1.3 Significance of the thesis**

Given the worldwide prevalence, socioeconomic impact and the range of health professionals who treat patients with PFJt pain it is important that measures used to investigate this problem are reliable, valid and standardised. For this thesis, a battery of clinical measures were identified for observational inquiry (cross-sectional) which established normal clinical reference values linking PFJt alignment to different foot

posture categories. This information was then used to examine the functional significance of these clinical values using plantar pressure measurement and was compared with patients presenting with PFJt pain. A better understanding of malalignments of the lower limb, along with their implications for functional performance, is important as this provides insight to the relationship between foot function and PFJt pain.

## Chapter 2

### Patellofemoral joint mechanics and pain in relation to the foot

---

This chapter provides an overview of the anatomical and functional characteristics of the PFJt. The terms related to pain and pathology of the PFJt and their clinical significance are briefly discussed. The proposed aetiologies are presented and the role of *envelope of function*, which considers the boundaries of how pathology may be induced, is also addressed. Special emphasis is placed on the functional consequences of lower limb malalignment with particular reference to the proposed link between abnormal foot pronation, femoral and tibial rotation.

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#### 2.1 Structure and function of the PFJt

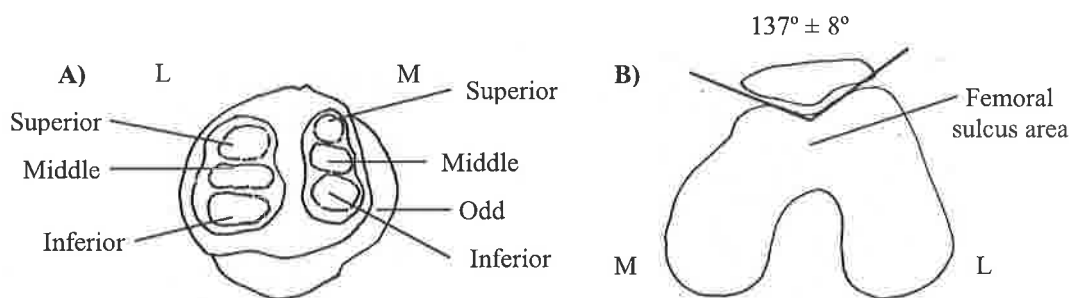
##### 2.1.1 Osseous and soft tissue features

The PFJt is a synovial sellar type of joint consisting of the articular surfaces of the distal anterior aspect of the femur (femoral sulcus) and the posterior facets of the patella (figure 2.1A and 2.1B). The patella is embedded within the tendon of the quadriceps femoris muscle and is the largest sesamoid bone in the body. It has a relatively constant width, length and thickness (Oatis, 2003). Evidence does suggest however a gender difference in the length and width of the patella with Schlenzka and Schwesinger (1990) noting an increase in length and width in 37 male compared to 13 female cadavers. The posterior surface of the patella is divided into inferior and superior regions. The inferior aspect includes the non-articulating portion which occupies 25% of the patella's total length. The remaining 75% is occupied by the superior portion which is covered by hyaline cartilage (Ficat *et al.*, 1996) which is up to 5mm thick making it the thickest in the body (Staubli *et al.*, 1999; Jiang *et al.*, 1994). A distinct midline longitudinal groove runs through the superior posterior portion of the patella forming the medial and lateral facets (Grelsamer and Klein, 1998). These are subdivided into 7 distinct facets; 3 medial, 3 lateral, and one odd (also known as the border facet) (Oatis, 2003). The 'odd' facet is located on the medial border of the medial facet (Kwak *et al.*, 1997) and whilst it is described as non-articulating it does achieve contact during extreme knee flexion (figure 2.1A).

Stability of the patella is provided by a number of key static and dynamic support mechanisms. The shape and depth of the PFJt provides the main static support. The normal femoral sulcus angle is considered to be  $137^{\circ} (\pm 8^{\circ})$ , with the lateral sulcus



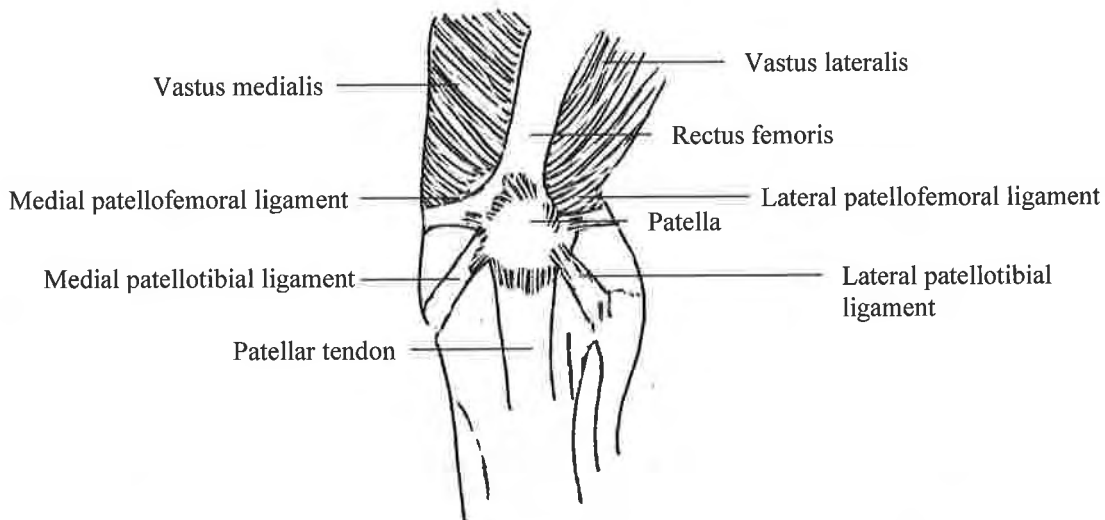
extending higher (Tria and Alicea, 1995) (figure 2.1B). Static stabilisation (non-contractile) is also provided by a number of soft tissue structures surrounding the PFJt which is described by Ficat *et al.* (1996) as a “*cruciform soft tissue system*” that tethers the patella in longitudinal and transverse directions to the femur, tibia and fibula. These structures include the patellar and quadriceps tendons, as well as components of the lateral and medial retinaculum which are divided further into the patellofemoral ligaments and patellotibial ligaments (Warren and Marshall, 1979). Conlan *et al.* (1993) comments that the medial patellofemoral ligament is the prime stabiliser of the patella providing 53% of the total force created by the medial retinaculum and is a view supported by others (Nomura *et al.*, 2000; Desio *et al.*, 1998; Hautamaa *et al.*, 1998). The components of the lateral retinaculum (i.e lateral patellofemoral ligament and patellotibial band) provide supero and inferolateral support to the patella (Ficat *et al.*, 1996; Reider *et al.*, 1981) and work collectively during flexion undergoing tension that forces the patella to become tilted and displaced laterally. These forces are neutralised by the medial stabilisers which are also placed under tension when the knee is flexed (Woodhall and Welsh, 1990) (figure 2.2).



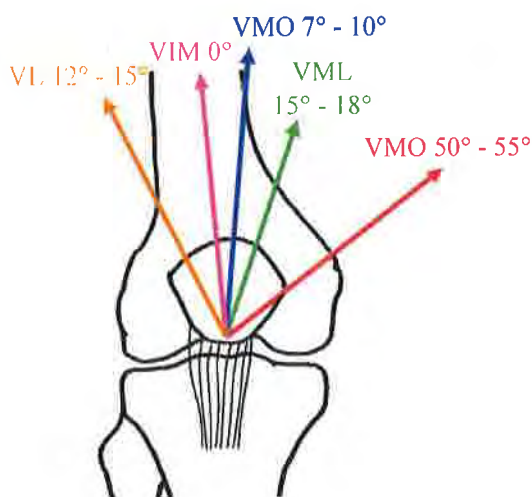
**Figure 2.1: Facets of the patella (A) and the femoral sulcus angle (B).** (M - Medial, L – lateral).

Another key element is dynamic muscular activity (contractile) of the semitendinosus and pes anserinus which internally rotate the tibia, and the biceps femoris and iliotibial band which externally rotate the tibia (Paulos *et al.*, 1980). The main dynamic stabilisation however is provided by the ‘*extensor mechanism*’ and include the quadriceps muscle group, the patella and the patellar ligament (Hamill and Knutzen, 2003; Malone *et al.*, 2002). The quadriceps muscle group consists of four muscles: *rectus femoris (RF)*; *vastus lateralis (VL)*; *vastus medialis (VM)* and *vastus intermedius (VIM)* (Blackburn and Craig, 1980). These 4 muscles unite to form the quadriceps tendon (Tria and Alicea, 1995). During walking the quadriceps are only

active during loading response (after heelstrike). The ground reaction force vector (GRFv) is posterior to the knee which creates a flexion moment. This moment is counterbalanced by the eccentric action of the quadriceps which acts as a shock absorber. As the GRFv moves anterior to the knee (midstance) the activity of the quadriceps muscles falls to almost zero (Inman *et al.*, 1981).



**Figure 2.2: Soft tissue restraints of the patella.** Illustration of important peripatellar structures (ligaments and tendons) which provide static support of the patella. It can be seen that the patella is tethered to the femur, tibia and fibula by a series of ligaments that can be thought of as “guy ropes”.



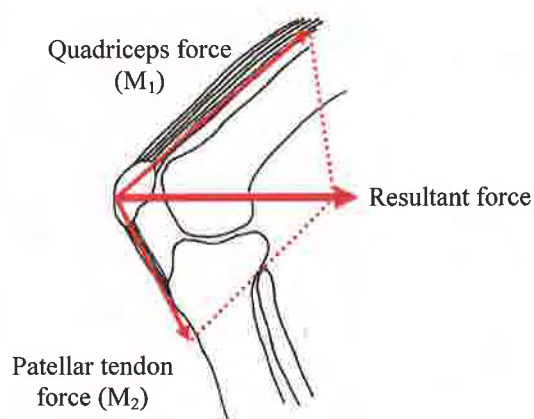
**Figure 2.3: Angle of insertion of muscle fibres of the quadriceps muscles.** This diagram illustrates the angle of insertion for all of the quadriceps muscles and their sub-sections. The angle of insertion for the VMO is the greatest at 50 - 55° whilst the angle for the VIM is the lowest (0°).

The RF and VIM muscles pull the patella in a proximal-to-lateral direction. The VL pulls the patella in a lateral direction whilst the VM pulls in a medial direction. Malone *et al.* (2002) cited the words of Smillie (1962) who pointed out that the VM was the “...key to the knee” (page 349) stating that this muscle was exclusively accountable for stability of the PFJt. The distal aspect of the VM has 2 divisions; the

vastus medialis longus (VML) and the vastus medialis obliquus (VMO) (Lieb and Perry, 1968). The VMO is the smaller portion of the division and is often involved in problems of the PFJt (Stensdotter *et al.*, 2008). It attaches to the mid-portion of the patella's medial border at an angle of  $65^\circ$  (Ficat *et al.*, 1996; Hughston *et al.*, 1984), although some authors report a range from  $50^\circ$  -  $55^\circ$  (Powers, 1998). Although this suggests anatomical variation it is thought that this angle assists in preventing lateral subluxation of the patella by counterbalancing the larger pull of the VL (figure 2.3).

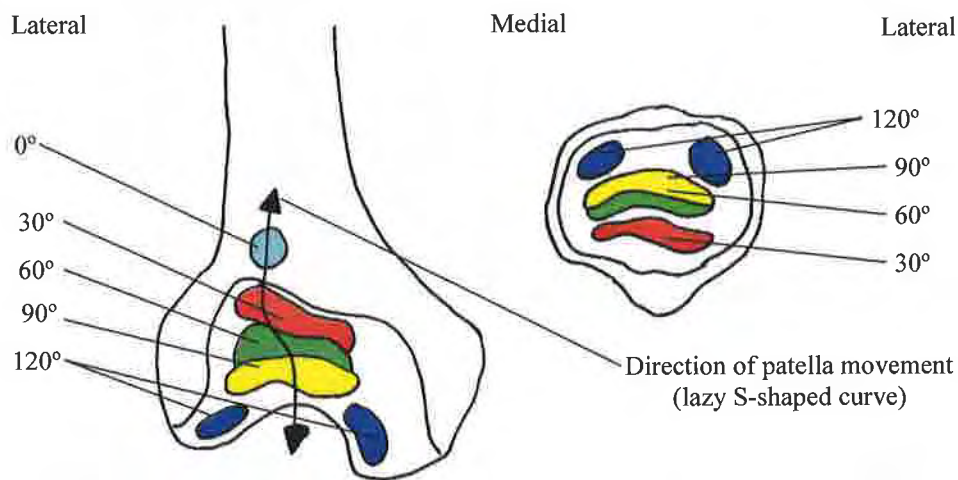
### 2.1.2 Function of the PFJt

The ability to improve the efficiency of the quadriceps muscle group by increasing the lever arm of the extensor mechanism is commonly referred to as the patella's major function (Grelsamer and Weinstein, 2001; Ficat *et al.*, 1996). The patella acts as a class I lever by acting as the fulcrum which is positioned between the force applied by the quadriceps and the opposite motion from the lower leg (Huberti *et al.*, 1984; Reilly and Martens, 1972). During different ranges of knee motion, the lever arms differ with the ratio of  $M_1$  (quadriceps tendon force) and  $M_2$  (patellar tendon force) failing to equal 1 (Ficat *et al.*, 1996; Ahmed *et al.*, 1983) (figure 2.4). Maquet (1976) demonstrated the complex link between  $M_1$  and  $M_2$  using static force analysis line drawings of the lateral aspect of the knee in different degrees of flexion. His work has since been developed further by many authors (Hehne, 1990; Buff *et al.*, 1988; Ahmed *et al.*, 1987; Van Eijden *et al.*, 1986; Huberti *et al.*, 1984). Other functions of the patella relate to its ability to increase the contact area on the femur which helps to distribute compressive forces within the PFJt during different activities. It has also been suggested the patella acts as a protective shield to the femoral condyles during flexion (Aglietti *et al.*, 1993).



**Figure 2.4: PFJt reaction force and lever arm system.** This diagram represents the reaction force and the amount of compression on the patella against the femur. This force is influenced by the amount of tension within the quadriceps tendon ( $M_1$ ) and patellar tendon ( $M_2$ ).

In the final 30° of knee extension, the tibia externally rotates guiding the patella through the femoral sulcus by the distal parts of the quadriceps muscle group. At maximal knee extension no contact is made on the patella and femur's articular cartilage. Instead the patella tendon is in contact with the femur and the patella rests on the supratrochlear fat pad (Aglietti and Menchetti, 1995). As the knee begins to flex (0° – 20°), the distal aspect of the patella comes in contact with lateral femoral condyle. As knee flexion increases the patella follows a lazy S-shaped curve through the femoral sulcus. Therefore as knee flexion increases the contact points change from distal to proximal (figure 2.5) (Besier *et al.*, 2005; Holmes and Clancy, 1998). Gender differences have been noted in these contact points. Csintalan *et al.* (2002) studied 12 cadavers (6 female/6 male) and found larger mean contact areas of 331mm<sup>2</sup> for males compared to 284mm<sup>2</sup> for females when the knee was flexed to 30°. These findings are supported by Salsich *et al.* (2003), Powers *et al.* (1998) and Huberti and Hayes (1984) but are in contrast to Besier *et al.* (2005) who reported 20 – 30% higher contact areas (females 284mm<sup>2</sup>, males = 494mm<sup>2</sup>). These observations may provide a rationale for the increased incidence of PFJt pain in females since smaller contact areas are linked to higher forces that can lead to focal pathology.



**Figure 2.5: PFJt contact areas during various stages of knee extension and flexion.** At 0° of extension no contact is made of the patella's and femur's articular cartilage. At 120° of flexion contact is made at the patella's lateral/medial superior portion to the lateral/medial sides of the femoral sulcus.

Compressive forces occurring within the PFJt vary with different activities and ranges of knee motion. Knee flexion causes the patella to be pulled into the femur increasing force whilst knee extension pulls the patella into a parallel position to the femur, decreasing force (Besier *et al.*, 2005; Hamill and Knutzen, 2003). During level walking compressive forces within the PFJt can be 0.5 times bodyweight (BW)

(Reilly and Martens, 1972) and increase to 2.8 - 3.3 times BW ascending and descending stairs (Taylor *et al.*, 1998). A squat produces forces 6 – 7.6 times BW (Dahlkvist *et al.*, 1982; Reilly and Martens, 1972) whilst activities such as running, jumping and dancing are thought to substantially increase the forces on the patella, increasing to almost 20 times BW (Simpson *et al.*, 1996; Flynn and Soutas-Little, 1995; Smith, 1975). Abnormalities in contact characteristics and loading can therefore be seen to have a clear potential to result in pathology.

## **2.2 The nature of PFJt pain**

### **2.2.1 Introduction and terminology**

PFJt pain is a common problem worldwide and has a large economic impact, even when compared with other common musculoskeletal problems (Lindgren, 1998; Grabiner *et al.*, 1994). The incidence and prevalence of PFJt pain in particular groups of individuals has been reported with many authors suggesting a predominance in children and young adults (Saxena and Haddad, 2003; Owings and Grabiner, 2002), females (Fithian *et al.*, 2004; Ireland and Ott, 2004), military recruits (Dorotka *et al.*, 2003) and sporting individuals of all ages (Kannus *et al.*, 1987). Callaghan and Selfe (2007) argue however that most, if not all of this data is obtained from military and sports medical settings and tend to be retrospective in nature. They further add that despite UK based epidemiological studies such as Jinks *et al.* (2004); McAlindon *et al.* (1992) and Fairbank *et al.* (1984) no attempt was made to distinguish between generalised knee pain and PFJt pain. Perhaps more importantly they conclude that the true prevalence and incidence of PFJt pain in the UK is unknown.

Despite the increased level of technology, improved understanding and treatment of many knee disorders, problems associated with the PFJt challenge the best of clinicians and surgeons (Wilk, 1998). Dye (1997) labels this condition as the “*Black Hole of Orthopaedics*” commenting that to date; no single description or treatment completely explains this problem (cited in Wilk *et al.*, 1998). Different terms have been used and include *chondromalacia patellae*, *patellar pain*, *patellofemoral arthralgia*, *subluxation*, *congruence* and *malalignment*. Whilst these terms are useful they are limited since their meaning can vary from one health professional to another with chondromalacia for example having up to 5 different meanings (Grelsamer, 2005). ‘*Anterior knee pain*’ and ‘*patellofemoral pain syndrome*’ are common terms

used in recent literature to describe a group of signs and symptoms of the PFJt (Herrington, 2008; Callaghan and Selfe, 2007). Despite their widespread use these terms have been criticised by Grelsamer (2007; 2005) who states that a list of signs and symptoms are unhelpful when attempting to formulate diagnoses. He suggests that these terms should be withdrawn and replaced with a diagnosis that is specific and descriptive to the patient's pain. Since there appears to be no definitive term to denote PFJt pathology, for ease of discussion the term '*PFJt pain*' is used throughout this thesis. This is based on the fact that the term 'PFJt' is suitable as it does not distinguish between structures of the patella and femur and the term 'pain' is a symptom that all patients experience.

### **2.2.2 Aetiology of PFJt pain and the role of lower limb malalignment**

PFJt pathology is considered to be multifactorial in origin. Suspected aetiologies, despite being divided into extrinsic and intrinsic categories, are felt to act through the single pathology of disrupting the osseous and soft tissue stability of the joint. Extrinsic causes focus predominantly on mechanical and malalignment problems such as an increased Q angle (Rauh *et al.*, 2007; Livingston and Mandigo, 1999), femoral rotation (Sikorski *et al.*, 1979), genu valgum, genu varum (Lubowitz *et al.*, 2008; Insall *et al.*, 1976), joint laxity (Cascells, 1979), tibial torsion (Turner and Smillie, 1981), abnormal foot pronation (Gross and Foxworth, 2003; Tiberio, 1987) and abnormal foot supination (Williams *et al.*, 2001). Intrinsic causes relate to an abnormal patella shape (Harrison, 1955), atrophy of the VMO (Berry *et al.*, 2008; Lin *et al.*, 2008; Gilleard *et al.*, 1998), poor healing following minor trauma (Insall *et al.*, 1976), patella instability (Hautamaa *et al.*, 1998; Dejour *et al.*, 1994), a shallow femoral sulcus (Aglietti *et al.*, 1983) and cartilage abnormalities (Darracott and Vernon-Roberts, 1971). There may however be relationships between these intrinsic and extrinsic categories. For example, it is likely that malalignment problems could be linked with VMO atrophy, genu valgum and patella instability.

The term '*malalignment*' is commonly applied to the PFJt to indicate dysfunction and is considered as an important determinant of pathology. Whilst '*malalignment*' can be described as a vague and overused term when referred to as a clinical diagnosis Post *et al.* (2002) provide a specific definition stating that PFJt malalignment:

*“...occurs where bony alignment, joint geometry, soft tissue restraints, neuromuscular control and functional demands combine to produce symptoms as a result of abnormally directed loads that exceed physiologic threshold of tissues...malalignment means malalignment of forces” (page 541).*

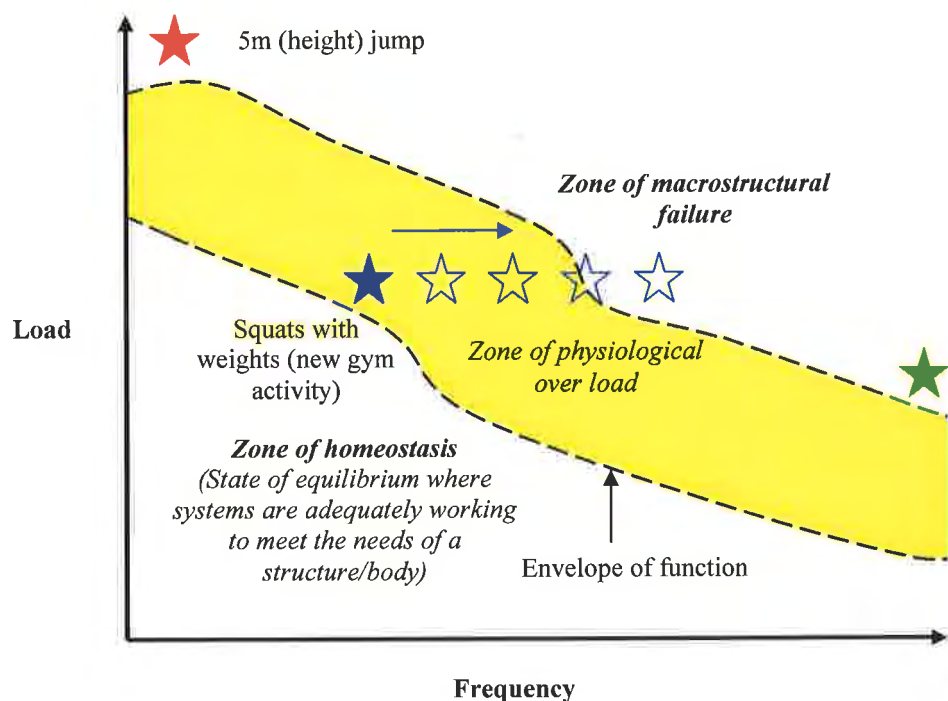
Whilst predisposing factors such as atrophy of the VMO (Lin *et al.*, 2008; Laprade *et al.*, 1998) may contribute to PFJt pain and malalignment Post *et al.* (2002) encourage clinicians and researchers to “...think limb alignment, not patella alignment” (page 541). Lower limb malalignment, ranging from torsional anomalies associated with the femur and/or tibia, and an abnormal Q angle to abnormal foot pronation are important features to consider. Understanding normal limb alignment is necessary for understanding how body mass is transferred to the supporting surface. Normal anatomy permits a balance of the transfer of weight, which is tolerated by biological tissues. Limbs that are malaligned could disrupt this balance overloading tissues such as articular cartilage, bone and ligaments which result in pain and other symptoms (Post *et al.*, 2002; Post, 2001).

### **2.2.3 The envelope of function and PFJt pain**

During clinical examination a series of questions are asked by the clinician to assist in formulating a diagnosis. These questions focus on predisposing factors (intrinsic/extrinsic) and precipitating factors (i.e. activity type, training errors) (Donatelli, 1996). Whilst this method is commonly used by many Dye (1996) adopts a more direct approach proposing the term ‘envelope of function’ (EoF). This concept describes the knee’s ability to accept, dissipate and transfer loads over time with no disruption to the macrostructure and physiological function (tissue homeostasis) of a joint system. The EoF relates to the ability of an individual to undertake activities with no pain or symptoms. Pain and symptoms are only experienced when an individual falls outside of their EoF. This concept, which can also be termed the ‘envelope of load acceptance’, has been applied to anterior cruciate ligament (ACL) injuries and reconstruction of the knee as well as PFJt pain (Dye, 2005; Zelle *et al.*, 2005; McConnell, 1999) and is an expression of a widely held belief (Peterson *et al.*, 2000; Porterfield and DeRosa, 1991).



Each individual has a different EoF, for example, a young professional footballer will have a larger EoF where the joint is able to cope with higher and repetitive loads before pain and symptoms occur compared to that of a sedentary elderly individual (McConnell, 1999; Dye, 1996). This upper limit of the EoF represents a threshold between homeostasis and over load which initiates a complex biological response of inflammation and repair that presents clinically as pain and swelling (Dye, 1996). This loading threshold is also referred to as 'optimal loading zone' where the level of activity does not over or under load affected structures (Brody and Thein, 1998). These optimal loading zones are decreased by a number of factors such as age (through effects on collagen), postural habits (shortening of muscle), lifestyle habits and previous injury (Brody and Thein, 1998) (figure 2.6). In addition to these general factors, Dye (1996) identifies 4 specific factors that determine the EoF of a joint and include anatomic (morphology), kinematic (dynamic control), physiologic (cellular homeostasis) and treatment factors.



**Figure 2.6: Loading zones across a joint and examples of loading for a young active adult.** The area under the dotted black line is the EoF ('zone of homeostasis'). The yellow area is the 'zone of physiological overload' which is not large enough to cause macrostructural damage. The 'zone of macrostructural failure' increases the loading to cause macrostructural damage. The left red star indicates that jumping from a height of 5 metres (m) exceeds the EoF disrupting the knee's homeostasis predisposing to damage. The blue star indicates that squatting with weights falls within the zone of physiologic overload but out of the EoF. Repetition of this activity (blue lined stars), which can involve extreme knee flexion can load areas of the PFJt which are not use to being loaded (i.e. the patella's odd facet) and may produce pain/symptoms. The green star shows how low loads over a period of time (5 kilometre [km] run and lower limb malalignment) could produce pain and symptoms.

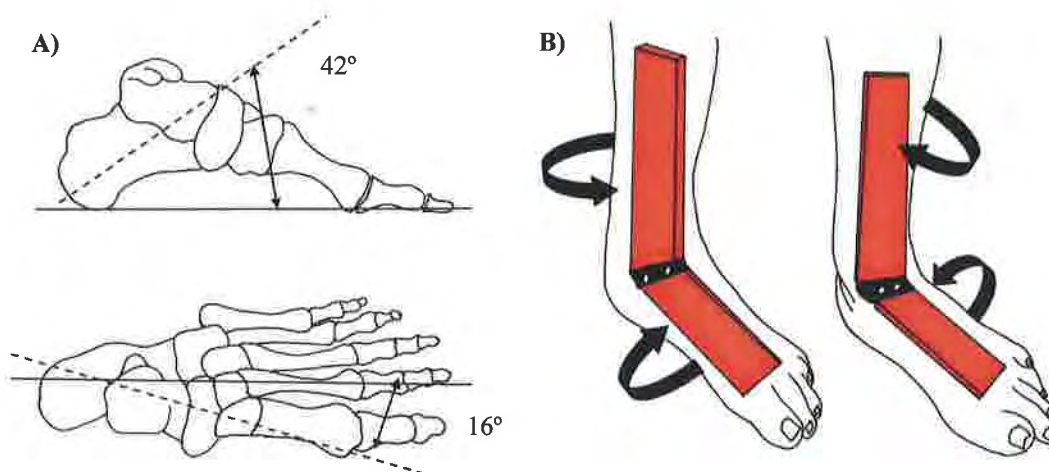


Although it is possible that malalignment of the PFJt and lower limb are major contributing factors to PFJt pain Watson *et al.* (1999a) urges caution to a statement provided by McConnell (1999) who commented that it is not ideal for the patella to be malaligned (i.e. laterally displaced). She also questioned how much patella displacement is needed to produce symptoms. A simple reason as to why some individuals with suboptimal alignment have no PFJt pain could be that adequate dynamic stabilisation of the patella is present during various activities (Post *et al.*, 2002) or that microtrauma has yet to exceed the EoF. These considerations can also be applied to high Q angles found in patients with PFJt pain and asymptomatic individuals (Livingston, 1998), and at what value the Q angle needs to be to cause symptoms. Although the causes of PFJt pain are multifactorial Dye (1996) asserts that patients with PFJt pain have symptoms because of physiologic overloading of normal PFJt anatomy. A successful treatment programme will restrict loading by staying within a patient's EoF allowing normal homeostasis to be restored. A successful outcome however is dependant on suitable treatment therapies (conservative and surgical) being provided as well as identification of predisposing and precipitating factors.

### **2.3 Relationship between foot function and PFJt mechanics**

In 1898 Von Beyer considered the importance of integrated function of the lower limb during weightbearing activities and introduced the concept of 'closed kinetic chain' (D'Amico, 1988). The lower kinetic chain is considered by Donatelli (1996) and others (Dananberg, 1986; Inman *et al.*, 1981) to include the spine, pelvis, hip, knee, ankle and foot. The last segment of this chain, the foot, is described as an intricate multi-articular structure that contributes significantly to the support and function of the lower limb (Leardini *et al.*, 2007). The foot functions as a *shock absorber* by attenuating the resulting forces at contact, a *mobile adapter*, accommodating to uneven ground, and finally a *rigid lever* for efficient propulsion. Pivotal to these functions is the foot's ability to coordinate the interdependent transverse plane rotations of the limb (Hamill *et al.*, 2004; Volger and Bojsen-Moller, 2000; Close *et al.*, 1967). The subtalar joint (STJt), which makes up the rearfoot, is the couple for this critical link and is related to the oblique triplanar orientation of the STJt axis. The axis of motion of the STJt extends from the lateral, plantar, posterior aspect of the calcaneus to the medial, dorsal, anterior portion of the foot. Mean reported values

suggest that the axis is angulated  $42^\circ$  from the transverse plane and  $16^\circ$  from the sagittal plane (Manter, 1941) (figure 2.7A). These values have been shown to vary between individuals (Nester, 1997; Kirby, 1989; Close *et al.*, 1967; Root *et al.*, 1966). Traditionally, it is thought that the orientation of the STJt axis is comparable to that of a mitred hinge which acts as a *torque converter* between the foot and rearfoot (Manter, 1941) (figure 2.7B). Lundberg *et al.* (1989) points out that more abduction and adduction occurs if the axis is positioned more perpendicular to the transverse plane, whilst greater inversion and eversion occurs if the axis is positioned more perpendicular to the sagittal plane. The obliquity of the STJt axis therefore influences the amount and direction of STJt motion, as well as motion proximal and distal to the joint (Razeghi and Batt, 2002; Nawoczenksi *et al.*, 1998).



**Figure 2.7: The axis of STJt (A) and 'torque conversion' (B).** Figure A shows the oblique orientation of the STJt, with an average inclination of  $42^\circ$  from the transverse plane and  $16^\circ$  from the sagittal plane. Figure B shows how internal tibial rotation produces pronation and how external tibial rotation produces supination. During pronation, the talus plantarflexes and adducts, the calcaneus everts and the height of the medial longitudinal arch (MLA) is reduced. The opposite occurs during supination, as the talus dorsiflexes and abducts, the calcaneus inverts increasing the height of the MLA.

Since the axis of the STJt is oblique, motion is described as triplanar, with coordinated motion occurring in the frontal, sagittal and transverse planes. Internal rotation of the limb is coupled with *pronation* of the STJt that is used to describe talar plantarflexion and adduction, and eversion of the calcaneus. External rotation of the limb results in *supination* of the STJt, which consists of dorsiflexion and abduction of the talus, and calcaneal inversion (Nester, 1997; Donatelli, 1996). Normal pronation of the STJt takes place during the first 30% of the gait cycle (Michaud, 1997; McPoil and Cornwall, 1996) with maximum calcaneus eversion ranging from  $8^\circ - 9^\circ$  (Dowdy

Youberg *et al.*, 2005; Toburn *et al.*, 1998; Pierrynowski and Smith, 1996). At this time the tibia rotates internally between 6° and 10° (Hamill *et al.*, 2004; Reischl *et al.*, 1999). The anterior tibiotalar ligament is thought to play a role in the transmission of internal limb rotation to the talus, whilst the posterior talotibial ligament contributes to the transfer of external limb rotation to the talus (Sarrafian, 1987; Huson *et al.*, 1986). In effect, the mechanism of torque conversion is reliant on the articulation and coupling behaviour of the distal tibio-fibular joint, motion of the talus, and triplanar talar motion on the calcaneus that is coordinated with rotation of the limb (Preece *et al.*, 2008; van den Bogert *et al.*, 1994; Lundberg and Svensson, 1993; Lundberg *et al.*, 1989).

The effects of the coupling behaviour of the foot and tibia have been demonstrated by a number of *in-vivo* and *in-vitro* studies. Rose (1962) examined the effects of the relationship in an *in-vivo* study by inserting steel rods into the anterior aspect of the tibia. The results demonstrated that internal rotation of the tibia reduced the height of the MLA, whilst external tibial rotation increased the height of the MLA (figure 2.7B). This supports the concept of a mitred hinge, which facilitates the conversion of motion between two planes. Using a custom made device which facilitated triplanar motions of leg-foot specimens Hintermann *et al.* (1994) showed a correlation between internal tibial rotation with foot pronation and external tibial rotation with foot supination. Lafortune *et al.* (1994) investigated the influence of footwear with lateral and medial wedges on the kinematic coupling of the entire extremity. Steinmann pins were inserted into 10 asymptomatic individuals to track the motion of the tibia and confirmed that the lateral and medial wedging resulted in the anticipated internal and external rotations of the lower limb. Whilst only small differences of 4° of internal tibial rotation were noted with the use of lateral versus medial wedged footwear, the study still offers support that the motion between the tibia and foot is interrelated. This study can be criticised since the author's failed to use markers to monitor foot function, therefore the effect of the wedge at foot level was unknown. In addition, recording foot function and footwear is limited since it obstructs the view of foot function. In an attempt to overcome this limitation Cornwall and McPoil (1996) devised a single '*tibial pointer*' to record rotation (2-dimensional analysis) of the tibia as an indicator of foot pronation in 8 symptom free individuals. Excellent correlations of 0.95 were noted between rearfoot eversion/inversion and tibial rotation. Gross and

Foxworth (2003) questioned the results of this study because the data was 'pooled' and the results failed to reflect the sample range of 0.52 and 0.96. Nevertheless, this study would seem to reinforce that frontal plane rearfoot motion and tibial rotation is associated; however the nature of this couple is variable.

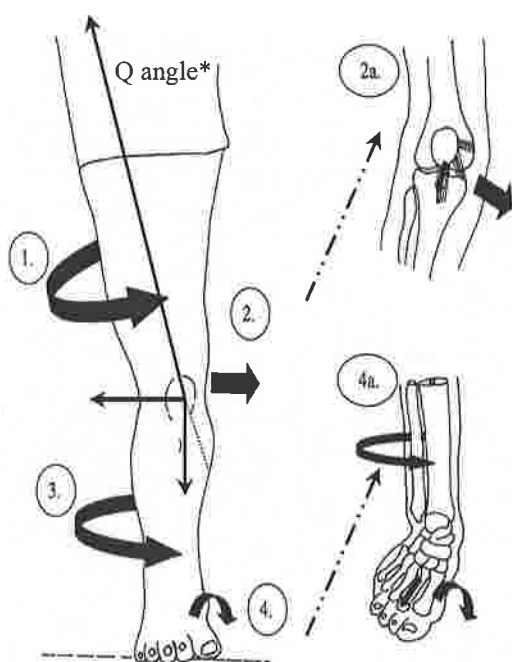
The associated variability of the relationship between the tibia and rearfoot probably originates from a range of anatomical factors (Nester, 2000; McPoil and Cornwall, 1996). These include variations in ankle and foot anatomy such as articular geometry, strength of ligaments and force of muscular contraction (Valderrabono *et al.*, 2003). More specifically, variations in the position of the STJt axis can also influence the amount of motion (Kirby, 1989; Green and Carol, 1983; Close *et al.*, 1967). Many of these variables however could be applied to various aspects of the human body and should not be restricted to the foot and lower limb. Reischl *et al.* (1999) used a 6 motion Vicon<sup>®</sup> system to investigate the coupled motions of the foot and lower limb. Inferiomedial motion was measured using dorsal foot reflective markers, whilst foot pronation was measured using frontal plane motion of the calcaneus (eversion) and 1<sup>st</sup> and 5<sup>th</sup> metatarsal head reflective markers. The results showed that peak pronation and timing was not correlated with timing and peak internal tibial rotation. The timing of peak tibial and femoral rotation however was correlated. These findings should be viewed with caution due to the methodology employed, as motion of all of the foot markers was required. Pronation at the STJt however, can occur without the 1<sup>st</sup> and/or 5<sup>th</sup> metatarsal moving during closed kinetic chain activity (Donatelli, 1996). Moreover, tibial rotation may take place even if the metatarsal head markers failed to move (Gross and Foxworth, 2003). These factors limit the author's conclusion that the relationship between lower limb rotations is not linked to foot pronation/function.

Whilst tibial and rearfoot function are related, the direction of the relationship has caused debate. Bellchamber and van den Bogert (2000) examined the direction of proximal and distal flow of lower limb motion during walking and running. Kinematic data was collected using 4 cameras (Motion Analysis Corporation<sup>®</sup>) which were placed around a Kistler force plate. Five reflective markers were positioned on the right tibia. A further 3 reflective markers were placed onto the foot. The results showed that during walking, the last 20% of stance phase '*motion-flow*' was

proximal-to-distal indicating that the femur was the primary source of tibial rotation. During running however, the results demonstrated that '*motion-flow*' was distal-to-proximal suggesting that the foot was the primary source of tibial rotation. These findings provide further support of the foot's (STJt's) ability to absorb and compensate for rotations of the lower limb that may enhance the understanding of the role of patella taping and foot orthoses in the treatment of PFJt pain.

### 2.3.1 Proposed mechanisms of association

Although foot pronation is considered a 'natural' triplanar motion it is considered abnormal if it occurs at the wrong time (i.e. foot fails to supinate when it should do), or if it is excessive. Abnormal pronation is described by Root *et al.* (1977) as compensation at the STJt for a range of lower limb malalignments. Eversion of the calcaneus of more than  $6^{\circ}$  –  $13^{\circ}$  is reserved for excessive or abnormal pronation (Johanson *et al.*, 1994; Eng and Pierrynowski, 1993). Since the foot acts as a torque converter that absorbs and transfers rotations of the lower limb in a coordinated manner, any change within this coordination will influence the functional link (Khamis and Yizhar, 2007). For example, abnormal foot pronation may precipitate or exacerbate symptoms associated with the PFJt (Grelsamer *et al.*, 1998) by prolonging/increasing internal tibial rotation. The relationship between abnormal foot function and PFJt mechanics is therefore based on two vital links – tibial and femoral rotation. To date a number of mechanisms have been proposed which focus on abnormal rotation of the tibia and femur, and the subsequent disruption to TFJt and PFJt function (figure 2.8). Each will be discussed in the following sections.



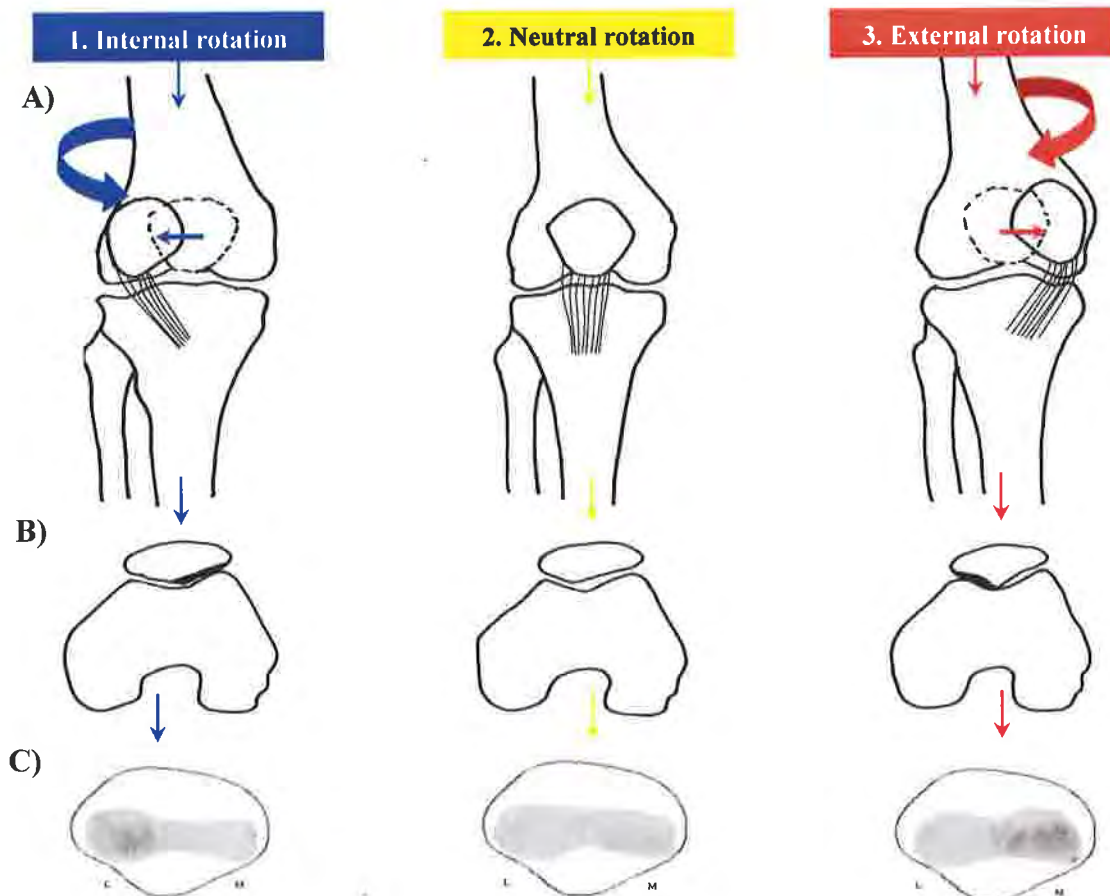
**Figure 2.8: Possible contributions of malalignment of the lower limb to PFJt pain.** 1. Internal femoral rotation; 2. Valgus angle at the knee (\*and an increased Q angle which increases the lateral directed forces); 3. internal tibial rotation; 4. abnormal foot pronation. Diagram 2a. shows the direct influence of these contributions at the knee. Specifically, force increases in certain soft tissue structures (e.g. medial patellofemoral ligament and patellar tendon) and contact pressures behind the patella. Diagram 4a. illustrates the characteristics of abnormal pronation.

### 2.3.2 The influence of femoral and tibial rotation on PFJt mechanics

Rotations of the femur and tibia and the effects on the PFJt are described as being distinctly different and can be supported by the work of Bellchamber and van den Bogert (2000) described earlier and by the work of Lee *et al.* (2003; 2001; 1994). This latter research group have described the influence of different primary motions on PFJt contact pressure distribution and point out the need for proper tibial and femoral alignment.

#### *Femoral rotation*

Femoral rotation is considered as being complex with the patella receiving combined forces from the femoral sulcus and the restraining mechanisms from the peripatellar retinaculum. These collective forces result in the motion of the patella on the femur to being translational (Lee *et al.*, 2003; Bull *et al.*, 2002). External rotation of the femur causes the medial part of the femoral sulcus to encroach against the medial articular facet of the patella. This motion is simultaneous with the rotation of the epicondyles of the femur which is the main attachment for the peripatellar retinaculum. This results in the patella being pulled in a lateral direction. The opposite happens for internal femoral rotation where the patella is pulled in a medial direction (Lee *et al.*, 2003). In their first paper, Lee *et al.* (1994) mounted 10 knee specimens on a custom made jig. Only small increases in the PFJt contact pressure were noted for fixed rotations of 0° – 20°. Femoral rotation of 20° – 30° however produced a significant increase in the contact pressures. Internal femoral rotation resulted in an increase on the lateral facet of the patella, whilst external rotation increased the contact pressure on the medial facet of the patella. They concluded that femoral rotation of 20° or more would compromise the mechanics of the PFJt. This is supported by recent *in-vitro* studies which have described values over 20° of femoral rotation (Powers *et al.*, 2002; Reischl *et al.*, 1999), which could be considered as a predisposing factor to PFJt pain (figure 2.9).



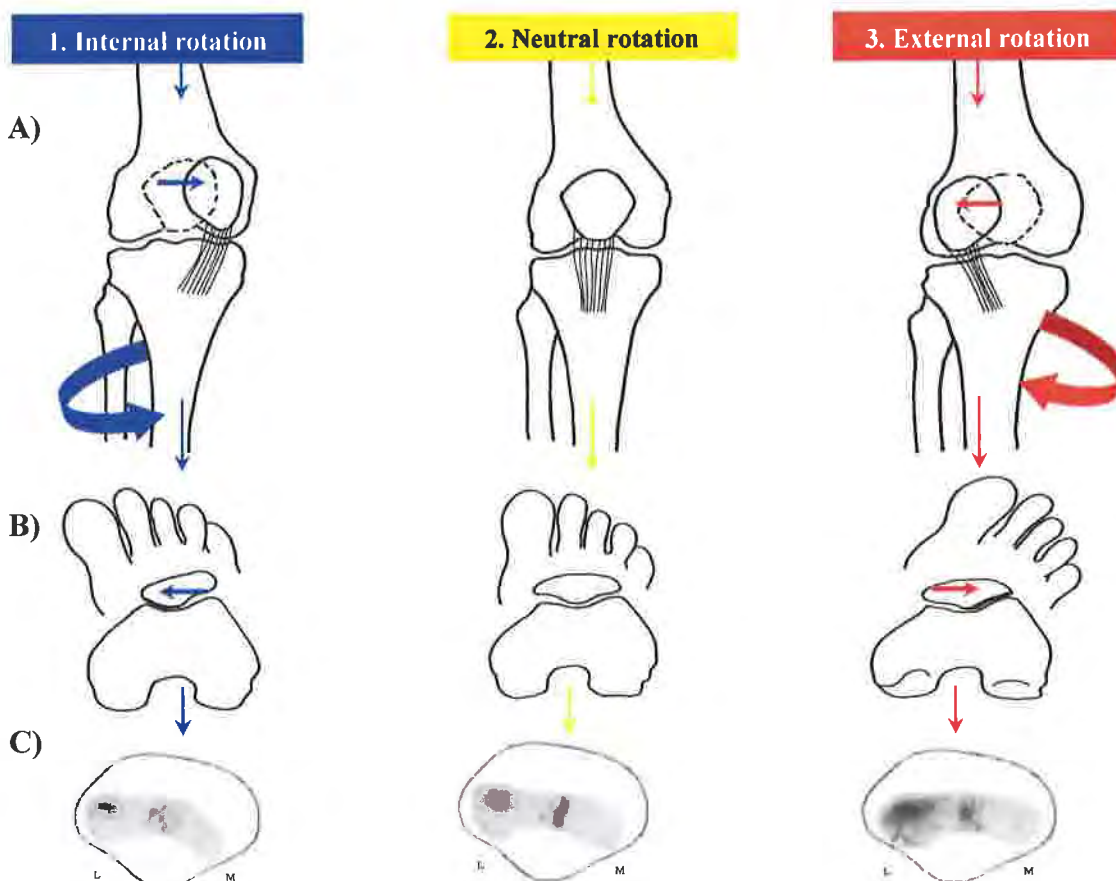
**Figure 2.9: Femoral rotation and its effect on the patella.** A) 1. *Internal rotation* causes the patella to move in a lateral direction which increases the contact and pressure on the lateral patella facet and femoral condyle (B and C). A) 2. *Neutral rotation* of the femurs results in equal contact and pressure distribution on patella facets and femoral condyles (C). A) 3. *External rotation* causes the patella to move medially which increases the contact of the medial patella facet and femoral condyle (B). The distribution of pressure results in higher loading of the lateral patella facet (C). Diagrams C - Lee *et al.* (2003, page 691) reproduced with permission of the Orthopaedic and Sports Physical Therapy Sections of the American Physical Therapy Association.

### *Tibial rotation*

Tibial rotation produces rotational motion of the patella and occurs because the patella is fixed to the tibia via the patellar tendon. Although the peripatellar retinaculum can be loaded during tibial rotation the net effect is less because the main attachment is at the femoral epicondyles. During internal rotation of the tibia, the tibial tubercle is positioned medially; the patellar tendon pulls from a medial direction on the distal pole of the patella. This causes the superior part of the patella to rotate laterally about an anteroposterior axis which is positioned close to the midpoint of the patella (Oatis, 2003). The reverse happens during external tibial rotation where the patella rotates medially. In their second paper Lee *et al* (2001) loaded six knee specimens onto a custom made jig and used Fuji pressure sensitive films to record the pressure and



contact areas within the PFJt. A neutral position of the tibia demonstrated moderate peak contact pressures for the lateral and medial patella facets. With the tibia fixed at 15° of external rotation, a significant increase in the peak contact pressures was noted in all ranges of flexion. The lateral patella facets also demonstrated increased pressures compared to medial facets. By comparison, at 15° of internal rotation the contact increased on the medial facet but only had a small effect on the peak contact pressures. These findings are supported by Ward *et al.* (2007) and Csintalan *et al.* (2002) who note that the largest increase occurred when the knee was near full extension. This supports clinical evidence that suggests that the PFJt is more vulnerable to instability and pain in this position (Salsich and Perman, 2007; Ward *et al.*, 2007; Post *et al.*, 2002; Hautamaa *et al.*, 1998) (figure 2.10).



**Figure 2.10: Tibial rotation and its effect on the patella.** A) 1. *Internal rotation* causes the patella to move medially which results in an increase in contact of the medial patella facet and femoral condyle (B). The distribution of pressure results in inferior loading of the medial patella facet (C). A) 2. *Neutral rotation* of the tibia causes equal contact and pressure distribution on patella facets and femoral condyles (C). A) 3. *External rotation* causes the patella to move laterally which increases the contact of the lateral patella facet and femoral condyle (B). The distribution of pressure results in higher loading of the lateral patella facet (C). Diagrams C - Lee *et al.* (2003, page 689) reproduced with permission of the Orthopaedic and Sports Physical Therapy Sections of the American Physical Therapy Association.



### 2.3.3 Abnormal foot pronation and PFJt mechanics

James (1979) was one of the first to recognise the link between abnormal pronation and PFJt mechanics and coined the term 'miserable malalignment'. He provided a list of factors that may produce '*excessive compensatory rotation*' of the tibia and commented that internal rotation of the tibia would alter the normal TFJt relationship and change the mechanics of the PFJt. James (1979) however did not detail the changes that may occur nor their effects on compressive forces at the PFJt. Similar discussions were presented by Larson (1979) and Paulos *et al.* (1980) who commented that internal femoral rotation and femoral anteversion caused the patella to be positioned medially which increased (laterally directed) the tension within the patellar tendon. Moreover, these authors stated further that during foot pronation there is external rotation of the tibia and extension of the knee. This statement however would appear to be erroneous since foot pronation causes internal rotation of the tibia and is likely to be due to an error in the terminology used. Buchbinder *et al.* (1979) offered the earliest anecdotal evidence and suggested that pronation beyond 25% of stance produced internal rotation of the lower limb at a time when it should be undergoing external rotation. This excessive internal rotation of the thigh and leg segments may be related to the patella being located medial to the proximal attachment of the RF and distal to the attachment of patellar tendon at the tibial tubercle altering PFJt mechanics.

In a discussion paper Tiberio (1987) agreed with the thoughts of Buchbinder *et al.* (1979), and advanced the model further. He suggested that in order to achieve extension of the knee during midstance, the tibia has to externally rotate on the femur, establishing the screw-home mechanism<sup>1</sup> of the TFJt. Since the foot is unable to resupinate due to abnormal pronation, he postulated that the femur would rotate internally on the tibia which makes the position of the tibia externally rotated. This internal compensation of the femur would theoretically initiate the screw-home mechanism. Tiberio's (1987) theory is supported by Sims and Cavanagh (1991) who used electromyography (EMG) to show that contraction of the quadriceps occurred before heel strike and continued through most of midstance. This increased

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<sup>1</sup> Screw-home mechanism occurs during the last 20° of knee extension and involves automatic rotation of the femur and tibia (TFJt) which provides stability to the lower limb.

quadriceps activity, abnormal foot pronation and secondary internal limb rotation could increase the compressive and shear forces at the PFJt.

An increase in internal femoral rotation is also thought to shift the patella in a medial direction, increasing the Q angle (Gross and Foxworth, 2003). The Q angle is formed by the connecting lines between the anterior superior iliac spine (ASIS), centre of the patella and tibial tuberosity and is used clinically to estimate the lateral pull of the quadriceps (Herrington and Nester, 2004; Livingston and Mandigo, 2003). Despite its widespread use its true clinical significance has come under scrutiny in recent years (Wilson, 2007; Livingston, 2002; Wilson and Kitsell, 2002). Lee *et al.* (2003) comments that an externally rotated tibia (coupled with foot supination), increased the Q angle, whilst an internally rotated tibia resulted in a reduction of the Q angle. This observation validates a statement offered by Powers (2003) who contended that abnormal pronation of the foot and the concomitant excessive internal rotation of the tibia would decrease the Q angle and the laterally directed forces acting on the patella. These comments conflict with several clinical studies that suggest that an increased Q angle is associated with abnormal pronation and tibial internal rotation. For example, Post *et al.* (2002) claim that due to the connection between the ligaments of the tibia and femur, the Q angle would not decrease with internal tibial rotation. They suggested further that internal rotation, either distal or proximal to the PFJt would increase the loading of the medial patellofemoral ligament and increase the lateral forces acting on the patella. Although STJt and tibial rotation are coupled the amount of rotation transmitted proximally to the knee and further up the kinetic chain is not clear. Using kinematic assessment, Nester (2000) examined transverse plane rotation of the tibia as an indicator of STJt pronation and supination in 20 healthy volunteers. Whilst this author recognised the limitations associated with skin mounted markers, no correlation was found between transverse plane rotation of the limb, hip and knee. To rationalise his findings Nester (2000) used the term 'lag' to describe the absorption of some of this limb rotation by the muscles, tendons, and ligaments at the knee. However, it is clear that many of the clinical studies reported in the literature are descriptive in nature and are based on anecdotal findings of case series which lacks scientific credibility. Rigorous examination of the link is therefore still required.

A number of studies have investigated the role of abnormal foot function in patients with PFJt pain. Messier *et al.* (1991) evaluated 36 runners (20 controls/16 PFJt pain) and found no significant differences for peak rearfoot motion. Similar findings were noted by Callaghan *et al.* (1994) however timings of peak eversion were significantly different between patients with PFJt pain. In another study using 3-dimensional motion analysis Powers *et al.* (2002) assessed 24 patients with PFJt pain and 17 controls during fast-selected and free-selected walking speeds. No significant differences were noted between the timing and amount of foot pronation and rotation of the tibia. However, the authors did note movement patterns of the tibia and femur previously described by Tiberio (1987) in a number of individuals. More recently, Levinger and Gilleard (2007) used a four camera motion system to determine the differences in tibia and rearfoot motion in patients with PFJt pain (13 females) and a control group (14 females). They found that patients with PFJt pain had significantly delayed peak eversion and early onset of peak dorsiflexion. No differences were noted between groups for transverse rotation of the tibia. Although these studies have focussed on kinematics, kinetics has also been investigated. The impact of forces at heel strike is considered to contribute lower limb pathology (Pohl *et al.*, 2008., Whittle, 1999; Collins and Whittle, 1989). For example, Duffey *et al.* (2000), Messier *et al.* (1991) and Levinger and Gilleard (2005) showed that patients with PFJt pain had a delayed and reduced loading of the rearfoot which was everted. This foot posture is thought to assist in shock absorption and also preserves the capacity of the quadriceps. Whilst this evidence does not provide conclusive support of a *cause-and-effect* relationship of abnormal pronation and PFJt pain, Powers (2003) does acknowledge that certain patients could present with abnormal foot pronation and lower limb rotations which may contribute to PFJt pain. This view seems to be supported by Levinger and Gilleard (2007, 2005), Gross and Foxworth (2003) and Post *et al.* (2002) as well as others (Rauh *et al.*, 2007; Fulkerson, 2002; Livingston and Spaulding, 2002; Cowan *et al.*, 1996; Tiberio, 1987) who recognise the importance of considering foot function and position in relation to PFJt alignment and pain.

#### **2.3.4 Frontal plane knee alignment and PFJt mechanics**

The terms *genu valgum* and *genu varum* are used to describe frontal plane alignment of the knee (TFJt). Genu valgum occurs when the angle of the distal portion of the

femur and proximal portion of the tibia opens laterally. Genu varum occurs when the angle opens medially (Oatis, 2003). Fujikawa *et al.* (1983a; 1983b) reported that genu valgum caused the contact pressures to increase on the lateral patella facet, whilst genu varum produced increased contact pressures on the medial patella facet. These findings are consistent with the work of Csintalan *et al.* (2002) and Lee *et al.* (2003; 2001; 1994). McClay and Manal (1998) investigated the association of abnormal foot pronation and an increased TFJt valgus angle using 3-dimensional kinematics. They concluded that the effect of this 'malalignment' profile is thought to be associated with an increase in the Q angle, and an increase in laterally directed forces acting on the patellar and quadriceps tendons. Further investigation of this alignment profile can contribute to further understanding of foot function and its relationship to PFJt alignment and pain.

#### **2.4 Foot orthoses and PFJt pain**

Foot orthoses have been used to successfully treat PFJt pain (Johnston and Gross, 2004; Saxena and Haddad, 2003; Bartold, 2001; Eng and Pierrynowski, 1993). Whilst the purpose of orthotic intervention varies between patients their use has been frequently described as being based on clinical observations (Razeghi and Batt, 2000). The basic biomechanical principle determining the success of a foot orthosis is based on altering foot function, which minimises the foot's ability to compensate. To date, studies which have used foot orthoses have shown a general reduction of pain ratings, improved satisfaction and improved function in patients with PFJt pain. Most of the studies presented in the literature however are all retrospective in nature and report successful satisfaction rates overall (Saxena and Haddad, 2003; Amell *et al.*, 2000; Gross *et al.*, 1991; Blake and Denton, 1985). Gross and Foxworth (2003) point out that this approach and its clinical application is often limited since they are dependant on the patient's memory of pain and symptoms weeks or months prior to data collection. In addition, as shown in table 2.1, all of these studies provided insufficient information concerning foot type and lower limb characteristics, details of foot orthosis fabrication, and the effects the foot orthoses had on symptoms and/or function. In contrast, other studies provide clear guidelines for describing participant's foot type characteristics for future studies (Johnston, 2001 cited in Gross and Foxworth, 2003; Eng and Pierrynowski, 1993) (table 2.1). Despite these limitations, evidence clearly suggests positive benefits on the use of foot orthoses for PFJt pain.

Table 2.1: Studies investigating the role of foot orthoses for PFJt pain. In all studies pain was measured before and after the use of foot orthoses (most recent to oldest).

Author (s)	Study type	Number / type of subjects / orthoses	Method of assessment / other information	Summary of results / outcome	Notes / limitations
Johnston and Gross (2004)	Repeated measures analysis of intervention	16 patients with PFJt pain and abnormal foot pronation.	WOMAC <sup>†††</sup> obtained at prior to, 2 weeks and 3-months after implementation of custom-made orthoses.	<ul style="list-style-type: none"> <li>Significant improvement at 2 weeks for pain and stiffness.</li> <li>All subscales of the WOMAC demonstrated significant improvement at 3-months compared to baseline recordings.</li> </ul>	Longitudinal arch angle and rearfoot angle were measures used to record foot type/posture. However, the WOMAC does not provide information, which relates to sporting activities/running this limits its sensitivity to assessing pain patterns in sports patients with PFJt pain.
Saxena and Haddad (2003)	Retrospective	102 patients (chondromalacia patellae; PFJt pain syndrome; PFJt retropatellar dysplasia) (custom made semi-flexible orthoses).	Lower extremity screening examination (e.g. Q angle, malalignment of knees, knee effusion, lateral retinaculum tightness, poor tracking of patella, crepitus of patella, foot type, limb length). Patients were asked to indicate if their symptoms were 'improved', 'no different', 'worse' or 'asymptomatic'.	<ul style="list-style-type: none"> <li>76.5% (78) patients had improvement in symptoms/pain. 2% (2) patients were asymptomatic.</li> <li>17 (16.7) of patients had no change whilst 1% (1) stated that their symptoms/pain were worse.</li> <li>11% (10.8) of patients required other forms of treatment.</li> </ul>	No information provided on patient's foot type or limb alignment despite these parameters recorded during screening. Subjectivity in response to pain (categorised) No information on the features of construction for the orthosis.
Johnston (2001 cited in Gross and Foxworth, 2003)	Interventional	15 patients with PFJt pain (> 2 months).	Patients also met a composite score of 200 or more out of 2400 for the WOMAC Osteoarthritis index <sup>†††</sup> . Measurement of pronation was defined using the rearfoot angle and longitudinal angle.	<ul style="list-style-type: none"> <li>Ratings of stiffness and pain were</li> </ul>	Limits of WOMAC as above.
Pitman and Jack (2000)	Intervention	57 patients with a PFJt pain (custom made orthoses).	Inclusion criteria: grade 3 knee pain (pain before, during and after exercise) grade 4 knee pain – unable to participate in exercise; a Q angle of >15° for females and >10° for males; "significant foot pronation at rest and/or during treadmill running". Questionnaire mailed 6-months after issue of orthosis.	<ul style="list-style-type: none"> <li>41% patients responded of which 38 were continuing to wear their orthoses.</li> <li>Mean reduction of pain was 67%.</li> </ul>	Author's calculations for pain the reduction of pain are uncertain since many of the responses were based on qualitative data. The author's did not define or state how they measured "significant pronation at rest and/or during treadmill running".

Table 2.1: Continued.

Author (s)	Study type	Number / type of subjects / orthoses	Method of assessment / other information	Summary of results / outcome	Notes / limitations
Amell <i>et al.</i> (2000)	Retrospective	21 patients with bilateral PFJt syndrome	<i>Questionnaire</i> employed to determine satisfaction with orthotic therapy. The <i>Likert</i> scale was used for patients to rate their improvement of their condition (0 = poor improvement; 3 = fair [50%] improvement; 5 = full improvement).	<ul style="list-style-type: none"> <li>85.7% of the 21 patients reported an improvement of 3 or greater; 47.6% reported an improvement of 4 or more; whilst 28.6% reported a full improvement (5); 14% indicated less than a fair improvement.</li> <li>80% of the total sample commented that '<i>...they would replace the orthotic if worn out or lost...</i>'</li> </ul>	Foot type characteristics were not reported. Clinical applicability is restricted since the study is dependant on the memory of patients of their condition months prior to data collection.
Way (1999)	Single subject design. (A-B-A-B) ††	One, 19-year old collegiate softball player unilateral PFJt pain (thermoplastic orthoses).	Pain was assessed using the Visual Analogue Scale (VAS); and the sections on daily living activities function, sports function and problem taken from the CINCINNATI KNEE RATING SYSTEM†.	<ul style="list-style-type: none"> <li>Significant improvement for the VAS and sections of the knee rating system for all phases of the study.</li> </ul>	Only one subject reported. Internal validity of study was increased due to the withdrawal and re-intervention of treatment.
Eng and Pierrynowski (1993)	Comparisons of two interventions	20 adolescent female patients with PFJt pain (Exercises and soft foot orthoses).	Following measurement recorded: forefoot varus / calcaneal valgus, Q angle, hours of activity. Random allocation of subjects into 2 groups, control group – isometric exercises only; treatment group exercises and soft foot orthotics. Subjects were monitored for 8 weeks; at 2-week intervals subjects completed VAS on 6 activities (walking, running, stairs ascent, stairs descent, 1 hour sitting and squatting).	<ul style="list-style-type: none"> <li>No significant differences between groups prior to commencement of treatment.</li> <li>Both groups demonstrated a significant reduction in symptoms, but this reduction was greater in the treatment group.</li> </ul>	Useful study however the inability to perform activities was not addressed 6 functional activities only recorded. Information provided on foot type and good general guidelines recognising the need to record and measure foot type.

Table 2.1: Continued.

Author (s)	Study type	Number / type of subjects / orthoses	Method of assessment / other information	Summary of results / outcome	Notes / limitations
Gross <i>et al.</i> (1991)	Survey	500 runners	<i>Questionnaire</i> Runners were questioned who were currently wearing or had used orthoses for lower extremity problems.	<ul style="list-style-type: none"> <li>12.6% of respondents reported that their orthoses were for patellofemoral joint pain.</li> <li>75% of these respondents commented that their pain had either greatly improved or resolved.</li> <li>90% of the runners reported that they still use their orthoses even though had no symptoms.</li> </ul>	The investigators failed to report whether other forms of treatment were used.
Blake and Denton (1985)	Retrospective	13 subjects with chondromalacia patellae (plastic rigid orthoses).	Patient selection was based on chronic pain (due to abnormal function) that had failed to respond to conservative treatment including foot orthoses; problems associated with biomechanical problems, such as severe pes planus or severe genu valgum. No evidence of measures performed.	<ul style="list-style-type: none"> <li>7 respondents reported that the orthoses were "definitely helpful".</li> <li>4 reported that they were of "some help".</li> <li>2 reported that they were of "not helpful".</li> </ul>	Inadequate information provided on patient's foot type/posture, activity levels, duration of pain/symptoms.
DeHaven <i>et al.</i> (1979)	Intervention	100 patients with chondromalacia patellae (soft and semi-flexible orthoses).	Clinical information was obtained and consisted of signs and symptoms of chondromalacia patellae (pain when at rest, and walking upstairs).	<ul style="list-style-type: none"> <li>82% success rate.</li> <li>18% failed to improve symptoms.</li> <li>8% required some form of surgical intervention.</li> </ul>	Limited conclusion. Treatment consisted of a combination of strengthening exercises, and knee braces as well as foot orthoses.

† CINCINNATI KNEE RATING SYSTEM represents a functional assessment of 6 important abilities for participation in sporting activities. The functional measures include,

1) Walking, 2) using stairs, 3) squatting and kneeling 4) straight running, 5) jumping and landing, and 6) hard twists and pivots. A maximum total of 420 points are available whilst a minimum score is 120. For each ability 40 points are awarded for unlimited/fully competitive; 30 points for some limitation of activities; 20 points for definite limitations and 0 points for an inability to perform activities (Barber-Westin and Noyes, 1999; Noyes *et al.*, 1989).

†† A-B-A-B – intervention phase, withdrawal phase and re-intervention phase.

††† WOMAC™ (Western Ontario and McMaster Osteoarthritis) Index or scale was developed in 1982 and measures disability, pain and joint stiffness associated with osteoarthritis of the hip and knee. This self-administered questionnaire contains a battery of 24 questions and assesses 17 functional activities, 5 pain related activities and 2 stiffness categories (Wolfe, 1999; Bellamy *et al.*, 1988).

#### **2.4.1 Foot orthoses, lower limb structure and function and PFJt mechanics**

Although the actual mechanism of how foot orthoses work is not entirely understood, a number of studies have demonstrated their ability to modify the kinematic behaviour of the lower limb during walking and running (Stacoff *et al.*, 2007; Cheung *et al.*, 2006; McPoil and Cornwall, 2000; Nawoczenksi *et al.*, 1998). Reports suggest that foot orthoses may exert a number of influences on rearfoot function such as reducing maximum pronation (Stacoff *et al.*, 2007; Nigg and Morlock, 1987; Taunton *et al.*, 1985), maximum pronation velocity (Taunton *et al.*, 1985; Claeys, 1983), decreasing the time to maximum pronation (Bates *et al.*, 1979) and total motion of the rearfoot (Novick and Kelley, 1990; Bates *et al.*, 1979). Using 3-dimensional analysis, Nawoczenksi *et al.* (1995) examined the effect of foot orthoses on rearfoot and leg kinematics. Twenty recreational runners with high or low arched feet were instructed to run wearing TEVA sports sandals (Flagstaff, AZ) with and without semi-rigid custom made orthoses. Whilst information on participant's foot characteristics and the construction of the orthosis posting were not reported, it was shown that maximum internal limb rotation was reduced by 2°. This reduction equated with a 31% reduction of internal limb rotation from heel strike to maximum internal limb rotation during the stance phase of running. These findings are supported by the work of McPoil and Cornwall (2000) who showed that soft and rigid pre-moulded foot orthoses significantly decreased the acceleration and magnitude of internal rotation of the leg when walking. However, no significant differences between the two sets of orthoses which challenges the notion of motion control as the fundamental mechanism of action.

As well as investigating outcomes in 10 female adolescent patients with PFJt pain, Eng and Pierrynowski (1993) also postulated that soft orthoses were beneficial by altering frontal and transverse plane rotations of the foot and ankle during treadmill walking and running. Markers were fixed onto the footwear to monitor motion of the lower leg and foot. Based on the screening assessment that identified a forefoot varus or rearfoot valgus of  $>6^\circ$ , all of the foot orthoses were posted medially. The orthosis produced a reduction of  $1^\circ - 3^\circ$  in the frontal and transverse plane rotations of the foot and ankle during the contact and midstance phases of walking. Frontal plane motion of the knee was also reduced during the contact and midstance phases of walking, although this motion increased during running. Eng and Pierrynowski (1993) propose



that a decrease in foot and leg motion of more than  $2.5^{\circ}$  requires the transmission of motion at the knee to be greater to achieve forward progression. These thoughts are similar to the 'lag concept' previously discussed (Nester, 2000).

In an attempt to examine the influence of foot orthoses on the Q angle, D'Amico and Rubin (1986) investigated 21 participants. Whilst all participants met the criteria that they had been wearing foot orthoses before the study began, the authors did not state the reasons why these individuals were receiving orthotic therapy and they failed to detail foot characteristics. Information on the construction and materials of the orthoses were also not provided, although the authors did state that the participants were wearing a wide range of foot orthoses. The standing Q angle was measured bilaterally using a standard goniometer. The Q angle was  $6^{\circ}$  less with the orthoses compared to that without the orthoses. In addition, 92% of the participants had a bilateral reduction in the Q angle standing with the foot orthoses. Despite these results the authors did not report the reliability of the measures or state whether each participant was in their own natural angle and base of gait. Nevertheless, this study suggests that foot orthoses may decrease the Q angle by reducing internal limb rotation thus reducing the laterally directed forces occurring at the PFJt. These findings are also supported by Nawoczenski *et al.* (1995) and McPoil and Cornwall (2000) who have conducted similar studies.

#### *Foot orthoses and PFJt mechanics*

Only 2 studies have documented the influence of an orthosis on the position of the patella, both of which used radiographs as a mean of analysis. During unilateral weightbearing, Klingman *et al.* (1997) assessed the influence of a medial wedge orthosis on the position of the patella in 10 healthy volunteers. Axial views of the PFJt were obtained with the orthosis and without (barefoot). The results revealed that the foot orthoses caused the patella to be displaced medially by 1.08 mm (standard deviation [SD] 0.52) relative to the femoral sulcus. Although all of the participants demonstrated evidence of abnormal pronation ( $>6^{\circ}$  of calcaneus eversion), it is not known if these results would be similar to patients with PFJt pain or if the displacement would be enough to increase the tension within the peripatellar retinaculum. In addition, it is questionable if patients could tolerate the standing

unilateral position (due to pain factor) and if footwear would have an effect on the position of the patella.

As well as assessing pain and function, Johnston (2001 cited in Gross and Foxworth, 2003) challenged some of the issues of Klingman *et al.*'s (1997) study by investigating the influence of custom made foot orthoses in 15 patients with PFJt pain. Each patient was asked to perform a unilateral squat to 70° of knee flexion. An axial radiograph was obtained during three different standing conditions; standing barefoot, standing with footwear, and standing with footwear and orthoses. No significant differences were noted in medial-lateral displacement of the patella for all 3 conditions. Johnston (2001 cited in Gross and Foxworth, 2003) believed that since the knee was flexed to 70°, the orthoses may only influence the patella's position at smaller ranges of flexion before the patella is stabilised within the femoral sulcus. This assumption is also supported by Ward *et al.* (2007) who comment that clinical examination and imaging of the PFJt should be undertaken with full knee extension. Whilst it is clear that foot orthoses can help reduce the Q angle for example, its approach is similar to other treatment interventions such as patella taping, VMO exercises and surgical intervention (i.e. Elmslie-Trillat procedure) (Ng *et al.*, 2008; Fulkerson, 2002) which attempts to re-align the PFJt.

Whilst MRI, radiography and other forms of imaging are thought to provide detailed information on the PFJt, a number of reports suggest that these findings do not directly correlate with functional restrictions and symptoms of PFJt pain (Bolga *et al.*, 2008; Wilson, 2007; Grelsamer, 2005; Powers *et al.*, 2003). For example, Gross and Foxworth (2003), Grabiner *et al.* (1994) and Maffulli (1993) suggest that pain and functional restrictions can be affected by the contact pressures of the PFJt as well as pressures transferred via the patella's articular cartilage to the neural subchondral bone. Post *et al.* (2002) and others (Grelsamer *et al.*, 2005; Brody and Thein, 1998; Grelsamer and Klein, 1998) comment that whilst 2 PFJt's may demonstrate similarities in their position on an MRI, the contact pressures and patterns may be very different. These variations can be explained by the forces from the soft tissues acting on both PFJts. The work of Huberti *et al.* (1984) can be used to illustrate this point by reporting the influence of the Q angle on the contact pressures of the PFJt. Using pressure sensitive film and 12 cadaveric specimens, they showed that a 10°

increase in the Q angle resulted in an increase in peak contact pressures of the PFJt. Twenty degrees of knee flexion also produced a 45% increase in PFJt contact pressures. In contrast a reduction in the Q angle produced a reduction in the lateral contact pressures of the PFJt and unloading of the retropatellar surface. The increase in PFJt contact pressure is interesting for the aetiology of PFJt pain and the role of abnormal pronation. For example, chronic foot pronation and a mildly flexed knee could produce pressures, by increasing the PFJt reaction force which could lead to subchondral sclerosis.

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## 2.5 Summary of chapter

- The PFJt is a complex joint and research supports the need for alignment of osseous and soft tissue structures for normal function;
  - Studies have shown the PFJt to be vulnerable to injury and reveal PFJt pain to be a common problem worldwide;
  - Whilst PFJt pain is complex, the EoF may offer an insight to variances such as malalignment;
  - Recent biomechanical research has concentrated on the effects of limb rotation on patella contact pressures and areas;
  - Studies show that abnormal foot function and lower limb rotation are linked as a cause of PFJt pain because foot orthoses improve symptoms. However, the scientific explanation for this relationship is still lacking;
  - Clinical and scientific evidence is reliant on measures that are able to link foot posture and PFJt alignment and will be explored in chapter 3.
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Sections 2.1 and 2.2 of this chapter were published as a review article in the *British Journal of Podiatry* (Curran *et al.*, 2006b).

## Chapter 3

### Identifying optimal measures for clinical observational inquiry

Having discussed the characteristics of PFJt function and its relation to normal and abnormal foot function in chapter 2, chapter 3 aims to consider and critically review the currently available clinical methods of PFJt alignment and foot posture. A set of rationalised criteria are proposed and the practical applications, strengths and limitations of these measures are objectively discussed and evaluated to investigate their suitability for use in clinical observational inquiry. This allowed the optimal measures to be identified together with ideas for validation. In particular, emphasis is placed on the value of establishing functional significance using plantar pressure measurement.

#### 3.1 Principles of clinical measurement

Identification of the true relationship between foot posture and PFJt alignment demands accurate measurement techniques. There are a number of techniques which can be used to examine PFJt alignment and foot posture (Cornwall *et al.*, 2008; Herrington, 2008; Herrington and Pearson., 2008; Billis *et al.*, 2007; Wilson, 2007; Razeghi and Batt, 2002). Although imaging techniques such as radiographs, computed tomography (CT), MRI, and ultrasound can be described as objective, reliable and valid because they offer a detailed insight into the geometry of a joint, they have a number of limitations for use in clinical observational inquiry. For example, many of these techniques are not always accessible to primary clinicians and their sophistication means they are costly and time consuming. In addition, they often require a range of health professionals to perform, interpret and analyse the data produced (Davies *et al.*, 2002; Post *et al.*, 2002; Post, 1996). These limitations have led to the development of simple, cost effective, easy-to-use clinical methods for measuring PFJt alignment and foot posture within the everyday clinical setting that can direct the clinician to further investigation. These methods are generally based on external anatomical bony landmarks and are thought to indicate, for example how the patella tracks and aligns and predicts how the foot functions.

#### 3.2 The criteria for the optimal PFJt alignment and foot posture measures

Methods of measuring PFJt alignment and foot posture should be based on their fitness-for-purpose. The qualities that define the ideal measures provide a benchmark or standard for the existing measures to be examined. This is however dependant on

the context of use. For example measures which are simple, practical and inexpensive are useful for clinical observational inquiry where large numbers of participants are required. In contrast, measures that are complex and expensive are more suited to laboratory based research where a small number of participants are recruited. The key dimensions characterising optimal measures for clinical observational inquiry can be devised by taking into account published research that considers the concepts of reliability and validity and from published clinical literature that presents the practical issues such as clinical efficacy.

### **3.2.1 Key dimensions characterising 'optimal'**

#### *Reliability and validity*

The optimal measures of PFJt alignment and foot posture should satisfy conditions of reliability and of validity. For example, in one report Arno (1990) commented on the need to provide reliable, valid and robust clinical methods of PFJt alignment, whilst Watson *et al.* (1999b) stated that “...a reliable and valid clinical measure of static patellar position is needed to help guide treatment for patellofemoral pain syndrome...”(page 379). The term *reliability* refers to the repeatability, consistency and precision of measures (Durward *et al.*, 2001a) and is considered by Wainer (2003) as “...a continuum and not an action potential (all or none)...” (page 488). Measures must however achieve acceptable reliability and are reported in the literature using descriptive terms such as ‘excellent’ and ‘good’. These relative terms are supported by the standard error of measurement (SEM) which provides information on the amount of error (i.e degrees) associated with the measurement. The SEM provides information on the absolute reliability of a measure and is considered as being clinically relevant (Daly and Bourke, 2000). Although a measure should be viewed on an individual basis and within the condition of its proposed use, measures which are not reliable will compromise validity (Portney and Watkins, 2003).

Validity is described as being more complex than reliability and refers to the nature and meaning of the variables measured (Bowling, 2004; Rothstein, 2001). There are a number of different forms of validity of which 4 of the most important types are briefly discussed. The simplest form of validity is *face validity* and is concerned with the apparent suitability of a measure upon initial inspection. If an instrument seems to measure what it is thought to, then on the face of it, it seems to be valid. Simple and

superficial in context face validity is considered the weakest type of validity (Durward *et al.*, 2001a; Polgar and Thomas, 2000). *Content validity* is more systematic than face validity and determines if separate aspects of the variable are being measured. If a number of dimensions have been identified to a particular variable and the instrument is able to assess each individually, the content is considered valid (Gass, 2004). *Criterion validity* investigates the relationship of one measure with the results of a gold standard measure already in use (Redmond *et al.*, 2002). If both sets of results are correlated then a critical criterion is satisfied. However, in some instances, there is no gold standard measure available and instead a 'proxy measure' is used (Bowling, 2004). *Predictive validity* is a subtype of criterion validity and is used to describe a measure's ability to predict changes in key variables in an expected direction (Gass, 2004). Lastly, *construct validity* examines the correlation between the instrument and the hypothesis it ought to measure. This is particularly relevant to the clinical outcome process such as patient prognosis (Wilkin *et al.*, 1992) which serves as a critical dimension of validity allowing the usefulness of the measurement to be tested. The optimal measures of PFJt alignment and foot posture should satisfy conditions of reliability and key dimensions of validity.

#### *Clinical efficacy*

Other key dimensions which require consideration relate to a standardised weightbearing approach to reflect functional position. This is supported by Gamble and Yale (1975) who suggest that during clinical and radiographic examination "...great care should exercised on posing the patient in his natural base and angle of stance because this position coincides within acceptable limits with foot position during the midstance phase of walking gait..."(page 71). This view is shared by Perlman *et al.* (1996) and Bryant (2001) who add that this position represents a standardised approach for establishing a natural stance position as opposed to a contrived stance position. Another key dimension for the optimal measure is its ability to predict and relate to the clinical diagnosis, prognosis and evaluation of the treatment intervention. Ethical issues and the ability of the measure to be used and communicated between health professionals are also key dimensions. Perhaps most importantly however is the need to consider how amenable the measurement is to learn and carry out; it's clinical usefulness and financial implications (Durward *et al.*, 2001b).

The key dimensions offer a base from which to develop set criteria for examining existing PFJt alignment and foot posture measures and are presented in table 3.1. The set of criteria provides a systematic approach to investigating the relationship between foot posture and PFJt alignment. It also recognises the need for a battery of clinical measures to be identified as no single measure can assess foot posture and PFJt alignment in a comprehensive manner (Sanner, 1998). Whilst all measures have inherent weaknesses and strengths, investigation is justified with an important concept being that the selected measures are influenced by the functional behaviour of the foot. Examples of categories of PFJt alignment and foot posture measures useful for clinical inquiry will now be presented and assessed against the criteria set. Imaging techniques (i.e MRI, CT) for PFJt alignment and foot posture will be excluded from this discussion because of the limitations outlined earlier in this chapter.

Key dimension	Specific comments/details
1. Reliability	Reliability (intrarater and interrater) of PFJt alignment and foot posture measures must be established.
2. Validity	<p>Validity must be established at different stages:</p> <ul style="list-style-type: none"> <li>▪ <i>Face validity</i> must be fulfilled. Measure (s) must be based on important aspects of PFJt alignment and foot posture and have significance to the clinician, the patient and researcher.</li> <li>▪ <i>Content validity</i> must be fulfilled. Consideration of the various aspects that are linked to PFJt alignment and foot posture must be identified.</li> <li>▪ <i>Predictive validity</i> must be fulfilled. Measures must have the capability to show a relationship which is clinically and functionally relevant. For example, PFJt alignment measures must respond to changes in foot posture (functional significance).</li> </ul> <p>Measures that are proven valid will help to reveal the complex link between foot posture and PFJt alignment.</p>
<i>Clinical efficacy</i> 3. Standardisation	A standardised approach to obtaining and recording the measures (PFJt alignment and foot posture) must be established.
4. Weightbearing measures	Although static in nature, all measures should be obtained in a double-limb stance position to simulate functional appearance. This position must also have the capability of evaluating PFJt alignment and foot posture at the same time.
5. Ethical issues	All measures must be ethical and not expose individuals to harmful radiation etc.
6. Financial issues	To allow large number of data to be collected, all measures must be inexpensive to perform.
7. Clinical application	<p>Clinical application to clinicians, researchers and patient requires consideration. The measure therefore should be simple to perform using accessible equipment (i.e. goniometers, rulers) and be diverse enough to be used in various locations.</p> <p>Measures must have potential to contribute to clinical practice.</p>

Table 3.1: Proposed criteria (7-item) for establishing optimal measures for clinical observational inquiry.

### 3.3 Measuring PFJt alignment

Clinical techniques focussing on patella position and related bony structures attempt to evaluate the underlying bony structure which determines PFJt alignment (Herrington, 2008; Wilson, 2007; Post *et al.*, 2002). The Q angle, A angle and tubercle sulcus (TS) angle are common clinical goniometric methods employed for evaluating alignment of the PFJt.

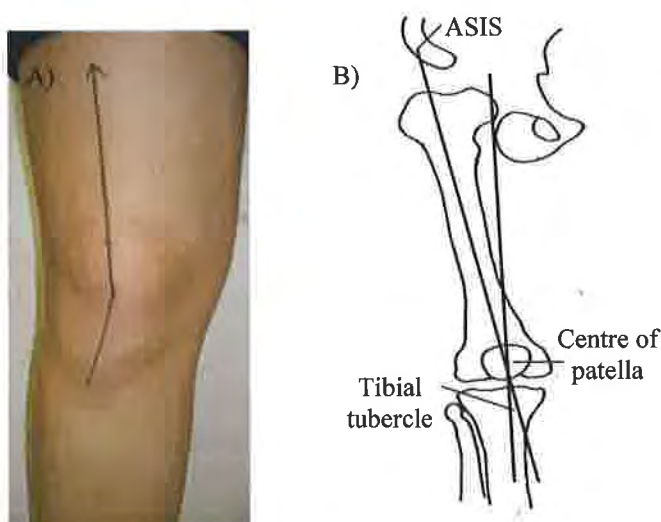
#### 3.3.1 Q angle

The Q angle is perhaps the most researched and popular clinical measure employed to assess PFJt alignment. Although the Q angle was originally reported by Brattstrom (1964) it was the method described by Insall *et al.* (1976) which became the most common and accepted technique. The Q angle is created by connecting lines joining the anterior superior iliac spine (ASIS), centre of the patella and tibial tubercle (Livingston and Mandigo, 2003) (figure 3.1). It is thought to provide a reasonable approximation of the resultant force vector acting on the patella during contraction of the quadriceps and patellar tendon (Grana and Kriegshauser, 1985). Whilst Q angles of more than 15° – 20° are alleged to contribute to PFJt pain (Post, 2005; Schamberger, 2002), values as low as 10° – 14° have also been implicated as being problematic (Caylor *et al.*, 1993; Hvid and Anderson, 1982). Normal Q angle values in healthy individuals range from 11° – 22°, with greater values recorded in females compared to males (Herrington and Nester, 2004; Woodland and Francis, 1992; Horton and Hall, 1989). This general lack of consensus as to what constitutes a 'normal' Q angle and the inability to consistently relate abnormal angles to PFJt pain have increased the uncertainty about the diagnostic value the Q angle provides (Livingston and Mandigo, 1999; Horton and Hall, 1989). These inconsistencies have been directed towards key areas and relate to measurement protocols, such as positioning of the subject, reliability and validity of the technique.

Although the bony landmarks for measuring the Q angle are standard and can be palpated with relative ease the protocols used to measure the Q angle are not. The original goniometric supine method adopted by Insall (1976) is a common method used by orthopaedic surgeons and requires the knee to be extended and quadriceps relaxed. Other health care professionals however prefer to measure the Q angle in situations that represent the functional position of the lower extremity (Livingston,



1998; Lattanza *et al.*, 1988) and recognise the need to develop protocols that are accurate, reliable and more likely to reflect functional orientation (Guerra *et al.*, 1994). This justifies the need for a change in traditional measurement protocols. Standing Q angles are reported to be higher when compared to a supine method (table 3.2). More specifically, studies have recorded the Q angle with individuals standing with 1) the knee fully extended, 2) standing with the knee flexed, and 3) with the quadriceps contracted (Herrington and Nester, 2004; Livingston and Spaulding, 2002; Woodland and Francis, 1992). The Q angle is at its maximum when the knee is fully extended and is due to the 'screw home' mechanism (Yormak and Scuderi, 1995).



**Figure 3.1: Clinical (A) and schematic (B) representation of the Q angle.**

The actual foot position, whether pronated, supinated, abducted or adducted are also other factors, which may influence the Q angle (Livingston and Spaulding, 2002; Livingston, 1998) (tables 3.2 and 3.3). A photographic study by Olreud and Berg (1984) examined the influence of foot position on the Q angle and revealed an increase in the Q angle when the foot was pronated and decreased when the foot supinated. Whilst this was a useful simple study, the paper lacked clarity and detail of the methodology used. For example, the authors failed to include the actual data and present descriptive statistics. The results only detailed if the Q angle increased or decreased with various foot positions. Only one limb was measured and it is uncertain whether it was the right or left limb. This is an important issue since evidence now indicates that Q angles can be asymmetric, even in normal healthy individuals (Livingston and Mandigo, 1999; Livingston and Mandigo, 1997). The authors also failed to report if the non-measured limb was held in the same position as

the limb being measured or if it were placed in a natural position. Furthermore, the rotational positions of the foot were only descriptive in terms of the longitudinal axis of the foot and it is unclear whether the distance between each heel centre was considered. These factors limit the ability to reproduce the method. Finally, the 3 positions used, 0°, 15° external rotation and 15° internal rotation differed significantly from that reported as an average natural or preferred stance position (7° external/abducted). More recently Livingston and Spaulding (2002) used the OPTOTRAK motion measurement system to assess the changes of the Q angle in relation to foot position. Light-emitting diodes were placed on both ASIS; centre of patellae's and tibial tuberosities and the sampling rate of the OPTOTRAK was set at 60Hz. Whilst their results are similar to that of Olreud and Berg (1984) their study overall is more robust, since they present appropriate data and describe their methods adequately. They found that the Q angle significantly differed ( $p < .001$ ) with various foot positions, increasing as the foot internally rotated and decreasing as the foot externally rotated. Although these results support the need to standardise and record foot position when examining the Q angle, this study only considered external and internal positions of the foot and not triplanar foot positions such as pronation and supination. It is clearly vital to standardise the foot posture and limb alignment.

Although the universal goniometer appears to be the preferred instrument for recording the Q angle, goniometer size seems to vary. Some authors have used an extended arm to align with the ASIS; others have used a string fixed to the centre of the goniometer, while others simply envisage a line that extends from a standard proximal arm of the goniometer to the ASIS. These methods in themselves have inherent flaws. For example, errors associated with the string may come from it not being tightly anchored to the ASIS, falsely increasing or decreasing the Q angle. In addition, alignment of the extended arm of goniometer to the position identified on the ASIS may move when recording the Q angle, affecting the value. This potential error could be reduced by fixing the top end of the goniometer to the ASIS enabling focus of the alignment on the anterior aspect of the knee. Table 3.3 demonstrates the inconsistency of the methods used and highlight the problem of similar Q angle values in asymptomatic individuals and patients with PFJt pain. A reasonable step forward for this latter problem would be to consider the thoughts of Downs and Bleibtrau (1972) who proposed that it might be more helpful to identify the range of normal

limits of variation, in this case the Q angle, instead of considering the deviation of the angle or pathology. Whilst further investigation is needed, it is important that a standardised protocol be developed.

Tomsich *et al.* (1996) assessed the reliability of the Q angle using 3 examiners and 27 healthy subjects. Intraclass correlation coefficients (ICC) values of 0.63 and 0.23 were reported for intrarater and interrater reliability respectively. The intrarater SEM was 2.7° whilst the interrater SEM was slightly higher at 3.7°. Although the position of the femur was standardised (by a KT100 system), the position of the foot or tibia was not considered. Placement of the foot may have varied from one measurement to the next affecting the rotation of the tibia either causing a lateral or medial shift of the tibial tubercle and increasing or decreasing the Q angle respectively (Ando *et al.*, 1993; Insall, 1982; Insall *et al.*, 1976). Although not discussed by the authors, a further limitation of this study could be the use of the string used to align the ASIS to the centre of the patella as discussed previously. Greene *et al.* (2001) also investigated the intrarater and interrater reliability of the Q angle. Twenty five individuals with different levels of training served as participants and examiners, as each individual measured the other 24 participants. The clinical method was also compared to a radiographic measurement. ICCs ranged from 0.14 – 0.37 for reliability whilst ICC values between the clinical and radiographic measures ranged from 0.13 – 0.32. These results suggest that the reliability of the Q angle is poor and questions its use within the clinical situation. Flaws within the methodology of the study may have compromised the measurement process. No clear instructions were provided for each examiner, the goniometer used did not have an extended arm and the level of training each individual had received differed. Before their data collection of 526 individuals, Woodland and Francis (1992) investigated the intrarater reliability of the right Q angle on 15 participants. The Pearson's *r* for the standing position was 0.76 and 0.81 for the supine position indicating good-to-excellent reliability. Livingston and Spaulding (2002) conducted a preliminary investigation of the intrarater reliability of the Q angle using the Romberg position<sup>2</sup> on 2 occasions, 1 week apart. Excellent reliability was noted with an ICC of 0.97 and an SEM of 1.4°. Recording and

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<sup>2</sup> Romberg's position is achieved when standing with both feet together and hands by sides.

standardising the foot position may help to increase the consistency of the Q angle and should be an area of focus for future studies.

The role of soft tissue displacement and markers used to identify the anatomical landmarks contribute to the limitation of the measurement. France and Nester (2001) noted that an error between 1 and 5mm for the medial and lateral location of the patella changed the Q angle between  $1.02^{\circ}$  and  $5.18^{\circ}$ . Wilson and Kitsell (2002) questioned whether the Q angle was an absolute or variable measure. Using video motion analysis they measured the Q angle over a 1 minute period in 51 normal subjects and noted that the Q angle varied on average  $3.12^{\circ}$  ( $1.46^{\circ} - 6.97^{\circ}$ ) had a repeatability coefficient of  $3.4^{\circ}$ . The authors concluded that the Q angle should not be considered an absolute measure, but one that changes constantly. They also suggested that the Q angle is not a definitive measure but rather a picture at that moment in time of the person's Q angle inside a known range. Whilst this may represent a limitation, put into context, this approach is logical and can be extended to any clinical measure. However, what is clear from discussion here is the need for the Q angle protocol to be standardised. For example, the protocol should record standing foot position, posture and finally the Q angle. This will allow for the true differences of Q angle values to be examined from study to study instead of the value being distorted, biased and confounded by the method employed.

Table 3.2: Various methods and reported normal Q-angles obtained from a supine and standing position (most recent to oldest) (F = females, M = male).

Author (s)	Subjects	Age (Mean/range)	Method (s) used	Foot Position	Limb	Q angle° (Mean ± SD)	Comment
(Rauh <i>et al.</i> , 2007)	393 total (F: 171 / M: 222)	15.6 / 13 - 19	Standing position. Standard goniometer with lengthened proximal arm. Quadriceps relaxed.	Feet shoulder width apart, facing anteriorly.	Both limbs measured.	Categorised: <10° 10° to 15° 15° - 20° >20°	Categories were devised to establish the Q angle as a risk factor for injury in cross-country runners. Study is limited as natural stance was not used. No information provided on foot posture.
(Herrington and Nester, 2004)	109 total (F: 58 / M: 51)	21.7 / 18 - 31	Standing position. Digital photograph (symmetrical expansion & printed onto A4 sheet. Lines then drawn for angle)	Standardise d. Mid heel and 2 <sup>nd</sup> digit aligned/perpendicular to frontal plane.	Left Right Left Right	M: 11.6±5.2 M: 11.3±4.9 F: 14.4±5.2 F: 13.3±5.5	Although foot position was standardised it fails to represent a natural stance position.
(Markeas <i>et al.</i> , 2003)	M: 1017 F: 938	Not stated / 7 - 12	Not specified	Not considered	Left M: 7-8 Right M: 7-8 Left F: 7-8 Right: 7-8 Left M: 9-10 Right M: 9-10 Left F: 9-10 Right F: 9-10 Left M: 11-12 Right M: 11-12 Left F: 11-12 Right F: 11-12	11.30 ± 7.4 11.52 ± 7.4 11.05 ± 7.2 11.20 ± 6.9 11.30 ± 7.8 11.38 ± 7.2 11.02 ± 7.7 11.51 ± 7.1 11.72 ± 8.8 11.56 ± 8.3 11.87 ± 8.3 12.06 ± 8.4	This epidemiological study provides useful yet limited information. No details were provided on how they obtained the Q-angle.
(Livingston and Spaulding, 2002)	20 total (F: 14 / M: 6)	22.1 / 19 - 30	Standing position with both knees fully extended. OPTOTRAK system (Northern Digital Inc, Waterloo, ON, Canada) Light emitting diodes were placed on the ASIS, centre of patella and tibial tubercle.	Self Select Self Select Preferred Preferred Romberg Romberg	Right Left Right Left Right Left	14.4 ± 3.0 11.4 ± 7.2 11.0 ± 6.4 7.2 ± 7.8 16.1 ± 6.2 12.7 ± 7.7	This study seems to validate the concept of the effects of foot position on the Q angle and recognises the need to standardise the position of the foot.
(Livingston and Mandigo, 1999)	50 total (F: 24 / M: 26)	F: 24.2 M: 27.6	Standing position. Goniometer (standard). Both knees were extended and quadriceps relaxed.	Not stated.	Left Left Right Right	M: 10.4 ± 5.7 F: 12.2 ± 5.2 M: 9.5 ± 4.6 F: 10.5 ± 4.2	Although this study stated that the Q angle is not bilaterally symmetric there is no mention of standardising or documenting foot position.

Table 3.2: Continued.

Author (s)	Subjects	Age (Mean/range)	Method (s) used	Foot Position	Limb	Q angle° (Mean $\pm$ SD)	Comment
(Woodland and Francis, 1992)	F: 257 M: 269	20/17 – 28 22.3/17 – 38	Standing and supine positions. Modified goniometer (long arm 60cm and short arm of 10 cm). Knees were extended and quadriceps relaxed for both positions.	Not considered.	Right Right	F: 17.0 $\pm$ 0.72 M: 13.6 $\pm$ 0.72	Measurements were taken 'regardless' of foot position which limits the comparability to other studies.
(Horton and Hall, 1989)	100 total F: 50 M: 50	22.6 / 18 – 33	Standing position with knees fully extended. Standard goniometer with string stretched from ASIS to centre of patella	Not considered	Not specified	F: 15.8 $\pm$ 4.5 M: 11.2 $\pm$ 3.0	It is unclear which limb was measured. There was no attempt to record foot position. Errors may have occurred with the string (i.e. slackness).
(Fairbank <i>et al.</i> , 1984)	F: 150 M: 160	14.8/ 14.6/	Standing position	Not considered	Unknown	F: 23 $\pm$ 1.2 M: 20 $\pm$ 1.2	No indication which limb was measured and if foot position was considered.
(Olerud and Berg, 1984)	34 (gender not specified)	Not specified	Standing position. Photographic & direct method using a traditional goniometer	Abducted Pronated Adducted Supinated	Not specified	Decreases Increases Increases Decreases	Although this study examined the influence of foot position the authors did not report any values for the Q-angle. The results were simply descriptive. This study can be considered as a qualitative representation of how foot position and posture influences the Q-angle.

Table 3.3: Various methods and reported Q angles in patients with PFJt pain (P) = pain/pathological group, (C) = control group. \* Denotes a significant difference was identified between the (C) and (P) groups (most recent to oldest).

Author (s)	Subjects	Age (Mean/range)	Method (s) used	Foot Position	Limb	Q angle° (Mean $\pm$ SD or SEM*)	Comment
(Thomee <i>et al.</i> , 1995)	Total of 60 females. <i>Subgroups</i> (P) 40 (C) 20	Overall, 20 / 15 – 28	Standing position with both knees fully extended. Video camera (Panasonic M7), measurements recorded with goniometer from a 28 inch television. Anatomical landmarks were marked with a black dot.	Medial borders of feet were positioned parallel at 10 cm apart	(P) Most pain (P) Least pain (C): Right (C): Left	16.8 $\pm$ 4.6 16.4 $\pm$ 5.4 17.9 $\pm$ 5.2 15.1 $\pm$ 4.9	Feet placed in a constrained position limiting the true functional significance. Results are confusing. Information presented on most symptomatic and least symptomatic knee for the (P) group, but fail to state which it was. This limits the comparability of left and right knees with both pathology and no pain.

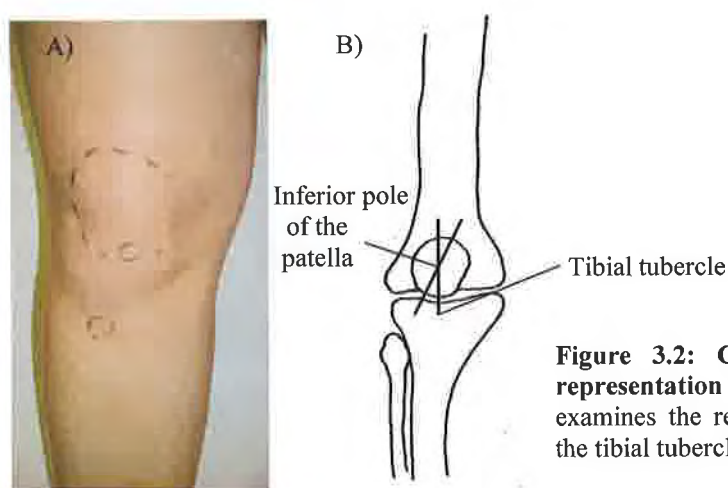
Table 3.3: Continued.

Author (s)	Subjects	Age (Mean/range)	Method (s) used	Foot Position	Limb	Q angle° (Mean $\pm$ SD or SEM†)	Comment
(Caylor <i>et al.</i> , 1993)	Total 102 Subgroups (P) 50 M: 18 / F: 32 (C) 20 M: 9 / F: 17	(P) mean = 23 (C) mean = 24.5	Extended Q angle: Standing comfortable position. Flexed Q angle: Standing comfortable position, one heel was placed on a 1 ¼ inch heel lift (flexion 24.3° $\pm$ 8.2). Ink pen for landmarks. Goniometer - string extended from proximal arm to ASIS.	Not considered	Right and left limbs were measured but both sets of data were pooled.	(P) 12.4 $\pm$ 5.1 (C) 11.1 $\pm$ 5.5 Both groups: Extended: 12.4 $\pm$ 6.05 Flexed: 10.80 $\pm$ 5.93	The authors failed to document foot position. Although a heel raise was used to flex the knee, it could be argued that the actual amount of flexion was not standardised. Generally, the results were quite difficult to interpret.
(Messier <i>et al.</i> , 1991)	Total 36 Subgroups (P): 16 total M: 12 / F: 4 (C): 20 total M: 14 / F: 6	16 – 50 Mean not stated.	Supine position. Goniometer – no modifications mentioned.	Not considered.	(P) Right (P) Left (C) Right (C) Left	17.19 $\pm$ 0.6* 17.19 $\pm$ 0.5* 11.05 $\pm$ 0.3* 10.90 $\pm$ 0.4*	It is assumed that this measurement was obtained in a supine position. Limited information was provided on the goniometer. It is not known if the proximal arm of the goniometer was extended. Furthermore, it is unclear as to whether the quadriceps were contracted or relaxed.
(Fairbank <i>et al.</i> , 1984)	Total 446 (M: 227 / F: 219) Subgroups M (P): 67 / F (P) 69 M (C): 160 F (C): 150	No mean provided only range (13 – 17).	Standing position with both fully extended. Vector stereograph (3 strings under constant tension run at 90° to each other). Output is transferred to a microcomputer - calculation of length of each string at sites using Cartesian coordinates of the pointer.	Subject stood in jig with feet parallel, knees extended and glutei square.	M: (P) Right F: (P) Right M: (P) Left F: (P) Left M: (C) Right F: (C) Right M: (C) Left F: (C) Left	22.5 $\pm$ 2.7† 23.4 $\pm$ 2.3† 19.6 $\pm$ 2.4† 21.7 $\pm$ 2.0† 18.3 $\pm$ 1.4† 24.8 $\pm$ 1.5† 19.6 $\pm$ 1.3† 22.7 $\pm$ 1.4†	While this method is weightbearing, the stance position is constrained, limiting its functional significance.
(Hughston <i>et al.</i> , 1984)	(P) 708 – not every case had Q angle recorded Subgroup M: 146 F: 209	Not specifically stated. Ranged from <15 – 45> of age.	Supine position with quadriceps contracted. Goniometer, no modifications made. Proximal arm was guided/aligned towards the ASIS.	Not considered.	Not available - see comment section.	Not available – see comment section.	The authors noted a continual trend for an increase in the Q angle and a decrease of individuals with chondromalacia patellae. Questions the link of pathology to an increased Q angle. Limited significance due to non-weightbearing measure. Presentation of the results is difficult to analyse and compare with other studies.
(Insall <i>et al.</i> , 1983)	65 cases (75 knees) F: 40 M: 25	20 / 13 - 32	Supine position with the quadriceps relaxed.	Not considered.	Not stated	No mean but 36/75 knees examined had a Q angle of at least 20°.	Very limited information on methods used. These authors did not detail the range, standard deviation or mean values of the Q angle measured. Non-weightbearing method - limited in functional significance.



### 3.3.2 A angle

In 1990 Arno introduced the 'A angle' to examine the frontal plane relationship of the patella and tibial tuberosity. He defined the A angle as "...the complement of the angle that is formed the intersection of the line that bisects the patella longitudinally and the line drawn from the tibial tubercle to the apex of the inferior pole of the patella" (page 238) (figure 3.2). Arno (1990) claimed that the measure could be used to assess glide, rotation and tilt of the patellar. However, whilst it is logical that the measure was capable of examining frontal plane rotation, there is debate as to how the measure could assess glide and tilt (Ehrat *et al.*, 1994; DiVeta and Vogelbach, 1992). Although never documented by Arno (1990), the A angle seems to provide quantitative analysis of the visual observations by Helfet (1970) who reported on the relationship between the patella and tibial tubercle in a flexed and extended knee (figure 3.3). Arno's (1990) presentation of the A angle was supported by a case study of an 11 year -old girl with PFJt pain who was treated with strengthening of the VMO and McConnell-type taping for tilt<sup>3</sup>, glide and rotation of the patella. He recorded the Q angle and the A Angle pre and post treatment and noted that the A angle significantly reduced from 55° to 13° (change of 42°). No change was reported in the Q angle which remained at 13°. Despite these changes, Arno (1990) did not report the reliability of the A angle and the Q angle and failed to mention if the patient was supine or standing, whether the knee (s) was extended or flexed or indicate the size of the goniometer used. These findings therefore cannot be realistically accepted and require verification.



**Figure 3.2: Clinical (A) and schematic (B) representation of the A angle.** This measurement examines the relationship between the patella and the tibial tubercle.

<sup>3</sup> McConnell taping: A common method of treatment introduced by McConnell in 1986 to treat chondromalacia patellae and other malalignment problems of the PFJt. Its role is to re-align the patella (medial direction) and improve its tracking.





**Figure 3.3: Movement of the tibial tubercle in relation to the patella during knee movement.** Knee flexion (A) results in the tibial tubercle being more or less in line with the medial part of the patella. Knee extension (B) causes external rotation of the tibial tubercle so that it lies lateral to the patella.

Compared to the Q angle, the A angle has received limited attention with only 4 studies detailing its reliability and efficacy in patients with PFJt pain (Selfe *et al.*, 1996; Tomsich *et al.*, 1996; Ehrat *et al.*, 1994; DiVeta and Vogelbach, 1992) (table 3.4). However, inconsistencies in the methods used limit the true value of this measure. For example, DiVeta and Vogelbach (1992) did not state the size of the goniometer and it is not known how the anatomical landmarks were identified making it difficult to replicate the study. In comparison, whilst Ehrat *et al.* (1994) provided information of their method it is not easy to follow and the approach does have some limitations. For example, to establish a longitudinal bisection of the patella, the authors measured 0.5 inches from the palpation marks. This distance may have induced errors since the length and width of the patella varies between females and males (Grelsamer *et al.*, 1994; Schlenzka and Schwesinger, 1990). Moreover, participants were asked to perform a squat test to help identify the patellar tendon and tibial tubercle. This palpation protocol is not consistent with the position in which the A angle is measured and is a factor that could contribute to poor results.

As well as examining the reliability of the A angle DiVeta and Vogelbach (1992) compared 30 patients with PFJt pain with the asymptomatic participants (control group). A total of 34 knees were examined, 15 (right knee only) from the control group and 19 (symptomatic knee only) from the PFJt pain group. The mean A angle of 12.3° (SD 3.4, range 6° – 18°) for the control group and 23.2° (SD 6.7, range 11° – 36°) for the PFJt group was reported. Although significant difference were noted between the 2 groups these values are much lower than the value of 35° or above reported by Arno (1990). The authors suggest that an increased A angle in the PFJt pain group is related to rotation or lateralisation of the patella and indicated that limb

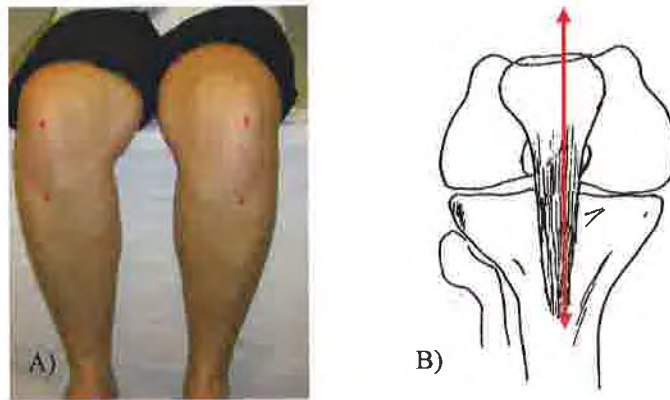
dominance may play a role in influencing the A angle. They also stated the need to examine the correlation of the Q angle and A angle in a resting calcaneal stance position (RCSP) to assess the lower kinetic chain relationship.

Author	Sample	Method	Reliability
Selfe <i>et al.</i> (1996)	6 participants 3 examiners	1 hour training session. Supine, blinded goniometer, fine marker pen for anatomical landmarks.	<i>Pearson's r moment</i> Intrarater 0.06 – 0.07 Interrater ANOVA* ( $p < 0.0001$ )
Tomisch <i>et al.</i> (1996)	27 participants 3 examiners	2 hour training session. Supine, goniometer, not known how anatomical landmarks identified.	<i>ICC</i> Intrarater 0.61 Interrater 0.49 <i>SEM</i> Intrarater 3.5° Interrater 6.8°
Ehrat <i>et al.</i> (1994)	36 participants 3 examiners	90 minute training session. Supine, blinded goniometer, fine marker pen for anatomical landmarks.	<i>ICC</i> Intrarater 0.20 – 0.40 Interrater 0.12 <i>SEM</i> Intrarater 5.3° – 7.9° Interrater 7.3°
DiVeta and Vogelbach (1992)	30 participants 2 examiners	No training provided. Supine, blinded goniometer, adhesive circles for anatomical landmarks,	<i>Pearson's r moment</i> Intrarater 0.87 Interrater 0.59

**Table 3.4 Summary of reliability studies on the A angle** (all participants were asymptomatic). The use of the ANOVA to assess reliability is not considered the most appropriate statistic to examine reliability and limits true comparability between studies.

### 3.3.3 Tubercle sulcus angle

The TS angle relates to the angle observed by the position of the tibial tuberosity in relation to the centre of the patella. The measure was first introduced by Hughston *et al.* (1984) and is described as a more accurate representation of the quadriceps vector due to the patella being secured within the femoral sulcus which allows rotational anomalies to be assessed (figure 3.4). Whilst the objective of the TS angle is described as being identical to that of the Q angle, its standardised approach is considered to improve reproducibility. The measure is undertaken whilst subjects are seated with both knees flexed to 90° that allows an indication of lateral displacement of the tibial tubercle in relation to the femoral sulcus (Post, 1996). As with the A angle, this measure provides quantitative analysis of the observations by Helfet (1970) discussed previously on page 44. Hughston *et al.* (1984) considers the normal TS angle as 0°, whilst (Kolowich *et al.*, 1990) suggests that 10° of lateral displacement is the normal upper limit. However, data is yet to be presented to validate this range and the reliability of this measure remains unknown (Muneta *et al.*, 1994). Examining the relationship of the tubercle to the sulcus is likely to be helpful in understanding the contribution of the tubercle position to the valgus alignment of the extremity (Post, 1996) which is an interesting area for future investigation.



**Figure 3.4: Clinical (A) and schematic (B) representation of the TS angle.** Circular stickers to the centre of patella and tibial tubercle provide the landmarks for the TS angle (A).

### 3.3.4 Tibiofemoral angle

Chapter 2 highlighted how frontal plane alignment of the knee (TFJt) may be a contributing factor to PFJt pain (Oatis, 2003; McClay and Manal, 1998). The terms *genu varus* and *genu valgus* are used to describe frontal plane alignment of the TFJt. The values of genu valgus and varus are dependant on the technique used to measure the TFJt angle. The *anatomical* or *mechanical axes* of the TFJt are used to measure this angle. The long axes of the femur and tibia are used for the anatomical axis whilst the mechanical axis employs the mechanical axis of lower limb, which is the centre of hip, knee and ankle joints (Levangie and Norkin, 2004). The reported normal adult values for the mechanical axis is 2° of varus, however this method can only be assessed using radiographs (Chao *et al.*, 1994; Hsu *et al.*, 1990). In contrast the normal angle produced using the anatomical axis is 5° of valgus (Chao *et al.*, 1994), although this value has been reported to be as high as 10° (Kapandji, 1970). These adult values are thought to be achieved by the age of 6 or 7 years (Oatis, 2003). Varus angles however are regarded as abnormal in healthy adults and are associated with osteoarthritis of the TFJt when the anatomical axis is employed (Andriacchi, 1994). Although the TFJt angle using the anatomical axis can also be measured radiographically (Hsu *et al.*, 1990), this method is costly and can expose individuals to radiation. A number of studies have reported the TFJt angle in a clinical setting (Cahuzac *et al.*, 1995; Heath and Staheli, 1993; Cheng *et al.*, 1991; Engel and Staheli, 1974). For example, Nguyen and Shultz (2007) examined 100 healthy individuals (50 females/50 males) aged between 18 – 34 and showed that the anatomical (clinical axis) reflected that of a valgus position with females demonstrating a higher TFJt (11°) compared to males (8° - 9°). The clinical approach employs the anatomical axis

and whilst various goniometric methods have been used to measure the TFJt angle, the values reported have been shown to be similarly reliable and correlate well with the values obtained from radiographs.

Limb alignment is a relatively stable entity and whilst it may change over time due to growth, age, injury or disease (Levangie and Norkin, 2004), measures such as the TFJt angle remain relatively unchanged throughout adulthood. In addition to being stable, this measure also has the potential to provide a baseline measure of lower limb posture (personal communication, Livingston, 2006). This supports the thoughts of Post *et al.* (2002) who encourage clinicians to consider limb alignment when examining the PFJt. Even so, it is unknown if this measure is affected by foot posture and therefore needs to be established.

### **3.4 Measuring foot posture**

Foot type is a common yet imprecise term that has been used to describe a variety of anatomical features of the foot and is thought to provide some evidence of dynamic function (Mathieson *et al.*, 2004). Valmassy (1996) suggests that various types of foot structure are linked to lower extremity dysfunction and pathology. Low arched and flexible feet are described as the most common aetiology of all biomechanical problems. In contrast, high arched and rigid feet have the potential to cause more significant problems to the foot itself and structures further up the lower kinetic chain (Razeghi and Batt, 2002; Williams *et al.*, 2001). In theory, these 2 examples of foot type have the potential to predispose certain individuals to injury of the lower limb (Crosbie and Burns, 2008; Burns *et al.*, 2005; McClay and Manal, 1998).

Measurement of foot posture is considered an important part of clinical examination for evaluating foot function, prescribing foot orthoses and identifying other sources of treatment (Billis *et al.*, 2007; Brushøj *et al.*, 2007). However, to date no valid and universally accepted classification method exists for measuring foot type in a clinical setting (Razeghi and Batt, 2002). This limitation has been recognised by a number of organisations such as the *Foot and Ankle Interest Group of the American Physical Therapy Association* (Davis, 2004; McClay, 2001) and the *Research Council of the American Orthopaedic Foot and Ankle Society* (Saltzman *et al.*, 1997) who have

identified a clear need for superior methods of measuring foot type. These recommendations focus on the need for measures to demonstrate improved reliability, be simple and easy to use, produce quantifiable data that reflects complexity of foot function, minimise subjectivity and finally, do not require expensive and complex equipment (Redmond *et al.*, 2005). There are a number of clinical techniques described for examining foot posture including footprint evaluation, anthropometric techniques and an observational scoring system.

#### **3.4.1 Footprint evaluation**

Footprint measures are a common technique used to classify foot type that can be obtained from a simple ink pad to more complex systems involving pressure transducers (Razeghi and Batt, 2002). Using clearly defined points on the print several indices have been reported that are based on angular and linear measurements. These indices include the *malleolar valgus index* (Song *et al.*, 1996), *arch index* (Cavanagh and Rodgers, 1987), *footprint index*, *Brucklen index*, *Staheli arch index*, *Chippaux-Sminak index* and *truncated arch index* (Razeghi and Batt, 2002). The basic premise for these footprint measures is that alterations in shape, structure and function of the foot when an individual is walking or standing maybe reflected in the print (Razeghi and Batt, 2002; Urry and Wearing, 2001; Welton, 1992). Despite the popularity of footprint techniques a number of authors have questioned the reliability and validity. Hawes *et al.* (1992) compared arch height (AH) and a range of footprint measures. They noted that variations in AH of 4 – 15% could only be reflected in footprint measures and concluded that footprint measures only provide information on the plantar surface of the foot. Likewise, Mathieson *et al.* (2004) identified that the *Staheli arch index* which compares the midfoot to rearfoot and *Chippaux-Sminak index* that compares the midfoot to forefoot were unable to respond to discrete changes in rearfoot motion. Whilst there is a range of footprint indices, each index can present with specific limitations. For example, Razeghi and Batt (2002) comment that indices such as the *footprint index*, *Brucklen index* and *truncated arch index* cannot be calculated from footprints obtained from severely flat or highly arched feet as the bisection lines cannot be determined.

### 3.4.2 Anthropometric techniques

A variety of anthropometric techniques have been developed that involve direct measurement of bony or surface landmarks of the foot which focus on the structure and function of the MLA. Three common anthropometric techniques, the AH; navicular height (NH) and navicular drop (ND), are provided as examples.

#### *Arch height*

This measure relates to the distance between the highest and most prominent point along the soft tissue margins of the MLA to the supporting surface. Using a Mitutoyo digital calliper, Hawes *et al.* (1992) examined 5 footprint measures to determine their ability to predict AH. Whilst the intrarater (0.99) and interrater (0.98) reliability was reported as being excellent no correlation between AH and the footprint measures was identified, questioning the validity of AH measurement. In a more recent study, Franettovich *et al.* (2007) used video analysis to show that the AH had excellent intrarater and interrater reliability for dynamic and static states (0.86 – 0.99). These findings are also supported by Butler *et al.* (2008) who used an AH index measurement system and showed that intrarater (0.98) and interrater (0.99) reliability was excellent. The most important limitation of this measure however is its inability to consider the flexibility of the foot. In addition, simple observation of AH is unable to determine the quantity of joint motion and is supported by the work of Nigg *et al.* (1993) who suggest that static AH was a poor predictor of rearfoot motion.

#### *Navicular drop and height*

The tuberosity of the navicular has been reported as being a consistent prominent anatomical feature (Menz, 1998) (figure 3.5). Brody (1982) introduced the term 'navicular drop' (ND) as a measure of pronation of the foot in a group of runners. His technique involved recording changes in the height of the navicular tuberosity (sagittal plane) from a seated, semi-weightbearing, STJt neutral position to a 50% weightbearing, RCSP. Brody (1982) suggested that a normal ND was 10mm whilst values above 15mm indicated abnormal foot pronation. Ten years later, Beckett *et al.* (1992) modified the technique by incorporating a full weightbearing standing position from a neutral STJt position and seated position. This approach was used to examine a group ( $n = 50$ ) with ACL injury and a control group ( $n = 50$ ), with no reported lower limb problems. An increased ND (mean 13mm) was noted for the ACL group



compared to the control group (mean 6.9mm). These observations are also supported by Woodford-Rodgers *et al.* (1994); Louden *et al.* (1996) and Trimble *et al.* (2002) and supports the notion that foot function is linked to ACL injury.



**Figure 3.5: ND measure.** The navicular tuberosity is palpated and marked and measured in relation to the supporting surface when the foot is in a neutral position (A) and resting position (B).

A more detailed assessment of the ND was undertaken by Mueller *et al.* (1993) who used a Metrecom<sup>®</sup> electromechanical 3D digitiser<sup>4</sup> to examine the intrarater reliability of the ND in 29 healthy participant. The reported mean value for ND was 7.3mm, with ICCs ranging from 0.78 to 0.83 suggesting acceptable reliability. They also investigated the relationship between ND, forefoot and rearfoot position, neutral and RCSPs and noted that ND was significantly influenced by the forefoot and even more so by the rearfoot. Sell *et al.* (1994) reported a similar mean value to Mueller *et al.* (1993) of 6mm and demonstrated excellent ICCs for intrarater (0.83) and interrater (0.73) reliability. Whilst reporting a slightly higher mean ND (9.5mm) Vinicombe *et al.* (2001) demonstrated moderate-to-excellent ICCs for intrarater (0.44 – 0.91) and interrater (0.56 – 0.78) reliability. More recently, Billis *et al.* (2007) assessed the intrarater and interrater reliability of the ND and reported ICCs of 0.95 – 0.99. It is clear that the ND, instrumented or non-instrumented, offers a reliable measure of motion but in terms of validity it requires exploration.

McPoil and Cornwall (1994) examined the ability of ND to predict dynamic function of the rearfoot. They used dynamic video analysis to assess patterns of rearfoot motion and noted a strong correlation of 0.94 between rearfoot motion and ND. These findings are also supported by Mathieson *et al.* (2004) who showed that the NH responded to changes in rearfoot motion. These features, moderate reliability and







<sup>4</sup> Metrecom<sup>®</sup> electromechanical 3D digitising device – measures the co-ordinates of x, y, and z for the position of the navicular and has an accuracy of 0.9mm.

clinical utility for recording the NH and ND are appealing for clinical observational inquiry. However, a limitation of navicular measures relates to what value constitutes 'abnormal' and 'normal'. Whilst some authors report normal values that range from 6mm (Sell *et al.*, 1994) to 7.3mm (Vinicombe *et al.*, 2001) and abnormal values of 10mm (Mueller *et al.*, 1993), 13mm (Beckett *et al.*, 1992) and 15mm (Brody, 1982). Menz (1998) argues that these values are flawed since foot size is not recorded and adds that a large foot with a ND of 15mm may be insignificant compared to a smaller foot with the same value. Moreover, Saltzman *et al.* (1995) suggest that the best anthropometric method is to measure the ratio of NH and foot length (FL). However, it is not clear if this is required for the association of rearfoot motion.

### 3.4.3 Foot Posture Index<sup>®</sup>

In recent years, a new approach has been developed and validated for measuring foot type which has been termed the Foot Posture Index<sup>®</sup> (FPI<sup>®</sup>). This multidimensional, multiplanar tool quantifies foot posture by scoring a range of foot characteristics and combining into one result (Redmond *et al.*, 2005). The FPI<sup>®</sup> consists of 6 criteria which are measured using a 5-point Likert scale that range from +2 to -2; a total score can range from -12 to +12. The FPI<sup>®</sup> has been developed from a comprehensive review of the clinical literature and was created for use during quiet double limb stance. Whilst earlier versions of the FPI<sup>®</sup> involved 8- items the final validated version consists of 6 (table 3.5). The FPI<sup>®</sup> has undergone a rigorous validation process (Keenan *et al.*, 2007; Redmond *et al.*, 2005; Scharfbillig *et al.*, 2004) and the reliability of this measure has been demonstrated by a number of clinical studies which reported moderate-to-excellent ICCs (0.62 – 0.91) (Yates and White, 2004; Evans *et al.*, 2003; Noakes and Payne, 2003). These findings however are in contrast to Cornwall *et al.* (2008) who demonstrated that the FPI<sup>®</sup> only had moderate reliability (0.52 – 0.65). The foot is a complex, multi-segmented unit and the FPI<sup>®</sup> is the first system to really recognise this and conduct more than a simple, single item measurement. In addition, it is inexpensive to perform and can be obtained when the individual is in double limb stance. These features make it a suitable measure for investigating the link between foot posture and PFJt alignment in studies using large numbers of participants. Moreover, the FPI<sup>®</sup> scoring system provides an opportunity to classify different postures.



Criterion	Method and scoring	Illustration
<b>Talar palpation</b>	<p>Head of the talus (medial and lateral).</p> <ul style="list-style-type: none"> <li>- 2 TH palpable on lateral side only.</li> <li>- 1 TH palpable on lateral side, but slightly palpable on medial side.</li> <li>0 TH palpable on lateral and medial sides (equal).</li> <li>+1 TH palpable slightly on lateral side, but more palpable on medial side.</li> <li>+2 TH palpable on medial side only.</li> </ul>	
<b>Supra and infra lateral malleolar curvature</b>	<p>Curves above and below the malleolus should be equal. In a supinated foot, the curve above the malleolus is more acute than below.</p> <ul style="list-style-type: none"> <li>- 2 Curve below malleolus is convex or straight.</li> <li>- 1 Curve below malleolus is concave, but flatter than curve above malleolus.</li> <li>0 Equal infra and supra malleolar curves.</li> <li>+1 Curve below malleolus is concave than curve above malleolus.</li> <li>+2 Curve below malleolus is <i>markedly</i> concave, than curve above malleolus.</li> </ul>	
<b>Calcaneal position (frontal plane)</b>	<p>Posterior aspect of the calcaneus visually bisected (longitudinal) by the observer. Angulation is based on visual appraisal.</p> <ul style="list-style-type: none"> <li>- 2 More than an estimated 5° varus.</li> <li>- 1 Between vertical and an estimated 5° varus.</li> <li>0 Vertical.</li> <li>+1 Between vertical and an estimated 5° valgus.</li> <li>+2 More than an estimated 5° valgus.</li> </ul>	
<b>Talo-navicular bulging</b>	<p>Skin in the area of the talonavicular joint (TNJ) will either be indented (supinated), prominent (pronated) or flat (neutral).</p> <ul style="list-style-type: none"> <li>- 2 TNJ markedly concave.</li> <li>- 1 TNJ slightly concave.</li> <li>0 TNJ flat.</li> <li>+1 TNJ slightly bulging.</li> <li>+2 TNJ markedly bulging.</li> </ul>	
<b>Height / congruence of the MLA</b>	<p>The height and shape of the arch has been described as being a good indicator of foot function.</p> <ul style="list-style-type: none"> <li>- 2 High arch with an acute angle towards the postero-medial end.</li> <li>- 1 Moderately high arch, slight acute angle towards postero- medial end.</li> <li>0 Height of arch normal and concentrically curved.</li> <li>+1 Lowered arch and flattening of central area.</li> <li>+2 Very low arch, severe flattening of central area touches ground.</li> </ul>	
<b>Abduction/adduction of forefoot on the rearfoot</b>	<p>Posterior view of the calcaneus the medial and lateral forefoot should be equally observed in a neutral foot.</p> <ul style="list-style-type: none"> <li>- 2 Lateral digits not visible, medial toes clearly visible.</li> <li>- 1 Medial digits more visible than lateral digits.</li> <li>0 Equal visualisation of lateral and medial digits.</li> <li>+1 Lateral digits more visible than medial digits.</li> <li>+2 Medial digits not visible, lateral toes clearly visible.</li> </ul>	

**Table 3.5: Overview of the FPI®.** All illustrations shown are of a right neutral foot (Minus sign = supinated/plus sign = pronated).

### 3.5 Standardising the clinical approach

A common thread in chapter 3 is the failure of many of the PFJt alignment studies to use a standardised weightbearing approach. The criteria set out in table 3.1 of this chapter (page 35) suggested that each PFJt alignment and foot posture measure should be obtained in a consistent, double limb stance position that is natural to each individual. Whilst this position is considered to reflect that of a dynamic closed kinetic chain situation the approach itself requires investigation. McPoil and Cornwall (1996) point out that performing static lower limb measurements allows for abnormalities to be determined and their influence during walking to be predicted (i.e. structure dictates function). Footprint data provides a simple and inexpensive method to quantifying the 'vital signs' of human gait which include the angle of gait (AOG) and base of gait (BOG) (Kirtley, 2007). These parameters can also serve as a standardised reference point for clinical and radiological examination of patients with musculoskeletal disorders and diseases. In particular, the AOG has been shown to correlate with pronation of the foot (Kernozek and Ricard, 1990; Williams *et al.*, 1987; Lapidus, 1963), whilst the BOG has been recognised as an important parameter for assessing patients with Parkinsonism (Murray *et al.*, 1978) and identifying gait and postural changes associated with the ageing process (Rigas, 1984; Guimaraes and Issacs, 1980; Murray *et al.*, 1969).

Determining a standardised approach that reflects an individual's functional double limb weightbearing position will not only provide a representation of alignment but also the symmetry of stance. Rys and Konz (1994) state that most individuals have their feet and lower limbs in a somewhat self-selected (efficient) static position the majority of the time. Two types of standing have been described in the literature; the first type refers to '*symmetric stance*' or '*standing at ease*'. In this stance, the shoulders are described as level, the hips are extended whilst the knee are flexed approximately 6°. The feet are in line with one another, which results in the centre-of-mass (CoM) placed midway between both feet and the same amount of weight borne is by each limb (Whittle, 2002). The second type of stance is '*asymmetric stance*' and is considered as the most common type of stance (Smith, 1954). A key characteristic of this type of stance is that one foot is slightly in front compared to other. This position results in one foot bearing as much as 80 – 90% of the body's weight compared to the other foot which helps to maintain balance bearing only a small amount of weight.

(Oatis, 2003; Rozendal, 1986). Information derived from the AOG and BOG could provide information on asymmetry or symmetry of stance which could be linked with lower limb musculoskeletal pathology (i.e PFJt pain).

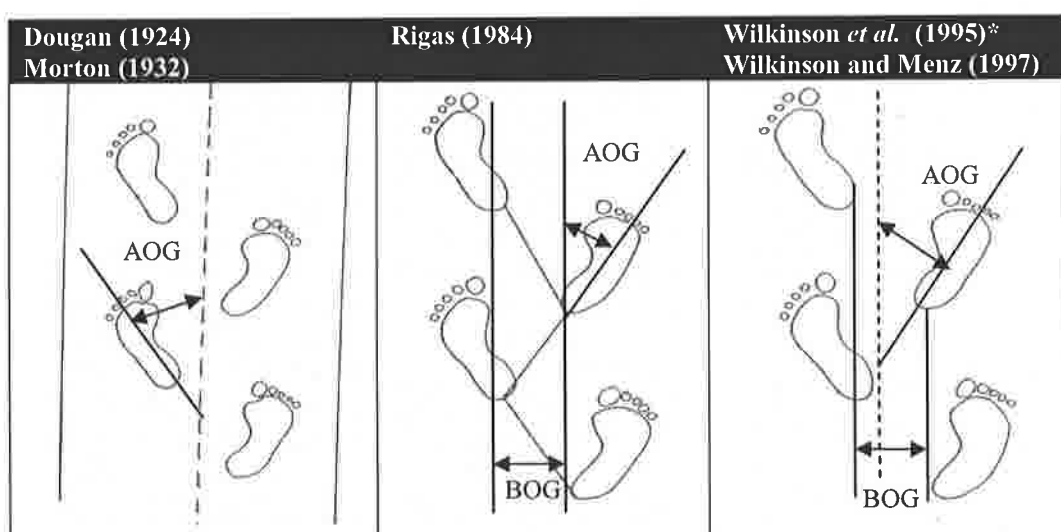
### 3.5.1 Angle and base of gait

Sgarlato (1965) describes the AOG or the '*foot placement angle*' as the deviation of the sagittal plane of the foot to the line of progression, with average values reported to be 7.5° - 10° abducted for each foot (Whittle, 2002; Wilkinson and Menz, 1997; Boenig, 1977) (table 3.6). The BOG is defined as the distance between both feet during the midstance phase of the gait cycle (Sgarlato, 1965). Other terms for the BOG include '*stride width*' (Rigas, 1984; Rose-Jacobs, 1983; Chodera, 1974), '*dynamic base*' (Ogg, 1963), '*step width*' (Donelan *et al.*, 2001; Bauby and Kuo, 2000), '*base of support*' (Shores, 1980). Many have reported various techniques for assessing the AOG and BOG (Levangie *et al.*, 1989; Rigas, 1984; Scrutton and Robson, 1968; Morton, 1932; Dougan, 1924). More recently, Wilkinson *et al* (1995) presented a reliable technique for analysing dynamic footprints. They point out that an essential criterion of the AOG should be to measure the AOG for each step in comparison to the line of progression for the whole body for each step; a feature not considered in early techniques (Morton, 1932; Dougan, 1924). To reduce potential sources of error when measuring the BOG linked with earlier studies (Ogg, 1963; Boenig, 1977) Wilkinson *et al.* (1995) also encourage a technique that relates one print to another minimising any potential sources of error (table 3.6, figure 3.6).

Although Wilkinson *et al.* (1995) and Wilkinson and Menz (1997) have produced a useful and reliable dynamic method for analysing the AOG and BOG, it is not convenient for clinicians or researchers due to time and lack of space. Therefore, a simple clinical method that predicts the dynamic would be useful. Arguably, only McIlroy and Maki (1997) detail their method of identifying the AOG and BOG from a clinical perspective but it is not known if their method and approach predicts that of a dynamic situation. This lack of information and guidance for obtaining and reporting the AOG and BOG indicates the need for a standardised approach.

Reported studies	AOG <sup>a</sup> (left foot)	AOG <sup>a</sup> (right foot)
Dougan (1924)	4.87 ( $\pm$ NR)	6.46 ( $\pm$ NR)
Boenig (1977)	9.0 ( $\pm$ 4.1)	8.0 ( $\pm$ 3.3)
Murray (1970)	6.4 ( $\pm$ 7.2)	5.1 ( $\pm$ 5.7)
Wilkinson and Menz (1997)	6.9 ( $\pm$ 7.2)	7.5 ( $\pm$ 5.2)

**Table 3.6: AOG values.** Mean values (SD) during dynamic assessment (NR = not reported).



**Figure 3.6: Selected examples of previous methods of analysis for AOG and BOG obtained from dynamic data collection.** \*The technique by Wilkinson *et al.* (1995) showed acceptable reliability using Pearson's *r* correlation with intrarater values of 0.92 – 1.00 and interrater values of 0.935 – 0.99.

### 3.6 Examining the functional significance of the relationship between foot posture and PFJt alignment

#### 3.6.1 Possibilities

The previous sections in this chapter have explored a range of static clinical measures (i.e. PFJt alignment and foot posture). However, understanding the functional significance of these measures is of critical importance. To date, this type of information is limited and establishing the link between PFJt alignment and foot function will be useful for providing further information on the relationship. Various approaches using instrumented gait analysis can be used to address this information deficit. For example, EMG (i.e. Delsys<sup>®</sup>, Boston, USA) could be used to examine whether various PFJt alignments influence different muscle activation patterns in key muscles such as the RF, VMO and VL. A kinematic approach could be adopted using 2-dimensional (i.e. Quintic video analysis, Quintic Consultancy Ltd, Coventry, UK) or 3-dimensional analysis (i.e. CODAmotion system, Charnwood Dynamics Ltd) to examine changes in PFJt alignment angles (i.e. surface markers) during the stance phase of gait. Finally, kinetics could be investigated to determine how PFJt alignment

influences foot contact characteristics and how it transfers load during the stance phase of gait. Of these, perhaps the most relevant in the context of foot function is kinetics because loading characteristics could be altered and may be important in the development of musculoskeletal pathology and PFJt pain. For example, Levinger and Gilleard (2007; 2005) showed that impact forces were reduced in patients with PFJt pain during the contact phase of walking. Nyland *et al.* (2002) also showed that medial patella taping shifted the peak plantar force towards the forefoot. It is suggested that a pronated foot will load the foot's medial plantar area whilst a supinated foot will load the foot's lateral plantar area (Crosbie and Burns, 2008; Cavanagh *et al.*, 1997) but are in contrast to De Cock *et al.* (2008) and Thijs *et al.* (2007). These loading patterns however are thought to travel proximally up the lower limb and can be demonstrated in genu valgum which is commonly observed with a pronated foot (Williams *et al.*, 2001).

### **3.6.2 Introduction to plantar pressure measurement**

Plantar pressure measurement systems such as the EMED<sup>®</sup>-m platform (Novel, Munich, GmbH, Germany) record plantar loading transitions at high data acquisition rates (50Hz) and therefore permit investigation of rapid loading characteristics of the foot and lower limb. Data collected from a pressure platform benefit from a greater number of sensors/higher resolution compared to in-shoe systems. In addition, because the sensors are positioned parallel to the ground a 'true' representation of vertical force can be achieved (Orlin and McPoil, 2000). Platform systems however have been criticised because of the mid-gait protocol used to collect data and increased risk of 'targeting' of the platform by the participant/patient which alters their walking pattern (McPoil *et al.*, 1995). The introduction of the 1-step protocol by Rodgers (1985, cited in Orlin and McPoil, 2000) and a superior 2-step protocol by Meyers-rice *et al.* (1994) and Bryant *et al.* (1999) have shown that similar results can be achieved when compared to the traditional mid-gait protocol. This is an important issue as it reduces the length of time (and distance walked) even though it has been shown that multiple trials of 3 – 5 are required for reliability (Van der Leeden *et al.*, 2004; Hughes *et al.*, 1991).

Plantar pressure measurement systems calculate a wide range of parameters such as peak pressure, contact area and pressure time integrals. Each parameter has a theoretical relevance which should be considered prior to data analysis. For example, determining the effect of PFJt alignment on foot function using parameters such as *maximum force* (MF), *force time integrals* (FTI), *centre of pressure* (CoP), *lateral medial area indices* (LMAI) and *lateral medial force indices* (LMFI) could help to understand the nature of the relationship between PFJt alignment, PFJt pain and foot posture (table 3.7). These parameters can be analysed during the early part of stance (contact and midstance) when a number of mechanisms are used to dissipate forces created as the foot makes contact with the ground. These impact forces are reduced by shock absorbing reactions from the hip, knee and foot. In particular, foot pronation and eccentric loading of the quadriceps to decelerate knee flexion during the early part of stance phase play a key role (Hamill and Knutzen, 2003; Perry, 1992). A delayed CoP could indicate reduced stability (Semple *et al.*, 2007) whilst a high MF may suggest a lack of absorption and hence a more rigid loading (Crosbie and Burns, 2008). Although the area of loading has been suggested to fall more medial in pronated feet (Wong *et al.*, 2008) some authors argue (De Cock *et al.*, 2008) that a pronated foot produces an increase in lateral loading. This observation has recently been found in patients with PFJt pain (Thijs *et al.*, 2007) and therefore needs to be explored to examine the relationship further.

Hughes *et al.* (1991) asserts that a 100% reliability cannot be expected when recording different aspects of gait because gait is a variable and learned process. Over the years, technology has improved and there have been different versions of EMED systems<sup>5</sup> which have been found to offer a good level of reliability for most repeated recordings of force and pressure parameters. Using the EMED® ST4 system Putti *et al.* (2008) demonstrated a coefficient of repeatability of less than 16.9% for all of the parameters investigated (i.e contact area, FTI, pressure time integral). Gurney *et al.* (2008) also showed a good level of reliability (ICCs >0.8 - 0.9) using the EMED® AT over multiple testing sessions. They did note however that the reliability was higher for increased loading areas such as the central forefoot compared to the medial

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<sup>5</sup> EMED® systems – Novel, Munich, GmbH, Germany. Many versions of the EMED have been presented and include the EMED® AT, EMED® SF, EMED® ST4, and most recently the EMED®-m. The spatial resolution and numbers of sensors differ from system to system.

midfoot which had a reduced loading. An important decision however is whether cadence should be standardised. Using the EMED<sup>®</sup> SF Taylor *et al.* (2004) noted significant differences in plantar pressures between slow and fast speeds using the 2-step protocol. No differences were found when a self-selected speed was used. A self-selected cadence which is typical to a patient/participant at the time of assessment is more meaningful than attempting to make a patient conform to a set of conditions that may be unnatural to them (Cavanagh and Ulbrecht, 1994). The objective information provided by plantar pressure measurement provides a useful reliable method for investigating the relationship between PFJt alignment and foot posture.

Variable	Definition	Calculations produced (if appropriate)	Theoretical relevance
MF (N/cm <sup>2</sup> s)	Mean of MF for each masked area for each measurement.		The MF can be used to assess how the amount of force applied for loading of the foot and specific areas of the foot.
CoP	Identifies where the reaction force is needed to be centred to balance the sum of forces.	<p>The CoP is calculated for 3 areas of interest these are:</p> <p>Rearfoot to midfoot = 69% of foot length (toes to heel);</p> <p>Midfoot to forefoot = 50% of foot length (toes to heel);</p> <p>Forefoot to toes = defined around the peak pressures of the toes.</p> <ul style="list-style-type: none"> <li>Maximum velocity of the CoP = <math>V_{CoP_{max}}</math> (milliseconds [m/s])</li> <li>Duration of the CoP = DCoP (% stance)</li> </ul>	The CoP is useful for examining the progression, stability and efficacy of loading of the foot.
FTI (%BW)	Mean value of FTI which represents the area under the force curve.		The FTI calculates load distribution over time. For example, it is thought that even low forces over a long period of time can contribute to lower limb pathology.
LMAI	Differences between the lateral and medial areas of the total area of the foot.	<p>No units are used because the LMAI is calculated as the (Area[lateral]-Area[medial]/Area[total foot])</p> <p>Formula for LMAI calculation:  <math>LMAI = [(A_L - A_M) / A_L + A_M] \times 100</math>.  <math>A_L</math> is the area lateral to the line of CoP;  <math>A_M</math> is the area medial to the line of CoP.</p>	The LMAI is useful for determining the loading of the lateral and medial areas of the foot. This may help to identify the influence of frontal plane deviations of the lower limb*.
LMFI (N)	Differences between the lateral and medial forces of the total area of the foot.	<p>Differences are presented in milliseconds and a percentage of the total contact time (contact, midstance and propulsion)</p> <p>Formula for LMFI calculation:  <math>LMFI = [(F_L - F_M) / F_L + F_M] \times 100</math>.  <math>F_L</math> is the area lateral to the line of the CoP and <math>F_M</math> is the area medial to line of CoP.</p>	The LMFI is useful for determining the loading of the lateral and medial areas of the foot. This may help to identify the influence of frontal plane deviations of the lower limb*.

**Table 3.7: Definitions, calculations produced and theoretical relevance of each plantar pressure parameter.** \*Negative values indicate greater load/force medial to the line of the CoP compared to the lateral (N = newtons).

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### 3.7 Summary of chapter

- A 7-point criteria was presented of which reliability, validity and standardisation were considered as key dimensions;
  - Literature showed that the Q angle was the most common PFJt alignment measure whilst the least reported were the A angle and TS angle. Many studies however lack consistency (standardisation) in their methods;
  - The TFJt angle was viewed as a useful benchmark measure for recording skeletal postural alignment as it remains relatively unchanged throughout adulthood;
  - Whilst it is widely acknowledged that standardising foot position is vital, few articles have investigated its influence on the Q angle, A angle and TFJt angle;
  - Studies using the FPI<sup>®</sup>, ND and NH show moderate-to-good reliability and can be obtained in the same standard reference position as other lower limb measures (i.e. PFJt alignment);
  - Plantar pressure measurement offers a useful method of determining the functional significance of PFJt alignment measures which could help to understand its relationship between foot posture and PFJt pain.
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# Chapter 4

## The preliminary studies

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This chapter presents 3 preliminary studies that were performed to investigate the most appropriate methods of detecting a relationship between PFJt alignment and foot posture for clinical observational inquiry. The results from each of these studies were developmental and influenced the approach adopted in the cross-sectional study presented in chapter 5.

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### 4.1 Comparative calculations for the angle and base of gait using dynamic footprints, static footprints and a clinical technique

#### 4.1.1 Rationale and aim

The traditional and accepted protocol for obtaining clinical measures of the lower limb is the double-limb stance weightbearing position. This is thought to reflect structural features and functional performance of the lower limb (Bryant, 2001; McPoil and Cornwall, 1996; Perry, 1992). Many clinical PFJt alignment measures however lack a standardised approach with some studies for example using a contrived stance position (Rauh *et al.*, 2007; Herrington and Nester, 2004). This approach does not give a true representation of functional alignment which can often distort and bias the measures. Whilst the AOG and BOG can serve as a standardised reference point for clinical measures, a simple clinical technique that predicts the dynamic has yet to be established. Wilkinson and co-workers (1997; 1995) have shown that the AOG and BOG can be reliably obtained from dynamic footprints. Although this approach is inconvenient within the clinical setting because of lack of time and space, the method can be used to investigate the reliability and predictability of a clinical technique. The first aim of this study was to investigate the intrarater reliability of analysing the AOG and BOG obtained from dynamic footprints, static footprints and a clinical technique. The second aim was to determine the differences between the three conditions for the AOG and BOG. The following 2 null hypotheses were set:

1. The AOG and BOG calculated from dynamic footprints, static footprints and a clinical technique will not demonstrate acceptable intrarater reliability;

2. There is no relationship between the AOG and BOG using dynamic footprints, static footprints and a clinical technique

#### **4.1.2 Method**

The study utilised a double session, repeated measures design using one examiner. Ethical approval was sought and granted from the School of Health and Social Sciences, University of Wales Institute, Cardiff (UWIC) Ethics Committee prior to the commencement of the study (appendix 1). The nature and purpose of the study was explained and written consent obtained from each participant (appendix 2). A power calculation was not performed to establish participant numbers because this study and the other preliminary studies (4.2 and 4.3) presented in this chapter predominantly examined reliability. Studies investigating reliability are characterised by low numbers and typically use 10 – 20 participants, with 3 – 5 repetitions measuring on 2 or more occasions (Bruton *et al.*, 2000; Van Gheluwe *et al.*, 2002). This is supported by Walter *et al.* (1998) who state that the use of 2 or 3 observations per participant minimises the total number of observations/participants required.

#### **Participants**

The study consisted of 25 (17 females and 8 males) staff and student volunteers from the Wales Centre for Podiatric Studies, UWIC. The participants had a mean age of 29.0 years (SD 7.9, range 20 – 46 years), mean weight of 73 kilograms (kg) (SD 16.8, range 50 - 123kg) and a mean height of 1.69m (SD 0.0, range 1.56 – 1.88m). All participants satisfied the following inclusion criteria:

- No apparent gait dysfunction based on visual inspection;
- No reported history of trauma or surgery to the lower limb in the previous 12 months;
- No reported history of systemic disease that could influence gait.

No criteria regarding lower limb posture or range of motion during dynamic and static activity were established.

#### **Equipment / materials**

- 10m quiet walkway;
- Lining paper (length 10m x 56 centimetres [cm] – dynamic footprints);

- Lining paper (56cm by 1m – static footprints and clinical technique);
- Tray containing a mixture of black powder paint and talcum powder;
- Artists fixative spray;
- 1.5m ruler;
- Marker pen (0.5 millimetre [mm] thick) and 2HB pencil (clinical technique);
- Tractograph (17cm, 8.5cm moveable arm, scale = 1° increments);
- Brown heavy duty tape (to anchor lining paper to supporting surface);
- Transparent film (3m x 65cm – for assessment of reliability).

## Procedures

### *Dynamic footprints acquisition*

The 10m walkway was covered with lining paper for each trial. Each participant was instructed to stand barefoot at one end of the walkway and asked to walk up and down the walkway twice for acclimatisation. At the beginning of the walkway, participants were instructed to place both feet in a tray of coloured talcum powder and asked to commence walking at their own cadence, looking straight ahead and continue to walk past the lined paper. Once a collection of footprints were obtained midgait analysis was employed to identify 3 consecutive prints. To prevent smearing each footprint was sprayed with artist's fixative.

### *Static footprints acquisition*

Each participant stood barefoot and was asked to step into a tray of coloured powder. Standing within the tray, participants were instructed to march on the spot, at their own pace looking straight ahead for a period of 20 seconds. Participants were then asked to step forward onto and then off the prepared lining paper. This was repeated until three footprints were obtained. This approach was termed as a '*quasi-static*' method that entails movement in a pragmatic manner. It allows for data to be collected in a standardised manner and estimates the natural functional stance of that individual. All footprints were sprayed with artist's fixative to prevent any damage.

### *Static clinical acquisition*

Participants were instructed to walk on the spot as previously stated and again asked to step onto the prepared piece of lining paper (*quasi-static* approach). The participant

maintained this position whilst the investigator drew around the left and right foot with a pencil. The investigator ensured that the pencil was kept in an upright or vertical position and snug against the foot. The participant was then asked to step forwards off the paper. This process was repeated 3 times, inadequate drawings of the heel or forefoot area were rejected and the process was repeated.

Each procedure was repeated 2 weeks later to establish intrarater reliability.

### Methods of Analysis

All sets of data were analysed using the technique developed by Wilkinson *et al.* (1995). An A4 sized transparent grid with parallel lines was placed on each footprint to obtain a longitudinal bisection. The grid was aligned with the tip of the hallux and the medial side of the forefoot. Figure 4.1 (A) demonstrates the grid placement for footprint analysis. The grid-identified previously was then used to produce a line across the posterior aspect of the calcaneus (parallel to line A). In order to obtain consistent and reliable measurements, the length of the foot was divided into three equal sections. Therefore, a further 2 lines were drawn that determined midpoints C and D. A further line was drawn longitudinally connecting the midpoints of C and D; and was extended anteriorly towards the second and third digits. This longitudinal bisection was also extended posteriorly towards the heel. The intersection of line E and B (equals X) and was the anatomical landmark for connecting other reference lines (Figure 4.1, B and C).

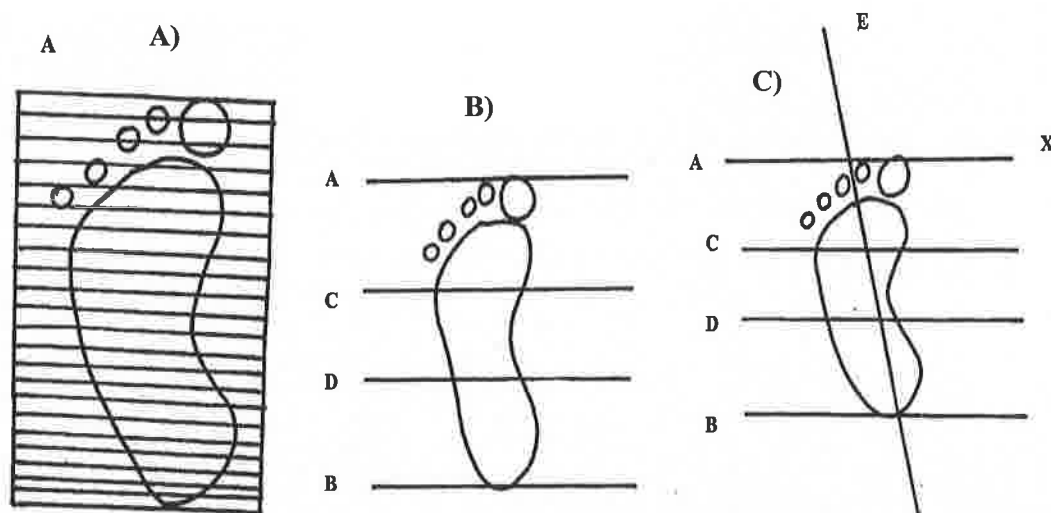
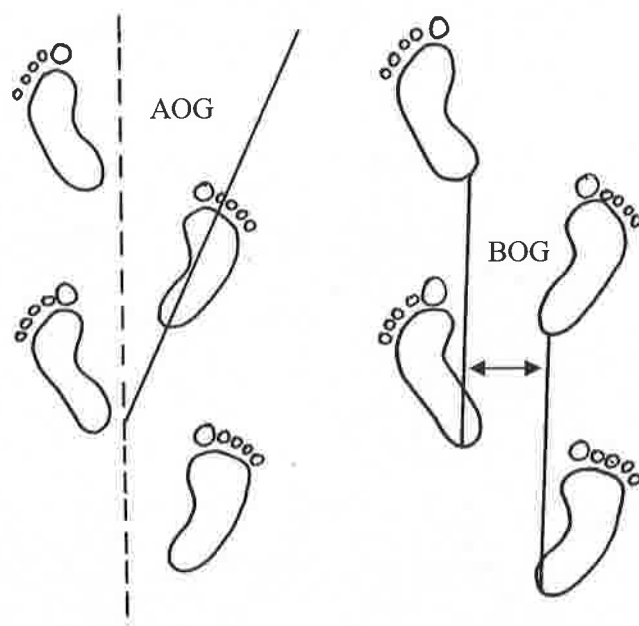


Figure 4.1: Transparent grid placement (A), bisection lines (B) and midpoints and longitudinal bisection (C) for the footprint technique.

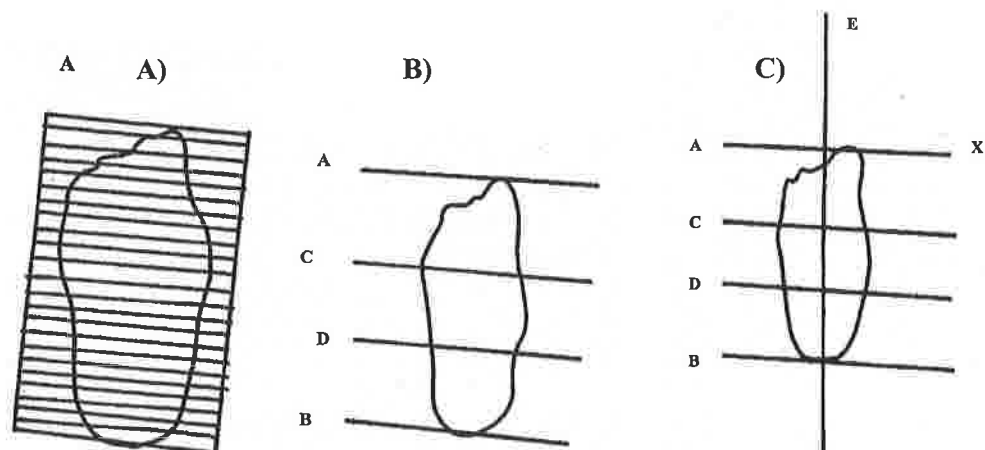
Once the bisection lines had been established the AOG and BOG was established. The BOG was identified by drawing a line from one heel reference point to next heel reference point of the same foot for left and right feet. The spatial distance between the lines of the right and left was then calculated in centimetres and formed the BOG. The 'line of progression' was also calculated by dividing the distance between the lines of the left and right foot. The AOG was formed by the intersection of the bisection of the footprint and the line identifying the line of progression. All of the measurements were made using a fine (0.5mm) non-permanent marker pen. The BOG was measured in centimetres with a ruler, whilst the AOG was measured in degrees using a standard tractograph (figure 4.2).



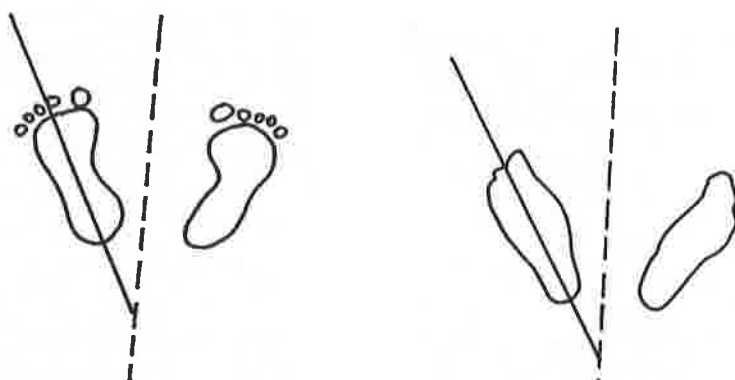
**Figure 4.2: Establishing the AOG and BOG of gait from dynamic footprints.**

As with the dynamic analysis, a transparent grid was placed over each foot for the static footprints and clinical technique (figure 4.3 A). The midpoint sections were also identified in the same manner (figure 4.3 B – C). Although in the dynamic analysis the bisection of the heel was connected to the bisection of the next heel of the same foot, this method cannot be used for the analysis static footprints and clinical technique. As a result the method was modified and involved the bisection of the heel being marked and a line drawn in a distal direction that was parallel to that of the lined paper which the footprint or clinical technique was produced. The line of progression or midline of the body was calculated by dividing the heel bisections of

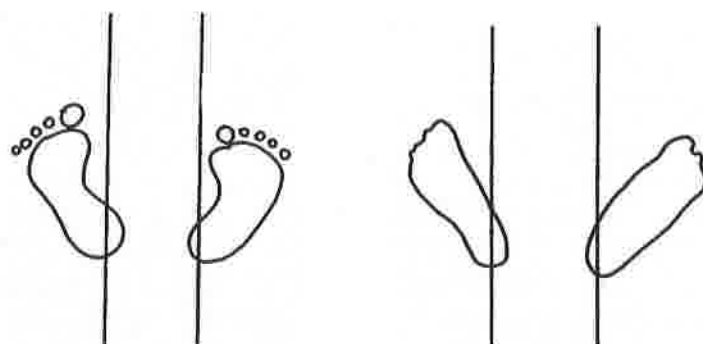
the left and right feet. The bisections and lines produced for the AOG and BOG for each static condition are illustrated in figures 4.4 and 4.5.



**Figure 4.3: Transparent grid placement (A), bisection lines (B) and midpoints (C) for the static footprint and clinical technique.** These diagrams illustrate the transparent grid placement, the three equal sections and the longitudinal bisection for the clinical technique.



**Figure 4.4: AOG for the static footprints and clinical technique.**



**Figure 4.5: BOG for the static footprints and clinical technique.**

### Statistical analysis

All data were examined and found to be normal in distribution using the Kolmogorov-Smirnov test of normality ( $p < 0.001$ ). Intrarater reliability of the AOG and BOG for all three conditions were assessed using ICCs [3, 1 model] (and 95% confidence intervals [CI]). ICCs were also employed to examine the reliability of the mean of the three measurements from each of the three conditions for the AOG and BOG. The ICC describes the overall agreement (random and systematic error) and is therefore considered a useful statistical assessment tool. The SEM was also calculated to provide an estimate of the amount of error associated with the measurement. The SEM is described as the statistical equivalent to the standard deviation (Daly and Bourke, 2000) and is considered to be useful by providing clinically relevant data (i.e. gives the amount of degrees of difference expected for repeated measures). Correlation coefficients (CoV) were also calculated to express the variation (as a percentage) between sessions/measurements.

To compare the relationship between each of the three conditions for the AOG and BOG was examined by comparing the mean dynamic, static and clinical values. A one-way analysis of variance (ANOVA) was performed to investigate the differences between each of the three conditions followed by Tukey's post hoc analysis to identify where the differences occurred, if any between the three conditions (Bland, 1995). In addition, a stepwise linear regression model was also employed to examine the ability of the static footprints and clinical measurement to predict a dynamic situation for the AOG and BOG. Paired  $t$  tests were also used to examine the difference between the left and right AOG for each of the three conditions. An alpha level of 0.05 was used for all tests of statistical significance. Finally, a Pearson's  $r$  correlation coefficient was further employed to investigate the consistency of the measurements obtained. Benchmarks endorsed by Fleiss (1981) were employed to interpret the ICC and Pearson  $r$  correlation values ( $>0.75$  excellent reliability; 0.4 to 0.75 fair-to-good reliability;  $<0.4$  poor reliability). All analyses were performed using the statistical package for social sciences (version 12.1) for Windows™ (SPSS™) (SPSS Science, London, UK). The significance level was set at  $p < 0.05$ .

### 4.1.3 Results

The mean, SD and range obtained for the AOG and BOG for each condition and session are summarised in table 4.1.

	Session 1 Mean $\pm$ SD (range)	Session 2 Mean $\pm$ SD (range)	Both sessions Mean $\pm$ SD (range)
<b>Left foot AOG (°)</b>			
Dynamic	9.8 $\pm$ 2.3 (4 – 14)	12.9 $\pm$ 3.1 (6 – 16)	9.9 $\pm$ 2.1 (4 – 16)
Static	10 $\pm$ 2.5 (6 – 16)	9.8 $\pm$ 2.1 (7.6 – 12.6)	9.8 $\pm$ 2.1 (6 – 16)
Clinical	10 $\pm$ 3.0 (6 – 18)	9.7 $\pm$ 2.7 (5 – 15.3)	9.7 $\pm$ 2.7 (5 – 18)
<b>Right Foot AOG (°)</b>			
Dynamic	12.9 $\pm$ 3.2 (6 – 22)	13.0 $\pm$ 2.9 (9 – 20)	13.0 $\pm$ 2.9 (6 – 22)
Static	13.7 $\pm$ 4.4 (8 – 28)	14 $\pm$ 3.9 (10 – 24.6)	14.0 $\pm$ 4.0 (8 – 28)
Clinical	13.6 $\pm$ 4.8 (4 – 26)	13.9 $\pm$ 3.5 (11 – 24)	13.9 $\pm$ 3.7 (4 – 26)
<b>BOG (cm)</b>			
Dynamic	9.8 $\pm$ 3.6 (4.1 – 17.5)	9.3 $\pm$ 3.3 (4.9 – 22.2)	9.5 $\pm$ 3.3 (4.1 – 22.2)
Static	14.2 $\pm$ 3.8 (8 – 23.1)	13.8 $\pm$ 3.1 (9.6 – 20.1)	13.8 $\pm$ 3.5 (8 – 23.1)
Clinical	13.8 $\pm$ 3.5 (7 – 20.7)	13.3 $\pm$ 3.2 (7.1 – 17.4)	13.3 $\pm$ 3.2 (7 – 20.7)

**Table 4.1: Mean values of the AOG and BOG for each condition and session.**

### Null hypothesis 1:

*The AOG and BOG calculated from dynamic footprints, static footprints and a clinical technique will not demonstrate acceptable intrarater reliability*

Intrarater reliability for each of the three conditions for the AOG and BOG are presented in table 4.2. The results demonstrate that a single examiner produced excellent reliability for the AOG and BOG for each condition with ICC values ranging from 0.872 – 0.947. The CoV was fairly small and ranged from 21.2% to 36.6%, with the largest variation noted for the dynamic AOG. The SEM varied from 1.5° to 2° for the AOG and 1.8cm to 1.9cm for the BOG. The values for intrarater reliability for the AOG and BOG for each condition are summarised in table 4.2.

	ICC (95% CI)	SEM	CoV (%)
<b>Left foot AOG</b>			
Dynamic	0.933 (0.855 – 0.970)	1.5°	21.2
Static	0.914 (0.816 – 0.961)	1.5°	21.4
Clinical	0.947 (0.884 – 0.976)	1.6°	27.8
<b>Right foot AOG</b>			
Dynamic	0.935 (0.858 – 0.971)	1.7°	22.3
Static	0.872 (0.731 – 0.941)	2°	28.5
Clinical	0.896 (0.779 – 0.953)	1.9°	25.1
<b>BOG</b>			
Dynamic	0.947 (0.883 – 0.976)	1.8cm	36.6
Static	0.944 (0.878 – 0.975)	1.9cm	25.3
Clinical	0.911 (0.809 – 0.960)	1.8cm	24

**Table 4.2: Intrarater reliability of the AOG and BOG for each condition.**



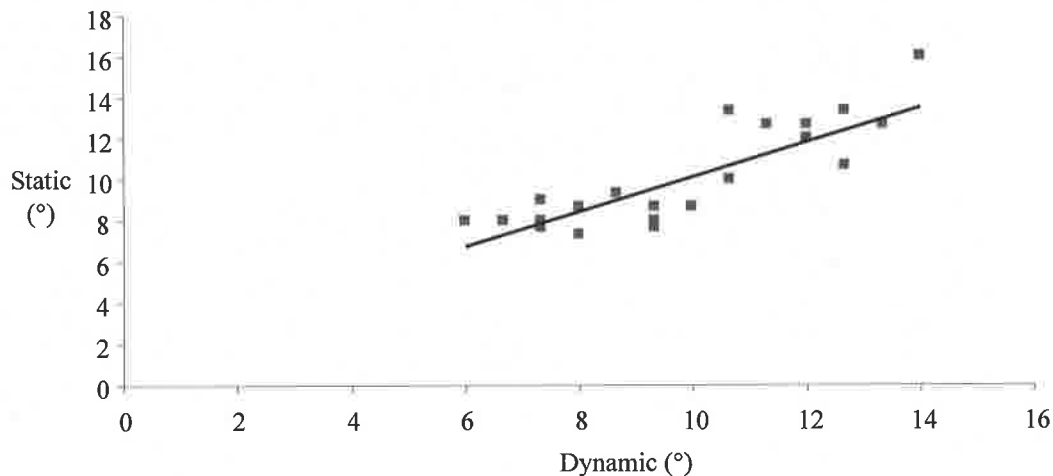
## **Null hypothesis 2:**

*There is no relationship between the AOG and BOG using dynamic footprints, static footprints and a clinical technique*

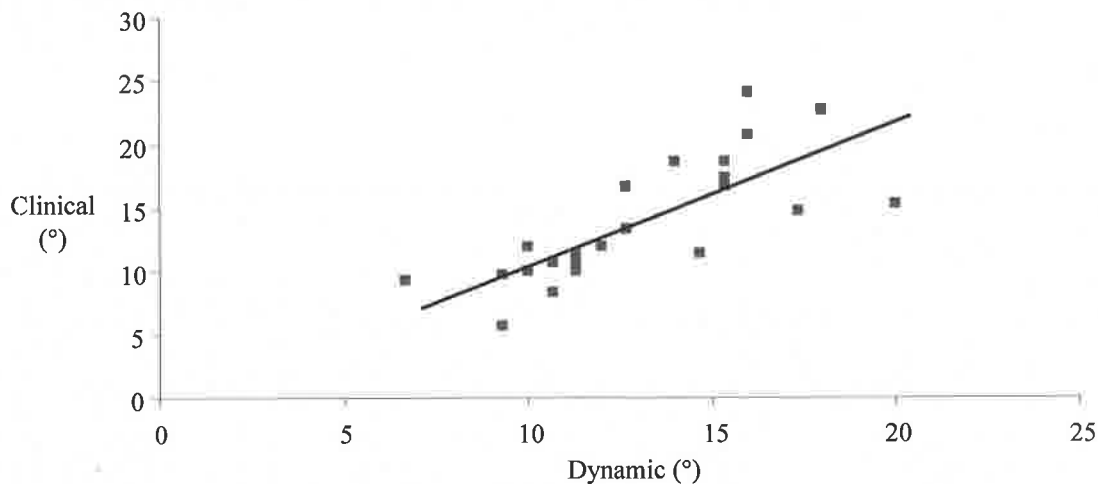
### **AOG**

The relationship between the three conditions for each parameter was examined by comparing the mean dynamic, static and clinical values of each parameter. The results of the one-way ANOVA demonstrated no significant differences between the three conditions for the left foot AOG ( $F=0.27$   $df$  2  $p=0.974$ ). However, it was noted that the dynamic footprint AOG was slightly lower (mean  $9.8^\circ$ ; SD 2.3) compared to AOG produced by the static footprints (i.e first session mean  $10^\circ$ ; SD 2.5) and clinical technique (mean  $10^\circ$ ; SD 3.0) and represents a mean difference of 0.20%. Linear regression analysis demonstrated that the static footprint of the AOG predicted 67.9% of that of a dynamic situation. This prediction however was somewhat lower at 53% for the clinical technique. Further linear regression analysis demonstrated that the clinical technique was able to predict 79% of that of the static footprint.

The one-way ANOVA also demonstrated no significant differences between the three conditions for the right foot's AOG ( $F=0.27$   $df$  2  $p=0.974$ ). Although, again it was identified that the dynamic footprint AOG was slightly lower (mean  $12.9^\circ$ ; SD 3.2) compared to the AOG produced by the static footprints (mean  $13.7^\circ$ ; SD 4.4) and clinical technique (mean  $13.6^\circ$ ; SD 4.8) and represents a mean difference of 0.8%. Linear regression analysis revealed that the right static footprint of the AOG predicted 60.4% of that of a dynamic situation. This prediction however was slightly lower at 57% for the clinical technique. Further analysis using linear regression revealed that the clinical technique was able to predict 82% of that of the static footprint. Pearson's  $r$  correlation ranged from 0.72 – 0.90 indicating good-to-excellent consistency between all measurements for the left and right AOG. The correlation between mean dynamic and mean static for the left foot AOG and mean static and mean clinical right foot AOG is illustrated in figure 4.6 and 4.7 respectively.



**Figure 4.6: Dynamic and static correlation for the AOG of the left foot.**



**Figure 4.7: Clinical and static correlation for the AOG of the right foot.**

### *BOG*

Analysis of the BOG using the one-way ANOVA identified significant differences between the three conditions ( $F 12.158$   $df 2$   $p < 0.001$ ). Tukey's post hoc test revealed that there were significant differences between the dynamic versus static and clinical conditions ( $p < 0.001$ ) with the static (mean 14.3, SD 3.8) and clinical (mean 13.8, SD 3.5) BOG being wider than that of the dynamic (mean 9.81, SD 3.6) BOG. This produced mean differences of 4.5% and 4% for the static and clinical conditions respectively. Linear regression assessment demonstrated that the static and clinical BOG predicted 54% and 48% of the variance calculated from the dynamic condition. Further inquiry using linear regression analysis revealed that the clinical technique

was able to predict 69% of that of the static footprint for the BOG. Pearson's  $r$  correlation coefficient demonstrated values of 0.71 – 0.83 and suggests fair-to-excellent consistency between these measures for the three conditions. Figure 4.8 illustrates the correlation between the dynamic and static BOG whilst table 4.3 provides a summary of comparative results between conditions for the AOG and BOG.

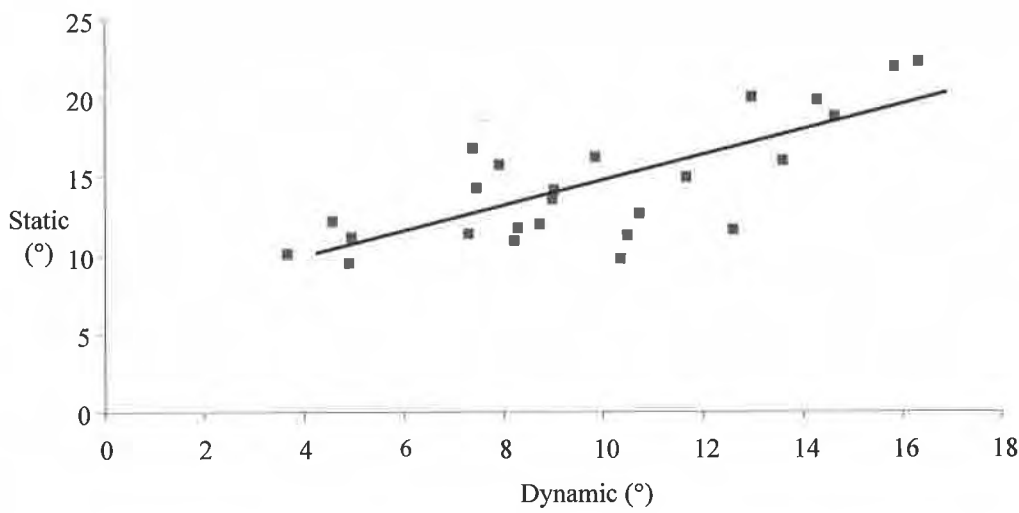


Figure 4.8: Dynamic and static correlation for the BOG.

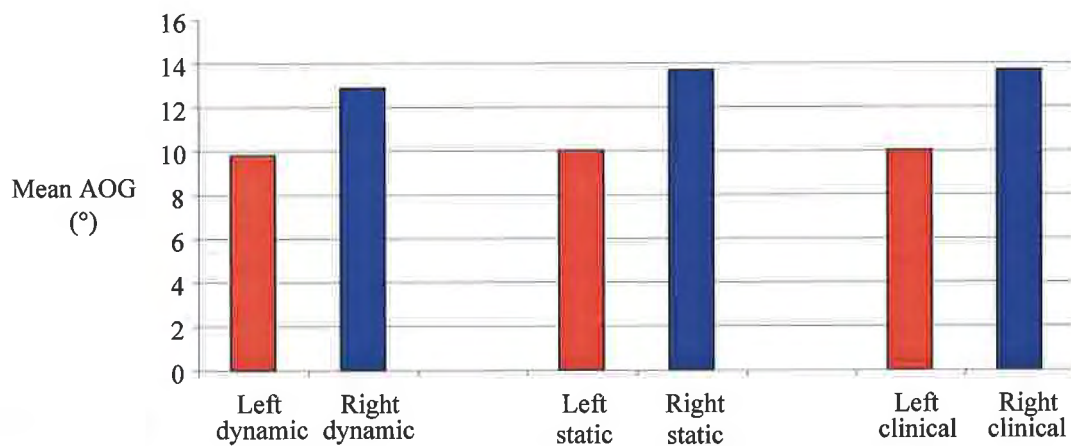
	<i>P</i> value	95% CO	Pearson's $r$ correlation
<b>Left foot AOG</b>			
Dynamic versus static	0.976	- 1.8240 – 1.5296	0.832
Dynamic versus clinical	0.981	- 1.8092 – 1.5444	0.728
Static versus clinical	1.000	- 1.6620 – 1.6916	0.887
<b>Right foot AOG</b>			
Dynamic versus static	0.775	- 3.5511 – 1.9759	0.788
Dynamic versus clinical	0.801	- 3.4979 – 2.0291	0.764
Static versus clinical	0.999	- 2.7103 – 2.8167	0.905
<b>BOG</b>			
Dynamic versus static	0.000*	-6.9289 – -2.0935	0.750
Dynamic versus clinical	0.000*	-6.5041 – -1.6687	0.710
Static versus clinical	0.907	-1.9929 – 2.8425	0.839

Table 4.3: Summary of results for the AOG and BOG. The  $p$  values for the Tukey's post hoc test illustrate significant differences.

#### *Comparisons between left and right foot AOG for all conditions*

The relationship between the left and right AOG was evaluated by comparing the mean value for each foot and each condition. For the dynamic condition the results revealed an increase of 3.1° (31%) for the right foot compared to the left foot. A

paired  $t$  test demonstrated that this variation to be significant ( $t = -6.66$ ,  $df = 24$ ,  $p < 0.001$ ). For the static condition, the AOG for the right foot was  $3.7^\circ$  (37%) larger compared to the left foot. This observation was supported by a paired  $t$  test which revealed this value to be significantly different ( $t = 5.53$ ,  $df = 24$ ,  $p < 0.001$ ). A larger AOG of  $3.7^\circ$  was also noted for the right foot compared to the left foot. Again, further inquiry demonstrated a significant difference ( $t = 5.38$ ,  $df 24$ ,  $p < 0.001$ ) (figure 4.9).



**Figure 4.9: Significant differences between the left and right AOG for the three conditions.**

### Summary of results

- Data from 25 participants were collected on two occasions and was measured by one examiner;

*Null hypothesis 1: The AOG and BOG calculated from dynamic footprints, static footprints and a clinical technique will not demonstrate acceptable intrarater reliability*

- Excellent intrarater reliability was obtained for the AOG and BOG for the three conditions;

*Null hypothesis 2: There is no relationship between the AOG and BOG using dynamic footprints, static footprints and a clinical technique*

- No significant differences were noted between the mean AOG values for all of the conditions;
- Significant differences were noted between mean static versus mean dynamic and mean clinical versus mean dynamic for the BOG;

- No significant differences were noted between the mean clinical versus mean static conditions;
- Linear regression revealed that the AOG for the left and right foot predicted 67 and 60% (static footprints), and 53 and 57% (clinical technique) of that of a dynamic situation;
- Linear regression for the BOG was slightly lower with the static footprint and clinical technique predicting 54% and 48% of that of a dynamic situation.

#### **4.1.4 Discussion**

The aims of this study were two fold. Firstly, the study aimed to establish intrarater reliability of a method employed to investigate the AOG and BOG from dynamic and static footprints as well as a static clinical technique. Secondly, it was the purpose of this study to establish if differences occurred between the conditions for the AOG and BOG. The first hypothesis that the AOG and BOG calculated from dynamic footprints, static footprints and a clinical technique will not demonstrate acceptable intrarater reliability was rejected. The second hypothesis that there is no relationship between the AOG and BOG using dynamic footprints, static footprints and a clinical technique was rejected for the AOG but accepted for the BOG.

The potential to predict dynamic alignment using simple, cost effective measures is appealing. Although several biomechanical measures are performed during static conditions, few if any have reported on a reliable and valid method of obtaining and recording the AOG and BOG. The suggestion that limb posture during static assessment infers that of a dynamic situation (McPoil and Cornwall, 1996; Perry, 1992) is supported by this study. Whilst it is considered that structural characteristics of the lower limb influence dynamic performance, a basic assumption of validity focuses on the ability of the static measure to reflect dynamic behaviour. Although data obtained from dynamic footprints provides useful and reliable information (Wilkinson and Menz, 1997; Kernozek and Ricard, 1990) its use within the clinical setting and clinical observational research is limited due to lack of space and time. In an attempt to overcome these limitations the present study employed a one-step, quasi-static method for evaluating the AOG and BOG from footprints and a clinical technique. This study demonstrated excellent intrarater reliability for the AOG and

BOG for the dynamic footprints, static footprints and clinical technique. The results demonstrated ICC values between 0.872 and 0.947 with relatively low CoV (highest 36.6%) and clinically acceptable SEM values of  $<2^{\circ}$  for the AOG and  $<2\text{cm}$  for the BOG. These results suggest that the original technique (dynamic) and the adopted technique (and quasi-static approach) for the static footprints and clinical technique is reliable with the latter method being justified for clinical and research purposes.

The dynamic mean values obtained for the AOG and BOG are similar to previous reports by Wilkinson and Menz (1997) and Rigas (1984) as well as others (Murray *et al.*, 1970; Murray *et al.*, 1969; Morton, 1932; Dougan, 1924). The range of values of  $6^{\circ}$  to  $28^{\circ}$  for the static footprint and clinical technique for the AOG are similar to those reported by McIlroy and Maki (1997) who identified an AOG which range from  $13^{\circ}$  to  $52^{\circ}$ , and Saltzman *et al.* (1995) who reported AOG values of  $7^{\circ}$  to  $22^{\circ}$ . Bryant (2001) however, detailed slightly smaller values in her study and reported a range of  $0^{\circ}$  to  $15^{\circ}$ . It was noted that the AOG was consistently higher compared to that of the left foot for all three conditions. These results are similar to the findings of Dougan (1924), Rigas (1984) and more recently Wilkinson and Menz (1997) from a dynamic perspective and Bryant (2001) and McIlroy and Maki (1997) clinically. These findings however conflict with that of Murray (1970) and Boenig (1977) who reported the left foot as demonstrating a higher AOG. Rigas (1984) comments that these asymmetries could have an important contribution in forming the characteristics of gait and stance of an individual and supports the thoughts of Smith (1954) on the attitude of standing. In addition, whilst it was not recorded during data collection, observation of static stance (footprint and clinical) revealed forward advancement of the right foot in comparison to the left foot. These observations not only offer a rationale for an increased AOG for the right foot, but also asymmetry of stance. In some cases, dominance of one side over the other could have been a factor. Determining whether participants were left or right handed/footed by having them kick or kick a ball could have added further clarity to this issue. Further inquiry could prove useful to establish these trends in static stance in a variety of musculoskeletal conditions such as those affecting the foot, knee and hip.

The BOG demonstrated significant differences between the dynamic versus static and dynamic versus clinical. This was also supported by the linear regression analysis which indicated that the static BOG (footprint and clinical technique) was a poor predictor of a dynamic situation. These results are possibly not surprising, since many individuals adopt a narrower BOG dynamically in comparison to a static position (Whittle, 2002). The mean values for the dynamic BOG reported in this study however support values reported by previously mentioned investigators (Wilkinson and Menz, 1997; Boenig, 1977; Murray *et al.*, 1970). Comparisons between the static and clinical BOG showed no significant differences and validate the representation of a clinical technique compared to footprint data. Despite the fact that significant differences were noted between the dynamic BOG and the two static conditions, the mean BOG values of 7cm to 23cm were similar to the values described by Bryant (2001) (5cm to 15cm) and McIlroy and Maki (1997) (6cm to 28cm).

Although excellent reliability of the techniques was attained during this study, potential errors of measurement associated with marker thickness obtained with the marker pen. Prior research has linked pen markings on rearfoot measurement as a significant contributing factor to poor reliability (Menz, 1995). Such factors therefore should be considered when assessing footprint parameters (Wilkinson and Menz, 1997). All participants were encouraged to walk at their own selected cadence, whilst many studies encourage the use of this method of data collection, participants may have been constrained to walk along the 10m paper path in a straight line. The width of the paper was 56cm, although this was not an apparent problem during data collection, wider pieces of paper would facilitate a less constrained direction of gait and would particularly useful during data collection of pathological and paediatric gait assessment. Operator error whilst tracing each foot during data collection for the clinical technique could have produced inaccurate representation of the foot, although the risk was recognised and minimised by the investigator being conscious to hold the pencil vertical and close to foot. During reliability analysis of the measurement technique, bowing of the microfilm occurred. However, this was minimised by anchoring of all edges to the supporting surface which reduced the possibility of any movement occurring during measurement.

#### 4.1.5 Conclusion

If clinical measures of the lower limb are to be used for clinical and research purposes it is vital that they are objective, valid and reliable. This study showed that using a single examiner the AOG and BOG has acceptable reliability when obtained from dynamic footprints, static footprints and clinical technique. Although the AOG was similar when measured in all conditions, the dynamic BOG was smaller compared to the static footprints and clinical technique. This suggests that dynamic is best and that static footprints and clinical technique is compromised. Nevertheless, the larger BOG recorded from both static conditions mirror the wider BOG used during static stance. Overall, this study suggests that static footprints and a clinical technique for the AOG and BOG have the capability to reflect that of a dynamic situation. The development of a reliable standardised clinical technique that employs a quasi-static approach presented in this study provides the foundation to a standardised referenced method which can be used when obtaining clinical measures of the lower limb.

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This study was adapted and published in *The Foot* journal (Curran *et al.*, 2005) and the *Journal of American Podiatric Medical Association* (Curran *et al.*, 2006a). The former article focussed on dynamic versus static assessment whilst the second article concentrated on the role of asymmetrical stance (*quasi-static approach*) and the development of the clinical technique.



## **4.2 An investigation of the A angle and tubercle sulcus angle: comparisons and reliability**

### **4.2.1 Rationale and aim**

Pain associated with the PFJt is a common and complex phenomenon. It is thought to have a multifactorial aetiology that includes malalignment of the patella. This provides the background to clinical measurement of PFJt alignment which involves measurement of frontal plane position of the patella and other osseous structures (Post *et al.*, 2002). Although the Q angle is the most popular reported method for examining PFJt alignment, other clinical measures such as the A angle and the TS angle have received limited attention (Arno, 1990; Hughston *et al.*, 1984). Both of these measures are thought to represent the relationship between the patella and tibial tuberosity but their reliability and clinical value have been questioned (Tomsich *et al.*, 1996). To date, no information exists on the reliability of the TS angle whilst the A angle in particular has been criticised due to its lack of reliability and difficulty in palpating bony landmarks. Additionally, the A angle is currently a non-weightbearing measure; therefore investigating whether the measure could be modified to a weightbearing measure would be useful to help investigate the relationship between PFJt alignment and foot posture. The aim of this second study was to establish optimal data collection methods for the A angle and TS angle and determine the intrarater and interrater reliability of these measures. The following 2 null hypotheses were set:

1. The A angle and TS angle will not demonstrate acceptable intrarater and interrater reliability;
2. There will be no differences between the A angle and TS angle.

### **4.2.2 Method**

The study utilised a double session, repeated measures design using three examiners. All participants were fully informed of the study's purpose and gave their informed consent (appendix 2) before participating in the study, which was approved by the Ethics Committee of the School of Health and Social Sciences, UWIC (appendix 3).

## Participants

Twenty volunteers (12 females and 8 males) were recruited from the undergraduate student population at the Wales Centre for Podiatric Studies, UWIC. The participants had a mean age of 28.6 years (SD 8.6, range 21 – 50 years), a mean height of 1.2m (SD 0.0, range 1.61 – 1.88m) and a mean weight of 71.4kg (SD 14.1, range 50 – 93kg). Ten of these participants however, were involved in part 1 (training session) of this study. All participants were included if they had no history of knee pain and were available for the training session (if required) and two measurement sessions. The examiners who took part in the study were 3 podiatrists with a minimum of 4 years postgraduate experience (mean 5.3, range 4 – 6 years). Although one examiner had some experience of using the A angle and TS angle the other two examiners had no experience of these measures.

## Equipment and materials

- Treatment couch with adjustable height;
- Large goniometer (30cm, 12.7cm moveable arm, scale = 1° increments);
- Small goniometer (17cm, 8.5cm moveable arm, scale = 1° increments);
- Circular adhesive paper markers (0.8cm in diameter);
- Data collection sheets, clipboard and black biro;
- A4 brown labelled envelopes (A, B and C) for completed data sheets.

Each examiner was allocated and positioned in separate areas (corners) of a large quiet, clinical room with multiple cubicles. The temperature of this room was ambient and all sessions (training and measurement) were held at the same time of day to allow for consistency.

## Part 1

### *Training session*

Seventy-two hours prior to the training session the three examiners were provided with written information on the technique of the measures to be investigated. This information focussed on the technique of Hughston *et al.* (1984) for the TS angle and a formulated technique established from the papers of Selfe *et al.* (1996); DiVeta and Vogelbach (1992) and Arno (1990) for the A angle (appendix 4). The training session

which involved 8 volunteers lasted around 90 minutes and was held to allow for discussion, practice of the technique and discussing any problems experienced. Particular emphasis was given to establishing and eliminating potential sources of measurement variance/errors relating to the clinician, participant, equipment, environment and method. During the training session all of the examiners felt comfortable performing the TS angle measure although it was noted that all of the examiners felt that the tibial tubercle proved the most difficult landmark to identify. It was noted that this bony landmark was in some individuals either very prominent, prominent with a lateral ridge or lacked a prominent aspect. To aid standardisation it was proposed that the most prominent aspect of this landmark should be palpated and marked with the adhesive circle. All examiners felt comfortable with the palpation of the patella and noted that the flexed knee position facilitated in the identification of the medial and lateral borders of the patella which allowed the centre of the patella to be marked. In addition, it was also proposed and agreed that the distal arm of the goniometer be vertically aligned to the tibial tubercle and the axis of rotation was placed between the two adhesive markers.

In comparison, the A angle measure proved more challenging with all examiners stating dissatisfaction with the technique. This was based on the palpation and identification of the inferior pole of the patella. To overcome this problem a suggestion was made that the centre of the patella was to be palpated and identified. This approach mirrors that of the palpation and landmarks of the patella used for the TS angle technique. The palpation and identification of the tibial tubercle was also performed in this manner. An agreement was also made that the distal arm of the goniometer was aligned vertically to the tibial tubercle and the axis of rotation was between the two markers. The A angle measure therefore was renamed the '*modified A angle*' and a decision was made to not pursue further inquiry into the traditional A angle measure. A proposal was made for the modified A angle to be obtained in a standing position, using a quasi-static approach. This strategy was thought to add a dimension of functional significance as well as allowing comparisons to be made between the modified A angle and the TS angle A further training session (60 minutes) allowed all of the examiners to practice the techniques and all felt satisfied with the modifications proposed. As a result these techniques were adopted for the second part of the study.

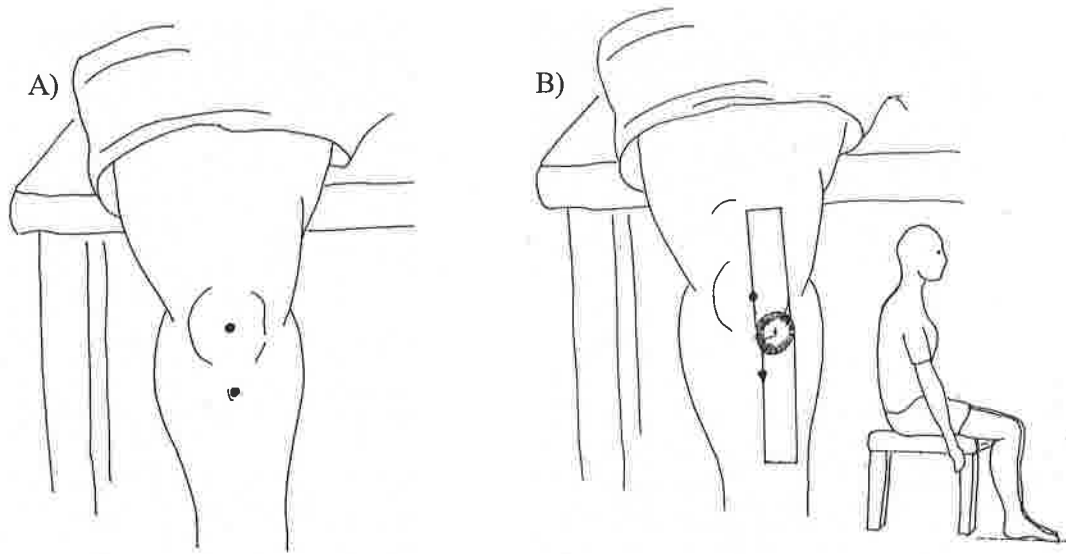
## Part 2

The second part of this study involved measuring the TS angle and the modified A angle established previously in part 1. For both measures all participants were barefoot and wore shorts to expose the anterior aspect of the knee. The right knee of each participant was examined which was determined at random (by flipping a coin). Each participant was randomly allocated a number; this randomised process was also used to divide all of the participants into 3 groups. Groups A and B contained 7 participants each, whilst 6 participants made up group C. Within these groups, each participant was given a number at random. Each group rotated through each examiner three times for the measurements to be performed. For each group, each examiner was provided data collection sheets for the TS angle and modified A angle measure which were labelled with examiner A, B or C and measurement 1, 2 or 3. Data were entered into the columns provided, the examiners were instructed to measure the TS angle of all the group participants first and then the modified A angle. In order to minimise recall bias the coded number and group allocation for each participant was changed at random for the second measurement session which was performed two weeks later. On completion of each of the measurements for each participant the examiner placed the data collection sheet into the allocated A4 envelope, which was sealed at the end of each data collection session.

### *TS angle measurement procedure*

Each participant was seated towards the edge of the examining couch with both knees flexed to 90° and both feet plantigrade. The height of the examination couch was adjusted accordingly for each individual. The examiner used the large goniometer to verify the position of 90° knee flexion by aligning the arms with the lateral aspects of the distal femur and proximal tibia. Each participant was instructed to sit relaxed, facing forwards, without contracting their quadriceps or hamstring muscle groups. The examiner palpated the lateral and medial perimeters of the patella and approximated the centre of the patella by marking with adhesive circular markers. The most prominent part of the tibial tubercle was palpated and marked in the same manner previously highlighted. A small goniometer was then used to measure the TS angle, each arm was aligned to each marker, and the distal arm in particular was vertically aligned with the tibial tubercle. The axis of the goniometer was positioned

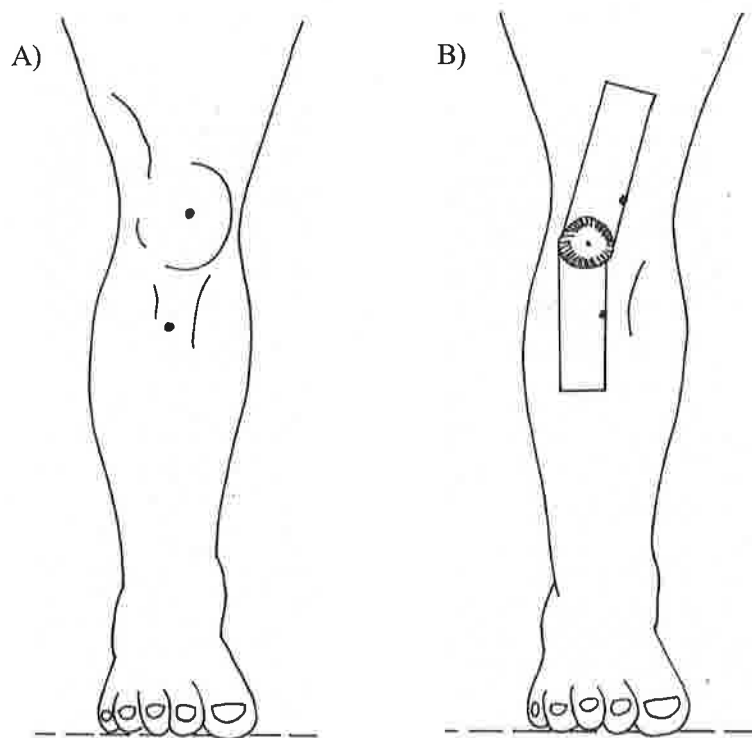
midway between each adhesive marker (figure 4.10). This measurement was repeated three times. Adhesive markers were removed at the end of each measurement.



**Figure 4.10: TS angle measure.** This simple drawing illustrates the seated position, marker placement and alignment of the goniometer to record the TS angle. The distal arm was vertically aligned with the tibial tubercle and the axis of the goniometer was positioned midway between each marker.

#### *Modified standing A angle measurement procedure*

The quasi-static method developed in study one was employed to ensure the approach to the measurement procedure was standardised. Each participant was instructed to march on the spot for approximately 20 seconds they were then asked to take one step forward, stepping into their own natural AOG and BOG. If the participant stumbled or moved out of position or the approach felt unnatural, they were asked to repeat this procedure. The participant was instructed to remain relaxed without contracting the quadriceps or hamstring muscle groups. The lateral and medial borders of the patella were palpated to help approximate the centre of the patella, which was identified using an adhesive circular marker. The most prominent part of the tibial tubercle was then palpated and marked in the same manner. Each arm of a small goniometer was then aligned to each marker (proximal to centre of the patella and distal arm to the tibial tubercle). In particular the distal arm was vertically aligned with the tibial tubercle and the axis of the goniometer was positioned midway between each adhesive marker (figure 4.11). This measurement was repeated three times. The adhesive markers were removed at the end of each measurement.



**Figure 4.11: Modified A angle measure.** The left (A) illustration shows the marker placement (centre of the patella and tibial tubercle). The illustration on the right (B) shows how the goniometer was aligned to the markers. The distal arm was vertically aligned with the tibial tubercle and the axis of the goniometer was positioned midway between each marker.

### Statistical analysis

All data were entered and analysed using SPSS™ version 12.1 (SPSS™, London, UK) software package and was found to be normal in distribution using the Kolmogorov-Smirnov test of normality ( $p < 0.001$ ). The intrarater and interrater reliability of a single measurement was compared with the mean of the three measurements for the TS angle and modified A angle. Reliability was determined using ICCs (and 95% CI). The ICC <sup>[3,1]</sup> model was employed to examine the reliability of the first measurement whilst the ICC <sup>[3, k]</sup> model was used to establish the reliability of the mean of the three measurements. Paired *t* tests were also conducted to make sure that there were no systematic differences between the repeated measures for each examiner. To determine the interrater reliability, the ICC <sup>[2, 1]</sup> model was employed to evaluate the reliability of the first of the three measurements, whilst the ICC <sup>[2, k]</sup> model was employed to examine the reliability between the mean of the three measurements obtained. As in preliminary study one (and to allow for consistency through the preliminary studies) the levels of acceptable reliability approved by Fleiss (1981) were adopted for the ICC values ( $>0.75$  excellent reliability; 0.4 to 0.75 fair-

to-good reliability; <0.4 poor reliability). The CoV was calculated to demonstrate the variation between sessions (expressed as a percentage) along with the SEM to provide an estimate of the amount of error associated with the measurement. Finally, the differences between the seated TS angle and modified A angle was determined by calculating a paired *t* test. All analyses were performed using a significance level set at  $p < 0.05$ .

### 4.2.3 Results

The TS angle and the modified A angle was measured three times by each examiner on each occasion. The mean, SD and range for each session and examiner for both measures investigated are presented in table 4.4.

	TS angle measure			Modified A angle		
	Examiner A Mean° ± SD (range°)	Examiner B Mean° ± SD (range°)	Examiner C Mean° ± SD (range°)	Examiner A Mean° ± SD (range°)	Examiner B Mean° ± SD (range°)	Examiner C Mean° ± SD (range°)
Session 1	2.6 ± 2.4 (0 – 8)	2.5 ± 2.4 (0 – 8)	1.6 ± 2.0 (0 – 8)	11.5 ± 3.0 (4 – 18)	12.1 ± 3.6 (2 – 19)	12.0 ± 2.7 (6 – 18)
Session 2	2.5 ± 2.6 (0 – 10)	3.0 ± 2.2 (0 – 8)	1.7 ± 2.0 (0 – 8)	11.7 ± 3.5 (4 – 18)	12.5 ± 3.0 (6 – 19)	11.8 ± 2.7 (6 – 18)
Both sessions	2.6 ± 2.5 (0 – 7.3)	2.8 ± 2.3 (0 – 7.3)	1.6 ± 2.0 (0 – 6)	11.6 ± 3.2 (6.6 – 18.6)	12.3 ± 3.3 (4.6 – 18.6)	11.9 ± 2.6 (6.6 – 15.6)

Table 4.4: Descriptives of the TS angle and the modified A angle for all examiners and each session.

### Null hypothesis 1:

*The A angle and TS angle will not demonstrate acceptable intrarater and interrater reliability*

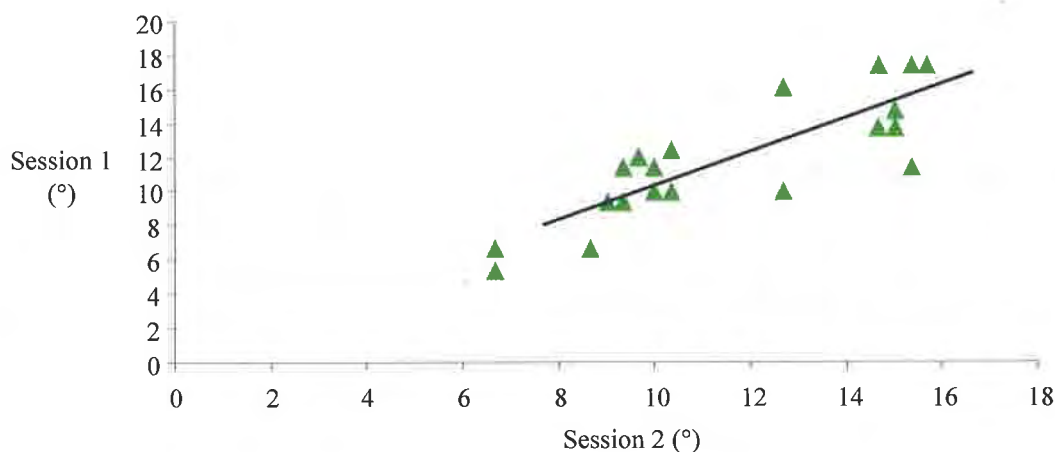
#### *Modified A angle*

Intrarater reliability of the modified A angle revealed that each examiner produced good-to-excellent reliability for a single measure and excellent reliability for the average of 3 measures with ICC values ranging from 0.685 to 0.779 and 0.778 to 0.829 respectively. The average of the 3 measures for intrarater reliability however showed the ICC values to be slightly higher. Paired *t* tests demonstrated that there were no significant differences ( $p > 0.05$ ) in the first measure and average of the three measures between the measurement sessions for each examiner. The CoV was small for all examiners and ranged from 3.6% to 4.6% which suggests that the measure

variation was small from one session to the next. The SEM varied from 1.6° to 1.8°. The values for intrarater reliability for the modified A angle are presented in table 4.5 below whilst figure 4.12 shows an example of the linear correlation for the most reliable examiner between session one and two for the average of the three measures.

Examiner	First measure			Average of the three measures		
	ICC (95% CI)	CoV (%)	SEM(°)	ICC (95% CI)	CoV (%)	SEM(°)
A	0.779 (0.55 – 0.906)	27	1.8	0.829 (0.619 – 0.929)	27	1.8
B	0.685 (0.359 – 0.862)	22	1.7	0.778 (0.521 0 0.906)	26	1.8
C	0.762 (0.491 – 0.898)	21	1.6	0.797 (0.556 – 0.914)	23	1.7

**Table 4.5: Intrarater reliability of the modified A angle.**



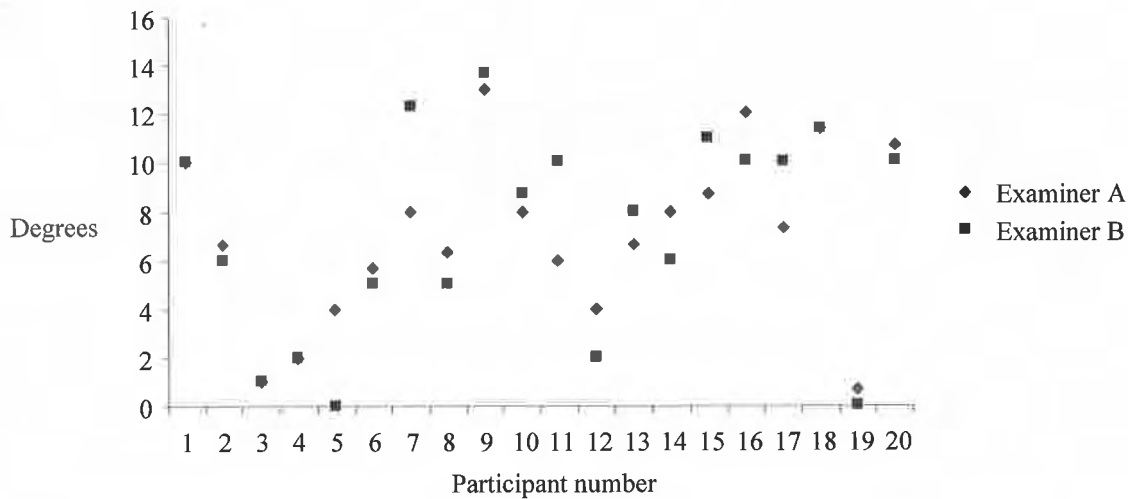
**Figure 4.12: Modified A angle intrarater reliability example, examiner A.** This figure presents the average of the three measurements between sessions one and two.

Interrater reliability demonstrated moderate-to-good (0.653 – 0.715) reliability for a single and average of the 3 measures. The CoV was small (range 23% – 26%) whilst the SEM ranged from 1.5° to 1.8°. The values of interrater reliability for the modified A angle are presented in table 4.6. Figure 4.13 demonstrates the differences in the modified A angle between examiners A and B.

Session	First measure			Average of the three measures		
	ICC (95% CI)	CoV (%)	SEM(°)	ICC (95% CI)	CoV (%)	SEM(°)
1	0.663 (0.432 – 0.835)	24.8	1.8	0.653 (0.417 – 0.829)	26	1.8
2	0.715 (0.504 – 0.863)	23	1.5	0.677 (0.451 – 0.843)	25	1.8

**Table 4.6: Interrater reliability of the modified A angle.**





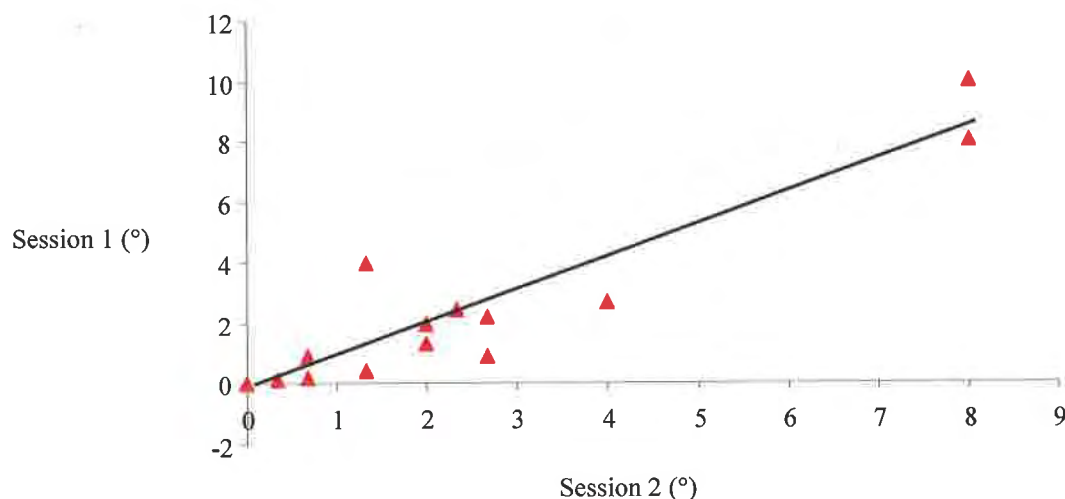
**Figure 4.13:** Example of the variations between examiners for the modified A angle. Paired measurement differences between average values of the modified A angle (session 1) from examiners A and B.

#### *TS angle*

Intrarater reliability of the TS angle demonstrated that each examiner produced excellent reliability for a single and average of 3 measures with ICC values ranging from 0.849 to 0.925. As with the modified A angle the ICC values for the average of the 3 measures were consistently higher (0.870 - 0.925). In addition, these values were slightly higher compared to that of the modified A angle. Paired *t* tests demonstrated that there were no significant differences ( $p > 0.05$ ) in the first measure and average of the three measures between the measurement sessions for each examiner. The CoV was small for all examiners and ranged from 9% to 19% indicating that there was a small variation in the measures between session one and two. The SEM for TS angle measurement were slightly better than the modified A angle which varied from 1.4° to 1.6°. Table 4.7 presents the intrarater reliability values for all examiners whilst figure 4.14 provides an example of the most reliable examiner.

Examiner	First measure			Average of the three measures		
	ICC (95% CI)	CoV(%)	SEM(°)	ICC (95% CI)	CoV(%)	SEM(°)
A	0.891 (0.746 – 0.955)	11	1.6	0.925 (0.822 – 0.970)	9	1.6
B	0.789 (0.542 – 0.911)	19	1.6	0.592 (0.592 – 0.923)	17.1	1.5
C	0.849 (0.658 – 0.937)	12	1.5	0.870 (0.701 – 0.946)	11.3	1.4

**Table 4.7:** Intrarater reliability of the TS angle.

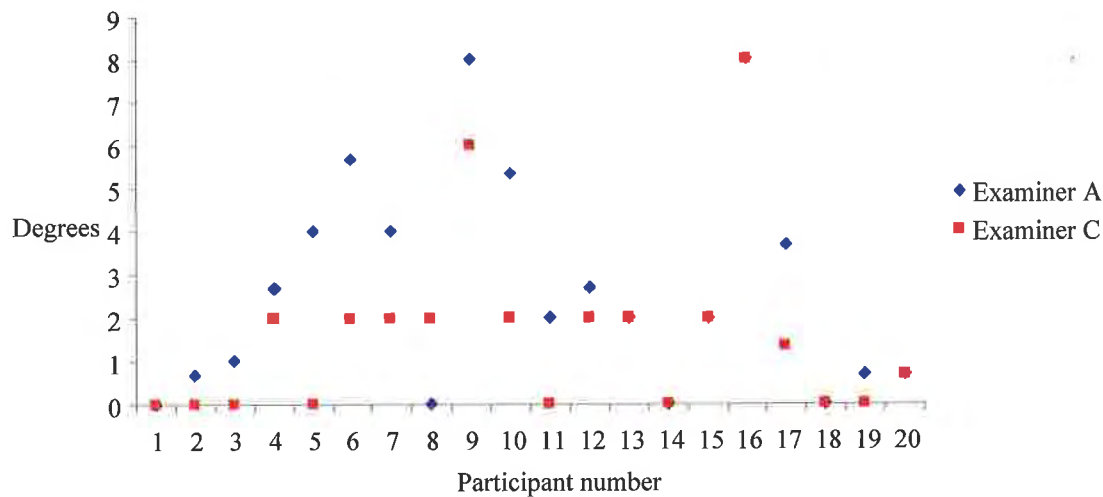


**Figure 4.14: TS angle intrarater reliability example, examiner A.** This figure presents the average of the three measurements between sessions one and two.

Interrater reliability demonstrated moderate-to-good (0.664 – 0.701) reliability for a single and the average of the 3 measures. It was noted that these values were slightly higher than the modified A angle ICC values. The CoV was small (range 10.5% – 19%). As with the intrarater reliability of the TS angle the SEM values were slightly lower and ranged from 1.5° to 1.6°. The values of interrater reliability for the modified A angle are presented in table 4.8. Figure 4.15 provides a visual representation of the differences in the TS angle between examiners A and C.

Session	First measure			Average of the three measures		
	ICC (95% CI)	CoV (%)	SEM(°)	ICC (95% CI)	CoV (%)	SEM(°)
1	0.664 (0.432 – 0.835)	11	1.6	0.701 (0.485 – 0.856)	10.5	1.5
2	0.665 (0.421 – 0.830)	11.2	1.6	0.696 (0.477 – 0.853)	19	1.5

**Table 4.8: Interrater reliability of the TS angle.**

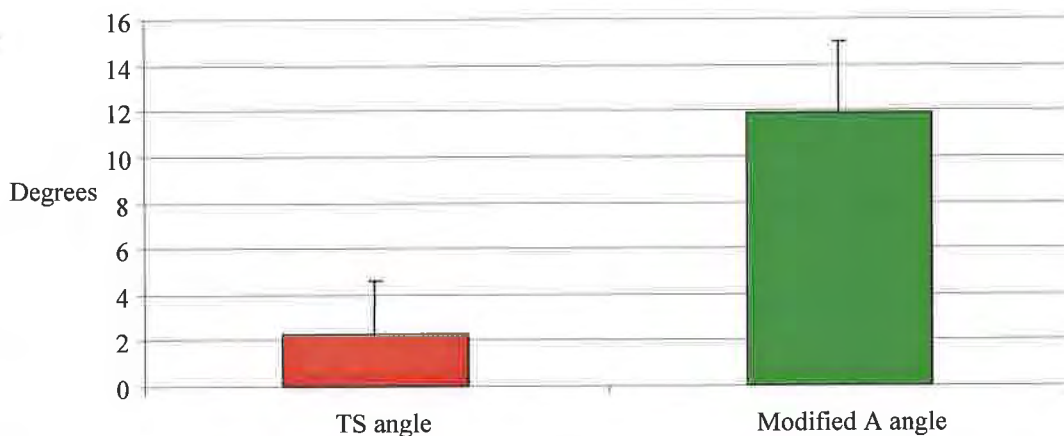


**Figure 4.15:** Example of the variations between examiners for the TS angle. Paired measurement differences between average values of the modified A angle (session 1) from examiners A and C.

### Null hypothesis 2:

*There will be no differences between the A angle and TS angle.*

The association between the two measures was examined by comparing the pooled mean values (from each data session) for each examiner. The results revealed that the modified A angle was larger by 9.6° (80.6%) (mean 11.9°, SD 3.1, range 4.6 – 18°) compared to the TS angle (mean 2.3°, SD 2.5, range 4.6 - 18°). A paired *t* test demonstrated this difference to be significant ( $t = -30.220$ ,  $df\ 119$ ,  $p = 0.000$ ). A visual impression of the mean variance for all examiners and each measure is presented in the figure 4.16.



**Figure 4.16:** Mean values (pooled from sessions one and two) of the TS angle and modified A angle for all examiners. The Y error bars represent the SD of the examiner's means.

## Summary of results

- Twenty participants were recruited, three examiners measured the modified A angle and TS angle three times on two separate sessions;

*Null hypothesis 1: The A angle and TS angle will not demonstrate acceptable intrarater and interrater reliability*

- Good-to-excellent intrarater reliability and moderate-to-good interrater reliability was established for both measures investigated. The average of the 3 measures proved to be more reliable;
- The SEM for both measures ranged from 1.4° to 1.8° for both intrarater and interrater reliability;

*Null hypothesis 2: There will be no differences between the A angle and TS angle*

- Significant differences were noted between the mean (pooled) modified A angle and TS angle.

### 4.2.4 Discussion

As with any clinical measurement, the key to its reliability centres on a strict standardised protocol and the identification of potential sources of error (Gass, 2004). Measurement error can come from a number of factors such as from the examiner, the individual being examined, the protocol, or more usually a combination of all factors. In particular, errors associated with the examiner typically relate to the identification of anatomical landmarks and the inconsistency of marker application (Rome, 1996). The first part of this study aimed to investigate the optimal methods for measuring the TS angle and the traditional A angle. Although the approach to the TS angle was relatively straightforward with no major issues identified, the A angle, originally introduced by Arno (1990) presented clear limitations. Difficulties in palpating the inferior pole of the patella were identified as the major limitation for this measure which was identical to the limitations identified by previous studies (Selfe *et al.*, 1996; Tomsich *et al.*, 1996; Ehrat *et al.*, 1994). Another limitation of this measure centred on the measure being conducted in a non-weightbearing position which limited the functional significance. The major outcomes of the training sessions therefore focussed on the A angle's anatomical landmarks. The modifications proposed for the A angle focussed on palpating and approximating the centre of the patella and measuring the angle from this anatomical landmark to the tibial tubercle in

a double limb stance position. This approach led to the measure being referred to as the *modified A angle*. The training sessions also finalised and outlined a strict standardised protocol for both sets of measures.

Intrarater and interrater reliability of the methods adopted for the TS angle and the modified A angle formed the second part of this study. The null hypothesis that the A angle and TS angle will not demonstrate acceptable intrarater and interrater reliability was rejected. For both measures, the intrarater reliability was consistently higher than the interrater reliability. Because little information exists on the reliability of both measures investigated, it is not known whether these results are typical. Nevertheless, the results do share some similarities with the reliability values of traditional clinical PFJt alignment measures such as the Q angle (Livingston and Spaulding, 2002; Livingston and Mandigo, 1999; Caylor *et al.*, 1993). It was noted however that both the intrarater and interrater reliability of the TS angle was slightly higher than that of the modified A angle. This could be due to the fact that upon 90° of knee flexion, the skin tension over the anterior aspect of the knee is more taut and the infra patellar and prepatellar bursa (infra prepatellar) are stretched proximally and distally which makes the palpation and identification of the patella easier. In contrast, the modified A angle is obtained in a standing weightbearing position. Palpation and identification of the patella in this position therefore is slightly more challenging since the overlying skin and other soft tissue are not taut.

As well as the reported ICC values the results were accompanied by clinically acceptable SEM values ( $<2^\circ$ ) and indicates good measurement accuracy. This is an important observation since the reliability of the modified A angle was only rated as moderate-to-good for interrater reliability. The importance of reporting reliability coefficients and the SEM values are supported by the work of Sell *et al.* (1994) and Van Gheluwe *et al.* (2002). Although these studies evaluate other methods of goniometric biomechanical measures of the limb and foot, the authors comment on the limitation associated with ICC values and highlight the need to complement the results with clinical SEM values.

The experience of examiners has been shown to influence measurement reliability of clinical measurement. Whilst some studies demonstrate no differences in intrarater

reliability between examiner experience (Payne and Richardson, 2000) a number of studies such as those by Pierrynowski *et al.* (1996) and Noakes and Payne (2003) as well as others (Van Gheluwe *et al.*, 2002; Bovens *et al.*, 1990; Elveru *et al.*, 1988b) found that intrarater reliability to be higher compared to that of inexperienced examiners. These observations of clinical lower limb measurements demonstrate similarity to the findings observed in this study, although the change was small. The mean post graduate clinical experience of the 3 examiners was 5.3 years. Although examiner C had the most experience, it was examiner A, the second most experienced, who demonstrated higher reliability overall for both measures. A reasonable explanation for this could be that examiner A had previous experience of the measures investigated and may indicate that the reliability of these measure could improve with practice (Curran, 2006). Furthermore, strict standardised protocols are thought to enhance the reliability of measures (Rome, 1996; Ekstrand *et al.*, 1982). This approach was adopted in this study and is thought to be a contributory factor in demonstrating the good-to-excellent reliability of both measures investigated. However, whilst this study was designed to replicate a clinical situation the repetition of measures collected may have led to tiredness and could have influenced the reliability of the results produced.

In addition to the reliability analysis, the pooled mean values for the TS angle and modified A angle were compared and resulted in the rejection of the second null hypothesis. Significant differences were noted between these measures with the modified A angle recording a higher value compared to the TS angle. Although no direct comparisons can be applied, the mean value of 11.9° for the modified A angle is similar to the value of control group reported by (12.3°) DiVeta and Vogelbach (1992). The mean pooled value of 2.3° for the TS angle in this study is similar to the values set by Hughston *et al.* (1984). The differences in the modified A angle and TS angle can be explained by noting the clear differences of the relationship between the patella and tibial tubercle. Flexion of the knee causes the tibia to internally rotate and results in the tibia tubercle to be medial or almost parallel to the midline of the patella. In contrast, when the knee moves into extension the tibial tubercle is placed lateral to the patella and therefore an increased angle. These assumptions are based on the visual observations outlined by Helflet (1982; 1970) and the test he introduced to visually estimate the relationship between the patella and tibial tubercle. More

specifically, when the knee is flexed, the medial aspect of the patella is in contact with the lateral surface of the medial femoral condyle. With extension of the knee, the patella follows a sinusoidal path (winding or a 'lazy S') where in full extension it rests snug in the femoral groove (Helfet, 1970). This final position is however dependant on soft tissue dynamic stabilisation which act as guy ropes (i.e. medial patellofemoral ligament). The thoughts of Arno (1990) and perhaps more importantly the practical observations offered by Helfet provides the foundation to modified A angle which could help to investigate the relationship between patella alignment and the effects of foot posture and position. Although the quasi-static approach was adopted for the modified A angle, foot posture and position was not recorded. This may be a reason why the values for this measure ranged from 6° – 19°, and as such different foot postures either a pronated or supinated foot could have increased or decreased the value of this angle.

#### **4.2.5 Conclusion**

This is the first study to report the intrarater and interrater reliability of the TS angle and the modified A angle. These simple and easy to perform measures demonstrated acceptable reliability and could be used in clinical practice to document PFJt alignment. The modified A angle is of particular use since it is performed in a weightbearing double limb stance position. This provides an element of functional significance. Further research is therefore required to investigate this measure's sensitivity to changes in foot posture and position.

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This study was presented at the 5<sup>th</sup> Staffordshire Conference on Clinical Biomechanics (Cyclic Crick Damage - A Biomechanics Viewpoint), April 2007. (Curran *et al.*, 2007).

### **4.3 Reliability and sensitivity of selected measures of PFJt alignment to changes in foot position and posture**

#### **4.3.1 Rationale and aim**

It is accepted that a coupling mechanism exists in the rearfoot (STJt) which permits the transfer of pronation and supination to rotation of the tibia (Nester, 1997). This motion is the link which controls rotation of the tibia and therefore the entire lower limb (Preece *et al.*, 2008). Abnormal foot pronation is coupled with internal tibial rotation which can alter the normal relationship of the TFJt and changes the mechanics of the vertically aligned PFJt by increasing the forces acting on the patella and changing the tension of its soft tissue structures (Post *et al.*, 2002). The AOG is also thought to be linked to lower limb pathology and abnormal foot function. For example some authors have reported an increased abducted AOG with abnormal pronation (Kernozek and Ricard, 1990).

Although evidence indicates that PFJt alignment could be influenced by foot posture and position, the nature of this relationship is not completely understood. Clinical measures such as the Q angle, the A angle, and the modified A angle involve palpating patella position and related bony structures to determine frontal plane alignment (Post *et al.*, 2002; Arno, 1990). These measures have demonstrated some form of reliability and have been shown to benefit from a standardised approach. To date, only the Q angle has been investigated to examine the effects of foot posture and position (Livingston and Spaulding, 2002; Olerud and Berg, 1984). This information however is limited and there is no evidence describing the clinical relationship between foot posture and PFJt alignment for the TFJt angle and modified A angle. The aims of this study therefore were to determine the intrarater reliability of the Q angle, modified A angle and TFJt angle and to examine the effect of changes in rearfoot posture (STJt position) and changes in foot transverse plane position (AOG) on these angles. The following 3 null hypotheses set were:

1. PFJt alignment measures will not reliably respond to changes in foot posture and position;
2. PFJt alignment measures do not change in value with 5° increments of frontal plane calcaneal motion;



3. PFJt alignment measures do not change in value with 5° increments of transverse plane foot position.

#### **4.3.2 Method**

The study utilised a double session, repeated measures design using one examiner. Ethical approval was sought and granted from the School of Health and Social Sciences Ethics Committee (UWIC) before the study began (appendix 5). The nature and purpose of the study was explained and written consent obtained from each participant (appendix 2).

#### **Participants**

The sample comprised of 10 males and 10 females and had a mean age of 32.6 years (SD 6.2, range 21 – 44 years), mean weight of 73.6kg (SD 11.8, range 51 – 94kg) and a mean height of 1.74m (SD 0.0, range 1.58 – 1.88m). The following inclusion criteria were used:

- No history of gait or balance disturbance based on visual inspection;
- No history of a systemic illness that may influence gait;
- No history of trauma or injury to the lower extremities;
- No limited motion of the STJt based on clinical assessment.

All measurements were obtained in double limb stance (weightbearing) from the right limb and foot, which was determined at random (by flipping a coin) before the study began. In addition, to enhance visibility participants were requested to shave the area over the patella and tibial tubercle. All participants were barefoot and wore shorts or thin loose fitting trousers.

#### **Equipment and materials**

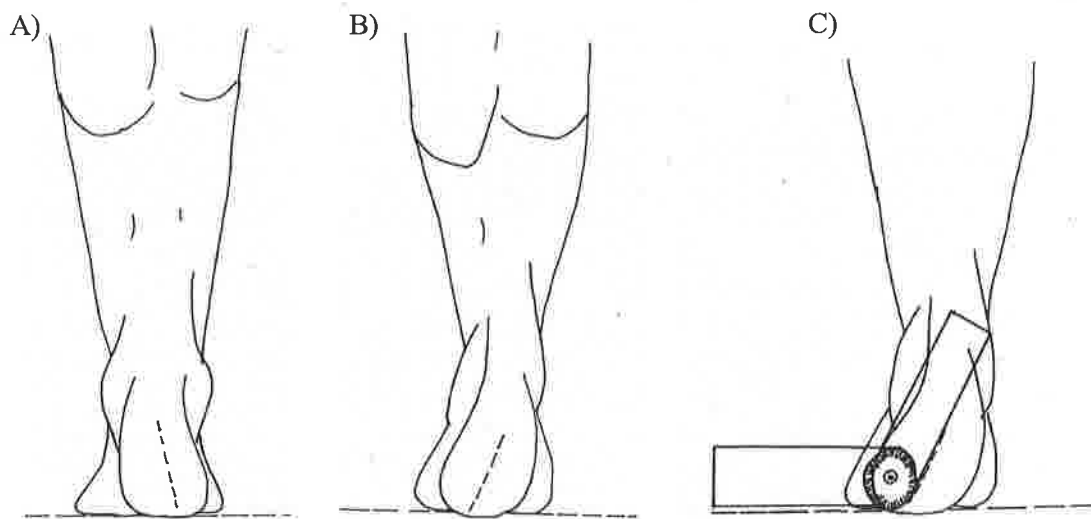
- Lining paper (56 cm by 1m);
- A4 transparent film;
- Various coloured fine tipped (0.5mm) non-permanent markers;
- Small goniometer (17cm, 8.5cm moveable arm, scale = 1° increments);
- Large goniometer (30cm, 12.7cm moveable arm, scale = 1° increments);

- To optimise the Q angle measurement, the length of the moveable arm was extended by adding a 30cm, 50cm or 60cm extension as required for alignment to the ASIS. The bisection line on the original arm was continued for the entire length of each extension arm using a fine tipped (0.5mm) permanent marker. Each extension arm was made out of laminated plastic (2mm thick and 3cm wide – equal in thickness and width of the goniometer) and attached firmly using two small dog clips;
- Double sided adhesive circles – for ASIS (0.20cm in diameter);
- Circular adhesive markers – for patella and tibial tubercle (0.8cm in diameter);
- Data collection sheets, biro, clipboard and A4 brown labelled envelopes.

## **Foot placement**

### *Foot posture*

The position of the STJt was measured by assessing frontal plane calcaneal alignment (small tractograph). Each participant was asked to march on the spot for approximately 20 seconds; looking straight ahead they were then instructed to step into their own AOG and BOG (quasi static approach). If they stumbled or the approach felt unnatural they were asked to repeat the manoeuvre. Each participant was asked to position their foot in the following separate positions: maximal pronation (without force), invert their foot 5° from this posture, then at 10°, 15° and 20°. In total, five different positions were produced and is a method which has been used by Mathieson *et al.* (2004). At each of these postures, the standing modified A angle, Q angle and the TFJt angle was recorded. Figure 4.17 illustrates an example of the calcaneal positions.

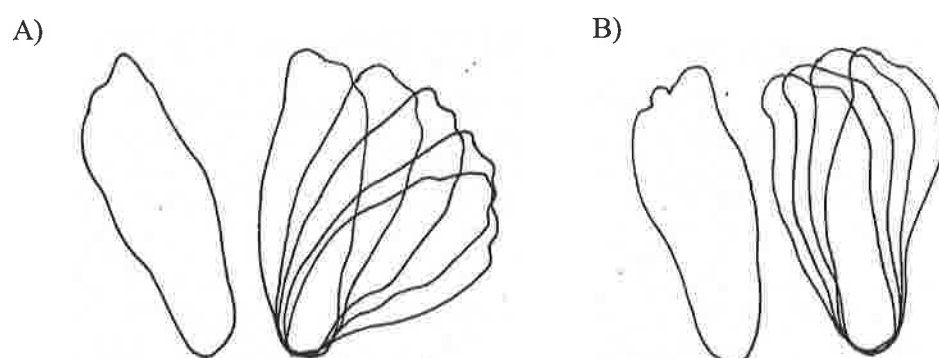


**Figure 4.17: Posterior view of right rearfoot used to record changes in foot posture.** Illustration A presents a maximally pronated foot whilst illustration B shows a foot which has progressed into inversion (supination). Illustration C shows how the small goniometer was placed against the posterior surface of the calcaneus (in line with the reference line) and supporting surface.

#### *Foot position*

Prior to data collection, the clinical method (using quasi-static approach) and technique described in study one was used. Clinical tracings of the foot were obtained from 4 – 11 sized feet. In total, 8 pairs of clinical tracings were produced which allowed the AOG to be calculated for each foot size. The researcher traced around the original tracing of the right foot on a transparent A4 sheet using a non-permanent marker pen. This tracing was then cut out producing a template which was then placed in a neutral foot position (neither adducted nor abducted) on a clean piece of lining paper. Using a felt pen, the researcher drew around the template which was then rotated in an outwards (abducted) direction, till 5° of abduction was identified. The researcher again drew around the template and rotated another 5° in an outward (abducted) direction. This process was repeated until the foot template achieved a position of 20° abduction. The template was then placed back into the neutral position, of the same foot drawing. From this position, the template was rotated inwards (adducted) until 5° was identified. This process was repeated until 10° and 15° of adduction was established. The maximum 15° adduction angle and 20° abduction angle was used since these values are linked to abnormal variations (Whittle, 2002; Kernozek and Ricard, 1990). In total 8 different tracings of the right foot were produced. To aid clarity during data collection each tracing was produced using different coloured pens. A template was also created for the left foot for each foot size and was positioned in 10° of abduction. This foot position reflects that of the normal

value identified in study 4.1 and other studies (Bryant, 2001; Mcllroy and Maki, 1997; Saltzman *et al.*, 1995). A total of 8 foot positions were produced. Figure 4.18 illustrates the marked template used for this study.



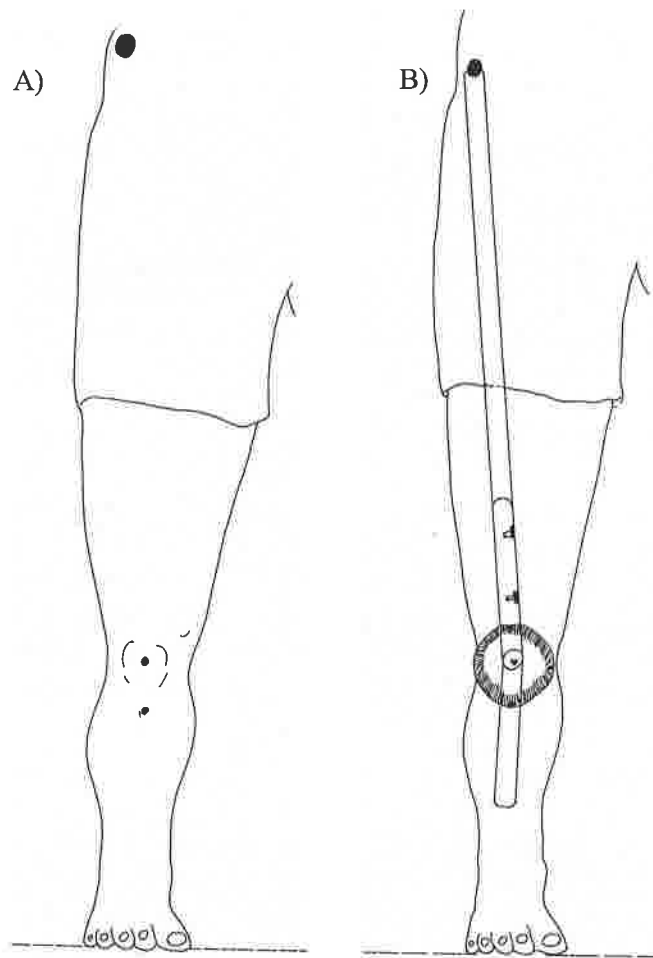
**Figure 4.18: Example of template of abducted and adducted foot positions.** Illustration A presents a neutral position through to 20° of abduction. Illustration B also provides a neutral position through to 15° of adduction. Both sets of foot positions were placed on the same sheet of paper and were colour coded but are presented separately here in black and white for clarity.

### **Clinical techniques for PFJt alignment**

Each participant stood in the requested stance position and placed their foot in one of the positions (i.e. neutral first) or postures (i.e. maximum pronation first) previously identified. Each participant was encouraged to look straight ahead and remain relaxed without contracting the quadriceps or hamstring muscle groups. Each of the following three measures were then performed three times: -

#### *Q angle*

The Q angle was measured by placing a double sided adhesive circle (0.20mm) onto the right ASIS, which was identified by palpation. The centre of the patella was then identified with a separate adhesive circle (0.8mm) by palpating the lateral and medial borders of the patella. A further adhesive circle (0.8mm) was then applied to the most prominent part of the tibial tubercle. Using the large goniometer and a similar approach adopted by Woodland and Francis (1992), the proximal (moveable) arm was extended using the manufactured extensions. This arm was affixed to the double-sided adhesive circle to help reduce movement of the arm at the ASIS during measurement. The distal arm was then aligned to the patella and tibial tubercle (figure 4.19). The value was then recorded.



**Figure 4.19: Q angle measurement.** Illustration A shows the marker placement (ASIS, centre of the patella and tibial tubercle) whilst illustration B shows how the goniometer (with extension and dog clips) was aligned to the markers.

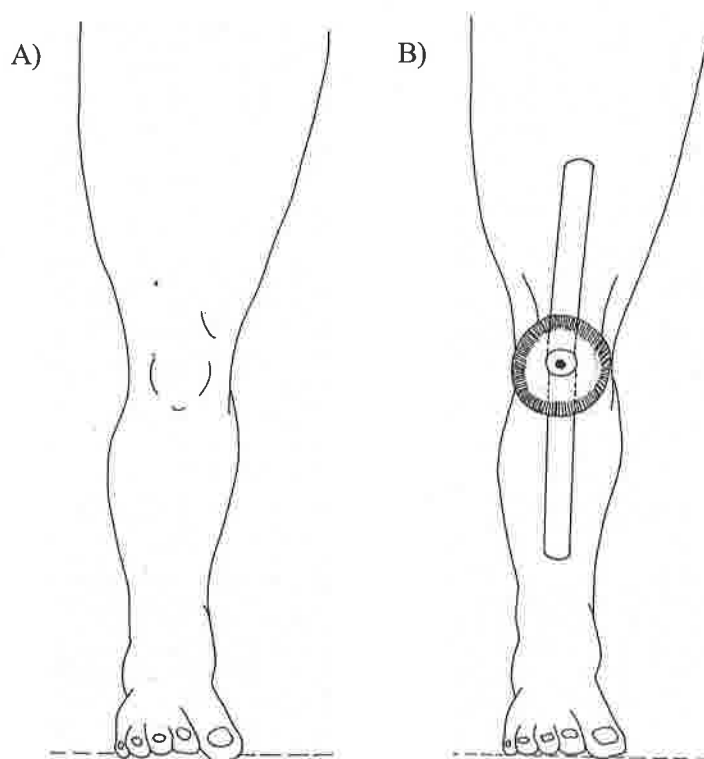
#### *Modified A angle*

The lateral and medial borders of the patella were palpated and the centre of the patella was identified using a circular adhesive marker. The most prominent part of the tibial tubercle was then palpated and identified with another adhesive marker. The proximal arm of the goniometer was then aligned with the centre of the patella and the distal arm was aligned with the tibial tubercle (this measure is illustrated in 4.11, page 82). The value was then recorded.

#### *TFJt angle*

This measure was obtained using the large goniometer which was placed over the midline (visual estimate) of the proximal (upper third) anterior shaft of the tibia and distal (lower third) anterior shaft of the femur. The axis of the goniometer was placed

over the centre of the knee (figure 4.20). This approach is similar to that reported by Ilahi *et al.* (2001) which demonstrated satisfactory reliability and that endorsed by the American Knee Society clinical rating system (Insall *et al.*, 1989)<sup>6</sup>.



**Figure 4.20: TFJt angle.** Illustration A represents the position of the limb; no marker placement was required for this measure. Illustration B shows how the goniometer was aligned (visual bisection of lower third of anterior of femur and upper third of anterior aspect of the tibia).

When each measure was completed for each incremental change in foot posture and position, each of the anatomical landmarks were re-palpated and adhesive markers re-positioned if necessary. Once all measures were completed for each participant on each session, the data collection sheets were placed into the A4 brown envelope which was then sealed.

<sup>6</sup> Before the study commenced a pilot study was run to establish optimal methods for data collection. In particular focus was given to the TFJt angle and the clinical method employed by Heath and Staheli (1993) which measured the entire limb. An extended (distal and proximal) goniometer was aligned from the ASIS to the anterior centre of the ankle joint. The fulcrum of the goniometer lay over the central aspect of the knee. Although this method provides an overall estimate of limb alignment that is based on TFJt alignment these authors performed this measure on children (aged 5 – 11). After a number of practice runs it was decided that this method was unsuitable for adult measurement since the investigator's arm span would be unable to steady the goniometer distal and proximal extensions (increase error of measurement).

### **Statistical analysis**

All data were entered and analysed using SPSS™ version 12.1 (SPSS™, London, UK) and was found to be normal in distribution using the Kolmogorov-Smirnov test of normality ( $p < 0.001$ ). ICCs <sup>[3, k]</sup> (and 95% CI) were conducted on each measure for each foot posture and position to determine the interrater reliability between two data collection sessions. Paired  $t$  tests were also conducted to determine that there were no systematic differences between the repeated measures for the single examiner. To allow for consistency throughout the preliminary investigations conducted for this thesis the levels of acceptable reliability approved by Fleiss (1981) were adopted for the ICC values ( $>0.75$  excellent reliability; 0.4 to 0.75 fair-to-good reliability;  $<0.4$  poor reliability) were chosen. The CoV was calculated to determine the variation between the sessions along with the SEM which estimates the amount of error associated with the measurement. A Pearson's  $r$  correlation was run to identify trends between the measured values for each change in foot posture and position. A one-way ANOVA was performed to identify if any significant differences occurred between the measured values to changes in foot posture and position. Tukey's post hoc test was used to evaluate where any differences occurred. Finally, the mean change and 95% CI were calculated for each PFJt alignment measure and each foot posture and position. All analyses were performed using a significance level set at  $p < 0.05$ .

#### **4.3.3 Results**

The TFJt angle, Q angle, and modified A angle was measured three times in five separate foot postures and eight separate foot positions. All measures were obtained on two occasions. The mean, SD and range for each measure and foot posture and position is presented in table 4.9.

	TFJt angle (°) Mean ± SD (range)	Q angle (°) Mean ± SD (range)	Modified A angle (°) Mean ± SD (range)
<b>Foot posture</b>			
Maximum pronated	13.7 ± 2.0 (10 – 17)	23.6 ± 2.1 (20 – 28)	15.2 ± 1.3 (12 – 17)
5° inverted	12.1 ± 1.7 (10 – 16)	22.6 ± 1.9 (20 – 26)	14.6 ± 1.3 (12 – 17)
10° inverted	8.8 ± 1.3 (7 – 11)	19.3 ± 1.7 (17 – 22)	13.9 ± 1.1 (11 – 15)
15° inverted	5 ± 1.0 (4 – 7)	16.1 ± 1.8 (14 – 19)	11.8 ± 1.1 (9 – 14)
20° inverted	0.6 ± 1.5 (-2 – 3)	13.1 ± 2.0 (10 – 17)	9.4 ± 1.4 (5 – 11)
<b>Foot position</b>			
15° adducted	1.0 ± 1.3 (-2 – 3)	8.9 ± 1.2 (7 – 11)	8.0 ± 1.4 (7 – 10)
10° adducted	3.7 ± 1.1 (2 – 6)	10.8 ± 1.5 (8 – 13)	9.7 ± 1.2 (7 – 12)
5° adducted	5.2 ± 0.9 (4 – 7)	12.3 ± 1.4 (10 – 15)	10.6 ± 1.3 (8 – 13)
Neutral	5.9 ± 0.9 (4 – 8)	12.7 ± 1.5 (10 – 15)	11.1 ± 1.2 (8 – 13)
5° abducted	6.3 ± 0.9 (5 – 8)	13.1 ± 1.7 (11 – 15)	11.6 ± 1.5 (8 – 14)
10° abducted	6.8 ± 0.7 (5 – 8)	14.1 ± 1.8 (12 – 17)	12.1 ± 1.5 (8 – 14)
15° abducted	8.4 ± 0.8 (8 – 10)	16.2 ± 2.0 (15 – 20)	13.6 ± 1.2 (10 – 15)
20° abducted	10 ± 1.0 (8 – 11)	18.4 ± 2.2 (16 – 22)	14 ± 1.2 (12 – 16)

**Table 4.9: Mean, SD and range for all three measures, for each incremental changes in foot posture and position (session one).**

### **Null hypothesis 1:**

*PFJt alignment measures will not reliably respond to changes in foot posture and position*

The reliability of one examiner of each measure to each incremental change in foot posture and position over the two sessions ranged from fair-good to excellent. ICCs ranged from 0.805 – 0.933 for the TFJt angle, 0.846 – 0.941 for the Q angle and 0.815 – 0.890 for the modified A angle. Paired *t* tests revealed that there were no systematic differences ( $p > 0.05$ ) in the mean values for each of the measures and each incremental change in foot posture and position between session one and session two. The CoV varied from 8% – 21% for the TFJt, 7% - 14% for the Q angle and 7% – 19.7% for the modified A angle indicating that the variability of these measures is relatively small when evaluated during various foot postures and positions. The SEM expressed in degrees varied from 0.8° – 1.6° for all of the measures investigated in each foot posture and position. The ICC values together with their confidence intervals, the CoV and SEM for the TFJt angle, Q angle and modified A angle are presented in tables 4.10 – 4.12.



<i>Session 1 vs. session 2</i>	<b>TFJt angle</b>		
<b>Foot posture</b>	<b>ICC (95% CI)</b>	<b>CoV (%)</b>	<b>SEM(°)</b>
Maximum pronation	0.933 (0.839 - 0.973)	14	1.4
5° inversion	0.922 (0.813 - 0.968)	12	1.3
10° inversion	0.855 (0.671 - 0.940)	15	1.2
15° inversion	0.805 (0.571 - 0.981)	21	1.1
20° inversion	0.910 (0.786 - 0.968)	20	1.2
<b>Foot position</b>			
15° adducted	0.882 (0.727 - 0.952)	8	1.2
10° adducted	0.880 (0.723 - 0.951)	9	1.1
5° adducted	0.875 (0.711 - 0.948)	15	0.8
Neutral	0.907 (0.781 - 0.962)	17	1
5° abducted	0.821 (0.601 - 0.925)	14	1
10° abducted	0.859 (0.679 - 0.942)	11	0.8
15° abducted	0.862 (0.685 - 0.943)	10	1
20° abducted	0.909 (0.786 - 0.963)	10	1

**Table 4.10: Intrarater reliability of the TFJt angle and changes to foot posture and position.**

<i>Session 1 vs. session 2</i>	<b>Q angle</b>		
<b>Foot posture</b>	<b>ICC (95% CI)</b>	<b>CoV (%)</b>	<b>SEM(°)</b>
Maximum pronation	0.904 (0.773 - 0.961)	9	1.6
5° inversion	0.925 (0.822 - 0.970)	9	1.5
10° inversion	0.886 (0.735 - 0.953)	7	1.2
15° inversion	0.879 (0.721 - 0.950)	11	1.5
20° inversion	0.912 (0.792 - 0.964)	14	1.5
<b>Foot position</b>			
15° adducted	0.920 (0.810 - 0.968)	13	1.2
10° adducted	0.896 (0.757 - 0.958)	12	1.2
5° adducted	0.846 (0.652 - 0.936)	11	1.2
Neutral	0.926 (0.823 - 0.970)	11.4	1.2
5° abducted	0.941 (0.857 - 0.976)	12	1.3
10° abducted	0.882 (0.726 - 0.951)	12	1.3
15° abducted	0.900 (0.766 - 0.959)	11	1.4
20° abducted	0.910 (0.788 - 0.964)	11	1.5

**Table 4.11: Intrarater reliability of the Q angle and changes to foot posture and position.**

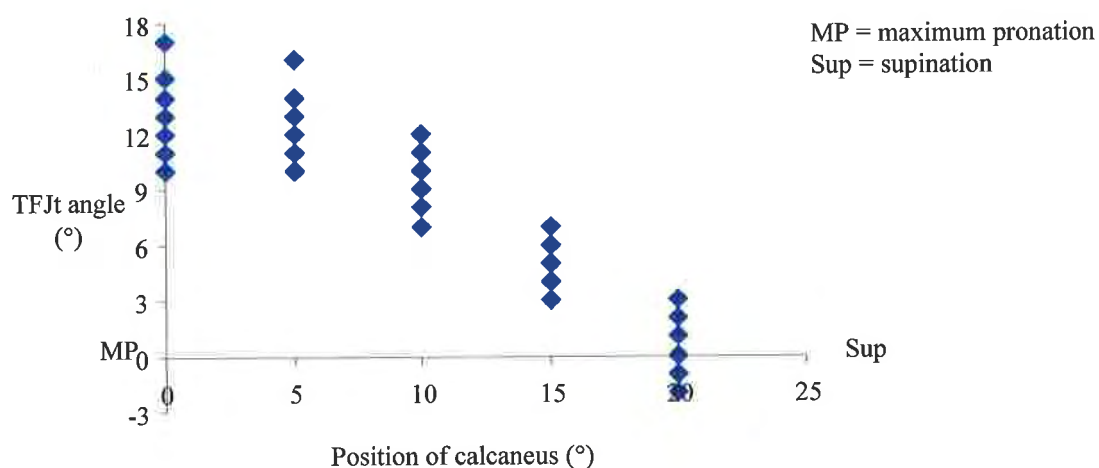
<i>Session 1 vs. session 2</i>	<b>Modified A angle</b>		
<b>Foot posture</b>	<b>ICC (95% CI)</b>	<b>CoV (%)</b>	<b>SEM(°)</b>
Maximum pronation	0.830 (0.620 - 0.929)	9.2	1.3
5° inversion	0.842 (0.644 - 0.934)	9	1.2
10° inversion	0.817 (0.593 - 0.923)	7	1.1
15° inversion	0.841 (0.642 - 0.934)	10.2	1
20° inversion	0.837 (0.634 - 0.932)	13	1.2
<b>Foot position</b>			
15° adducted	0.880 (0.721 - 0.951)	19.7	1.3
10° adducted	0.810 (0.581 - 0.920)	11.2	1.1
5° adducted	0.843 (0.646 - 0.935)	10.5	1.1
Neutral	0.890 (0.744 - 0.955)	12	1.1
5° abducted	0.877 (0.717 - 0.950)	13.2	1.2
10° abducted	0.843 (0.647 - 0.935)	12	1.2
15° abducted	0.815 (0.590 - 0.922)	8	1.2
20° abducted	0.833 (0.626 - 0.931)	9	1.1

**Table 4.12: Intrarater reliability of the modified A angle and changes to foot posture and position.**

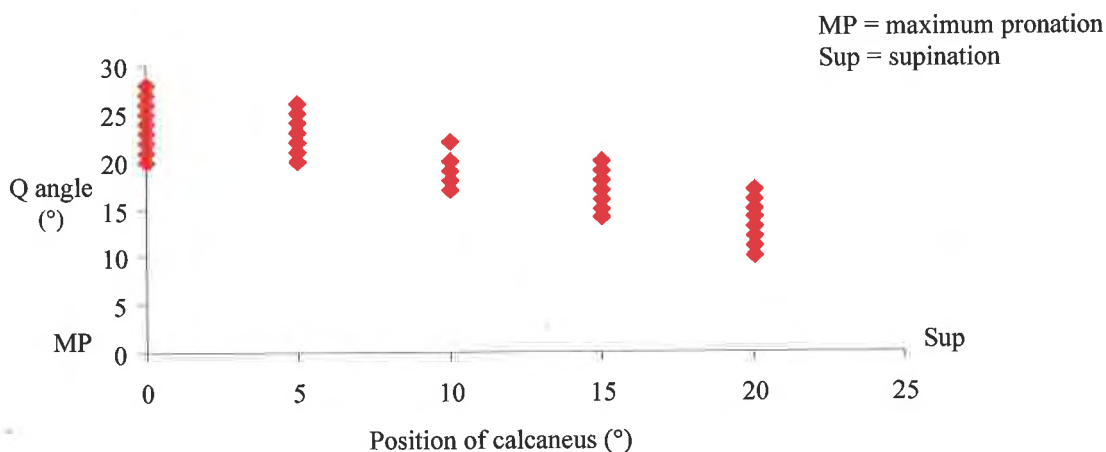
### Null hypothesis 2:

*PFJt alignment measures do not change in value with 5° increments of frontal plane calcaneal motion*

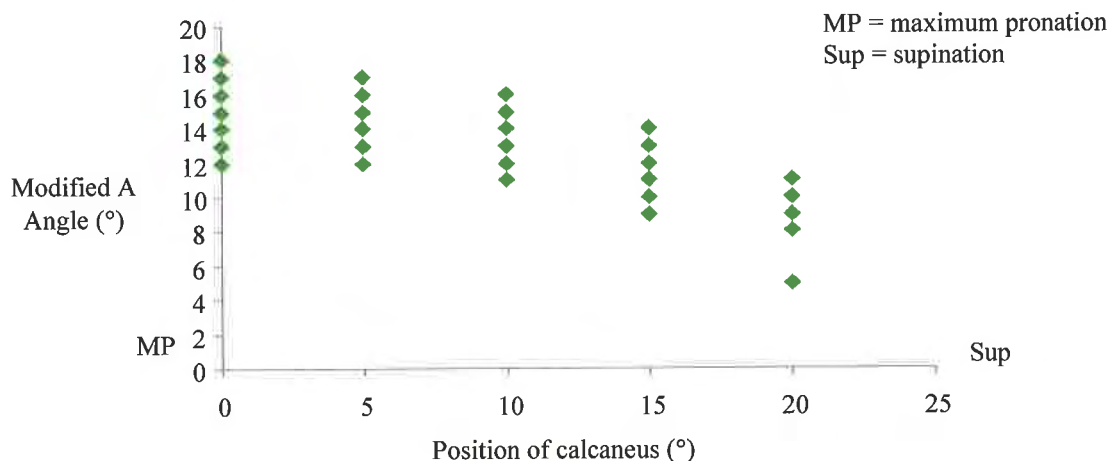
The Pearson's  $r$  correlation coefficient revealed that each of the three measures investigated decreased in value as inversion progressed. Correlations of 0.9 for the TFJt angle, 0.8 for the Q angle and modified A angle and were significant at the  $p < 0.01$  level. A visual representation of these correlations is presented in figures 4.21 – 4.23.



**Figure 4.21:** The association between the position of the calcaneus and the TFJt angle ( $r = 0.9$ ;  $P < .01$ ).



**Figure 4.22:** The association between the position of the calcaneus and the Q angle ( $r = 0.8$ ;  $P < .01$ ).



**Figure 4.23:** The association between the position of the calcaneus and the modified A angle ( $r = 0.8$ ;  $P < .01$ ).

Further investigation using a one-way ANOVA revealed significant differences between the position of the calcaneus for the TFJt angle ( $F = 271.310$ ;  $df\ 4$ ;  $p < 0.001$ ), Q angle ( $F = 100.423$ ;  $df\ 4$ ;  $p < 0.001$ ) and the modified A angle ( $64.764$ ;  $df\ 4$ ;  $p < 0.001$ ). Post hoc analysis using Tukey's test revealed that an incremental change of  $10^\circ$  produced significant differences in the measure values for all of the three measures ( $p < 0.001$ ). Although significant, the change in value for the modified A angle at  $10^\circ$  was slightly lower ( $p = 0.027$ ) compared to the TFJt angle and Q angle. Further analysis using the Tukey's test demonstrated that the measured values of the TFJt angle and Q angle produced significant differences ( $p < 0.001$ ) from incremental changes of  $5^\circ$  (i.e.  $5^\circ - 10^\circ$ ,  $10^\circ - 15^\circ$ ,  $15^\circ - 20^\circ$  of inversion). In comparison the modified A angle was less sensitive and could only recognise significant differences ( $p < 0.001$ ) from  $10^\circ - 15^\circ$  and  $15^\circ - 20^\circ$  of inversion.

To aid clinical understanding of these differences, the actual change in each of the measure value related to the incremental change of the position of the calcaneus can also be evaluated. Table 4.13 presents the actual mean change and 95% CI of each of the three measures to each  $5^\circ$  increment. This information indicates that an alteration of  $4.4^\circ$  (95% CI  $4.0^\circ - 4.7^\circ$ ),  $4.1^\circ$  (95% CI  $3.5^\circ - 4.6^\circ$ ) and  $3.3^\circ$  (95% CI  $2.8^\circ - 3.7^\circ$ ) is required for the TFJt angle, Q angle and modified A angle respectively in order to be certain that the position of the calcaneus had moved a significant amount. These values however must be considered with each measure's SEM which ranged from  $0.8^\circ - 1.6^\circ$  (tables 4.10 – 4.12) and suggests that practically, at least  $2^\circ$  is required for

a difference to make a difference. Despite this, it is clear that as the more the position of the calcaneus changes the significant change becomes stronger (15° - 20° increments). Figure 4.24 displays a selected visual representation of a clear trend for the TFJt to reduce in value as the rearfoot inverts.

	Mean (95% CI) change			
	5° increment	10° increment	15° increment	20° increment
TFJt angle	1 (0.7 – 1.2)	4.4 (4.0 – 4.7)*	7.5 (6.9 – 8.0)*	10.4 (9.8 – 10.9)*
Q angle	1 (0.7 – 1.2)	4.1 (3.5 – 4.6)*	7.4 (6.7 – 8.0)*	10.5 (9.9 – 11)*
Modified A angle	0.5 (0.2 – 0.7)	1.2 (0.9 – 1.5)	3.3 (2.8 – 3.7)*	5.7 (5.1 – 6.2)*

Table 4.13: Mean change and 95% CI from maximum pronation to changes in calcaneal position of 5°, 10°, 15° and 20°. \*Indicates significant change.

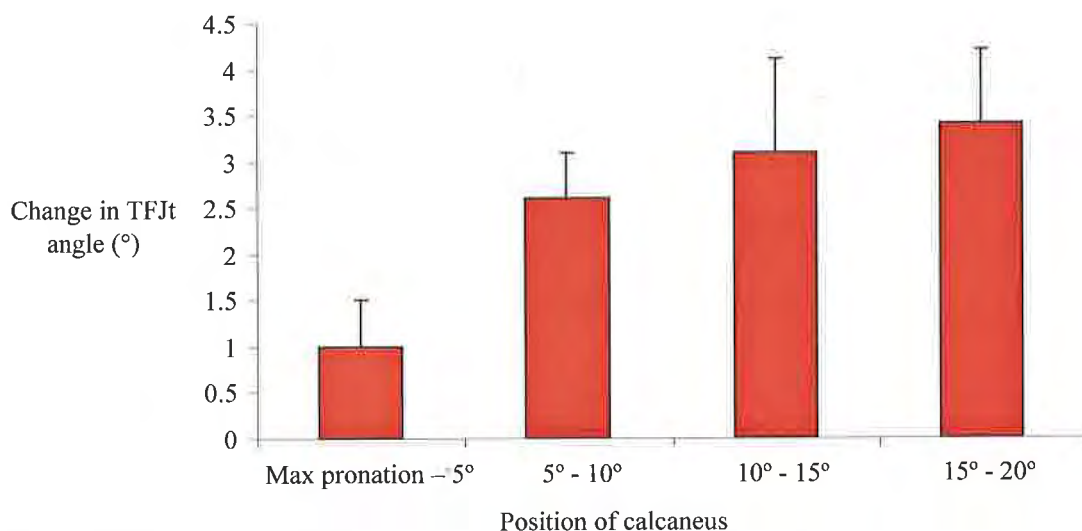


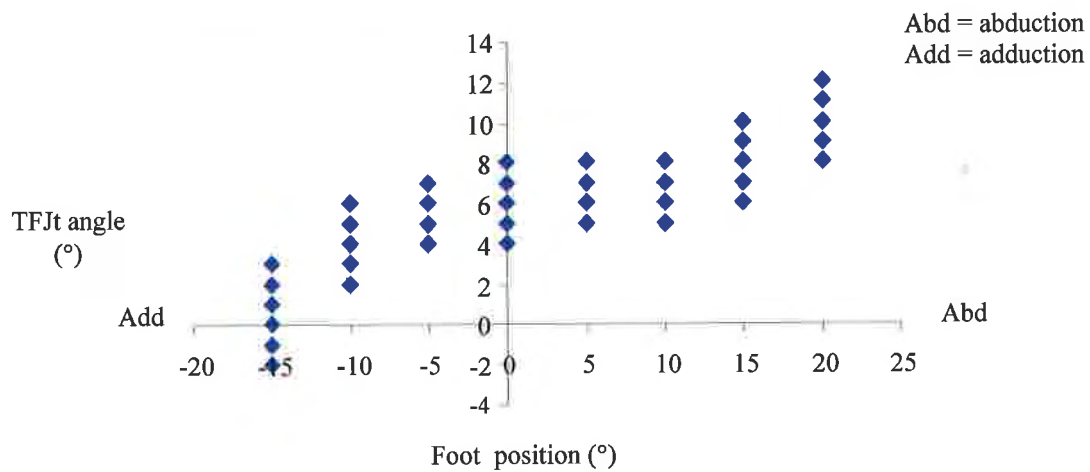
Figure 4.24: TFJt angle mean change using 5° increments from maximum pronation to 20° of inversions. Y error bars represent the SD.

### Null hypothesis 3:

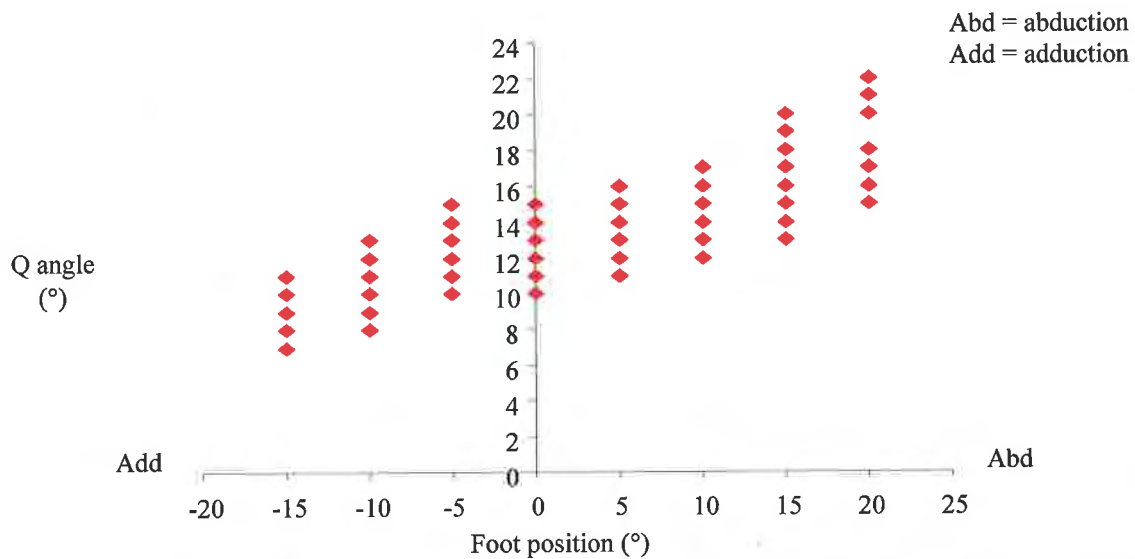
*PFJt alignment measures do not change in value with 5° increments of transverse plane foot position*

Pearson's  $r$  correlation coefficient revealed that all PFJt alignment measures reduced in value as the foot was placed in a more adducted position. However, as the foot was placed in an abducted all of the three measures demonstrated a tendency to increase in value. Correlations of 0.8, 0.7 and 0.6 were established for foot adduction for the TFJt angle, Q angle and modified A angle respectively. The abducted foot position produced correlations of 0.8 for the TFJt angle, 0.7 for the Q angle and 0.6 for the modified A angle. Whilst these correlations for foot position are significant at the level of  $p < 0.01$  level, the TFJt angle seemed to be the most sensitive measure to foot

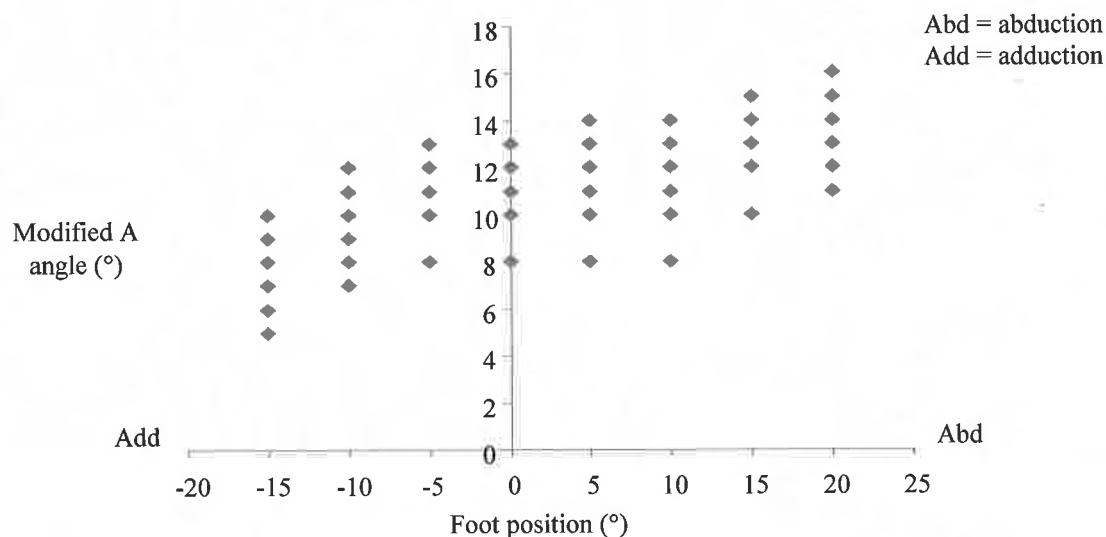
position. A visual representation of these correlations is presented in figures 4.25 – 4.26.



**Figure 4.25:** The association between the position of the foot (AOG) and the TFJt angle ( $r = 0.8$ ;  $P < .01$ ).



**Figure 4.26:** The association between the position of the foot (AOG) and the Q angle ( $r = 0.8$ ;  $P < .01$ ).



**Figure 4.27:** The association between the position of the foot (AOG) and the modified A angle ( $r = 0.8$ ;  $P < 0.01$ ).

#### *Adduction of the foot*

The one-way ANOVA indicated that there were significant differences between a neutral foot position and an adducted position of the foot for TFJt angle ( $F = 76.314$ ,  $df\ 3$ ,  $p < 0.001$ ), the Q angle ( $F = 27.346$ ,  $df\ 3$ ,  $p < 0.001$ ) and modified A angle ( $F = 20.776$ ,  $df\ 3$ ,  $p < 0.001$ ). The results of the Tukey's post hoc analysis demonstrated that significant differences ( $p < 0.001$ ) occurred at  $10^\circ$  of adduction for all of the three measures. However, whilst significant for the modified A angle the level of significance was lower ( $p < 0.05$ ) compared to the TFJt angle and the Q angle. Further analysis using the Tukey's test demonstrated significant differences between the measured values of the TFJt angle and the Q angle producing significant differences ( $p < 0.001$ ) from incremental changes of  $5^\circ$  of foot position (i.e.  $10^\circ - 15^\circ$  adduction,  $15^\circ - 10^\circ$  adduction). The modified A angle was less sensitive and only produced significant differences between  $10^\circ - 15^\circ$  of adduction.

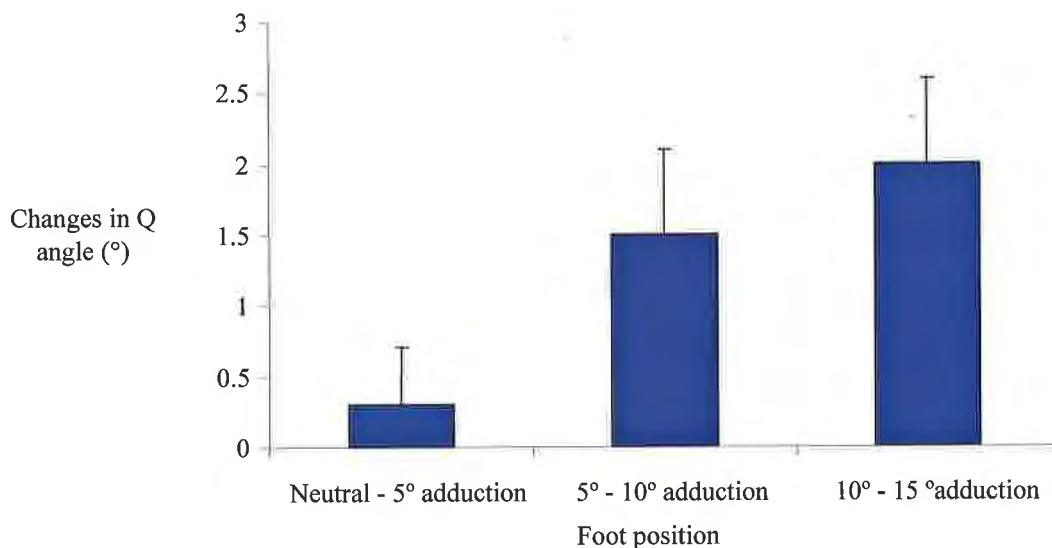
These differences can also be applied clinically by considering the actual change in measured values to the changes in foot adduction. Table 4.14 provides the actual mean change and 95% CI of the three measures to each  $5^\circ$  change in the position of the foot. This information demonstrates that an alteration of  $2.2^\circ$  (95% CI 1.8 – 2.5) for the TFJt,  $1.8^\circ$  (95% CI 1.5 – 2.0) for the Q angle, and  $1.4^\circ$  (95% CI 1.1 – 1.6) for the modified A angle is necessary to be certain that various degrees of foot adduction

is required to produce a change in these measures. These results must be viewed with caution when interpreting the clinical differences between changes for each position. For example, the Q angle had an SEM of 1.5° (largest value) therefore a change of at least 2° is needed for a true difference to be established. These results however do show a clear trend that significant changes are associated with greater changes in foot position (15° adduction). Figure 4.28 presents an example of a visual representation of the tendency for the Q angle to decrease as the foot is placed in an adducted position.

	Mean (95% CI) change		
	5° adduction	10° adduction	15° adduction
<b>TFJt angle</b>	0.6 (0.4 – 0.7)	2.2 (1.8 – 2.5)*	4.8 (4.4 – 5.1)*
<b>Q angle</b>	0.3 (0.1 – 0.4)	1.8 (1.5 – 2.0)*	3.7 (3.3 – 4.0)*
<b>Modified A angle</b>	0.6 (0.3 – 0.8)	1.4 (1.1 – 1.6)*	3.1 (2.7 – 3.4)*

**Table 4.14: Mean change and 95% CI from neutral position to 5°, 10° and 15° of adduction.**

\*Indicates significant change.



**Figure 4.28: Q angle mean change using 5° of adduction from neutral to 15° of adduction. Y error bars represent the SD.**

#### *Abduction of the foot*

The results of the one-way ANOVA demonstrated that significant differences were also noted between a neutral foot position and an abducted position of the foot for the TFJt angle ( $F = 68.681$ ,  $df\ 4$ ,  $p < 0.001$ ), Q angle ( $F = 31.676$ ,  $df\ 4$ ,  $p < 0.001$ ) and the modified A angle ( $F = 15.983$ ,  $df\ 4$ ,  $p < 0.001$ ). Tukey's post hoc analysis determined these significant differences to occur at 15° of abduction in the values produced by the three measures ( $p < 0.001$ ). The Tukey's test also demonstrated that significant



differences ( $p < 0.001$ ) occurred from changes of foot position of  $5^\circ$  between  $10^\circ - 15^\circ$  and  $15^\circ - 20^\circ$  for all three measures. Again, despite being these differences being significant the  $p$  values of the modified A angle were slightly lower at  $p = 0.012$  and  $p = 0.001$  for  $10^\circ - 15^\circ$  and  $15^\circ - 20^\circ$  of abduction respectively.

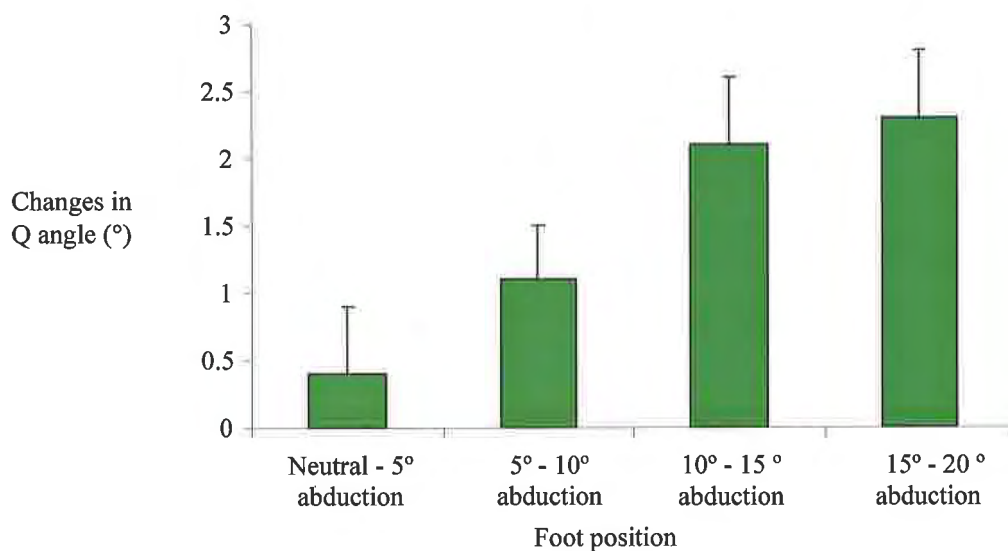
Again these differences can be considered from a clinical perspective by evaluating the actual change in measured values produced by abduction of the foot. Table 4.15 presents the actual mean change and 95% CI of the three measures to each  $5^\circ$  of abduction of the foot. This information reveals that an alteration of  $2.6^\circ$  (95% CI 2.3 – 2.9) for the TFJt,  $3.5^\circ$  (95% CI 3.1 – 3.8) for the Q angle, and  $2.4^\circ$  (95% CI 2.1 – 2.6) for the modified A angle is necessary to be certain that various degrees of foot abduction produces a change in these measures. Caution must be drawn however when interpreting differences between conditions and the SEM must be borne in mind. For example, the TFJt angle had an SEM of  $1.2^\circ$  (largest value) and indicates that practically, a change of at least  $2^\circ$  is needed for a true difference to be established. In spite of this, it is clear that the more the foot changes position the significant change becomes stronger ( $15^\circ - 20^\circ$  abduction). Figure 4.29 illustrates the tendency for the Q angle to increase as the foot is placed into an abducted position.

	Mean (95% CI) change			
	5° abduction	10° abduction	15° abduction	20° abduction
<b>TFJt angle</b>	0.4 (0.1 – 0.6)	0.9 (0.6 – 1.1)	2.6 (2.3 – 2.9)*	4.2 (3.7 – 4.6)*
<b>Q angle</b>	0.4 (0.1 – 0.5)	1.4 (1.2 – 1.6)	3.5 (3.1 – 3.8)*	5.7 (5.2 – 6.1)*
<b>Modified A angle</b>	0.4 (0.1 – 0.6)	1 (0.7 – 1.2)	2.4 (2.1 – 2.6)*	2.8 (2.5 – 3.0) *

**Table 4.15: Mean change and 95% CI from a neutral position to  $5^\circ$ ,  $10^\circ$ ,  $15^\circ$  and  $20^\circ$  of abduction.**

\*Indicates significant change.





**Figure 4.29: Q angle mean change using 5° of abduction from neutral to 20° of abduction. Y error bars represent the SD.**

### Summary of results

- The TFJt angle, Q angle and modified A angle was measured 3 times on two occasions in 5 different foot postures (maximum pronation to inversion) and 8 different foot positions (abduction to adduction);

*Null hypothesis 1: PFJt alignment measures will not reliably respond to changes in foot posture and position*

- ICC values revealed good-to-excellent intrarater reliability between session one and two for each of the three measures. It was noted that the TFJt angle was the most reliable measure followed by the Q angle and then the modified A angle;

*Null hypothesis 2: PFJt alignment measures do not change in value with 5° increments of frontal plane calcaneal motion*

- Pearson's  $r$  correlation demonstrated that all measures had a tendency to decrease in value with progressive calcaneal inversion;
- Significant differences were noted at 10° of calcaneal inversion for the TFJt angle and the Q angle;
- Significant differences were noted at 15° of calcaneal inversion for the modified A angle;

*Null hypothesis 3: PFJt alignment measures do not change in value with 5° increments of transverse plane foot position*

- Pearson's  $r$  correlation demonstrated that all measures had a tendency to decrease in value when the foot was placed in an adducted position but increased in value as the foot was placed in an abducted position;
- Significant differences were observed for 10° abduction for each of the three measures. These differences were also noted at 10° of adduction for the TFJt angle and Q angle but at a larger range of adduction (15°) for the modified A angle.

#### **4.3.4 Discussion**

The purpose of this study was to investigate the intrarater reliability and the sensitivity of three clinical measures of PFJt alignment, two previously described in the literature and the third developed from study 4.2 of this thesis. The approach adopted was centred on a series of key assumptions. Firstly, a standing, weightbearing position was selected since it provides information of the functional closed kinetic relationship of the lower limb and the role of PFJt alignment (Livingston and Spaulding, 2002). Secondly, the actual position of the foot not only provides evidence of how this may influence clinical measures but also highlights the need for standardisation. Thirdly, frontal plane alignment of the calcaneus provides an insight into the motion of the STJt. Since the total range of motion of the STJt is considered to be 30° (Root *et al.*, 1977), 5° changes of calcaneal position represents a significant amount (16.4%) of the STJt's range of motion. In this respect, because motion of the STJt is coupled with movement of the tibia it is assumed that positional changes in foot posture, and rotation of the tibia could have an effect on the PFJt and TFJt. Therefore, the ability of clinical measures of PFJt and TFJt alignment to respond to changes in foot posture and position can contribute to satisfying both *face* and *predictive* validity.

This study determined good-to-excellent reliability for all patterns of foot posture and position for a single examiner and led to the rejection of the first hypothesis that PFJt alignment measures will not reliably respond to changes in foot posture and position. It was noted that the TFJt angle was the most reliable measure whilst the modified A angle was the less reliable with ICCs ranges of 0.6. Although it is difficult to

exclusively compare the reliability results of this study to other studies, certain aspects compare favourably with reports published by Livingston and Spaulding (2002) who identified ICC values of 0.92. The intrarater reliability SEM and CoV were similar to that of the ICCs with all of measures investigated displaying SEM values of less than 1.6° and a CoV of no greater than 21% for all patterns of foot posture and position. The SEM serves as a useful statistic which can be applied to a clinical situation by establishing a 'zone' or 'threshold' for variation in measurement (Van Gheluwe *et al.*, 2002). It is thought that the higher reliability values are likely to be due to the fact that the approach adopted and method of obtaining foot posture and position was standardised. In light of this, caution must be drawn when interpreting differences between each foot posture and position. For example, the TFJt angle had an SEM of 1.4° (largest value); therefore a change of at least 2° is needed for a true practical difference to be established.

The second null hypothesis that PFJt alignment does not change in value with 5° increments of frontal plane calcaneal motion was also rejected. The TFJt angle displayed the greatest sensitivity to changes in foot posture, followed by the Q angle and modified A angle ( $p < 0.01$ ). Whilst the correlation between changes in the modified A angle and change to foot posture was not as strong compared to the other two measures, it was able to recognise significant changes with 15° of calcaneal inversion. In contrast the TFJt angle and Q angle measures demonstrated significant changes with 10° of calcaneal inversion. For all of the measures investigated the mean values showed a tendency to decrease from maximum pronation to 20° inversion, with greater mean values noted for the TFJt angle and the Q angle. This larger mean change for these measures can be explained in part because of the longer leverage created by the positioning of the goniometer over the anatomical landmarks (i.e. shaft of femur and tibia – TFJt angle; ASIS, centre of the patella and tibial tubercle – Q angle) which has the potential to create larger angles. At maximum pronation, all of the measured values were at their largest value. For example the mean value for maximum pronation for the Q angle was 23.6° and the TFJt angle was 13.7°, whilst the mean value for the modified A angle was 15.2°. These measures could be increased since the tibia and femur internally rotates, producing a genu valgus effect at the TFJt and supports the thoughts of Post *et al.* (2002) and McClay and Manal (1998). More specifically, it can be assumed that internal tibial rotation results in the

tibial tubercle moving medial to the patella (Hamill and Knutzen, 2003) thus increasing the angle of the Q angle and modified A value. Overall, these findings support previous work which correlates foot posture with rotation of the tibia, the inter-relationship of the TFJt and PFJt alignment and their dependence on calcaneal position (Khamis and Yizhar, 2007; Klingman *et al.*, 1997; Stergiou and Bates, 1997; Cornwall and McPoil, 1995).

The final hypothesis that PFJt alignment does not change in value with 5° increments of transverse plane foot position was also rejected. A foot position of 5° and 10° abduction resulted in TFJt angle values of 6° and 8° respectively and fall within the normal suggested TFJt angle (anatomical axis) (Ilahi *et al.*, 2001; Heath and Staheli, 1993). Additionally, these foot positions are suggested to be within the normal range for the AOG (5° to 10° abduction) as outlined in study 4.1 and other investigations (Bryant, 2001; McIlroy and Maki, 1997; Saltzman *et al.*, 1995). The TFJt angle, Q angle and the modified A angle reduced in value as the foot was placed into an adducted position and increased as the foot was placed into abduction. These observations confirm the findings of Livingston and Spaulding (2002) and Olreud and Berg (1984).

This study has several limitations. It was noted that as inversion of the foot progressed it was difficult in some individuals to palpate and re-identify the patella. Fatigue may have set in for some of the participants. For participants 3 and 10, it was noted that half way through the measurement procedure (during second data collection session) the measurements had to be stopped as they felt uncomfortable due to the constrained position. After a short break these measurements were repeated with no further problems. The examiner may have also fatigued during the measurement sessions, however this limitation was recognised before the data collection began with only 5 participants recorded in a morning session, data collection therefore occurred over 4 successive mornings, which was repeated two weeks later.

This is the first study to systematically describe the influence of foot posture and position on the TFJt angle, Q angle and modified A angle. These finding have important clinical implications since interventions such as foot orthoses and surgical procedures are aimed at reducing the Q angle (Fulkerson, 2002; D'Amico and Rubin,

1986). Perhaps most importantly, the results of this preliminary study appear to support the foot-leg coupling concept: the premise that foot function is coupled with rotation of the tibia. Whilst PFJt malalignment and abnormal foot posture have been indirectly and directly linked to PFJt malalignment induced pain there have been no objective investigations to support this idea. This present study represents a step forward in establishing this concept. Moreover, this study demonstrated that the TFJt angle, the Q angle and the modified A angle are influenced by foot posture and position. It should be noted however that each foot posture and position was induced by internal factors by asking each participant for example to maximally pronate and place their foot into 15° of abduction. Exposing asymptomatic individuals to these induced conditions accentuates the instant effect on the lower kinetic chain relationship but may not reflect a prolonged, adaptive effect. Further inquiry is required to expand upon this information. This should include clinical categories of foot posture allowing the relationship of PFJt alignment, foot posture and position to be established.

#### **4.3.5 Conclusion**

This preliminary study was able to determine differences in the TFJt angle, Q angle and modified A angle with changes in foot posture (frontal plane) and position (transverse plane). The results presented support the concept of a coupling mechanism within the lower limb, where pronation produces internal limb rotation changing PFJt alignment. For example, the change in alignment increased the Q angle, TFJt angle and the modified A angle whilst progressive calcaneal inversion and external limb rotation decreased these angles. These interactions were evaluated in specific and strict conditions which allowed the identification of the optimal measures. This information can now be used to establish the relationship of normal PFJt alignment in clinically relevant foot postures (i.e. pronated, neutral and supinated) in a cross-section of healthy (asymptomatic) individuals.

## Chapter 5

### **A cross-sectional study to investigate normal patellofemoral joint alignment values for different categorised foot postures**

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This chapter presents a cross-sectional study which aimed to investigate clinical PFJt alignment values for categorised foot postures (pronated, neutral and supinated) in normal healthy individuals. Comparisons and correlations were made between groups. The information on PFJt alignment was then taken forward to be used in the final study which examined their functional significance using plantar pressure measurement.

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#### **5.1 Rationale and aim**

It has been suggested that abnormal foot posture such as excessive pronation is related to PFJt malalignment (Wilson, 2007). Previous studies in this thesis (sections 4.1, 4.2 and 4.3) have shown that when a standardised weightbearing approach is used the Q angle, modified A angle and the TFJt angle reliably respond to changes in foot posture and position. Clinical measures of PFJt alignment and foot posture provide a simple and cost effective way of examining the relationship in large numbers of individuals. At this time the collective effects of specific foot postures on PFJt alignment remain unclear and have yet to be established in a healthy (normal/asymptomatic) population. The principal aim of this study was to determine if a relationship exists using a battery of clinical PFJt alignment (and foot posture measures). A secondary aim was to establish the influence of different foot postures on other characteristics of foot posture, namely the NH, AOG and BOG. The following 4 null hypotheses were set:

1. There are no significant differences between foot posture groups for PFJt alignment measures;
2. There are no significant differences between foot posture groups for NH, AOG and BOG;
3. There is no relationship between different foot postures, PFJt alignment measures and foot measures;
4. PFJt alignment measures are unable to discriminate between foot posture groups.

## 5.2 Method

The study utilised a cross-sectional design using one examiner to collect a series of clinical measures (PFJt alignment and foot measures).

### Participants

A total of 335 healthy individuals volunteered for this study. Participants were recruited from the staff and student population at the UWIC and volunteers from the surrounding community (friends and family of the researcher). Prior to the commencement of the study, all participants were informed of the nature of the study (appendix 6) and signed an informed consent form (appendix 2), which was approved by the School of Health Sciences Ethics Panel at UWIC (appendix 5). All participants were over the age of 18 and met the following inclusion criteria:

- No history of traumatic injury or surgery to the lower limb within the past two years;
- No history of patella dislocation or obvious meniscal pathology;
- No evidence of major joint effusion of the anterior aspect of the knee and tenderness over the inferior pole of the patella and tibial tubercle;
- No evidence of balance or postural problems (visual observation).

All measures were obtained with the participant barefooted; each participant wore shorts or thin/loose fitting trousers. In addition, to ensure that the adhesive labels stuck to the tibial tubercle and the centre of the patella, individuals were requested to shave these areas. Limb dominance was obtained by asking each participant to kick a ball which is a common method employed to determine dominance (Didia and Nyenwe, 1988). All measures were collected in a quiet clinical setting (cubicle/gait laboratory) based at the Wales Centre for Podiatric Studies, UWIC.

### Screening process for classification of foot type

As well as meeting the inclusion criteria described above, each participant was screened to determine their foot type category using the FPI<sup>®</sup>. The FPI<sup>®</sup> consists of 6 clinical criterions, each of which is scored on a 5-point scale (range -2 to +2)<sup>7</sup>

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<sup>7</sup> FPI<sup>®</sup> 6 clinical criteria: 1 talar head palpation, 2 supra and intra lateral malleolar curvature, 3 calcaneal frontal position, 4 prominence in the area of the talonavicular joint, 5 congruence of the medial longitudinal arch, 6 adduction/abduction of the forefoot on the rearfoot (see table 3.5, page 53).

(Redmond, 2005). The total score therefore had the potential to range from -12 (highly supinated) to +12 (highly pronated). For the purposes of this study the range of potential summated scores (-12 to +12, including a zero score) was divided into three. This allowed three foot posture categories to be identified which were supinated (-12 to -5), neutral (-4 to +4) and pronated (+5 to +12) (table 5.1). Although the FPI<sup>®</sup> has demonstrated good reliability (Evans *et al.*, 2003) there was a need to establish the reliability of this method of categorisation and is presented in the pilot study section.

Supinated								Neutral								Pronated								
12	11	10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	11	12
Minus (-)												=	Plus (+)											

**Table 5.1: Classification of foot posture using the FPI<sup>®</sup>.** Table formed to establish the foot posture of each foot using the FPI<sup>®</sup>. Total values for a supinated foot posture ranged from -12 to -5, values for a neutral foot posture ranged from -4 to +4 whilst the values for a pronated foot posture ranged from +5 to +12.

### Equipment and materials

- Lining paper (1m by 56cm);
- Standard tractograph (17cm, 8.5cm moveable arm, scale = 1° increments)
- A4 transparent film (for reliability/pilot);
- Large goniometer (30cm, 12.7cm moveable arm, scale = 1° increments:
  - For the Q angle measurement the length of the moveable arm was extended which is detailed in section 4.3.2 (page 94);
- Double sided adhesive circles – for ASIS (0.20cm in diameter);
- Circular adhesive markers – for patella, tibial tubercle and navicular tuberosity (0.8cm in diameter);
- Plastic ruler (15cm in length);
- Data collection sheets, biro and clipboard;
- A4 brown labelled envelopes (first/second sessions – pilot study only).

### Pilot study

Before a pilot study was performed a pattern for the order of collecting each of the measures was established. This focussed on identifying the most energy efficient and consistent approach for the examiner and participant. It was decided that weightbearing measures be obtained first (using the quasi-static method), each foot was drawn around which was then followed by NH measurement. The PFJt alignment



measures were then obtained in the following sequence: modified A angle, TFJt angle and the Q angle. This was then followed by the seated assessment for the TS angle. It was felt this approach was the most appropriate to ensure consistency and standardisation throughout the entire study. The right limb and foot was measured first. This sequence is illustrated in figure 5.2 (page 121).

The pilot study was conducted to determine the intrarater reliability of the protocol for the following clinical measures: TFJt angle, Q angle, NH, and the FPI<sup>®</sup>, TS angle, modified A angle and the AOG and BOG. Using the procedures described in the subsequent section, 20 dominant limbs and feet were measured twice, 2 weeks apart. The sample comprised 11 females and 9 males with a mean age of 20.4 years (SD 8.4, range 20 – 44), mean weight of 73kg (SD 14.0, range 53 – 88kg) and a mean height of 1.7m (SD 0.7, range 1.55 – 1.88m). It should be noted however that whilst good-to-excellent reliability had been achieved for the AOG, BOG, modified A angle and TS angle a significant period of time had lapsed since these measures were used. It was therefore considered important and good practice that the examiner regained familiarity and re-established reliability of these measures. As with the preliminary studies the intrarater reliability of all measures was examined using ICCs <sup>[model 3, k]</sup>. A paired *t* test was also used to establish if there were any systematic differences between the repeated measures. The Fleiss (1981) criteria for acceptable reliability was used to evaluate the ICC values (>0.75 excellent reliability; 0.4 to 0.75 fair-to-good reliability; <0.4 poor reliability). The SEM and the CoV were also reported, the former of which shows the amount of error in degrees and the latter used to show the percentage variation between the measurement sessions.

The ICC values for all measures were all excellent and ranged from 0.833 – 0.902. The CoV for all measures ranged from 4.3% – 27% suggesting the variability between measurement sessions were reasonably small. The SEM values were clinically acceptable and ranged from 1.5° – 2.1° and 0.3cm – 1.4cm. Table 5.2 presents the ICC, CoV and SEM values for all measures.

	ICC (95% CI)	CoV (%)	SEM
<b>PFJt alignment measures</b>			
TS angle	0.856 (0.720 – 0.929)	11	1.5°
Modified A angle	0.846 (0.701 – 0.923)	19.6	1.5°
Q angle	0.833 (0.678 – 0.917)	11.8	2.1°
TFJt angle	0.901 (0.803 – 0.952)	4.3	1.6°
<b>Foot measures</b>			
NH	0.879 (0.762 – 0.941)	20	0.85cm
NNH	0.881 (0.768 – 0.944)	14.2	-
FL	0.891 (0.790 – 0.982)	4.6	0.3cm
FPI <sup>®</sup>	0.877 (0.757 – 0.974)	-	-
AOG	0.902 (0.788 – 0.974)	27	1.7°
BOG	0.923 (0.788 – 0.974)	18.6	1.42cm

**Table 5.2: Intrarater reliability of measure 1 versus measure 2 for the protocol and battery of measures used in this study (dominant limb and feet).**

### **The clinical measures: Approach adopted for obtaining all measures**

#### *Double-limb stance weightbearing*

To ensure a standardised approach to the measurement process each participant was instructed to march on the spot looking straight-ahead for a period of 20 seconds, after which they were then instructed to take one step forward, onto a piece of prepared lining paper, stepping into their own natural AOG and BOG. If the approach felt unnatural or the participant hesitated they were instructed to repeat the procedure. Once in this position, the participant was asked to continue to looking straight-ahead with their arms by their sides. They were also instructed to remain relaxed without contracting their quadriceps or hamstring muscle groups. This position was maintained until all of the weightbearing measures were obtained. If a participant moved from this position then the whole process was repeated.

#### **1. AOG and BOG**

Once the participant had stepped into their own AOG and BOG, the examiner drew around the left and right foot with a pencil which was kept snug to the foot in an upright position. When all of the measures were obtained, the participant was then asked to step forwards off the paper. The AOG and BOG was then determined using the technique developed in study 4.1 of this thesis (page 61).

## 2. *NH*

This measure was modified from that used by Brody (1980) and Sell *et al.* (1994). The technique employed only involved the height of the relaxed position of the navicular and not when the STJt was placed in a neutral position. The most prominent palpable part of the navicular tuberosity was identified using an adhesive circle (0.8cm). A 15cm plastic ruler was positioned vertically on the medial side of the foot, in line with the circle. The distance from the supporting surface and the circle on the navicular tuberosity was then recorded (figure 5.1) to establish NH. To standardise NH the length of the foot was measured. FL was obtained by measuring from the heel to the longest toe (cm) (Queen *et al.*, 2007, Evans 2005). This measurement was obtained from the tracings which were used to calculate the AOG and BOG. NH was divided by FL which produced the normalised navicular height (NNH) (Evans, 2005; Saltzman *et al.*, 1995).

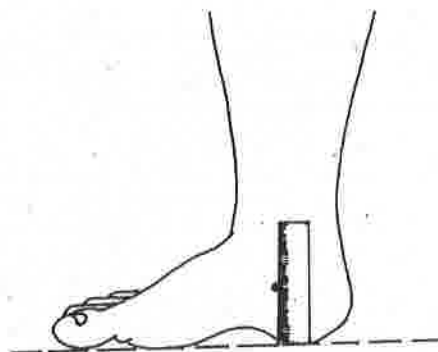


Figure 5.1: Direct measurement of NH using a ruler.

## 3. *Modified A angle*

The lateral and medial borders of the patella were palpated and the centre of the patella was identified using an adhesive marker. The most prominent part of the tibial tubercle was then palpated and identified with another adhesive marker. The proximal arm of the goniometer was then aligned with the centre of the patella and the distal arm was aligned vertical with the tibial tubercle. The axis of the goniometer was positioned midway between each adhesive marker. The value was then recorded.

## 4. *TFJt angle*

A large goniometer was placed over the midline (visual approximate) of the lower third of the anterior aspect of the femur and upper third anterior aspect of the tibia. The axis of rotation of the goniometer was positioned over the centre of the anterior of

the knee and the value was recorded. This method is similar to that approved by the American Knee Society clinical rating system (Insall *et al.*, 1989).

### 5. *Q angle*

The Q angle was measured by placing a double sided adhesive circle (0.20mm) onto the most prominent part of each ASIS. The centre of the patella was then identified with a separate adhesive marker (0.8mm) by palpating the lateral and medial borders of the patella. Another marker (0.8mm) was applied to the most prominent part of the tibial tubercle. Using the large goniometer and a similar approach described by Woodland and Francis (1992), the proximal arm was extended using the manufactured extensions. This arm was affixed to the double-sided adhesive circle to help reduce movement of the arm at the ASIS during measurement. The distal arm was aligned to the patella and tibial tubercle with the axis of rotation overlying the centre of the anterior aspect of the knee. The value was then recorded.

#### *Semi-weightbearing position (seated)*

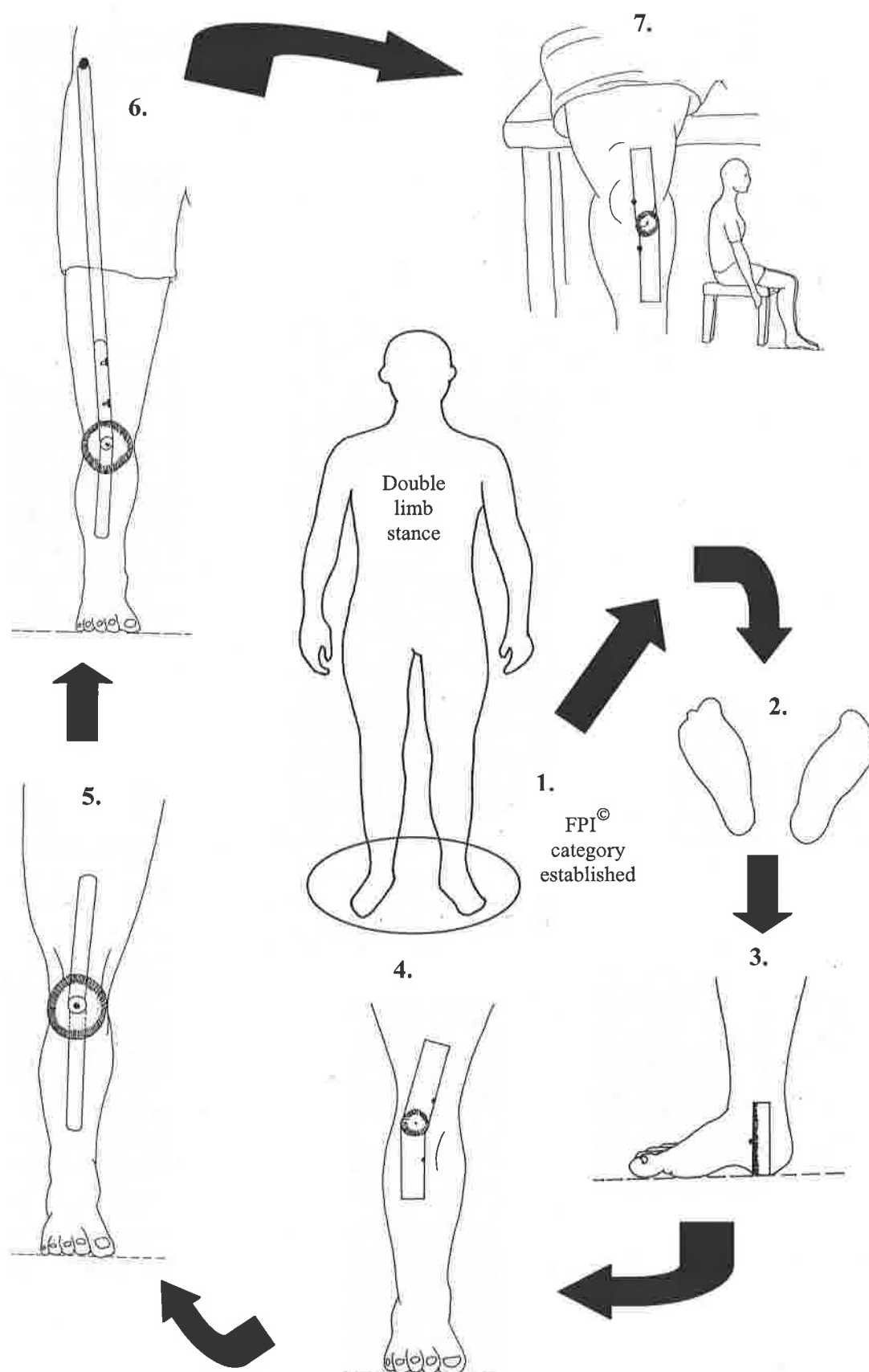
The participant was seated towards the edge of the examining couch; both knees were flexed to 90°, which was verified using a large goniometer. The height of the couch was adjusted accordingly for each individual. Each participant was instructed to sit up straight, in a relaxed manner looking straight-ahead, with their feet flat on the ground and arms hanging at their sides. All participants were encouraged not to contract their quadriceps or hamstring muscle group.

### 6. *TS angle*

The examiner palpated the lateral and medial perimeters of the patella and applied an adhesive marker (0.8mm) to the centre of the patella. The most prominent part of the tibial tubercle was then palpated and again marked with an adhesive circle (0.8mm). A goniometer was used and each arm was aligned to each marker with the distal arm in particular aligned vertical to tibial tubercle. The axis of the goniometer was positioned midway between each marker and the value was recorded.

All measurements were obtained by one examiner, left and right limbs and feet were measured from each participant. Three measurements were taken for each of the clinical measures and the mean calculated for further investigation.

**Figure 5.2: Order of sequence for PFJt alignment and foot measures obtained** (after limb dominance was identified, the right limb was measured first). At the end of each data collection session the completed sheets were placed in a sealed envelope until all data had been collected.



### Statistical analysis

The mean, SD and range were calculated for all of the clinical measures. Apart from limb dominance and gender all data were found to be normal in distribution using the Kolmogorov-Smirnov test of normality ( $p < 0.001$ ). Descriptive statistics were reported for all participants and further examined for each group (supinated, neutral and pronated) and for each of the 6 measures obtained. A series of paired  $t$  tests were run to determine if significant differences occurred between the dominant and non-dominant limbs for each measure. Age, height and weight were assessed using a one-way ANOVA and Tukey's post hoc test to identify differences between the foot posture groups. The ANOVA and post hoc assessment was further employed to examine if differences existed for each measure between the foot posture groups. Pearson  $r$  correlation was also used to determine the relationship the PFJt alignment measures and the categorised foot postures. In addition, the relationship between each PFJt alignment measure, the FPI<sup>®</sup>, the NH, AOG and BOG was also determined.

Receiver operator characteristics (ROC) were performed to assess the accuracy of each PFJt alignment measure at discriminating between different foot postures (i.e. pronated versus neutral). ROC analysis makes no assumptions regarding the statistical nature of the study (Zweig and Campbell, 1993). The ROC can be defined as the plot of sensitivity ( $y$  coordinate) versus its 1-specificity or false positive rate ( $x$  coordinate) (Obuchowski, 2003). Each separate point is created using various cut off levels for a positive result (Park *et al.*, 2004). The accuracy of the measure is evaluated by determining the area under the curve (AUC) and is interpreted as the mean value of sensitivity for all potential values of specificity. Values can range from 0 – 1.0 and are illustrated using a graph. A measure or test with a value nearer to 1.0 has a good ability to discriminate between conditions. A value nearer to 0.5 is considered very poor and unpractical where the results may simply occur by pure chance (Turner *et al.*, 2004). More specifically, these values can be classified further and range from excellent (0.90 – 1.0), good (0.80 – 0.90), fair (0.70 – 0.80), poor (0.60 – 0.70) and fair (0.50 – 0.60) (Tape, 2007). This classification was adopted for the interpretation of the AUC and a cut off level of 0.5 was used to indicate a failed point of sensitivity (Obuchowski, 2003). All data were analysed using SPSS<sup>TM</sup> (version 12.01) and a significance level set at  $p < 0.05$ .

### Sample size and power calculations

For this study a prospective calculation was performed, the power level was set at 80% whilst a significance level of 5% was chosen. All power calculations were performed in SPSS<sup>TM</sup> (version 12.1). PFJt alignment measures (TS angle, modified A angle and Q angle) were considered as the primary measures for this study. Estimates of variance and minimal significant differences were obtained from literature and data obtained from the reliability pilot study before the commencement of the study. Minimal clinical significant differences were set at 3° for all of the PFJt alignment measures<sup>8</sup>. These values along with the calculation performed indicated that per group, a minimum of  $n = 184$  participants was required for the Q angle,  $n = 138$  for the modified A angle and  $n = 73$  for the TS angle. The largest figure of  $n = 184$  was accepted as the target, although a data collection period of 8-months was set as a practical limit. However, it was accepted that given the time frame the target figure may be difficult to accomplish. Table 5.3 presents a summary of these values.

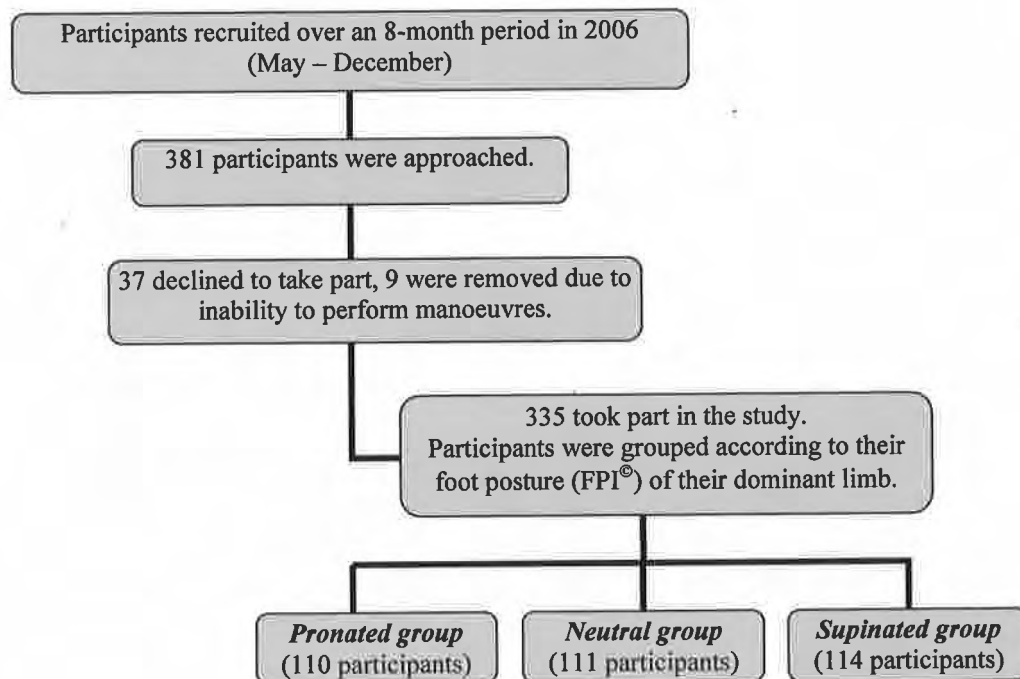
Measure	Number ( $n=$ )	Mean (SD)	Power calculation value (subjects/group)
<b>Q angle (°)</b> (stance/weightbearing assessment)	20 (F: 11 / M: 9)	15.8 ± 2.9	$n = 183.8$
<b>Modified A angle (°)</b> (stance/weightbearing assessment)	20 (F: 11 / M: 9)	R: 11.2 ± 2.7	$n = 138.0$
<b>TS angle (°)</b> (seated/semi-weightbearing assessment)	20 (F: 11 / M: 9)	R: 2.4 ± 2.3	$n = 72.8$

**Table 5.3: Sample size calculations.** Estimated values of PFJt alignment obtained from pilot study for sample calculations using SPSS<sup>TM</sup> (version 12.1). All measures were obtained from the dominant limb and were measured directly using a goniometer. A power value of 0.80 was set for all calculations performed.

<sup>8</sup> Although the modified A angle and TS angle values could have been used from study 4.2 for the power calculation it was felt good practice to obtain and use the values for the calculation from the same set of participants for all measures.

### 5.3 Results

During an 8-month period 381 participants were invited to take part in the study. Twenty nine of these individuals refused to take part, explanations given included general reluctance (with no specified reason), lack of time, self-conscious of the look of their legs and/or feet, an unwillingness to reveal weight, and religion (e.g. Muslim faith). A further 6 participants who took part in the study could not be included in the final analysis due to difficulty in complying and executing the manoeuvres required. The foot posture of the dominant limb categorised each participant into each foot posture group. One hundred and ten participants made up the pronated group, 111 the neutral group and 114 the supinated group. Figure 5.3 presents the flow of participants through the study.



**Figure 5.3:** Flow chart of how participants were recruited into the study. The pronated, neutral and supinated groups will be discussed throughout the presentation of the results.

#### Participant characteristics

Basic demographic information which included gender, age, height and weight was obtained from all participants. Limb dominance was also recorded as previously stated. Two sub groups, dominant limb and dominant limb were formed for each of the 3 foot posture categories. Of the 335 participants who took part in the study, 181 (54%) were female and 154 (46%) were male. Two hundred and fifty four (76%)

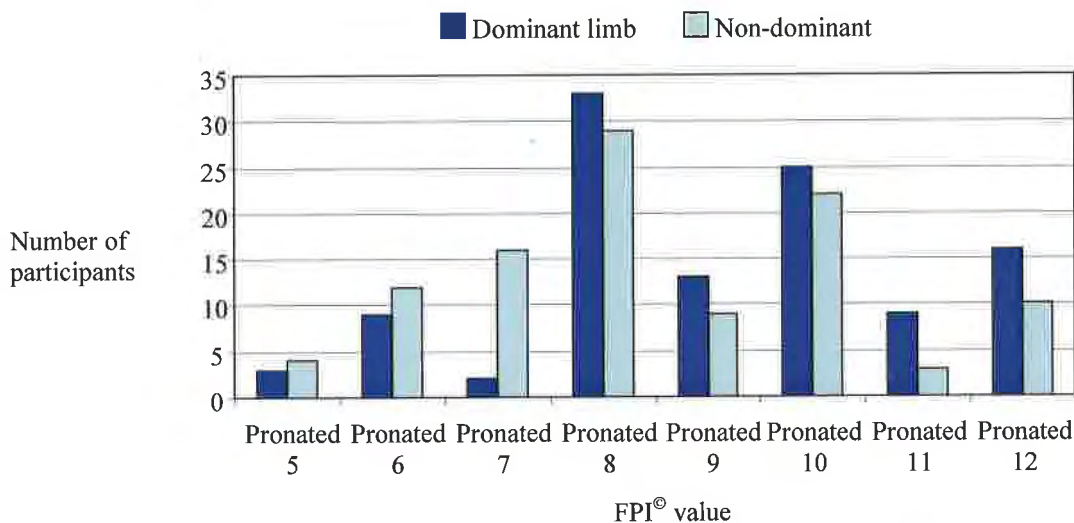


participants were right-limb dominant and 81 (24%) were left-limb dominant. None of the participants reported themselves as being ambidextrous. The distributions of gender and limb-dominance values were similarly reproduced in the three foot posture groups, with 52 (47%), 66 (59%) and 63 (55%) females forming the pronated, neutral and supinated groups respectively (limb dominant). Fifty eight (53%), 45 (39%) and 51 (45%) males formed the respective pronated, neutral and supinated groups for the dominant limb. The right limb was the most dominant limb with values ranging from 83 – 86 (75% - 77%) for the three groups. As can be seen in table 5.20, the participants from the pronated and supinated groups (for both dominant and non-dominant limb) were slightly older, taller and had a greater BW compared to the neutral group. A one-way ANOVA and post hoc analysis (Tukey's test) indicated these observations to be significant ( $p < 0.001$ ). Paired  $t$  tests revealed that there were no significant differences between participant demographics for the dominant and non-dominant limbs. A summary of all the participants' demographics and the demographics of the dominant limb and non-dominant limb for the pronated, neutral and supinated groups is provided in table 5.4.



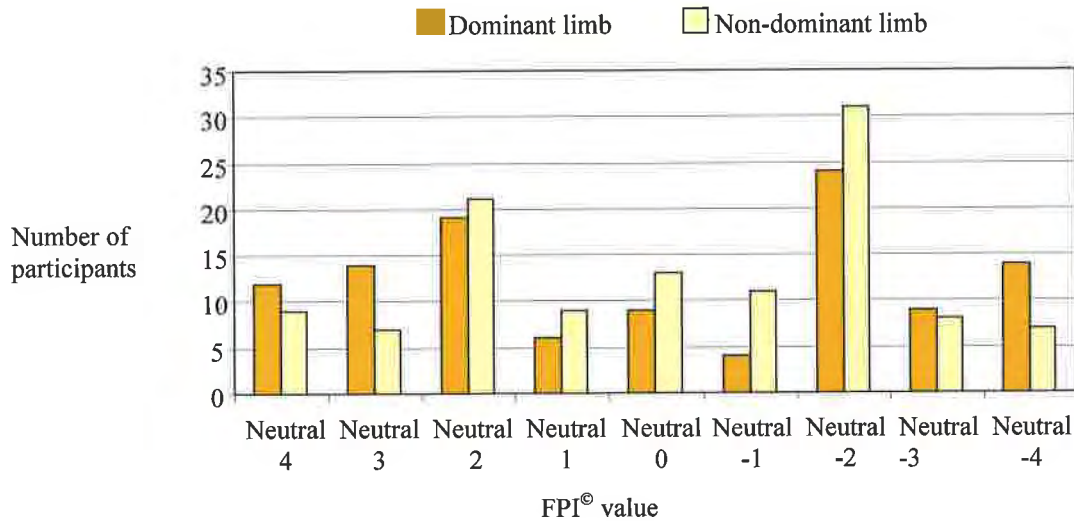
### Descriptives for foot posture categories

Of the 110 individuals who formed the dominant limb for the pronated group, the most common FPI<sup>®</sup> value was 8 (30% of participants of this group). The least categorised FPI<sup>®</sup> value for the dominant limb was 5 and 7 with only 3 participants (5%) assigned these values. The number of participants for the non-dominant for the pronated group however closely resembled that of the dominant limb values, although these figures were slightly less. Fourteen participants from the dominant limb group demonstrated asymmetry in their foot posture category with 8 assigned to the neutral group and 6 into the supinated group for their non-dominant limb. Figure 5.4 illustrates the nature of the distribution of the pronated FPI<sup>®</sup> values.



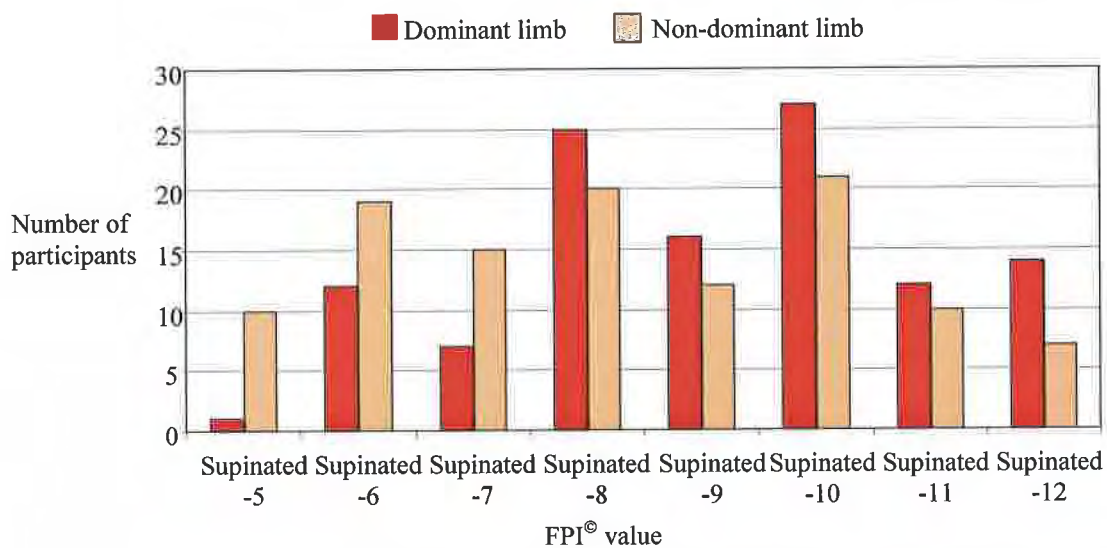
**Figure 5.4: Distribution of FPI<sup>®</sup> values for dominant and non-dominant limbs for the pronated group.**

The FPI<sup>®</sup> values of -2 and 2 were the most common values categorised for dominant and non-dominant limbs of the neutral group. Although the values of the neutral category were similarly distributed for both the dominant and non-dominant limbs, the number of participants for the FPI<sup>®</sup> value of -2 was 5% higher (22% dominant and 27% non-dominant) yet only 1% higher for the non-dominant (18%) compared to the dominant (17%) limb. These values however are minimal but are likely to be due to the slight increase in the sample size of the non-dominant limb ( $n = 116$ ) compared to the dominant limb ( $n = 111$ ). Thirteen participants also demonstrated asymmetry of the foot posture for their non-dominant limb, of which 4 were categorised to the pronated group and 9 to the supinated group. Figure 5.5 presents the FPI<sup>®</sup> distribution of the neutral foot category.



**Figure 5.5: Distribution of FPI® values for dominant and non-dominant limbs for the neutral group.**

The most common supinated FPI® values for the dominant limb were -8 and -10, with the former and latter making up 22% and 24% of the 114 participants respectively. The least common assigned supinated value was -5 with only 1 (0.5%) participant assigned to that value. The spread of supinated FPI® values of -8 to -12 was similar for the non-dominant limb, although more participants had a lower FPI® score of -5 (9%), -6 (17%) and -7(13%). Asymmetry of foot posture was also noted in this group in 15 participants, 4 demonstrated a pronated foot posture whilst 11 had a neutral foot posture of the non-dominant limb. The distribution of the FPI® values for the supinated category are presented in figure 5.6.



**Figure 5.6: Distribution of FPI® values for dominant and non-dominant limbs for supinated the group.**

### Descriptives for PFJt alignment and foot measures of each group

The mean, SD and range of values for all of the measures from all participants and their respective groups are presented in tables 5.5 and 5.6 (A, B and C). A series of paired *t* tests were run to establish if there were significant differences in each of the measures between the dominant limb and non-dominant limb. Although the means and SDs of all of the measures appear similar (less than 2° difference) a paired *t* test revealed significant differences ( $p < 0.001$ ) between the dominant limb and non-dominant limb for the Q angle, TFJt and the AOG for the pronated group and the AOG of the neutral group. On average the Q angle (20.4, SD 3.9), TFJt (mean 8.2°, SD 1.9) and the AOG (mean 16°, SD 3.4) was 8% (1.8°), 7% (0.6°) and 10% (1.6°) higher compared to the respective Q angle (mean 18.6°, SD 2.8), TFJt angle (mean 7.6°, SD 1.3) and AOG (mean 14.4°, SD 2.9) of the non-dominant limb for the pronated group. For the neutral group the mean difference for the AOG of the dominant limb (mean 11.1°, SD 2.8) was 12% (1.3°) higher compared to the non-dominant limb (mean 9.8°, SD 2.3).

Observational analysis during assessment of the AOG and BOG revealed that on the whole (62%), the foot of the dominant limb was placed in a more forward position compared to the foot of the non-dominant limb. A further breakdown of this observation revealed that this position was most common in the pronated group (70%), followed by the neutral (58%) and supinated group (57%).

All groups	Dominant limb Mean $\pm$ SD (range)	Non-dominant limb Mean $\pm$ SD (range)	P values	SEM
TS angle (°)	2.6 $\pm$ 2.7 (-2 – 10)	2.5 $\pm$ 2.6 (0 – 10)	0.324	1.5
Modified A angle (°)	10.1 $\pm$ 2.5 (5 – 18)	9.9 $\pm$ 2.0 (5 – 15)	0.076	1.5
Q angle (°)	16.1 $\pm$ 4.1 (8 – 28)	15.5 $\pm$ 3.0 (8 – 27)	<0.001*	2.1
TFJt angle (°)	5.8 $\pm$ 2.4 (-1 – 12)	5.7 $\pm$ 1.9 (1 – 11)	0.468	1.6
NH (cm)†	3.1 $\pm$ 0.9 (0.8 – 3.5)	3.1 $\pm$ 0.7 (0.6 – 5.5)	0.983	0.85
NNH††	0.11 $\pm$ 0.03 (0.02 – 0.19)	0.11 $\pm$ 0.02 (0.02 – 0.18)	0.991	-
AOG (°)	11.2 $\pm$ 4.9 (0 – 24)	10.3 $\pm$ 4.1 (6 – 22)	<0.001*	1.7
BOG (cm)	11.1 $\pm$ 2.0 (7.6 – 15.2)	11.0 $\pm$ 2.1 (6.4 – 15.4)	-	1.4
Foot placement	Forward: 207 (62%) Equal: 85 (25%) Backward: 43 (13%)	- - -	- - -	- - -

**Table 5.5: Values of all measures for all participants.** †The absolute height is included to provide a clinical perspective, but the ratio†† is potentially more valuable as it controls for foot size.\*Denotes a significance difference between the dominant and non-dominant limb. Whilst this difference may be statistically significant it may not be clinically significant given the minimal error of measurement (<2°/2cm). For example, the mean Q angle was 16.1° and 15.5° but has an SEM of 2.1° which would indicate no clinically significant difference.

A) Pronated group	Dominant limb Mean $\pm$ SD (range)	Non-dominant limb Mean $\pm$ SD (range)	P values	SEM
TS angle (°)	5.8 $\pm$ 2.3 (1 – 10)	5.7 $\pm$ 2.2 (2 – 10)	0.813	1.5
Modified A angle (°)	12.6 $\pm$ 2.2 (10 – 18)	12.1 $\pm$ 1.6 (8 – 15)	0.061	1.5
Q angle (°)	20.4 $\pm$ 3.9 (16 – 28)	18.6 $\pm$ 2.8 (14 – 27)	<0.001*	2.1
TFJt angle (°)	8.2 $\pm$ 1.9 (5 – 12)	7.6 $\pm$ 1.3 (6 – 11)	<0.001*	1.6
NH(cm)	2.4 $\pm$ 0.9 (0.8 – 5.5)	2.5 $\pm$ 0.5 (0.6 – 3.5)	0.562	0.85
NNH	0.08 $\pm$ 0.04 (0.02 – 0.13)	0.09 $\pm$ 0.05 (0.02 – 0.11)	0.603	-
AOG (°)	16.0 $\pm$ 3.4 (11 – 24)	14.4 $\pm$ 2.9 (9 – 22)	<0.001*	1.7
BOG (cm)	12.7 $\pm$ 3.9 (7.8 – 15.2)	12.8 $\pm$ 1.9 (7.8 – 15.4)	-	1.4
Foot placement	Forward: 78 (70%) Equal: 27 (25%) Backward: 5 (5%)	- - -	-	- - -

B) Neutral group	Dominant limb Mean $\pm$ SD (range)	Non-dominant limb Mean $\pm$ SD (range)	P values	SEM
TS angle (°)	1.2 $\pm$ 1.0 (0 – 4)	1.3 $\pm$ 1.1 (0 – 4)	0.578	1.5
Modified A angle (°)	9.9 $\pm$ 0.9 (8 – 12)	9.8 $\pm$ (8 – 12)	0.877	1.5
Q angle (°)	14.9 $\pm$ 2.0 (13 – 18)	14.6 $\pm$ 1.6 (14 – 20)	0.314	2.1
TFJt angle (°)	5.7 $\pm$ 0.8 (4 – 8)	5.8 $\pm$ 0.7 (3 – 7)	0.617	1.6
NH (cm)	3.2 $\pm$ 0.5 (2.4 – 4.8)	3.2 $\pm$ 0.5 (2.8 – 4.4)	0.808	0.85
NNH	0.11 $\pm$ 0.02 (0.08 – 0.12)	0.12 $\pm$ 0.02 (0.08 – 0.13)	0.892	-
AOG (°)	11.1 $\pm$ 2.8 (6 – 17)	9.8 $\pm$ 2.3 (6 – 14)	<0.001*	1.7
BOG (cm)	10.2 $\pm$ 1.2 (7.8 – 13.1)	10.1 $\pm$ 1.3 (7.2 – 13.8)	-	1.4
Foot placement	Forward: 64 (58%) Equal: 36 (32%) Backward: 11 (10%)	- - -	- - -	- - -

C) Supinated group	Dominant limb Mean $\pm$ SD (range)	Non-dominant limb Mean $\pm$ SD (range)	P values	SEM
TS angle (°)	1.0 $\pm$ 1.1 (-2 – 4)	0.9 $\pm$ 1.2 (-2 – 4)	0.652	1.5
Modified A angle(°)	8.0 $\pm$ 1.4 (5 – 10)	8.1 $\pm$ 1.4 (5 – 11)	0.350	1.5
Q angle (°)	13.2 $\pm$ 2.3 (8 – 18)	13.4 $\pm$ 1.9 (8 – 16)	0.701	2.1
TFJt angle (°)	3.4 $\pm$ 1.6 (-1 – 6)	3.9 $\pm$ 1.5 (1 – 8)	0.012	1.6
NH (cm)	3.8 $\pm$ 0.7 (2.7 – 5.5)	3.7 $\pm$ 0.6 (2.6 – 5.5)	0.097	0.85
NNH	0.15 $\pm$ 0.04 (0.08 – 0.19)	0.14 $\pm$ 0.03 (0.06 – 0.18)	0.990	-
AOG (°)	6.7 $\pm$ 3.1 (0 – 13)	7.0 $\pm$ 3.2 (0 – 12)	0.457	1.7
BOG (cm)	10.2 $\pm$ 1.8 (7.6 – 13.1)	10.3 $\pm$ 1.8 (6.4 – 13.5)	-	1.4
Foot placement	Forward: 65 (57%) Equal: 22 (19%) Backward: 27 (24%)	- - -	- - -	- - -

**Table 5.6: Values of all measures for the pronated (A), neutral (B) and supinated (C) group.** †The absolute height is included to provide a clinical perspective, but the ratio†† is potentially more valuable as it controls for foot size.\*Whilst this difference may be statistically significant it may not be clinically significant given the minimal error of measurement (<2°/2cm). For example, the mean TFJt angle was 8.2° and 7.6° (A) but has an SEM of 1.6° which would indicate no clinically significant difference.

## Analysing differences in PFJt alignment and foot measures between groups

### Null hypothesis 1:

*There are no significant differences between foot posture groups for PFJt alignment measures*

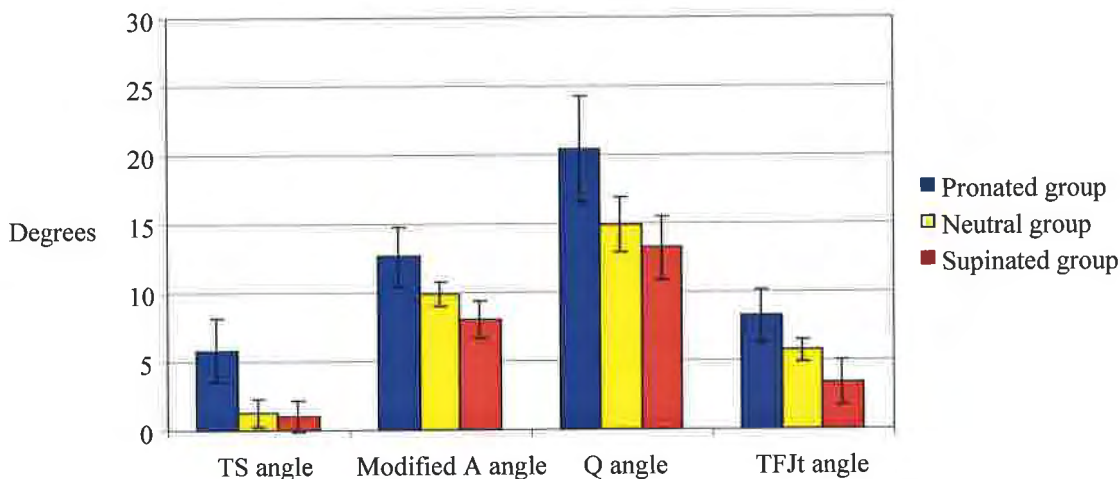
A one-way ANOVA revealed significant differences among groups for the TS angle ( $F = 310.967$ ;  $df = 2$ ;  $p < 0.001$ ), modified A angle ( $F = 220.420$ ;  $df = 2$ ,  $p < 0.001$ ), the Q

angle ( $F = 185.342$ ,  $df\ 2$ ,  $p < 0.001$ ) and the TFJt angle ( $F = 257.182$ ,  $df = 2$ ,  $p < 0.001$ ). Post hoc analysis using Tukey's test showed these differences among the pronated and neutral, and pronated and supinated groups ( $p < 0.001$ ) for the TS angle with mean values of the pronated group (mean  $5.8^\circ$ , SD 2.3) being larger compared to that of the neutral (mean  $1.2^\circ$ , SD 1.0) and supinated (mean  $1.0^\circ$ , SD 1.0) groups. This resulted in a mean difference of 79% (4.6°) and 83% (4.8°) for the neutral and supinated groups respectively. No significant differences were noted between the neutral and supinated TS angle values ( $p = 0.520$ ). Tukey's analysis also identified significant differences between the pronated and neutral, pronated and supinated, and neutral and supinated groups ( $p < 0.001$ ) for the modified A angle, Q angle and TFJt angle. Mean values of the modified A angle (mean  $12.6^\circ$ , SD 2.3), Q angle (mean  $20.4^\circ$ , SD 3.9) and TFJt angle (mean  $8.4^\circ$ , SD 1.9) for the pronated group were larger compared to that of the respective neutral (mean  $9.9^\circ$ , SD 0.9) and supinated groups (mean  $8.0^\circ$ , SD 1.4). The mean values for the Q angle (mean  $20.4^\circ$ , SD 3.9) and TFJt angle (mean  $8.4^\circ$ , SD 1.9) was also higher for the pronated group compared to the neutral and supinated groups. This resulted in differences of 30% (6°) for the Q angle and a 30% (2.7°) for the TFJt for the neutral group. The supinated group produced slightly larger differences of 35% (7°) for the Q angle and 60% (5°) for the TFJt. A summary of the Tukey values for each measure is presented in table 5.7 and the changes noted among groups are illustrated graphically in figure 5.7.

Measure	Group	Mean difference	95% CI		P value
			Lower	Upper	
TS angle	Pronated vs. neutral	4.55684	4.0459	5.0678	<0.001
	Pronated vs. supinated	4.79155	4.2840	5.2991	<0.001
	Neutral vs. supinated	.23471	-.2717	.7411	=0.520
Modified A angle	Pronated vs. neutral	2.65414	2.1324	3.1759	<0.001
	Pronated vs. supinated	4.60909	4.0907	5.1274	<0.001
	Neutral vs. supinated	1.95495	1.4378	2.4721	<0.001
Q angle	Pronated vs. neutral	5.48124	4.5662	6.3963	<0.001
	Pronated vs. supinated	7.11994	6.2109	8.0290	<0.001
	Neutral vs. supinated	1.63869	.7317	2.5457	<0.001
TFJt	Pronated vs. neutral	2.57969	2.0696	3.0898	<0.001
	Pronated vs. supinated	4.88054	4.3738	5.3873	<0.001
	Neutral vs. supinated	2.30085	1.7953	2.8064	<0.001

**Table 5.7: Summary of post hoc (Tukey's) values for PFJt alignment measures.**





**Figure 5.7:** Comparison of mean values of each group for PFJt alignment measures. Y error bars represent SD.

The clinical value of each PFJt alignment for each foot posture category needs to be considered. In other words, for a variable to be different it must make a difference. For example, the mean TFJt angle was 8.2°, 5.7° and 3.4° for the pronated, neutral and supinated groups respectively. Since this angle has an SEM of 1.6° only a true (clinical) difference can be established between the pronated and supinated groups.

### Null hypothesis 2:

*There are no significant differences between foot posture groups for NH, AOG and BOG*

The results of the one-way ANOVA revealed significant differences among groups for NH ( $F = 94.945$ ;  $df = 2$ ;  $p < 0.001$ ), AOG ( $F = 235.866$ ;  $df = 2$ ,  $p < 0.001$ ), and BOG ( $F = 81.905$ ,  $df = 2$ ,  $p < 0.001$ ). Tukey's post hoc analysis indicated these differences to occur between the pronated and neutral, neutral and supinated ( $p < 0.001$ ), and pronated and supinated groups ( $p < 0.001$ ) for NH and AOG. It was noted that NH was lower in the pronated group (mean 2.4cm, SD 0.9) compared to that of the neutral (mean 3.2cm, SD 0.5) and supinated (mean 3.8cm, SD 0.7) groups. This produced a mean difference of 16% (0.6cm) and 38% (1.4cm) and was noted for the neutral and supinated groups respectively. The AOG for the pronated group (mean 16°, SD 3.4) was larger compared to AOG of the neutral (mean 11.1°, SD 2.8) and supinated (mean 6.7°, SD 3.1) groups) which produced a mean 30% (4.9°) difference for the neutral group and 58% (9.3°) difference for the supinated group.



Tukey's post hoc analysis also demonstrated differences in the BOG between the pronated and neutral, and pronated and supinated groups ( $p < 0.001$ ) with the wider BOG noted for the pronated group (mean  $12.7^\circ$ , SD 3.9) than that of the neutral (mean  $10.2^\circ$ , SD 1.2) and supinated (mean  $10.1^\circ$ , SD 1.8) groups. These values represent a mean difference 20% (2.5cm) for the neutral group and 21% (2.6cm) for the supinated group. Finally, no significant differences were noted between the BOG of the neutral and supinated group ( $p = 0.965$ ). A summary of the Tukey values for each foot measure is presented in table 5.8 and the changes noted among groups are illustrated graphically in figures 5.8 and 5.9.

Measure	Group	Mean difference	95% CI		P value
			Lower	Upper	
NH	Pronated vs. neutral	-.74170	-.09797	-.5037	<0.001
	Pronated vs. supinated	-1.38344	-1.6199	-1.1470	<0.001
	Neutral vs. supinated	-.64175	-.8777	-.4058	<0.001
AOG	Pronated vs. neutral	4.76470	3.7630	5.7664	<0.001
	Pronated vs. supinated	9.18006	8.1849	10.1752	<0.001
	Neutral vs. supinated	4.41536	3.4225	5.4082	<0.001
BOG	Pronated vs. neutral	2.49700	1.9596	3.0344	<0.001
	Pronated vs. supinated	2.55411	2.0202	3.0880	<0.001
	Neutral vs. supinated	.05711	-.4755	.5898	=0.965

Table 5.8: Summary of post hoc (Tukey's) values for foot measures.

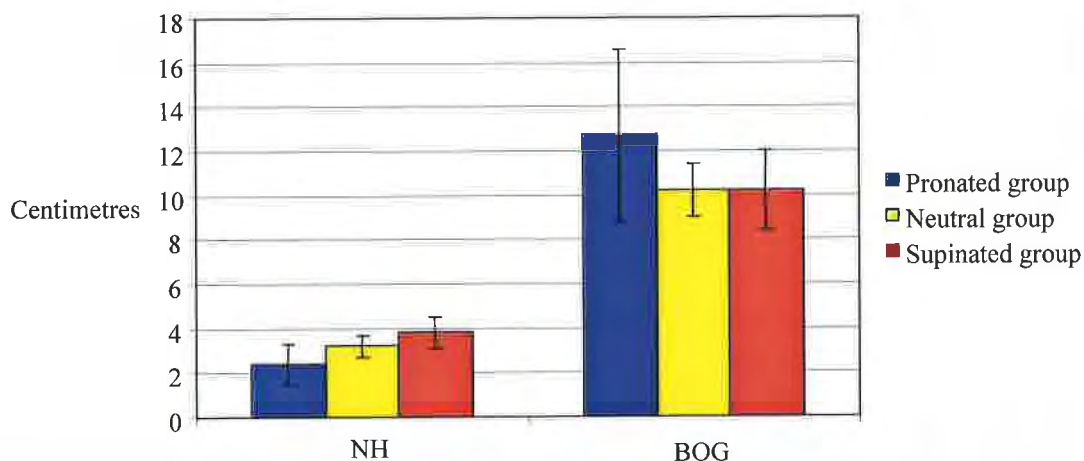
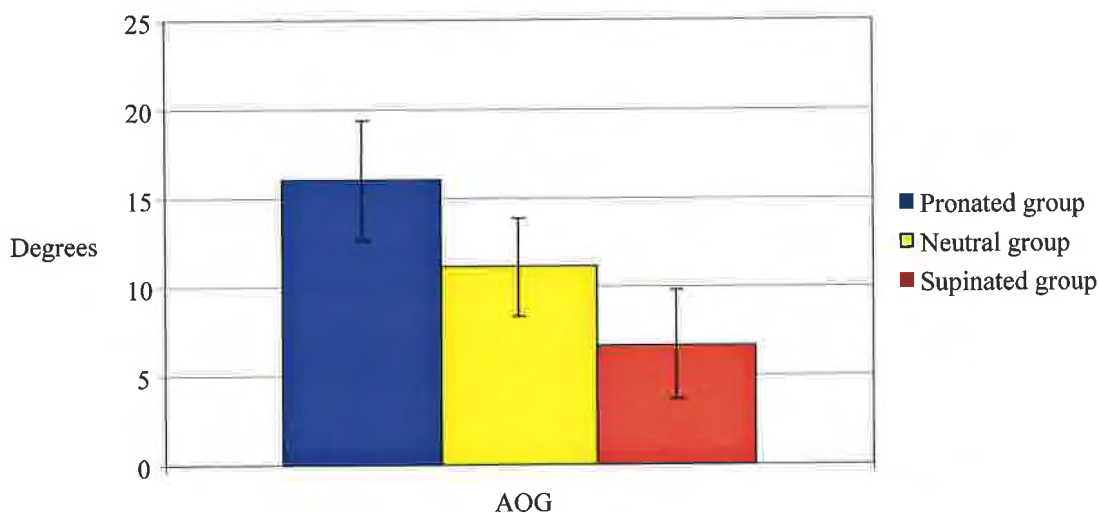


Figure 5.8: Comparison of mean values of each group for NH and the BOG measure. Y error bars represent SD. Note: The values of these measures are presented together because they have the same units and do not attempt to infer a relationship between the 2 measures.



**Figure 5.9: Comparison of mean values of each group for the AOG measure. Y error bars represent SD.**

As with the PFJt alignment measures, caution must be drawn when interpreting differences between each foot measure for each category. For example, the mean NH was 2.4cm, 3.2cm and 3.8cm for the pronated, neutral and supinated groups respectively. Although the range of this measure is small compared to others, when the SEM of 0.85cm is considered only a very small difference can be established between the categorised foot posture groups and this is likely to be difficult to detect clinically.

### **Null hypothesis 3:**

*There is no relationship between different foot postures, PFJt alignment measures and foot measures*

The level of association between the PFJt alignment measures and each foot posture category ranged from  $r = 0.34$  to  $0.82$  ( $p < 0.001$ ). Overall the strongest relationship occurred between the modified A angle and the neutral group. More specifically, the neutral group appeared overall to have a slightly better relationship (range  $r = 0.34 - 0.63$ ) between each of the PFJt alignment measures compared to the pronated and supinated groups (range  $r = 0.34 - 0.50$ ). The level of association between the AOG and BOG of each foot posture category ranged from  $r = 0.28 - 0.75$ . The AOG in general had a higher relationship overall for all foot posture groups. NH demonstrated an inverse (negative) relationship which and was at its highest for the pronated group ( $-0.49$ ) (tables 5.9 and 5.10).

	PFJt measures				Foot measures		
	TS angle	Modified A angle	Q angle	TFJt angle	NH	AOG	BOG
All groups	$r = 0.77$	$r = 0.81$	$r = 0.74$	$r = 0.82$	$r = -0.65$	$r = 0.84$	$r = 0.59$
Pronated group	$r = 0.52$	$r = 0.50$	$r = 0.40$	$r = 0.49$	$r = -0.49$	$r = 0.75$	$r = 0.60$
Neutral group	$r = 0.58$	$r = 0.63$	$r = 0.40$	$r = 0.53$	$r = -0.33$	$r = 0.56$	$r = 0.35$
Supinated groups	$r = 0.43$	$r = 0.50$	$r = 0.34$	$r = 0.37$	$r = -0.38$	$r = 0.45$	$r = 0.28$

**Table 5.9: Association between PFJt alignment measures and foot measures.**

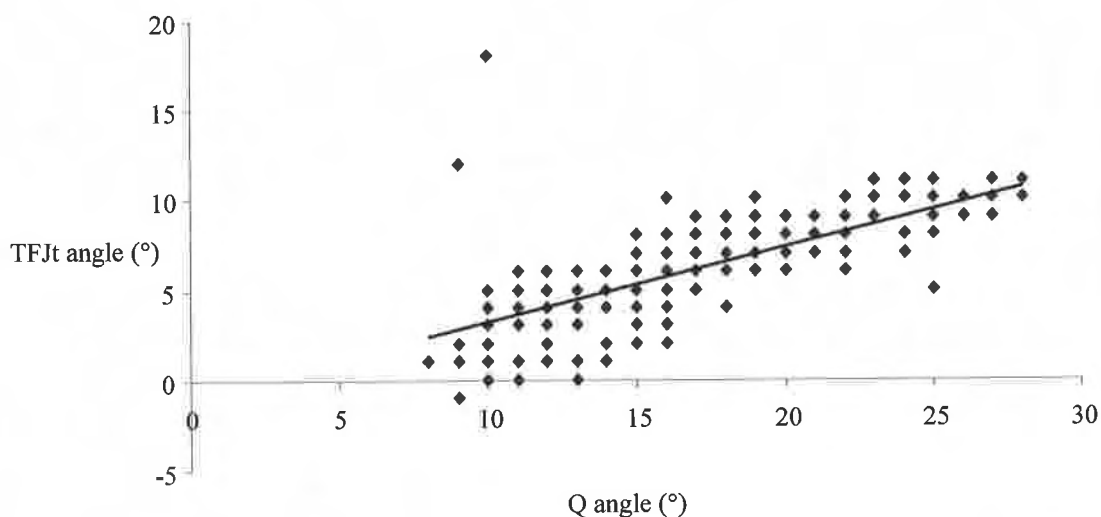
Compared measures	All participants	Pronated group	Neutral group	Supinated group
FPI category and AOG	$r = .706$	$r = .320$	$r = .304$	$r = .481$
FPI category and NH	$r = .750$	$r = .500$	$r = .331$	$r = .500$
FPI category and BOG	$r = .694$	$r = .392$	$r = .373$	$r = .551$
NH and AOG	$r = .511$	$r = .563$	$r = .401$	$r = .511$

**Table 5.10: Relationship between each of the foot measures.**

The level of association between the PFJt alignment measures was also investigated. There was a good level of association ( $p < 0.001$ ) between the Q angle and TFJt measures ( $r = .706$ ) and the Q angle and modified A angle ( $r = .750$ ). Again, the pronated and supinated groups overall demonstrated a better albeit fair association between measures compared to the neutral group. Table 5.11 provides specific values generated from the Pearson  $r$  correlation analysis for each PFJt alignment measure whilst figure 5.10 illustrates the association between the TFJt angle and Q angle.

Compared measures	All participants	Pronated group	Neutral group	Supinated group
Q angle and TFJt angle	$r = .706$	$r = .420$	$r = .304$	$r = .481$
Q angle and modified A angle	$r = .750$	$r = .500$	$r = .331$	$r = .500$
TFJt angle and modified A angle	$r = .694$	$r = .492$	$r = .373$	$r = .551$
TS angle and modified A angle	$r = .511$	$r = .563$	$r = .401$	$r = .511$
Q angle and TS angle	$r = .335$	$r = .647$	$r = .434$	$r = .335$

**Table 5.11: Relationship between each of the PFJt alignment measures.**

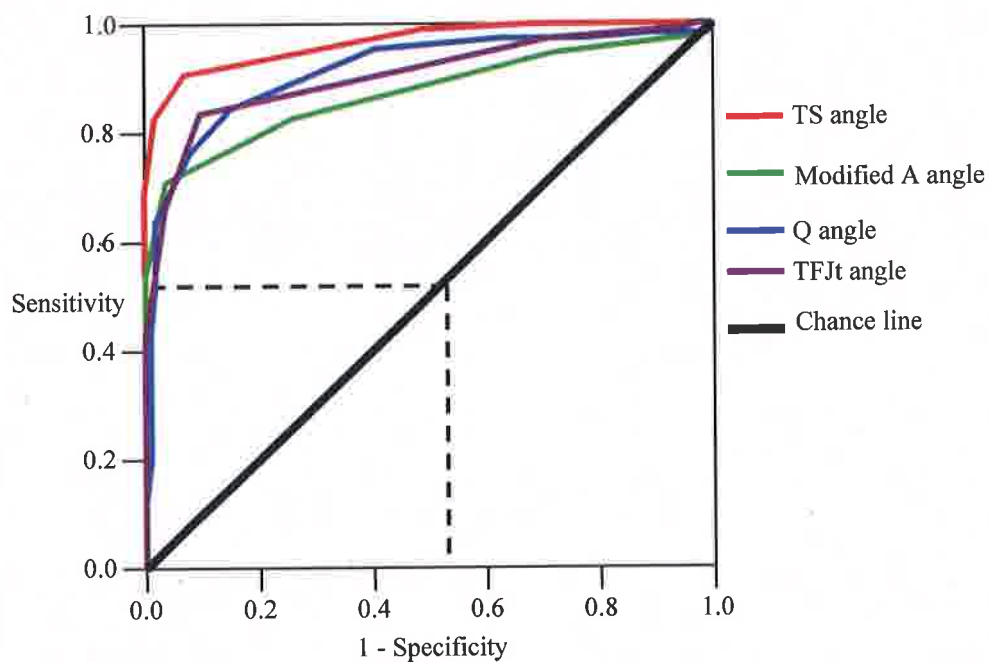


**Figure 5.10:** Association between the TFJt angle and Q angle for all participants.

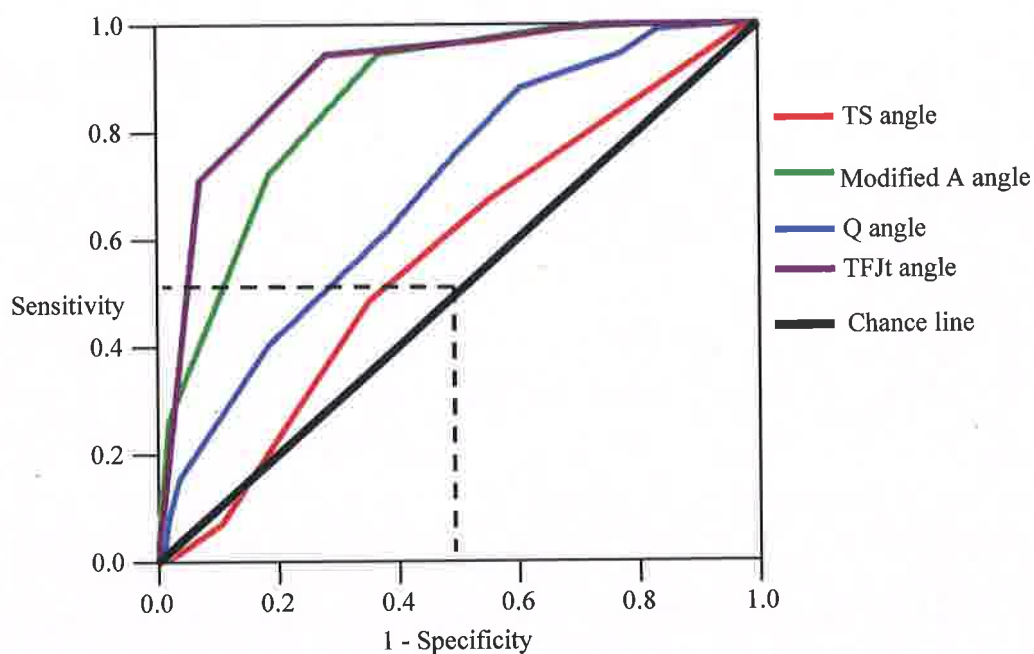
#### **Null hypothesis 4:**

*PFJt alignment measures are unable to discriminate between foot posture groups*

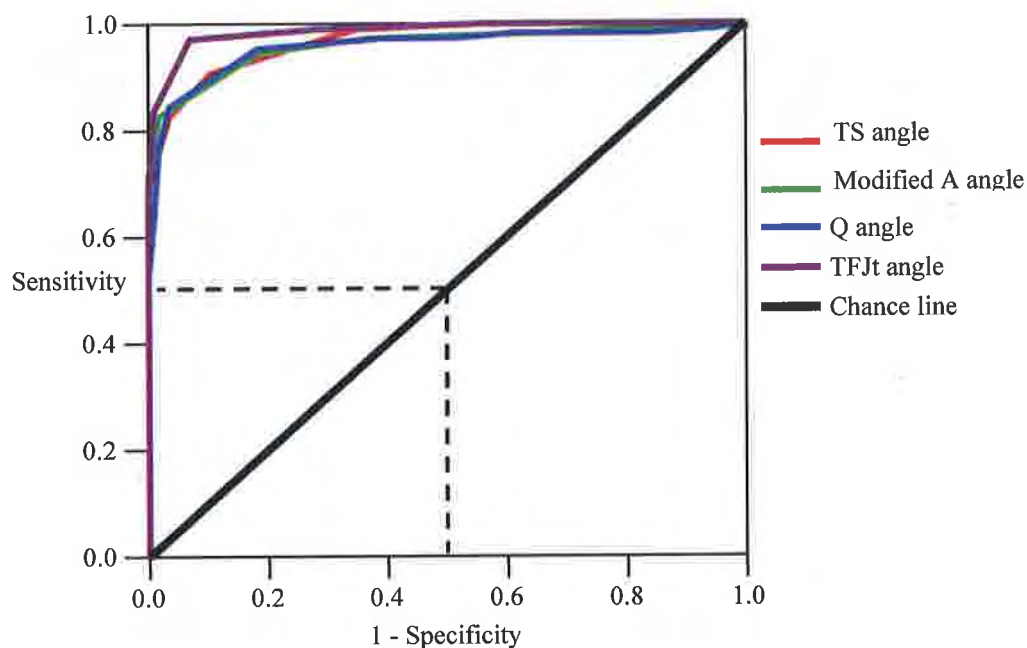
The ROC curves as seen in figure 5.11 show that for the pronated versus neutral group the TS angle and the Q angle yielded the highest specificity and sensitivity with an AUC of 0.967 (95% CI 0.946 – 0.988) and 0.913 (95% CI 0.873 – 0.953). The ROC curves for the TFJt angle and modified A angle were excellent-to-good returning values of 0.905 (95% CI 0.863 – 0.946) and 0.872 (95% CI 0.822 – 0.922) respectively. For the neutral versus supinated group the ROC curves shown in figure 5.12 were also excellent at 0.906 (95% CI 0.866 – 0.946) for the TFJt angle and good at 0.860 (95% CI 0.812 – 0.907) for the modified A angle. The ROC curves for the TS angle and Q angle demonstrated a weak (fail) sensitivity and specificity at 0.567 (95% CI 0.492 – 0.642) and (poor) 0.692 (95% CI 0.624 – 0.760) respectively. Finally, figure 5.13 illustrates the ROC curves for the pronated versus supinated group which showed excellent sensitivity and specificity for the TS angle at 0.969 (95% CI 0.951 – 0.981), the TFJt angle at 0.987 (95% CI 0.976 – 0.998), the modified A angle at 0.959 (95% CI 0.932 – 0.986) and the Q angle at 0.956 (95% CI 0.928 – 0.985).



**Figure 5.11: ROC curve analysis pronated vs. neutral group for PFJt alignment measures.** The fail point of 0.5 sensitivity (cut-off point) is marked (dotted line) on the  $y$  and  $x$  axis.



**Figure 5.12: ROC curve analysis neutral vs. supinated group for PFJt alignment measures.** The fail point of 0.5 sensitivity (cut-off point) is marked (dotted line) on the  $y$  and  $x$  axis.



**Figure 5.13: ROC curve analysis pronated vs. supinated group for PFJt alignment measures.** The fail point of 0.5 sensitivity (cut-off point) is marked (dotted line) on the y and x axis.

## Summary of results

### *Participant characteristics*

- Three hundred and thirty five participants were examined, slightly more females (54%) than males (46%) took part;
- The right limb was the most dominant (76%);
- Average age, height and weight for all participants was 32.6 years, 1.73m and 74.4kg respectively;
- One hundred and ten participants made up the pronated group, 111 the neutral group and 114 the supinated group;

### *Descriptive data for measures*

- For the pronated group the Q angle, TFJt angle and AOG was larger in the dominant limb compared to the non-dominant limb whilst these values were the smallest in the supinated group;
- Differences were also noted between dominant and non-dominant limb for the AOG of the neutral group;

- No differences were noted however between the dominant and non-dominant limb for the neutral and supinated groups for all PFJt alignment measures;

*Null hypothesis 1: There are no significant differences between foot posture groups for PFJt alignment measures*

- Differences were noted between the pronated versus neutral group, pronated versus supinated group for the TS angle;
- Differences were also noted between the pronated versus neutral group, neutral versus supinated group, and pronated versus supinated group for the modified A angle, Q angle and the TFJt angle;

*Null hypothesis 2: There are no significant differences between foot posture groups for NH, AOG and BOG*

- Differences were found between the pronated versus neutral group, neutral versus supinated group, and pronated versus supinated group for the NH and AOG.
- No differences were found between the neutral and supinated groups for the BOG but differences were noted between the pronated and supinated groups;

*Null hypothesis 3: There is no relationship between different foot postures, PFJt alignment measures and foot measures*

- A better relationship occurred between the PFJt alignment measures for the neutral group compared to the pronated and supinated groups;
- The AOG had a better relationship for all foot posture groups, whilst the NH had an inverse relationship for all foot posture groups;

*Null hypothesis 4: PFJt alignment measures are unable to discriminate between foot posture groups*

- All PFJt alignment measures were excellent at discriminating between a pronated and supinated foot posture;
- All PFJt alignment measures were generally good at discriminating between a pronated and neutral foot posture;
- The TFJt angle and modified A angle were the only measures to produce good discrimination between the neutral and supinated foot posture.



## 5.4 Discussion

The main aim of this study was to examine the relationship between different foot posture categories and PFJt alignment. A secondary aim was to establish the influence of different posture categories on other characteristics of foot posture – the AOG, NH and the BOG. This information was obtained using a battery of reliable and valid clinical measures that were identified from the previous literature and developed prior to this study (chapter 4, 4.1 – 4.3). The results of this study suggest that PFJt alignment is related to foot posture. The battery of clinical measures of PFJt alignment – TS angle, modified A angle; Q angle and the TFJt angle were all found to be different between the categorised foot posture groups. Although these measures need to be considered within the context of the SEM, the likelihood of an association is supported by the fact that all PFJt alignment measures showed a similar and clear trend whereby measured values increased with foot pronation and decreased with a foot supination. The 4 null hypotheses proposed at the beginning of this study can therefore be rejected.

### *The sample*

Overall, the sample provided a slightly higher predominance of females (54%) compared to males (46%). This distribution was similar in the pronated and supinated groups but a larger predominance of females (59% and 60%) compared to males (41% and 40%) was noted for the neutral group for both the dominant and non-dominant limbs. This may provide a logical rationale as to why the height and weight of the neutral group were lower and is supported by Mannie (2005) who suggests that females are generally smaller in stature and weight when generally compared to males. The right limb was reported as the most dominant limb (76%) and concurred with the literature which refers to the right limb/foot being the most common (Previc, 1991; Didia and Nyenwe, 1988; Peters, 1988). The sample produced a wide age range overall with the oldest participant noted at 59 years of age. Whilst it is acknowledge that osteoarthritis of the TFJt and PFJt is a common finding as individual's age (Dieppe, 2000; Yanagida and Asami, 1997), the older participants in this study were asymptomatic. Although not within the scope of the study it is worth noting that these individuals may have had radiographic features associated with joint degeneration which could have influenced the results but is likely to have been minimal. The study however did not set out to examine the relationships between age,



gender, weight and height and concentrated on structural/functional alignment of the lower limb.

#### *PFJt alignment measures*

The mean values of the TS angle for all participants was  $2.6^{\circ}$  and are slightly higher than the values proposed by the measure's originators Hughston *et al.* (1984) but are similar to the value ( $2.3^{\circ}$ ) established in a preliminary study of this research programme (section 4.2, page 77). With respect to the pronated group the TS angle values demonstrated mean values ( $5.6^{\circ}$ ) that was larger than the neutral ( $1.2^{\circ}$ ) and supinated groups ( $1.0^{\circ}$ ). In addition, the range of values for the pronated group was the largest out of the three groups ranging from  $1^{\circ}$  –  $10^{\circ}$ . These findings support the observations of Kolowich *et al.* (1990) who described an upper normal limit of  $10^{\circ}$ . The TS angle values for neutral and supinated groups produced very similar values; however the range of values for the supinated group was slightly larger, with some individuals recording a  $-2^{\circ}$ . An explanation for the larger TS angle values for the pronated group in this study could be because there was more internal rotation of the tibia when the knee was flexed to  $90^{\circ}$ . It is important to bear in mind however that foot posture and the TS angle were recorded in two different positions, with the latter measure obtained in a semi-weightbearing position. Despite this, the measure does provide some useful information of limb alignment and could infer that alignment of the patella and tibial tubercle is related to the posture of the foot.

The modified A angle is based on the thoughts of Arno (1990) and observations of Helfet (1982, 1970). The overall mean value of this measure was  $10.1^{\circ}$  and compared favourably to the values obtained in preliminary study (section 4.2, page 77) of this research programme. Although this measure is based on the principles of the A angle, direct comparability with the previous literature is limited. Whilst the mean values presented in the present study are lower than the reported A angle values of  $12.3^{\circ}$  (DiVeta and Vogelbach, 1992) these differences could be due to variation in landmark palpation which was discussed in section 4.2.4 of chapter 4 (page 88). The overall mean value for Q angle was  $16.1^{\circ}$  and is generally higher compared to previous studies (Herrington and Nester, 2004; Livingston and Mandigo, 1999; Horton and Hall, 1989). This comparison however is restricted since many of these studies

independently recorded the Q angle for males, females, right limb and the left limb. Nevertheless, it is worth noting that the overall mean Q angle value for females was 16.8° compared to 15.2° for males. This seems to suggest that there is minimal difference when gender is considered and is a finding consistent with Grelsamer *et al.* (2005) and others (Livingston and Mandigo, 1997; Skalley *et al.*, 1993) but disagrees with the work of Woodland *et al.* (1992) and others (Hsu *et al.*, 1990; Horton and Hall, 1989; Aglietti *et al.*, 1983) with a 3° to 4.6° difference noted. More interesting however, are the Q angle values for each of the three groups, in particular the pronated group presented with the largest mean value of 20.4°, whilst the neutral group had a lower mean of 14.9°. The supinated group presented with lowest values of 13.2°. The spread of values across the groups may explain why the overall mean value of the Q angle was higher compared to other studies. In addition, these values provide a reasonable explanation as to why the Q angle varies so much between studies. For example, studies such as those conducted by Fairbank (1984) and Woodland *et al.* (1992) reported normal mean Q angle values which ranged from 13.6° to 23°. At best however the accuracy of this assumption can never be tested since all of these investigators never documented foot posture or position.

Although the overall mean values for the TFJt was 5.8° supporting the observations of Cahuzac *et al.* (1995) and Chao *et al.* (1994), like the PFJt alignment measures these values differed significantly amongst the foot posture groups. Again, the pronated group demonstrated the largest value of 8.2°, followed by 5.7° for the neutral group and 3.4° for the supinated group. Whilst all of these measures represent a valgus position it should be noted that for the range of values for the supinated group a varus angle of -1° was recorded. Taken together, these findings imply that the patella alignment measures and the TFJt measure are significantly influenced by foot posture and can be explained in part by the theoretical relationship of the patella, tibia and rearfoot. Since foot pronation is coupled with internal tibial rotation, excessive internal rotation of the tibia causes the tibial tubercle to move more medial to the patella (Helfet, 1970), increasing the Q angle, modified A angle and the TFJt angle. The coupled motions of the tibia and rearfoot also influence the TFJt in the sagittal plane which results in slight flexion. This may not only affect the actual position of the patella and increase the contact forces on its posterior surface but also change the

balanced dynamic stabilisation mechanism of the soft tissue structures which surround it (Berry *et al.*, 2008; Farahmand *et al.*, 2004; Heegaard *et al.*, 1994).

### *Foot measures*

To examine the foot posture categories further the selected foot characteristics were also examined. The NH was employed to measure the height of the arch and produced an overall mean value of 3.1cm and is slightly lower than the average values (4.4cm) reported by Evans *et al.* (2003). The supinated group produced the greatest mean value of 3.8cm, the neutral group had a slightly, although significantly different lower mean of 3.2cm. The lowest value was recorded (2.4cm) for the pronated group. Although the range of NH for each group was large, these findings on the whole provide supportive evidence that participants were categorised into the most appropriate foot posture category. This assumption is further supported by the AOG which demonstrated overall mean values of 11.2° and falls within the normal AOG (Whittle, 2002; Boenig, 1977). The range of values for all participants was 0° to 24°, and are similar to the values reported in study 4.1 of this research programme and Saltzman *et al.* (1995). Mean AOG for the pronated group were larger at 16.0° than the neutral (11.1°) and supinated groups (6.7°). These results provide further evidence that supports findings of Kernozek and Greer (1990) and others (Williams *et al.*, 1987; Lapidus, 1963) who suggest that the AOG is larger in individuals with foot pronation. In addition, the mean AOG for the neutral group falls within the normal value, which again may suggest that the FPI<sup>®</sup> category was suitable for categorising individual's foot posture for this study. The lower mean value for the supinated group could be explained purely by the biomechanical behaviour associated with this type of foot posture whereby there is potentially less forefoot adduction.

The overall mean BOG values overall were also similar to previous reports (Bryant, 2001; McIlroy and Maki, 1997). Significant differences were only noted between the pronated group and neutral group, and pronated group and supinated group. The mean and range of values for the pronated group was wider. A simple explanation for this could be related to an increase in the TFJt angle which may have produced a more genu valgum angulation (Oatis, 2003). This frontal plane deviation commonly results in the distance between both feet being wider. In contrast, the range and mean values

were very similar for the neutral and supinated group. Whilst it can be argued that the BOG cannot directly influence alignment of the PFJt and TFJt, it could be considered as an adaptive mechanism to how an individual preferred stance. Furthermore, although the BOG has a lower predictive dynamic value as shown in study 4.1 (page 61) it can provide a foundation for reliability and standardisation of measures. This assumption can be supported by Rossner Buchanan (2005) who used a gait template (foot template) to ensure that measures were obtained in the same stance position.

### *Correlations and ROC analysis*

Whilst the relationship is not strong for some of the measures used in this study, it is of a sufficient extent to justify that there are different PFJt alignment values for specific foot postures (i.e. pronated, neutral and supinated). Of course, correlations do not prove cause (Petrie and Sabin, 2005) and it was never the intention of this study to establish this. However, the analysis appears to lend support to the theoretical assumptions and findings of other studies that show a relationship between foot posture and PFJt alignment (Gross and Foxworth, 2003; Klingman *et al.*, 1997; Tiberio, 1987; Olerud and Berg, 1984). The relationship between PFJt alignment measures for each foot posture category also demonstrated a relationship. Overall, a good relationship was identified between the Q angle and TFJt angle, Q angle and modified A angle and the TFJt angle and modified A angle. Interestingly however it was noted that a stronger relationship existed between each PFJt alignment measure for the pronated and supinated groups compared to the neutral group. This information may suggest that a neutral foot posture does not influence the alignment at the knee compared to a more extreme foot posture (i.e. pronated and supinated) whereby as the malalignment increases the relationship between these measures becomes more evident. This assumption could be applied to most structural malalignments. These observations also provide further support to the work of McClay and Manal (1998) who suggested that an increased valgus angle was correlated with an increase in the Q angle.

The relationship between the FPI<sup>®</sup>, AOG, NH and BOG were also investigated and demonstrated a relationship. The FPI<sup>®</sup> category and the NH demonstrated the strongest relationship. As with the PFJt alignment measures a slightly stronger

relationship was noted for the pronated and supinated groups compared to the neutral group. This may also indicate that the neutral foot posture does not influence foot characteristics (i.e. AOG, NH, BOG) in contrast to a more extreme foot posture (i.e. pronated and supinated). These observations are further supported by the comparative analysis discussed previously in this section and provide evidence that these foot characteristics are identified in certain foot postures when categorised by the FPI<sup>®</sup>.

The results of the ROC analysis provide some useful information for establishing the most suitable measures when related to specific categories of foot posture. Overall, whilst all of the PFJt alignment measures had good capability of discriminating between different foot postures, the ROC curves showed that the TFJt angle and the modified A angle were more able to identify between a neutral and pronated foot posture and a neutral and supinated foot posture. It might therefore be worthwhile to direct further inquiry investigating the relationship of PFJt alignment and foot posture to these predictive clinical measures.

#### *Asymmetric stance and limb dominance*

In this study 335 participants were measured sampling both limbs and feet for an initial total of 670. In order to respect the assumption of independence, only data from one limb/foot (the dominant limb) from each participant was selected for further analysis. Menz (2004) described how it is possible for data to be inflated when measures from the left and right limbs/feet of the same person are pooled for further investigation. This assumption is also supported by the thoughts of Sutton *et al.* (1997) and others (Murdoch *et al.*, 1998; Zhang *et al.*, 1996). To overcome this problem, these authors suggest that the data could be averaged from both limbs/feet, by randomly selecting the left or right limb, or by using the dominant limb. This latter approach was adopted for this study and whilst there is a possibility that important information may be concealed or lost the advantage is that the assumption of independence is not breached. This potential limitation was recognised during the initial data analysis phase where paired *t* tests were employed to examine if significant differences ( $p < 0.001$ ) existed between the dominant and non-dominant limb. The Q angle, TFJt angle and AOG of the pronated group demonstrated significant differences between limbs. The AOG was also found to be significantly different

( $p < 0.001$ ) in the neutral group and since the AOG for the pronated group was larger. This evidence could suggest an asymmetrical stance, influencing a measure of one limb to the other. These differences however should be considered with caution because of each measure's SEM.

Asymmetry of the stance position, (one foot in front of the other) was also noted in 62% of the studied population. This observed difference appears to support the work and thoughts of Smith (1954) and Rigas (1984), as well as the observations noted in study one (5.1) of this research programme. This information coupled with the noted higher proportion of participants having a right dominant limb can be explained further by the contributions of each limb during weightbearing activities. Hirasawa (1989) claims that the left limb contributes mainly to support whilst the right limb was more responsible for propulsion. More importantly to this study however is the statement provided by Bodine (1969) who suggests that the left foot is put forward first when starting to walk. These assumption shares similarities to this study since a high proportion of participants were right limb dominant. Such observations should be investigated further to establish the true significance of limb dominance in normal participants and patients with lower limb pathology.

#### *Limitations of the study*

There are several limitations to this study. The FPI<sup>®</sup> was chosen because it represented the most comprehensive measure available for examining foot posture. The FPI<sup>®</sup> value relates to a composite score of 6 separate observations of the foot to give a total score of -12 to +12 (Redmond, 2005). Redmond *et al.* (2001) state that normal foot posture is thought to score between 2 and 7, and an abnormal pronated and supinated foot posture score of more than +12 and -12 respectively. This range however was stated for the 8 item criteria which produced values between -16 to 16+ and limits direct comparability for this study since the 6 item criteria was used. In this study, all of the available range of scores was used to screen an individual's foot posture which was from -12 to 0 and 0 to 12+ producing a range of 25. For this study the potential scores were simply divided into three which allowed the optimal range of FPI<sup>®</sup> values to be used. Zero was kept as the base value and therefore contributed to the unequal value of the neutral category. The categories identified for this study may

represent a limitation. For example 3 participants had a FPI<sup>®</sup> value of 5 (pronated) and 1 participant had a -5 value (supinated). This could have potentially been a 4 or -4 placing an individual into the neutral category. Whilst this may be a limitation to the categorisation adopted it was felt that this approach was the most suitable during the design phase of the study. Further analysis could have been employed by analysing each FPI<sup>®</sup> and all the measures but this would have distracted away from the original aim. Future studies however could focus on specific FPI<sup>®</sup> values such as values over 10 and -10 represent a pronated and supinated foot posture, a neutral category could range from 2 to -2. Whilst this approach may allow for better defined foot postures it limits the inclusion criteria and does not allow a wider range of foot posture to be examined. Moreover, by not including the available range of the FPI<sup>®</sup> values seem to contradict its use as a clinical tool. Evans *et al.* (2003) points out the possible ambiguity associated with the summed FPI<sup>®</sup> values. For example the same FPI<sup>®</sup> value may be obtained from different items of the FPI<sup>®</sup> and therefore represents a limitation. Whilst this should be acknowledged this study did show that a lower NH and larger AOG was associated with a pronated foot posture and a higher NH and smaller AOG was related to a supinated foot posture. It is acknowledged however that the findings of this study may only be generalised to individuals with no pain and whose foot structure can be defined by the FPI<sup>®</sup> categorisation employed.

Of the 335 participants who took part in the study, 42 demonstrated asymmetrical foot postures. This may reveal a limitation of the study, the dominant limb could be favoured and more pronated (i.e loading more than the other limb thus increasing the measures obtained). In light of this, favouring a particular limb/foot could be linked to pathology and would require separate analysis. Another limitation relates to problems associated with marker placement precisely over the anatomical landmarks which may have induced error. However the results of the intrarater reliability of the all of the measures used produced good ICC values and clinically acceptable SEM values. Whilst it could be argued that the measures used in this study have an element of subjectivity, they do provide objectivity. Whilst many clinicians carry out static examinations with the assumption that structure dictates function (McPoil and Cornwall, 1996) the dynamic situation presents with a larger variability (Hamill *et al.*, 1989; Harrington, 1983). The results of this study reported static values (quasi-static

in nature) and are therefore limited to this situation. These measures should now be examined to establish their functional significance.

### **5.5 Conclusion**

This study has presented initial normal clinical PFJt alignment reference values for 3 different foot postures – pronated, neutral and supinated. The results revealed that the TS angle, modified A angle, Q angle and TFJt angle were larger with a pronated foot posture and smaller with a supinated foot posture. These findings therefore suggest that a clear trend exists between PFJt alignment and foot posture. An improved understanding of lower limb malalignment along with their effect on functional parameters may help to provide a further insight into the functional consequences of PFJt alignment, foot posture and PFJt pain. Future work should now examine the functional effects of these reported normal clinical PFJt alignment values.

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This study was presented as a poster at the Research student's committee 1<sup>st</sup> annual poster day, UWIC, September, 2007 and was awarded 2<sup>nd</sup> place (Curran, 2007).



## Chapter 6

### **Influence of PFJt alignment on plantar pressure distribution: Comparisons between normal participants and patients with PFJt pain**

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This chapter presents the final study of the thesis, which aimed to investigate the functional significance of the key PFJt alignment measures that were investigated in chapter 5. Plantar pressure measurement was used to examine if foot contact and loading characteristics were different in 'asymptomatic' participants grouped according to PFJt alignment and patients with PFJt pain. Plantar pressure data were analysed and comparisons made between groups.

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#### **6.1 Rationale of the study**

The previous studies in this thesis focussed on reliability and validity in their broadest context. However, the most important clinical issue concerns the functional significance of different PFJt alignment categories, asking if there is any implication for functional performance of having a knee aligned in a particular way. This issue focuses on predictive, or criterion validity which refers to the relationship between measures and relevant outcome measures (Durward *et al.*, 2001a). In recent years plantar pressure measurement systems have become more accurate and reliable, less expensive and transportable (Orlin and McPoil, 2000). Plantar pressure data is important because it provides important objective information about how force is attenuated during contact, and how it is then directed through the articulations of the lower limb. This is important because it is likely to be related to the potential for pathology such as PFJt pain. To date, no study has been published investigating the relationship between plantar pressure distribution and PFJt alignment.

Establishing the influence of different PFJt alignment values on foot function using different force and pressure variables offers a potentially useful insight into the relationship between PFJt alignment, PFJt pain and foot function. For example, identifying if more loading occurs on the medial side of the plantar aspect of the foot compared to the lateral side may provide useful information on the relationship with frontal plane knee (PFJt) alignment. The aim of this final study therefore was to consider the relationship between PFJt alignment, PFJt pain and foot function by comparing plantar pressure distribution between groups of participants arranged

according to PFJt alignment and patients with PFJt pain. To examine the relationship of PFJt alignment angles and PFJt pain on plantar pressure characteristics, the following 3 null hypotheses were set:

1. MF, FTI and the CoP during the contact phase of walking (rearfoot loading) are not significantly different between PFJt alignment groups and the PFJt pain group.
2. MF, FTIs and CoP during the midstance phase of walking (midfoot loading) are not significantly different between PFJt alignment groups and the PFJt pain group.
3. The LMAI and LMFI are not significantly different between PFJt alignment groups and the PFJt pain group.

## **6.2 Method**

The study utilised a 4 group comparison of measures design using one examiner. Ethical approval was obtained from the Cardiff School of Health Sciences Ethics Committee, UWIC before the study began (Appendix 7). All participants were fully informed of the nature of the study (appendix 8) and written informed consent was obtained from all before taking part (appendix 2). Data collection was undertaken in the gait laboratory at the Wales Centre for Podiatric Studies, UWIC.

### **Participants and patients**

Data from 3 groups of normal asymptomatic individuals were collected. These groups were defined using data obtained from the cross-sectional study (chapter 5) which was first investigated using the Kolomogorov-Smirnov test to show that it was normally distributed ( $p < 0.001$ ). Distribution curves were then plotted for the Q angle, TFJt angle and modified A angle. From this, the mean  $\pm$  1 SD was defined as the 'central' (normal) values (Kirtley, 2007). The values to the right of the mean were defined as 'high' and those to the left as 'low' (figure 6.1). Although the values to the left and right included some extreme values, it should be noted that they were asymptomatic individuals. From this an objective 3 group classification was produced and each participant was screened to determine group assignment. A fourth group was also formed solely on the basis of PFJt pain. Key participant characteristics for all groups were recorded, including gender, age, height and weight to allow useful basic

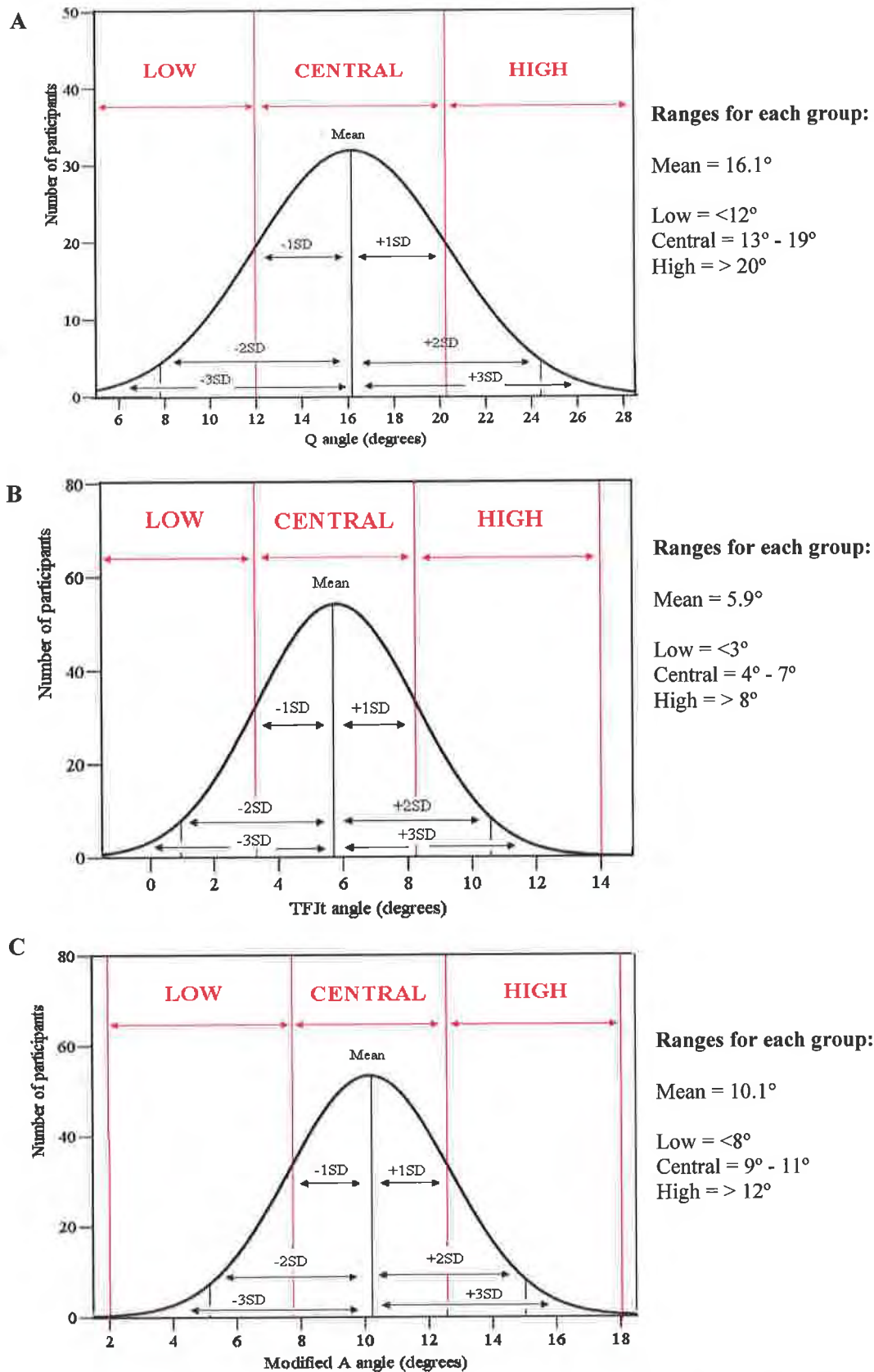
demographics to be presented. The age range for all participants was 19 – 40 years. This age range was chosen to minimise the possibility of participants presenting with osteoarthritic changes to the TFJt and PFJt (Dieppe, 2000; Yanagida and Asami, 1997).

The inclusion criteria for the normal, asymptomatic individuals were as follows:

- No obvious foot or gait abnormalities, no history of foot or lower limb pathology or treatment within the past 12-months.

The inclusion/exclusion criteria for the PFJt pain patients were based on established criteria and approaches used to classify PFJt pain and were as follows:

- PFJt pain that is aggravated during walking, running, squatting, kneeling, ascending and/or descending stairs (Fulkerson, 2002);
- Patients will have not received treatment before data collection;
- Patients will be excluded if they have signs and symptoms that indicate other types of knee conditions these will include clicking, locking giving way and swelling of the knee (Aglietti *et al.*, 1993);
- Patients must have a negative response to the following: anterior and posterior draw test (indicating cruciate damage), McMurray's test (indicating meniscal damage) and valgus/varus stress tests (indicating collateral ligament damage);
- Patients who report a traumatic injury or surgery to the TFJt and PFJt in the past 12-months will be excluded;
- Patients with unilateral PFJt pain of their non-dominant limb will also be excluded.



**Figure 6.1: Distribution of normal PFJt alignment values.** Graphs A – C show the distribution of knee alignment values based on data from a cross-section of 335 healthy individuals (chapter 5). Mean values and 3 SD are shown for each measure and from this a value range can be determined for 'low', 'central' and 'high' Q, TFJt and modified A angles. The graphs are not to scale and are for illustration purposes only.

### Sample size and power calculation

Power calculations for participant numbers were performed in SPSS™ (version 12.1) using plantar pressure data from previous studies. These studies were identified because they examined key variables (i.e. FTI, CoP and LMFI) using different versions of the EMED® system (Novel, GmbH, Munich, Germany), both of which were to be used in the present study. The power calculations suggest that a minimum number of participants per group required ranged from  $n = 2$  to 20, depending on the variable used, with most of the sample sizes being under 10. However, to obtain adequate power for all of the variables  $n = 20$  participants were recruited for each group giving a total of 80 participants for the entire study (table 6.1).

Author	System	Parameter	Mean (SD)	Power calculation
Putti <i>et al.</i> (2008)	EMED®-ST4	FTI (Ns) <i>Midfoot</i> <i>Third to fifth toes</i>	28 (23) 6 (5)	$n = 19$ per group $n = 20$ per group
Nielsen (2000)	EMED®-SF	LMFI	0.92 (0.12)	$n = 6$ per group
Cornwall and McPoil (2000)	EMED®-SF	CoP: Maximum velocity (m/s) <i>Forefoot</i> CoP: Average velocity (m/s) <i>Toes</i>	0.95 (0.49) 0.66 (0.32)	$n = 9$ per group $n = 8$ per group

**Table 6.1: Sample size calculations.** Power calculations using SPSS™ (version 12.1) based on previous studies (mean and SD values) using different versions of the EMED® system and parameters. Only the largest sample size calculated from each study for key variables to be used in the present study are presented and represents a range of  $n = 6$  to  $n = 20$  participants per group. A power value of 0.80 was set for all calculations performed.

### Clinical measurements for screening and participant characteristics

For consistency with the other studies performed in the thesis, only the dominant limb was recorded which was identified by kicking a ball. For the PFJt pain group however, data was recorded from both limbs and feet regardless if they had bilateral or unilateral pain, although the dominant limb was still identified.

#### *All participants*

The following clinical measures were obtained from all participants. *Foot measures:* AOG, BOG and NH were recorded. To standardise NH (cm) the NNH was calculated and has been described in chapter 5 (page 119). The FPI®, which is described later, was recorded but primarily served as a screening tool for the normal groups. The TS

angle was recorded which primarily established mean values for the PFJt pain group and allowed for comparisons to be made between this group and the 3 normal groups. A detailed description of these measures and the protocol used has already been presented in chapter 5 (pages 118 – 121).

#### *Normal groups – screening*

Participants were screened into ‘low’, ‘central’ or ‘high’ PFJt alignment groups as previously highlighted (figure 6.1, graphs A - C). This screening process provided further inclusion/exclusion criteria for participants. Each measured value must have fallen into the appropriate category. If a participant had a low Q angle and a high TFJt angle for example, no further analysis was performed. This is unlikely to have happened as the data from the cross-sectional study clearly demonstrated consistency between measurements. For example, a high Q angle and high TFJt angle had a correlation of  $r = 0.706$  (80% of pronated group). Participants were also excluded from further analysis if one or more of the PFJt alignment values fell around the threshold zone. The pilot study data (5.1.5) from chapter 5 was used to incorporate the SEM associated with the Q angle, TFJt angle and the modified A angle. The SEM values reported ranged from 1.5° for the TFJt angle and the modified A angle and 2.1° for the Q angle. Therefore 2° of error was used either side of each threshold zone (table 6.2).

PFJt alignment measures	Low values		Central values		High values	
	Range	Range with SEM	Range	Range with SEM	Range	Range with SEM
Q angle(°)	<12	<11	13 – 19	14 – 18	>20	>21
TFJt angle(°)	<3	<2	4 – 7	5 – 6	>8	>9
Modified A angle (°)	<8*	<6*	9 – 11*	9 – 11 *	>12*	>14*

**Table 6.2: Criteria (definition) values of each PFJt alignment category.** This table shows the range of low, central and high values identified from graphs A – C presented in figure 6.1 and the threshold range with SEM used for screening participants into 1 of the 3 groups. \*Because of the limited range of ‘central’ (normal) values for the modified A angle, 2° has been taken from the ‘low’ and ‘high’ values to allow a range of 3° for the central values. A detailed description of these measures and the protocol used has already been presented in chapter 5.

Participants were also required to fulfil the criteria of foot posture for either the ‘low’ (supinated), ‘central’ (neutral) and ‘high’ (pronated) values. For example if a participant presented with high PFJt alignment values but a neutral foot posture no further analysis was performed. Since the FPI® is based on an ordinal scale, no SEM

values can be determined. To minimise any error that may have occurred from determining a participant with a neutral or pronated foot posture and a neutral or supinated foot posture the threshold range for each foot posture was reduced (table 6.3).

Foot posture measure	Low values (supinated)		Central values (neutral)		High values (pronated)	
	Range	Threshold range	Range*	Threshold range*	Range	Threshold range
FPI <sup>®</sup>	-12 – -5	-12 – -6	-4 – +4	-4 – +4	+12 – +5	+6 – +12

**Table 6.3: Criteria (definition) for foot posture values of each PFJt alignment category.** This table shows the ranges used for foot posture categorisation in the cross sectional study (-12 - -5; -4 - +4; +5 - +12). Because the FPI<sup>®</sup> is based on ordinal data the SEM cannot be calculated however participants who have values of -5 and +5 will be excluded. \*Includes '0' as baseline measure for neutral values.

#### *Clinical interpretation for each normal group*

The objective categorisation criteria described previously was based on clinical anatomical alignment of the lower limb. This alignment relates to the position of the limb during a quasi-static examination. Rather than label groups 'high', 'central' and 'low' as dictated by the PFJt alignment measures, the terms '*pronated*', '*neutral*' and '*supinated*' were used for each group. These terms are instantly recognisable and were simply defined to facilitate a meaningful discussion to aid the reader when thinking about the clinical picture. Table 6.4 provides the clinical description of the anatomical alignment for each group. However, whilst it is useful to adopt this terminology, the absolute validity of the categories requires assessment, and this should be borne in mind.

Group =	Definition of measures	Description of clinical anatomical alignment
<b>Pronated</b>	High Q, modified A and TFJt angle values; <i>pronated</i> foot posture	<b>Internal tibial rotation</b> is linked with foot pronation, an abducted foot position and genu valgum. This results in an increased Q, modified A and TFJt angle.
<b>Neutral</b>	Central Q, modified A and TFJt angle values; <i>neutral</i> foot posture	<b>Neutral tibial rotation</b> is linked with a foot which is not pronated or supinated; foot position may be slightly abducted (normal AOG 10° - 12°). At the knee there will be no obvious genu valgum or varum which results in central ranges of the Q, modified A and TFJt angle.
<b>Supinated</b>	Low Q, modified A and TFJt angle values; <i>supinated</i> foot posture	<b>External tibial rotation</b> is linked with foot supination, an adducted foot position and genu varum. This results in a decreased Q, modified A and TFJt angle.

**Table 6.4: Definition of measures, group terminology and clinical anatomical alignment used for this study.**

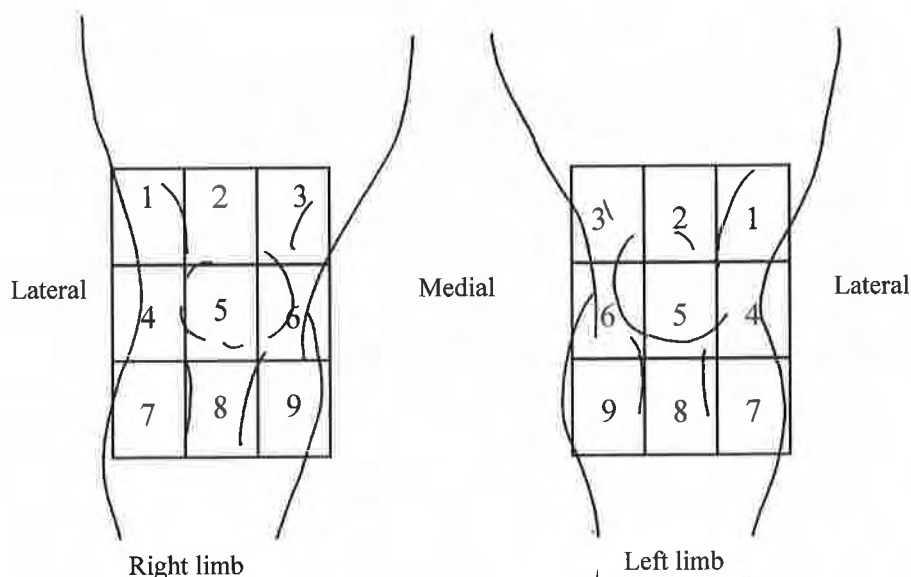
### *PFJt pain group*

In addition to the TS angle and the foot measures the Q angle, TFJt angle, modified A angle and the FPI<sup>®</sup> were also obtained from each patient. The protocol for obtaining these measures was the same as for the normal groups as outlined in chapter 5 (pages 118 - 121). Before data was collected information on pain levels and areas of pain were obtained. Whilst descriptive, this information was collected to examine if areas of pain, alignment and foot function (pattern of loading) were related. A VAS was used to determine the level of pain in the previous 48 hours (figure 6.2) and was chosen because it is simple to use and has been shown to be a valid indicator of pain in patients with PFJt pain (Chesworth *et al.*, 1993). They were also asked to shade the area (s) where they experience pain on a simple line drawing of the anterior aspect of the knee. Full instructions were provided. For the analysis a map was placed over the anterior aspect of the knee which divided it into 9 different regions. The choice for these regions was based on the anatomy of the PFJt and the signs and symptoms associated with PFJt pain (Grelsamer, 2007). The regions were numbered 1 – 9 and related to the superior lateral (1), superior central (2), superior medial (3), central lateral (4), central (5), central medial (6), inferior lateral (7), inferior central (8) and the inferior medial (9) (figure 6.3). The shaded area within each region had to be at least 50% of that region to qualify as an area of pain. This approach is similar to that used by Birrell *et al.* (2005) for hip pain drawings.



**Figure 6.2.** Unmarked 10cm VAS scale for level of pain for patient group.





**Figure 6.3: PFJt pain drawing and map analysis.** The grid divides the anterior aspect of the knee into 9 regions: the superior lateral (1), superior central (2), superior medial (3), central lateral (4), central (5), central medial (6), inferior lateral (7), inferior central (8) and the inferior medial (9). The grid was not shown to patients and was only used for the analysis stage.

## Plantar pressure measurement

### Equipment

The EMED<sup>®</sup>-m platform system (Novel, GmbH, Munich, Germany) was used to record plantar pressures. The platform has a dimension of 610 x 323 x 20mm<sup>2</sup> and a sensor area of 380 x 240mm. Within this area are 3792 individual sensors that have a spatial resolution of 4/cm<sup>2</sup> and an accuracy of  $\pm 5\%$ . A sampling rate of 50Hz was used to collect data and is consistent with standard practice (Mittlemeier and Morlock, 1993), which minimises the likelihood of missing critical events in normal walking. The system was mounted flat within the centre of a standard EMED<sup>®</sup> foam walkway (3-metres long). Although the accuracy of the EMED<sup>®</sup>-m system is presented as  $\pm 5\%$ , a simple static test was performed on each participant before data collection to confirm the system's accuracy (Putti *et al.*, 2008). This involved each participant standing on one limb on the EMED<sup>®</sup>-m plate. The accuracy of the EMED-m<sup>®</sup> system was verified when the measured force fell within 5% of the participant's weight.

### Procedure

Data was collected from both feet using the 'two-step' protocol described by Meyers-Rice *et al.* (1994) and which enjoys continued use (Bryant *et al.*, 2000). Before data collection each participant familiarised themselves with the procedure. The starting

position for each participant was determined so that they began walking with the contralateral foot to that being recorded; this ensured that they made contact with the platform on the second step. This was a practical decision to increase the strike rate with a small platform. Each participant completed 3 practice trials and their starting position was marked to ensure that their foot struck the platform. To minimise the risk of targeting, each participant was instructed to look straight-ahead and not down at the platform. If however a participant appeared to target the platform or if the researcher observed an atypical foot placement the trial was repeated. All measurements were taken with the participants walking barefoot over the pressure plate at a self-selected speed. Five plantar pressure recordings of both feet were collected to minimise bias but only recordings from the dominant foot were used for further analysis.

### **Pilot and reliability study**

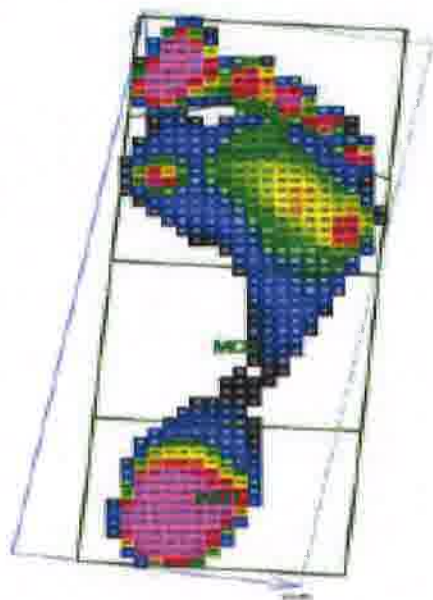
Before data collection began a pilot study was performed to familiarise and define the data collection protocol. During these sessions it was established that it would take between 20 – 25 minutes to collect data from each participant. Intrarater reliability of the protocol and the EMED<sup>®</sup>-m system for the key study variables was also performed on a group of 20 normal asymptomatic individuals (16 females, 4 males, mean age 26.2 years [SD 8.0, range 18 – 39], mean weight 67.9kg [SD 15.5, range 40 – 105], mean height 1.66m [SD 0.0, range 1.60 – 1.78]). Data were collected from the dominant foot (19 right feet, 1 left foot) on 2 occasions, approximately 2 weeks apart. ICCs<sup>[model 3, k]</sup> and the CoV were used to assess reliability. Acceptable reliability was found for all variables with ICCs ranging from 0.832 – 0.979 whilst the CoV ranged from 5.7 to 26%. Lower ICCs and larger CoVs were noted for the midfoot in general which is to be expected since lower areas of force (and pressure) are associated with less reliability (Gurney *et al.*, 2008). Table 6.5 presents a summary of the reliability results.

Variable	Area of foot	ICC	(95% CI)	CoV (%)
MF	Rearfoot	0.846	(0.651 – 0.936)	10
	Midfoot	0.937	(0.849 – 0.975)	15.8
FTI	Rearfoot	0.959	(0.900 – 0.984)	15.6
	Midfoot	0.903	(0.773 – 0.961)	26
VCoP <sub>max</sub>	Rearfoot	0.867	(0.695 – 0.945)	7
	Midfoot	0.902	(0.769 – 0.960)	8.7
DCoP (% of stance)	Rearfoot	0.938	(0.850 – 0.975)	6.8
	Midfoot	0.832	(0.632 – 0.943)	5.7
LMAI	N/A	0.938	(0.851 – 0.975)	8
LMFI	N/A	0.979	(0.948 – 0.992)	5.7

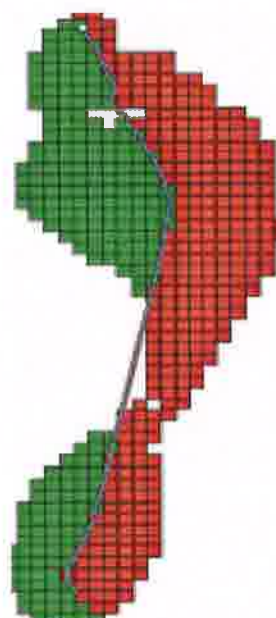
**Table 6.5: Intrarater reliability of the EMED-m<sup>®</sup> system using the 2-step initiation protocol (N/A – not applicable).**

### **Data analysis – plantar pressure measurement**

All plantar pressure data was visually inspected before analysis to ensure high quality data acquisition and that the appropriate sensors had been activated during each trial. The mean of the five steps recorded were analysed and all data were normalised to BW and foot size. Using EMED<sup>®</sup> analysis ‘multimask-e’ software the foot was divided into the following four areas of interest: rearfoot, midfoot, forefoot and toes (four division, rectangular mask) (figure 6.4). The MF (N/cm<sup>2</sup>s) and FTI (%/BW) were calculated for the rearfoot (contact) and midfoot (loading) areas only. The MF and FTI was chosen to provide information on the magnitude and timing of forces acting on the foot during the contact and midstance phase of gait. The EMED<sup>®</sup> ‘gaitline and geometry’ software was used to analyse CoP variables for the rearfoot (rearfoot contact) and midfoot (midstance loading) which included maximum velocity (VCoP<sub>max</sub>) and the duration of the CoP (DCoP). The variables of the CoP were chosen to identify the pattern and efficacy of progression of foot loading. Using the same software the LMAI and the LMFI which divide the foot into lateral and medial portions were also assessed (figure 6.5). These indices were selected because they may identify the influence of frontal deviations of the lower limb (i.e. genu valgum and genu varum) (Cornwall and McPoil, 2003). The definitions, calculations and theoretical relevance of each variable analysed have been presented in table 3.7 (page 59).



**Figure 6.4: Four division (rectangular) mask.** This mask divides the foot into the heel, midfoot, forefoot and toes. Seventy three percent of the foot length makes up heel to midfoot whilst 45% makes up from the midfoot to forefoot divisions. This mask has been chosen because the CoP can still be recorded even if it travels outside the maximum pressure picture area and because it can be used for the regional velocity of the CoP program (gaitline and geometry software). Reproduced with permission of Novel GmbH, Munich, Germany, Scientific Manual, May 2004, version 12.3, page 13.



**Figure 6.5: LMAI and LMFI.** This figure illustrates the lateral and medial areas which will be used for the calculation of the LMAI and LMFI. The areas are divided by the CoP line. Reproduced with permission of Novel GmbH, Munich, Germany, Scientific Manual, May 2004, version 12.3, page 63.

### Statistical analysis

The mean, SD and range were calculated for all of the clinical measures and plantar pressure parameters investigated. All data were found to be normal in distribution using the Kolmogorov-Smirnov test of normality ( $p < 0.001$ ). Differences between groups were compared using a one-way ANOVA and Tukey's post hoc analysis was used to determine where differences occurred. Differences among the groups were regarded as statistically significant if  $p < 0.05$ . All statistical tests were carried out using SPSS™ (version 12.1).

### 6.3 Results

#### Participant characteristics

The total sample consisted of 80 participants ( $n = 20/\text{group}$ ) of which 58 (72.5%) were female and 22 (27.5%) were male. The mean age was 27.4 years (SD 6.7, range 19 – 39), the mean weight was 73.2kg (SD 15.8, range 45 - 125) and the mean height was 1.70m (SD 0.09, range 1.45 – 1.89). Of the total sample 70 (87.5%) participants had a right dominant limb whilst 10 (12.5%) participants were left limb dominant. A one-way ANOVA showed no significant differences ( $p < 0.001$ ) between the groups for age, weight and height confirming that the groups were closely matched. Table 6.6 presents information on participant demographics for each group for these variables.

Participants	Pronated group	Neutral group	Supinated group	PFJt pain group	P value
Gender†	F: 13 / M: 7	F: 16 / M: 4	F: 17 / M: 3	F: 12 / M: 8	0.242
Age (years)					
Mean $\pm$ SD	27.8 $\pm$ 7.3	27.3 $\pm$ 6.8	25.6 $\pm$ 6.4	29.1 $\pm$ 6.3	0.437
(range)	(19 – 38)	(20 – 39)	(19 – 39)	(20 – 38)	
Weight (kg)					
Mean $\pm$ SD	73.8 $\pm$ 18.0	69.8 $\pm$ 9.5	73.5 $\pm$ 22.5	75.6 $\pm$ 9.7	0.714
(range)	(40 – 115)	(45 – 82)	(45 – 125)	(65 – 90)	
Height (m)					
Mean $\pm$ SD	1.70 $\pm$ 0.0	1.65 $\pm$ 0.0	1.68 $\pm$ 0.0	1.74 $\pm$ 0.11	0.116
(range)	(1.56 – 1.85)	(1.45 – 1.88)	(1.50 – 1.80)	(1.60 – 1.95)	
Limb dominance†	L: 3 / R: 17	L: 0 / R: 20	R: 19 / L: 1	R: 14 / L: 6	0.021

Table 6.6: Group participant demographics ( $n = 20/\text{group}$ ). †Chi-square test performed.

#### Clinical measures for each group

##### *PFJt alignment measures*

The mean, SD and range of values for the PFJt alignment measures for the 4 groups are presented in table 6.7. It was noted that the mean value for the PFJt group was similar to that of the high value group for all of the PFJt measures. Whilst it was considered that the categories were mutually exclusive because of the categorisation process performed a one-way ANOVA was performed as a confirmatory exercise to ensure that the normal groups truly represented the different categories they were intended to. The one-way ANOVA showed significant differences between each of the 4 groups ( $p < 0.001$ ). This was supported by Tukey's post hoc analysis although no significant differences were found between the pronated and PFJt pain group for the Modified A angle ( $p = 0.829$ ). In addition, whilst significant differences were noted

between these groups the level of significance was not as strong for the TS angle ( $p = 0.072$ ). However, the TS angle measure was not used during the categorisation process and was primarily included to establish values in the PFJt pain group.

	Pronated group Mean $\pm$ SD (range)	Neutral group Mean $\pm$ SD (range)	Supinated group Mean $\pm$ SD (range)	PFJt pain group Mean $\pm$ SD (range)	P value
Q angle ( $^{\circ}$ )	24.8 $\pm$ 2.2 (21- 29)	16.8 $\pm$ 1.7 (14 -19)	10 $\pm$ 1.2 (7 - 11)	21 $\pm$ 2.9 (17 - 28)	<0.001
TFJt angle ( $^{\circ}$ )	10.7 $\pm$ 1.3 (9 - 13)	6.1 $\pm$ 0.7 (5 - 7)	-0.15 $\pm$ 1.7 (-4 - 2)	8.8 $\pm$ 1.6 (7 - 12)	<0.001
Mod A angle ( $^{\circ}$ )	15.3 $\pm$ 1.4 (14 - 19)	10 $\pm$ 0.6 (9 - 11)	3.3 $\pm$ 2.0 (0 - 6)	11.9 $\pm$ 1.9 (8 - 16)	<0.001
TS angle ( $^{\circ}$ )	6.7 $\pm$ 1.8 (3 - 10)	2.8 $\pm$ 1.5 (0 - 6)	1.4 $\pm$ 1.3 (0 - 4)	6.2 $\pm$ 2.3 (7 - 16)	<0.001

Table 6.7: Mean, SD and range of the clinical PFJt alignment measures for all groups.

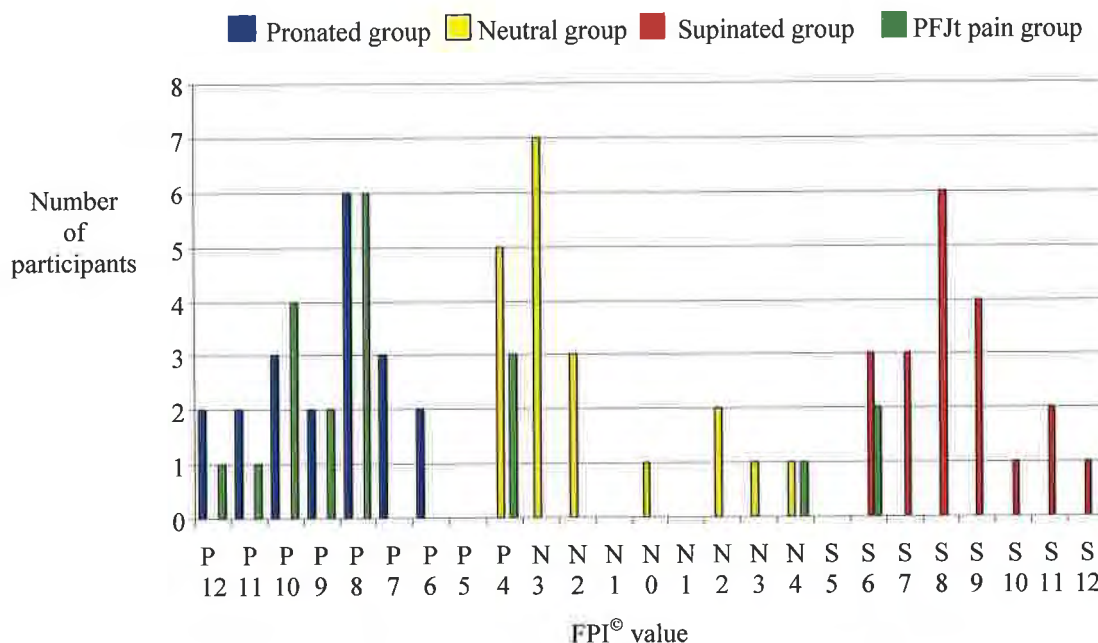
#### *Foot measures*

The mean, SD and range of values for the foot measures for the 4 groups are presented in table 6.8. As with the PFJt alignment measures it was noted that the mean value for the PFJt pain group was similar to that of the pronated group for all of the foot measures. Again, the one-way ANOVA was also performed to confirm that the normal groups truly represented the different categories they were intended to. The ANOVA showed that significant differences occurred between each of the 4 groups ( $p < 0.001$ ). This was supported by Tukey's post hoc analysis but no significant differences were noted between the pronated and PFJt pain group for the AOG ( $p = 0.802$ ). In addition, whilst a significant difference was noted between these groups the level of significance was not as strong for the BOG ( $p = 0.042$ ).

The distribution of the FPI<sup>®</sup> for the PFJt pain group is similar to the distribution exhibited by the pronated group. Only 2 participants from the PFJt pain group displayed a neutral 4 and supinated 5 posture (figure 6.7). As performed in study 5, observation of foot placement was also noted (during AOG and BOG analysis). A forward position of the dominant limb was the most common for all participants (83.5%); however all of the participants from the PFJt pain group placed their dominant in a forward position.

	<b>Pronated group</b> Mean $\pm$ SD (range)	<b>Neutral group</b> Mean $\pm$ SD (range)	<b>Supinated group</b> Mean $\pm$ SD (range)	<b>PFJt pain group</b> Mean $\pm$ SD (range)	<b>P value</b>
<b>AOG (<math>^{\circ}</math>)</b>	15.4 $\pm$ 2.4 (12 – 22)	12.2 $\pm$ 2.4 (9 – 16)	8.4 $\pm$ 2.9 (1 – 12)	16.1 $\pm$ 3.1 (10 – 23)	<0.001
<b>BOG (cm)</b>	11.9 $\pm$ 2.7 (7.9 – 15.2)	8.1 $\pm$ 1.4 (5.5 – 10.2)	6 $\pm$ 1.7 (2.8 – 9.1)	11.6 $\pm$ 3.6 (7.2 – 20.2)	<0.001
<b>NH (cm)†</b>	2.1 $\pm$ 0.6 (1.1 – 3.2)	3.1 $\pm$ 0.3 (2.5 – 3.8)	3.7 $\pm$ 0.6 (2.5 – 4.5)	2.6 $\pm$ 0.4 (1.9 – 3.4)	<0.001
<b>NNH††</b>	0.07 $\pm$ 0.0 (0.03 – 0.12)	0.12 $\pm$ 0.0 (0.03 – 0.15)	0.14 $\pm$ 0.0 (0.01 – 0.19)	0.10 $\pm$ 0.0 (0.09 – 0.16)	<0.001
<b>Foot placement</b>	Forw: 17 (85%) Equal: 2 (10%) Back: 1 (5%)	Forw: 15 (75%) Equal: 4 (20%) Back: 1 (5%)	Forw: 15 (75%) Equal: 3 (15%) Back: 2 (10%)	Forw: 20 (95%) Equal: 0 (0%) Back: 0 (%)	= 0.145

**Table 6.8: Mean, SD and range of the clinical foot measures for all groups** (Abbreviations Forw = forward, Back = backward). †The absolute height is included to provide a clinical perspective, but the ratio†† is potentially more valuable as it controls for foot size



**Figure 6.7: Distribution of the FPI® for all groups.** A pronated 5 and supinated 5 foot posture were removed by screening. (Abbreviations P = pronated, N = neutral and S = supinated).

### Levels and areas of pain for PFJt pain group

Eight of the 20 patients from the PFJt pain group had bilateral involvement whilst 12 had unilateral involvement. The mean VAS score for the group was 6.5 (SD 1.2, range 4 – 9). All of the patients with bilateral PFJt pain ( $n = 10$ ) had a higher mean VAS score of 6.9 (SD 1.1, range 6 - 9) for their dominant limb compared to a mean VAS score of 5.9 (SD 0.7, 5 – 7) for their non-dominant limb. Six patterns were



produced for the area of pain. A pattern of 6, 9, 8; a pattern of 4, 7, 8 and a pattern of 3, 6, and 9 were the most reported areas of pain. The distribution for all patterns of pain for the PFJt pain group is presented in figure 6.7. For clarity, the 3 most common patterns of pain are also illustrated in figure 6.8.

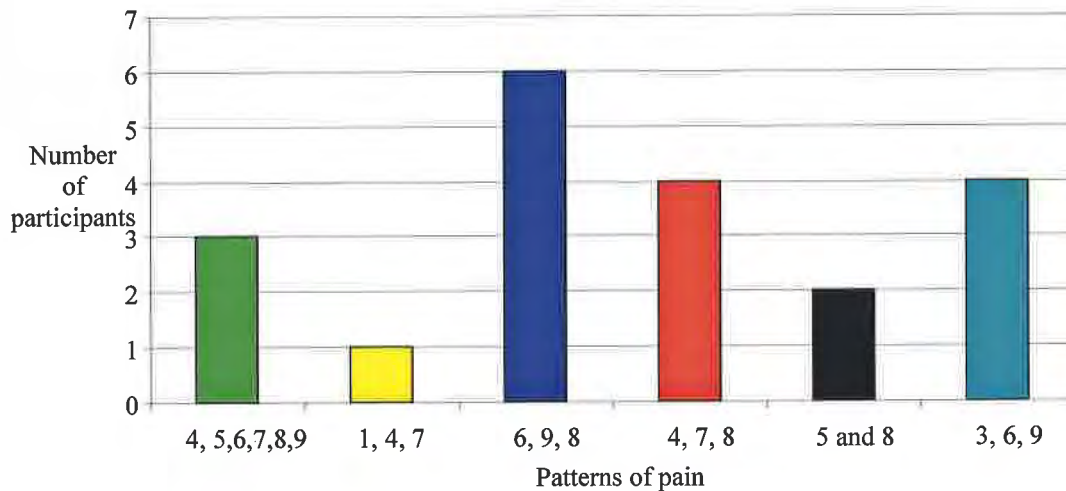


Figure 6.7: Distribution of patterns of pain for the PFJt pain group.

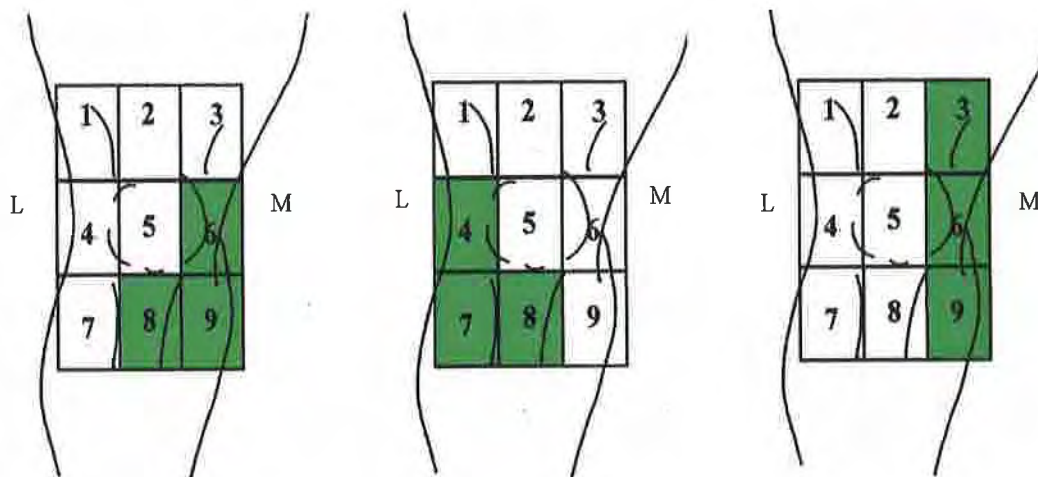


Figure 6.8: Illustration of the common patterns of pain for the PFJt pain group.

## Plantar pressure measurement

### Null hypothesis 1:

*MF, FTI and the CoP during the contact phase of walking (rearfoot loading) are not significantly different between PFJt alignment groups and the PFJt pain group.*

The one-way ANOVA test indicated that significant differences occurred at the rearfoot between the 4 groups for MF ( $F = 21.226$ ;  $df\ 3$ ;  $p < 0.001$ ), FTI ( $F = 4.921$ ;  $df\ 3$ ;  $p < 0.001$ );  $VCoP_{max}$  ( $F = 4.542$ ;  $df\ 3$ ;  $p < 0.001$ ) and  $DCoP$  ( $F = 6.528$ ;  $df\ 3$ ;  $p < 0.001$ ).



### MF and FTI post hoc analysis

Tukey's post hoc analysis revealed the differences to be between each of the 4 groups ( $p < 0.001$ ) except for the pronated and PFJt pain groups ( $p = 0.855$ ) for MF. The lowest MF was found in the pronated (mean  $67.5 \text{ N/cm}^2$ , SD 3.2) and PFJt pain ( $63.3 \text{ N/cm}^2$ , SD 3.3) groups whilst the supinated group demonstrated the highest MF (mean  $93.7 \text{ N/cm}^2$ , SD 4.3). Tukey's post hoc analysis for the FTI only revealed differences between the pronated and supinated ( $p < 0.001$ ), pronated and PFJt pain groups. The lowest FTI was found in the supinated group (mean  $17.2 \text{ %/BW}$ , SD 3.2) whilst the PFJt pain group had the highest FTI (mean  $41.9 \text{ %/BW}$ , SD 2.7). The mean and SD values and a summary of post hoc analysis for MF and FTI are shown in table 6.9.

Variable A)	Pronated group Mean (SD)	Neutral group Mean (SD)	Supinated group Mean (SD)	PFJt pain group Mean (SD)
MF ( $\text{N/cm}^2$ )	67.5 (3.2)	77.5 (3.9)	93.7 (4.3)	63.3 (3.3)
FTI (%/BW)	38.4 (3.1)	20.0 (2.5)	17.2 (3.2)	41.9 (2.7)

Variable B)	Group	Mean difference	95% Confidence Interval		P value
			Lower	Upper	
MF	Pronated vs. neutral	-11.72650	-23.0340	-.4190	<0.001
	Pronated vs. supinated	-28.31350	39.6210	-17.0060	<0.001
	Pronated vs. PFJt pain	2.36850	-8.9390	13.6760	=0.946
	Neutral vs. supinated	-16.58700	-27.8945	-5.2795	<0.001
	Neutral vs. PFJt pain	14.09500	2.7875	25.0425	<0.001
	Supinated vs. PFJt pain	30.68200	19.3745	41.9895	<0.001
FTI	Pronated vs. neutral	-8.60150	-37.3270	20.1240	= 0.860
	Pronated vs. supinated	-35.77500	-64.5005	-7.0495	<0.001
	Pronated vs. PFJt pain	-30.51300	-59.2385	-1.7875	<0.001
	Neutral vs. supinated	-27.17350	-55.8990	1.5520	= 0.070
	Neutral vs. PFJt pain	-21.91150	-50.6370	6.8140	= 0.196
	Supinated vs. PFJt pain	5.26200	-23.4635	33.9875	=0.963

**Table 6.9: Mean (SD) of the rearfoot for MF and FTI for each group (A) and a summary of Tukey's post hoc analysis (B).** A total of 6 significant differences were found between groups.

### CoP post hoc analysis

A slower  $\text{VCoP}_{\text{max}}$  was noted in the pronated group (mean  $0.67 \text{ m/s}$ , SD 0.15) and PFJt pain group (mean  $0.64 \text{ m/s}$ , SD 0.22) but post hoc analysis only showed this to be statistically significant between the pronated and supinated ( $p < 0.001$ ) and PFJt pain and supinated groups ( $p < 0.001$ ). The DCoP was longer in the PFJt pain group (mean  $27.3\%$ , SD 5.3) whilst the shortest DCoP was found in the supinated group

(21.1%, SD 4.4). Significant differences were noted between the normal groups (pronated, neutral and supinated) and the PFJt pain group ( $p < 0.001$ ). Table 6.10 shows the mean (SD) values for each CoP variable for each group and provides a summary of tukey's post hoc analysis.

Variable A)	Pronated group Mean (SD)	Neutral group Mean (SD)	Supinated group Mean (SD)	PFJt pain group Mean (SD)
VCoP <sub>max</sub> (m/s)	0.67 (0.15)	0.78 (0.18)	0.87 (0.30)	0.64 (0.22)
DCoP (% stance)	22.5 (3.9)	21.1 (4.4)	21.8 (5.6)	27.3 (5.3)

Variable B)	Group	Mean difference	95% Confidence Interval		P value
			Lower	Upper	
VCoP <sub>max</sub>	Pronated vs. neutral	-.10910	-.2954	.0772	= 0.420
	Pronated vs. supinated	-.20055	-.3868	-.0143	<0.001
	Pronated vs. PFJt pain	0.3385	-.1524	.2201	= 0.964
	Neutral vs. supinated	-.09145	-.2777	.0948	= 0.572
	Neutral vs. PFJt pain	0.14295	-.0433	.3292	= 0.191
	Supinated vs. PFJt pain	.23440	.0481	.4207	<0.001
DCoP (% stance)	Pronated vs. neutral	1.40905	-2.6861	5.5042	= 0.803
	Pronated vs. supinated	.72500	-3.3701	4.8201	= 0.996
	Pronated vs. PFJt pain	-4.80295	-8.8981	-.7078	<0.001
	Neutral vs. supinated	-.68405	-4.7792	3.4111	= 0.972
	Neutral vs. PFJt pain	-6.21200	-10.3071	-2.1169	<0.001
	Supinated vs. PFJt pain	-5.52795	-9.6231	-1.4328	<0.001

Table 6.10: Mean (SD) of the rearfoot variables for each group (A) and a summary of Tukey's post hoc analysis (B).

### Null hypothesis 2:

*MF, FTIs and CoP during the midstance phase of walking (midfoot loading) are not significantly different between PFJt alignment groups and the PFJt pain group.*

The one-way ANOVA test indicated that significant differences occurred at the rearfoot between the 4 groups for FTI ( $F = 36.306$ ;  $df$  3;  $p < 0.001$ ), VCoP<sub>max</sub> ( $F = 6.678$ ;  $df$  3;  $p < 0.001$ ) and DCoP ( $F = 7.520$ ;  $df$  3;  $p < 0.001$ ). Although higher mean values for MF were noted for the pronated (mean 35.8 N/cm<sup>2</sup>, SD 3.1) and PFJt pain groups (mean 33.8 N/cm<sup>2</sup>, SD 3.5) compared to the neutral (mean 16.5 N/cm<sup>2</sup>, SD 3.0) and supinated (mean 21.8 N/cm<sup>2</sup>, SD 4.0) groups the difference did not reach statistical significance ( $F = 2.424$ ;  $df$  3;  $p = 0.072$ ).

### FTI post hoc analysis

For the FTI post hoc analysis demonstrated differences between each of the 4 groups ( $p < 0.001$ ) except for the neutral and supinated groups ( $p = 0.855$ ). The highest FTI was found in the PFJt pain group (mean 34.4 %/BW, SD 3.4), followed by the pronated group (mean 29.4 %/BW, SD 3.4). The lowest FTI was found in the neutral group (mean 2.9 %/BW, SD 1.1). The mean and SD values for the MF and FTI and a summary of post hoc analysis for the FTI are shown in table 6.11.

Variable A)	Pronated group Mean (SD)	Neutral group Mean (SD)	Supinated group Mean (SD)	PFJt pain group Mean (SD)
MF*	35.8 (3.1)	16.5 (3.0)	21.8 (4.0)	33.8 (3.5)
FTI	29.4 (3.4)	2.9 (1.1)	6.4 (1.6)	34.4 (2.6)

Variable B)	Group	Mean difference	95% Confidence Interval		P value
			Lower	Upper	
FTI	Pronated vs. neutral	26.49650	14.7994	38.1936	<0.001
	Pronated vs. supinated	22.94000	11.2429	34.6371	<0.001
	Pronated vs. PFJt pain	-13.32550	-25.0226	-1.6284	<0.001
	Neutral vs. supinated	-3.55650	-15.2536	8.1406	= 0.855
	Neutral vs. PFJt pain	-39.82200	-51.5191	-28.1249	<0.001
	Supinated vs. PFJt pain	-36.26550	-47.9626	-24.5684	<0.001

**Table 6.11: Mean (SD) of the midfoot variables for each group (A) and a summary of Tukey's post hoc analysis (B).** \*No significant differences were found between groups for MF, therefore no post hoc analysis was performed on this variable.

### CoP post hoc analysis

A slower VCoP<sub>max</sub> was noted in the pronated (mean 0.52 m/s, SD 0.16) and PFJt pain groups (mean 0.49 m/s, SD 0.18) with the quickest VCoP<sub>max</sub> noted for the supinated group (mean 21.4 m/s, SD 4.5). Post hoc analysis demonstrated significant differences between the pronated and neutral, pronated and supinated groups ( $p < 0.001$ ). Differences were also noted between each of the normal groups (pronated, neutral and supinated) and the PFJt pain group ( $p < 0.001$ ). The DCoP was longer in the PFJt pain group (mean 28.7%, SD 5.6) whilst the shortest DCoP was found in the supinated group (21.4%, SD 4.5). Post hoc analysis showed significant differences between the pronated and supinated groups, between neutral and supinated groups and PFJt pain group ( $p < 0.001$ ). Table 6.12 shows the mean (SD) values for each variable for each group and provides a summary of tukey's post hoc analysis.

Variable A)	High value group Mean (SD)	Central value group Mean (SD)	Low value group Mean (SD)	PFJt pain group Mean (SD)
VCoP <sub>max</sub>	0.52 (0.16)	0.64 (0.08)	0.65 (0.09)	0.49 (0.18)
DCoP (% stance)	27.3 (5.6)	22.9 (5.4)	21.4 (4.5)	28.7 (6.8)

Variable B)	Group	Mean difference	95% Confidence Interval		P value
			Lower	Upper	
VCoP <sub>max</sub>	Pronated vs. neutral	-.12090	-.2356	-.0062	<0.001
	Pronated vs. supinated	-.11890	-.2336	-.0042	<0.001
	Pronated vs. PFJt pain	.035275	-.0820	.1475	= 0.876
	Neutral vs. supinated	.00200	-.1127	.1167	= 1.000
	Neutral vs. PFJt pain	.15365	.0389	.2684	<0.001
	Supinated vs. PFJt pain	.15165	.0369	.2664	<0.001
DCoP (% stance)	Pronated vs. neutral	4.10185	-.5877	8.7914	= 0.108
	Pronated vs. supinated	6.00585	1.3163	10.6954	<0.001
	Pronated vs. PFJt pain	-1.40740	-6.0969	3.2821	= 0.860
	Neutral vs. supinated	1.90400	-2.7855	6.5935	= 0.711
	Neutral vs. PFJt pain	-5.50925	-10.1988	-.8197	<0.001
	Supinated vs. PFJt pain	-7.41325	-12.1028	-2.7237	<0.001

Table 6.12: Mean (SD) of the midfoot variables for each group (A) and a summary of Tukey's post hoc analysis (B).

### Null hypothesis 3:

*The LMAI and LMFI are not significantly different between PFJt alignment groups and the PFJt pain group.*

The one-way ANOVA test demonstrated that significant differences occurred between the 4 groups for the LMAI ( $F = 13.432$ ,  $df 3$ ;  $p < 0.001$ ) and the LMFI ( $F = 5.420$ ;  $df 3$ ;  $p = 0.002$ ).

### *LMAI and LMFI post hoc analysis*

For the LMAI tukey's post hoc analysis showed these differences to be between the pronated and neutral ( $p < 0.001$ ), the pronated and supinated ( $p < 0.001$ ), PFJt pain and neutral ( $p = 0.002$ ) and the PFJt pain and supinated groups ( $p = 0.002$ ). It was noted that the mean values for the pronated and PFJt pain groups showed medial loading with the former group demonstrating a slightly larger value of -0.1845, (SD 0.30) compared to the latter group who had a mean value of -0.1008 (SD 0.26). Post hoc analysis showed a similar trend for the LMFI with medial force noted for the pronated (mean -0.1067, SD 0.29) and PFJt pain groups (mean -0.0991, SD 0.24). As with the LMAI post hoc analysis showed differences between the pronated and neutral ( $p = 0.001$ ), pronated and supinated ( $p = 0.039$ ), PFJt pain and neutral ( $p = 0.009$ ) and the

PFJt pain and supinated groups ( $p < 0.001$ ). Table 6.13 shows the mean (SD) values for each variable for each group and provides a summary of tukey's post hoc analysis.

Variable A)	Pronated group Mean (SD)	Neutral group Mean (SD)	Supinated group Mean (SD)	PFJt pain group Mean (SD)
LMAI	-0.1845 (0.30)	0.1476 (0.07)	0.15435 (0.07)	-0.1008 (0.26)
LMFI	-0.1067 (0.29)	0.08823 (0.20)	0.10275 (0.07)	-0.0991 (0.24)

Variable B)	Group	Mean difference	95% Confidence Interval		P value
			Lower	Upper	
LMAI	Pronated vs. neutral	-.33210	-.5074	-.1568	<0.001
	Pronated vs. supinated	-.33885	-.5142	-.1635	<0.001
	Pronated vs. PFJt pain	-.08370	-.2590	.0916	= 0.596
	Neutral vs. supinated	-.00675	-.1821	.1686	= 1.000
	Neutral vs. PFJt pain	.24840	.0731	.4237	<.0001
	Supinated vs. PFJt pain	.25515	.0798	.4305	<0.001
LMFI	Pronated vs. neutral	-.19493	-.3780	-.0118	<0.001
	Pronated vs. supinated	-.20945	-.3925	-.0264	<0.001
	Pronated vs. PFJt pain	-.00760	-.1907	.1755	= 1.000
	Neutral vs. supinated	-.01452	-.1976	.1686	= 0.997
	Neutral vs. PFJt pain	.18733	.0042	.3704	<0.001
	Supinated vs. PFJt pain	.20185	.0188	.3849	<0.001

Table 6.13: Mean (SD) of the midfoot variables for each group (A) and a summary of Tukey's post hoc analysis (B).

## Summary of results

### Demographics

- There were 80 participants and 4 groups ( $n = 20$  per group);
- Seventy two percent of the total sample were female, the mean age, weight and height were 27.4 years, 73.2kg and 1.70m respectively;

### PFJt measures

- The PFJt pain group had Q, modified A and TFJt angle values that were more similar to the pronated group than any other, although significant differences were still noted between these groups;

### Foot measures

- All foot measures had similar values between the pronated group and PFJt pain group but no significant differences were noted;
- A forward position was noted in the majority of the total sample (83.5%) with the entire PFJt pain group displaying a forward position;

#### *Levels and areas of pain*

- Twelve patients (PFJt pain group) had unilateral involvement;
- The mean VAS score was 6.5 and there were 3 common patterns for the area of pain (6, 8 and 9, 4, 7 and 9, 3, 6, and 9) which accounted for pain in 70% of patients;

*Null hypothesis 1: MF, FTI and CoP during the contact phase of walking (rearfoot loading) are not significantly different between PFJt alignment groups and the PFJt pain group*

- A significantly lower MF was found at the rearfoot between the pronated and PFJt pain group compared to the neutral and supinated group;
- A significantly higher FTI was noted for the supinated group compared to the pronated and PFJt pain group;
- A significantly slower VCoP and a longer DCoP was noted for the pronated and PFJt pain groups compared to the neutral and supinated groups;

*Null hypothesis 2: MF, FTIs and CoP during the midstance phase of walking (midfoot loading) are not significantly different between PFJt alignment groups and the PFJt pain group*

- Significant higher FTIs were found in the pronated and PFJt pain groups;
- A significantly slower and longer CoP (VCoP and DCoP) was noted for high value and PFJt pain groups compared to the central and low value groups;

*Null hypothesis 3: The LMAI and LMFI are not significantly different between PFJt alignment groups and the PFJt pain group*

- The LMAI and LMFI were significantly different between the neutral and supinated groups compared to the pronated and PFJt groups who demonstrated medial loading;

#### *Comparisons between phases – contact and midstance*

- More significant differences between groups ( $n = 5$ ) were found at the rearfoot (contact) for MF whilst more significant differences were noted at the midfoot (midstance) for FTI ( $n = 5$ ) and the VCoP ( $n = 4$ ).

#### **6.4.1 Discussion**

The aim of this study was to investigate the functional relationship between PFJt alignment, PFJt pain and foot function using plantar pressure measurement. The null hypotheses (1 and 2) that PFJt alignment are not different during the contact and

midstance phase of walking between participants grouped according to their alignment and participants with PFJt pain was rejected. The null hypothesis (3) that the LMAI and LMFI are different between normal participants grouped according to their PFJt alignment and participants with PFJt pain was also rejected.

## **Measurement variability**

### *PFJt alignment measures*

Although a higher SD was noted for the PFJt pain group for the Q angle, TFJt angle and modified A angle, indicating greater variability between participants, the mean values were most similar to the pronated group. In particular, the present study revealed a mean Q angle of 21° which are similar to the findings of Fairbank *et al.* (1984) but in contrast to Messier *et al.* (1994) and Thomee *et al.* (1995). However, all of these studies either used a constrained standing position or supine position which would have influenced the Q angle measure making it difficult to compare and contrast the data presented here. Although an ANOVA was performed to confirm that participants were assigned to the correct category the inclusion of the SEM suggests that the true difference between groups may be quite small. In response to this and to gain further insight into the effects of alignment on foot function it may be necessary to define categories using values that are further apart to accentuate the differences in future studies.

### *Foot measures*

The mean foot measure values for the PFJt pain group showed a similar trend to the pronated group with significant differences only found between PFJt pain group and neutral and supinated groups for the AOG, BOG and NH. These findings were also supported by pronated FPI<sup>®</sup> values for the PFJt pain group (80%) with an FPI value of 8 (pronated) being the most common finding sharing similar distribution to the pronated group. As with the PFJt alignment measures the inclusion of SEM only suggests a small difference between groups which requires further inquiry. Whilst a sample of 20 could be considered as small, the findings of this study demonstrate a clear trend for a pronated foot posture and high PFJt alignment angles in the PFJt pain group. This provides further evidence to the belief that a pronated foot posture is linked to PFJt pain (Gross and Foxworth, 2003; Eng and Pierrynowski, 1993).

However, this does not provide information on the temporal nature of the relationship, and it may also reflect a higher prevalence of pronation compared to neutral and supination in the general population. As with the data presented in chapter 5 (page 114), the right limb was the most dominant (87.5%) along with forward placement of the dominant limb. In particular, all of the participants from the PFJt pain group placed their dominant limb forward. Whilst the preferred stance is likely to be a reason for this asymmetry, pain avoidance by unloading the affected limb could also have been a factor, and warrants exploration.

#### *Level and areas of pain*

The PFJt pain group patients complained of moderate pain before data collection the last 48 hours (VAS 6.5). In contrast, the results of the areas of pain were more interesting with 3 common patterns of pain reported. These patterns can be related to anatomical components associated with the PFJt. For example, the most common pattern of 6, 9 and 8 and 4, 7 and 8 can be linked to pain associated to small nerve damage (Maffulli, 1993) from chronic imbalance associated with an increase in tension within the medial patellotibial ligament, lateral patellotibial ligament and the patellar tendon. Moreover, pain within areas 6 and 4 (figure 6.8) could be related to pain associated with unequal transmission of the PFJt reaction to the medial or femoral condyle. Forces applied more to one condyle compared to the other are thought to increase load to the patella facets (Eng and Pierrynowski, 1993). These thoughts are supported by Salsich and Perman (2007) who used MRI to show that the TFJt rotation angle could predict (46%) of the contact area within the PFJt in patients with PFJt pain. Therefore by controlling TFJt rotation pain associated with the PFJt could be reduced. These factors are important since participants with PFJt pain in the present study demonstrated a trend for higher than normal PFJt alignment angles and a pronated foot posture type of both of which are linked with internal rotation of the tibia.

#### **Plantar pressure measurement**

##### *Contact and midstance phases*

More significant differences were noted between all of the groups for MF during the contact phase. The results suggest a higher impact force for the supinated group followed by the neutral group compared to the pronated and PFJt pain groups. These



findings are supported by Crosbie and Burns (2008), Cavanagh *et al.* (1997) and Burns *et al.* (2005) who also state that higher forces at the rearfoot can be found in neutral (normal) foot postures. The higher impact forces are thought to be due to the concentration of loading at contact and a more rigid limb due to external tibial rotation. The varus alignment and extension produced at the TFJt due to external tibial rotation and a supinated foot posture are frequently linked with stress fractures and low back as supported by Williams *et al.* (2001) and others (Pohl *et al.*, 2008; Milner *et al.*, 2007; Milner *et al.*, 2006; Collins and Whittle, 1989). However, this limb position and contact characteristics could increase the traction on the lateral retinaculum and may provide even more power to VL over the VM and more specifically the VMO. Depending on an individual's activity (i.e. running) over a period of time, this imbalance may alter PFJt contact characteristics which could predispose to PFJt pain (Schamberger, 2002) because of compensatory mechanisms. These may include an altered rearfoot loading strategy, altered knee flexion (Dillon *et al.*, 1983) and hip motion (Nadeau *et al.*, 1997) or a combination of all three mechanisms.

For the FTIs, DCoP and VCoP, more significant differences were noted at the midfoot between the normal groups with a reduced loading time for the supinated group followed by the neutral group. This was an expected finding since loading at the midfoot is reduced in supinated foot postures (Crosbie and Burns, 2008). These results imply that the limb was more rigid and supportive achieving stability for forward propulsion. In contrast the results for the pronated group and PFJt pain group had higher FTIs and a slower VCoP and longer DCoP. These findings are thought to be due to everted position of the rearfoot, internal tibial rotation and knee flexion which helps to reduce the forces occurring at contact (Levinger and Gilleard, 2005). These findings support a delayed forward progression for weight to transfer through to the midfoot and forefoot in preparation for propulsion (Williams *et al.*, 2001) and result in reduced stability which are likely to increase stresses and forces at the PFJt. The results of this study can be related to the work of Nyland *et al.* (2002) who showed that medial patella taping shifted the peak plantar force towards the forefoot helped to promote stability and forward progression of the foot.

Further significant differences were noted between the pronated group and PFJt pain group for the FTI, VCoP and DCoP. This may indicate that initial contact and loading is more painful and causes a guarded, antalgic loading strategy. Malalignment of the patella and an increase in compressive forces are commonly associated with PFJt pain (Post *et al.*, 2002). This can result in an inhibition of quadriceps contraction during the early part of stance (contact and midstance phase), leading to atrophy and subsequently further deterioration of patella control (Oatis, 2003). The quadriceps are normally active at initial contact throughout early stance when there is an external flexion moment acting on the knee (Powers, 2003). It is common for people with PFJt pain to inhibit quadriceps contraction. Its function however, is easily compensated for if a person has normal hip extensors and ankle plantarflexors (Hamill and Knutzen, 2003). This could not be assessed however because other forms of gait analysis were beyond the scope of this study.

#### *LMAI and LMFI*

Mean values for the pronated and PFJt groups showed medial loading with the former group demonstrating slightly larger values for the LMAI (mean -0.1845, SD 0.30) and LMFI (mean -0.1067, SD 0.29) compared to the latter group (mean -0.1008 (SD 0.26). Significant differences were noted between groups (except between the pronated group and PFJt pain group). These findings clearly indicate that there is a relationship between frontal plane deviations at the knee (i.e. genu valgum) (Van Gheluwe *et al.*, 2005) and the loading and area of loading is linked to alignment with the highest TFJt angle (pronated group) related to the largest LMAI and LMFI. These frontal plane deviations in alignment are likely to have an effect on the strength and contraction of the quadriceps (i.e. VMO) which could be a contributing factor to PFJt pain. This could increase pain and change the foot loading pattern, although which comes first is not clear. The findings presented in this study conflict with De Cock *et al.* (2008) who showed that load is more lateral in a pronated foot compared to a supinated foot. This is also supported by Thijs *et al.* (2007) who stated that individuals with PFJt pain directed load laterally. These authors however did not document foot posture or PFJt alignment. In contrast, like the present study Wong *et al.* (2008) used the FPI<sup>®</sup> to categorise 83 participant's feet into supinated, neutral and pronated and noted that a larger lateral loading was linked with a supinated foot

posture whilst a smaller lateral loading was associated with a pronated foot posture. These observations not only support the work presented here but also provide further information on categorisation using the FPI<sup>®</sup> in relation to dynamic foot function.

#### *General observations and clinical implications*

Although the total sample was mainly made up of females (72.5%) that were evenly distributed through the groups, this should have not influenced the results since plantar pressures are thought to be similar (Soames *et al.*, 1982; Bennett and Duplock, 1993). Whilst walking speed was not controlled it is important to recognise that force/pressure is a function of the acceleration of the mass, and therefore a slower gait would explain a reduced force/pressure profile (Fuller, 1996). However, Powers *et al.* (1997) do suggest that slower speeds reduce the demands placed upon the quadriceps during early stance by reducing the flexion moment and pain associated with the PFJt. Yang *et al.* (2003) stated that the dominant limb is used to control the walking speed path which may result in changing of ground reactions. The entire PFJt pain group experienced pain in their dominant limb (in bilateral cases the dominant limb was worse) and it is possible that asymmetry of plantar pressures existed with individuals transferring weight onto the unaffected or less painful side. However, Duffey *et al.* (2000) found no differences in MF in a group of runners and suggests that other forms of compensation may be involved.

Differences in PFJt alignment, foot posture, and contact and loading characteristics identified in this study seem to be clearly related, and as such it can realistically be suggested that they are associated with an increased risk of PFJt pain. Whilst it is difficult to determine the direction of the relationship, there is a clear link between alignment at the PFJt and foot posture. For example, it is acknowledged that pronation is associated with internal limb rotation that will in turn increase the valgus orientation of the TFJt to influence the direction of pull of the quadriceps, which is visible as a change in the Q angle. An increased Q angle also influences pronation by increasing internal limb rotation to shift load medially within the foot whilst increasing the AOG and BOG. However, this link requires careful consideration as it is likely to be complex and context-dependent. For example, in runners who are prescribed orthoses that have medial rearfoot posting to reduce pronation in an effort

to improve PFJt alignment reducing pronation may compromise shock absorption to the extent that further symptoms develop. The cross-sectional nature of this study however does not indicate if the relationship is of 'cause' or 'effect'. Whilst further studies are warranted to explore this relationship the findings presented here can still be used clinically. For example, this could relate to the development of screening and treatment programmes to reduce the risk of PFJt pain. In particular, it is reasonable to infer that the use of a foot orthoses or PFJt taping may help to reduce forces and promote optimal functioning to restore alignment and forward progression.

Although this study used plantar pressure measurement to gain an objective insight into the relationship between PFJt alignment, foot posture and foot function, it did not incorporate an analysis of muscle activity. It is possible that participants with PFJt pain had quadriceps muscle activity similar to that of the pronated group, but they may have also had excessive hamstring activity (Liebensteiner *et al.*, 2008) which may result in a lower net extensor moment (increase in PFJt reaction force) compared to the normal participants. Future studies should address the specific roles of agonist and antagonistic muscle activity between different PFJt alignment groups and patients with PFJt pain during walking and other activities.

## **6.5 Conclusion**

This study showed that PFJt alignment and PFJt pain had a significant influence on the amount and timing of loading of the foot. The PFJt pain group had similar PFJt alignment measures and foot measures to the pronated group. In general, plantar pressure measurement showed a lower MF, higher FTI, a slower VCoP and longer DCoP for the PFJt pain group and the pronated group compared to the neutral and supinated groups. The plantar pressure data presented in this study represents new objective information by providing an insight into the effects of PFJt alignment, foot function and PFJt pain, on plantar pressure characteristics.

# Chapter 7

## Discussion, conclusions and recommendations

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In this final chapter a summary discussion on the key findings of the thesis are presented. Particular consideration is given to clinical interpretation and implications for clinical practice. The strengths and limitations of the thesis are highlighted and suggestions for future research are made.

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### 7.1 Introduction

The main aim of this thesis was to investigate the relationship between foot posture and PFJt alignment. This aim has been satisfied and despite the complexity of this association the investigation provides a useful insight and moves understanding forward. Although further investigation is required this thesis has made significant additions to the existing literature which includes:

- The development of a reliable, standardised, quasi-static method for assessing PFJt alignment and the identification of the optimal PFJt alignment measures responsive to changes in foot posture and position;
- A cross-sectional study of 335 asymptomatic individuals using the optimal clinical measures which provided information on the range of normal clinical values of PFJt alignment found in discrete foot posture categories. A pronated foot posture was found to be associated with high PFJt alignment angles whilst a supinated foot posture was linked with low PFJt alignment angles;
- The functional significance of these normal clinical reference values were then examined using plantar pressure measurement. It was shown that contact loading and timing characteristics were slower in participants with a pronated foot posture and high PFJt alignment angles. These observations were also noted for patients with PFJt pain who demonstrated a pronated foot posture and high PFJt alignment angles.

Although the main findings of each study conducted have already been discussed in chapters 4, 5 and 6, a summary discussion on the conclusions of the thesis is provided here. The significant implications, limitations and areas for future investigation are also presented.

## 7.2 Clinical approach and measurement: the preliminary studies

Throughout this thesis a clinical approach was employed to ensure that the results were applicable to the clinical environment and population studied to increase external validity. Rothstein (1985) states that measures must have some generalised applicability and be based on sound theoretical assumptions for scientific credibility to be claimed. In this respect, identifying PFJt alignment measures that are responsive to foot posture and position was an important factor for this thesis. This information supports the inclusion of the preliminary series of studies performed to facilitate examination of the relationship between PFJt alignment and foot posture. Despite acknowledgement of the importance of this standard approach, few have adopted such a position. These results indicate that it is important, and should be considered in future research.

### *Standardising the approach*

In section 3.3 (pages 36 – 48) it was clear that many PFJt alignment measures lacked a standardised approach (Markeas *et al.*, 2003; Livingston and Spaulding, 2002; DiVeta and Vogelbach, 1992; Olerud and Berg, 1984). The aim of the first preliminary study (chapter 4.1) was to investigate a standardised approach which could be used for recording clinical measures. It was important for the approach to reflect that of an individual's functional double limb weightbearing position as it was felt that any other (i.e. contrived) position would not give a true representation of functional alignment. However, whilst the anatomical position can be considered the default reference position, it does not reflect the dynamic AOG and BOG which are considered to provide information on the 'vital signs' of human gait (Kirtley, 2007). Within this study a straightforward clinical technique using the AOG and BOG was developed and compared against dynamic and static footprints. The term *quasi-static* was used to explain the pragmatic manner in which the approach to the static footprint and clinical technique was obtained. The results revealed that the AOG for the clinical technique correlated well with static and dynamic footprints. The dynamic BOG however was slightly smaller compared to clinical technique and static footprints, a finding which was to be expected because a narrower BOG is used during walking. These results suggested that the quasi-static approach had functional significance but more importantly provided the foundation to a standardised referenced approach which could be used for future studies.

### *Reliability*

The reliability of measures played an important part throughout this thesis and was aimed at determining if variation in the measured values occurred because of the technique employed, or due to true changes within the measure (Haas, 1991). Several clinical measures were employed in this thesis, and the reliability of each was examined. In studies 4.1 – 4.3 (chapter 4), reliability was a central aim whilst the studies performed in chapters 5 and 6 examined reliability in the form of a pilot to re-establish measurement reliability for the context of their intended use. All of the reliability studies revealed good-to-excellent intrarater reliability, although it was noted in study 4.2 that the modified A angle and TS angle achieved only moderate reliability. Whilst the Fleiss (1981) guidelines used to interpret ICC values provide a uniformed benchmark, the arbitrary nature of this approach is often criticised because ICCs cannot be directly applied to the intended use (Rothstein, 2001; Bruton *et al.*, 2000). This has led to the inclusion of a combination of measures such as the CoV and SEM (Bruton *et al.*, 2000) to help provide an understanding of the amount of variation associated with the measure, in scale units, for the population studied (Keating and Matyas, 1998). The SEM values presented within the studies were clinically acceptable ( $<2^\circ$ ) (Sell *et al.*, 1994) whilst the CoV was noted to be low for all the measures investigated. In addition, throughout the reliability analysis, no assumptions were made, always incorporating the SEMs into classifiers to err on the side of caution. Whilst these figures may be criticised when compared to automated measurement, for clinical use they are useful because they provide information of measurement trends. However, laboratory based studies would probably strengthen conclusions.

Although direct comparisons of all of the measures investigated in this thesis are difficult because of different methods used within the literature, it is clear that the reliability findings presented here compare favourably to previous studies in general. For example, these studies have confirmed that intrarater and interrater reliability is improved when an average of 3 measures are used (Vinicombe *et al.*, 2001) and that intrarater reliability is better than interrater reliability (Evans, 2005; Van Gheluwe *et al.*, 2002; Jonson and Gross, 1997; Tomsich *et al.*, 1996). The use of a strict standardised protocol and practice sessions in this thesis are also likely to have

increased the reliability of the measures and are also supported by Cornwall *et al.* (2008); Billis *et al.* (2007) and others (Brushøj *et al.*, 2007; Piva *et al.*, 2006; Evans *et al.*, 2003; Van Gheluwe *et al.*, 2002). Whilst measurement error can be associated with a lack of reliability, repeated and future investigations need to understand why the errors occur and how they can be overcome using effective revised strategies (Gross, 1997). This approach was adopted in part 1 of study 4.2 (pages 78 – 79) where the technique of the traditional A angle (Arno, 1990) was investigated. This measure had a history of poor reliability which can be explained in part by the anatomical landmark of the inferior pole of the patella. The study replicated the earlier studies of Arno (1990) and others (Tomsich *et al.*, 1996; Ehrat *et al.*, 1994; DiVeta and Vogelbach, 1992) but implemented a series of revised procedures. Whilst further study is required the revised approach, and the adopted name of the ‘modified A angle’ created a way forward for further clinical investigation.

### *Validity*

Validity is a developing concept that is clearly more complex than reliability (Bowling, 2004). The present state of knowledge and understanding on PFJt alignment measures and the consideration of the various subtypes of validity influenced the choices made in this thesis. The main aim of PFJt alignment measures is to reflect the alignment and mechanical behaviour of the patella in relation to the femur and tibia (Post *et al.*, 2002). In study 4.2 (part 2) the TS angle and the modified A angle were investigated. This particular study addressed the issues of face and content validity. The basis of these measures was related to the observations provided by Helfet (1982; 1970) and the A angle measure introduced by Arno (1990) which were outlined in chapter 3.3.2 (pages 44 – 45). Whilst the assumptions offered by these authors were theoretically sound because of the proposed relationship between the patella and tibia, the methods and approach were limited. Study 4.2 assessed the relationship between the tibial tubercle and the patella using a goniometer. Although goniometry has been criticised due to its lack of reliability and accuracy (Boone *et al.*, 1978) many studies have demonstrated improved reliability when the procedure and method is practised and standardised (Van Gheluwe *et al.*, 2002; Wright and Feinstein, 1992). These studies influenced the investigations conducted in this thesis (4.1 – 4.3). A major problem however related to the identification of anatomical landmarks and in particular the inferior pole of the patella for the A angle. This



limitation was recognised in part 1 of the study (4.2) by selecting a different landmark and led to the measure being renamed as the 'modified A angle'. Improving the identification of various anatomical landmarks for clinical use is an important area and deserves further inquiry using more complex analysis such as MRI. As well as changing the landmark the modified A angle was transformed into a weightbearing (quasi-static method, study 4.1) measure. The development of the modified A angle in study 4.2 represents an important addition to the literature and provided a further clinical measure which could be used to investigate the relationship of PFJt alignment and foot posture.

Study 4.3 was based on predictive validity which focussed on the ability of the modified A angle, Q angle and the TFJt angle to respond to 5° changes in foot posture (rearfoot alignment) and position (abduction-neutral-adduction). This study was performed to identify the optimal measures and this involved the measure's having the ability to be responsive to a range of foot postures and positions. Again the observations of Helfet (1982, 1970) are clearly supported as well as the findings of Salsich and Perman (2007) who showed that tibial rotation influenced the PFJt. However, what was more important from this study was support for the hypothesis of the coupling mechanism of the tibia and rearfoot (Khamis and Yizhar, 2007; Klingman *et al.*, 1997). Although the method of obtaining foot position could be praised for its standardised approach (pre-drawn templates) the method of influencing changes in foot posture could be criticised. This comes from the subjectivity and inaccuracies created by the reference line on the posterior surface of the calcaneus, the reference position of maximal comfortable pronation and the measurements (using a goniometer) made to indicate a 5° change. These factors were minimised and the process was repeated two weeks later to establish intrarater reliability. This study provided some important conclusions and showed that the Q and TFJt angle were able to reliably respond to changes in foot posture and position. In addition, whilst it was found that the modified A angle required slightly larger changes in foot posture and position it was still considered an important measure because of the relationship between the patella and tibial tubercle. This final preliminary study therefore provided information on the best measures that could be used for establishing normal PFJt alignment profile in a cross-section of healthy (asymptomatic) participants.

### 7.3 Value of observational research: the cross-sectional study

Observational research is dependent upon studies that attempt to show associations between specified characteristics (Stroup *et al.*, 2000) and whilst there are several study designs linked with observational research, a cross-sectional study was employed in chapter 5 (page 114). Cross-sectional studies seek associations, generate and tests hypotheses and are focussed on certain characteristics (Gordis, 2004). These studies are sometimes considered to provide a 'snapshot' of characteristics of a health phenomenon. Although this type of research has been criticised for being descriptive and weak, Bhopal (2004) argues that these claims are inappropriate and states that the weakness of a study lies in the quality of data, and not within its design. Over the years a number of tools have been developed to enhance the quality of observational research. The **STROBE Statement**, (**ST**rengthening the **R**eporting of **OB**servational studies in **E**pidemiology) has been developed for the evaluation of cross-sectional, cohort and case-control studies. This tool was used to evaluate the cross-sectional study (chapter 5) and is presented in table 7.1 which shows that the study provided sufficient information overall. In particular, items 7, 8 and 9 demonstrated how the preliminary studies were used to provide key information on standardisation of a clinical approach and the reliability and validity of the measures to be investigated (i.e. PFJt alignment). In addition to this, the information presented in items 8 and 9 provide clear guidelines for describing and recording foot type and PFJt alignment characteristics which can be used for future studies. The use of ROC analysis was also demonstrated in item 18 which showed the ability of PFJt alignment measures to discriminate between each foot posture category. It also demonstrated that the relationship between PFJt alignment and foot posture depends on the PFJt measure used, and the theoretical and practical significance (validity) of the selected PFJt measures. Whilst the complexity of the subject is acknowledged the evidence from this cross-sectional study clearly suggests there is a relationship between foot posture and PFJt alignment (item 22).

Table 7.1: Evaluation of the cross-sectional study using the recommendations of the STROBE statement (version 3, September 2005).

Section	Item #	Information required	Comment	Section (page number)
TITLE / ABSTRACT	1	Identify the study is cross-sectional?	Clearly identifies that the study is cross-sectional. No abstract provided (not applicable).	5 (114)
<b>INTRODUCTION</b>				
Background	2	Explain scientific background and rationale for study.	A clear rationale was provided which outlined the need to establish the collective effects of specific categorised foot postures on PFJt alignment.	5.1 (114)
Aims/objectives	3	State specific aims/objectives and any hypotheses.	Study aimed to investigate the relationship of PFJt alignment and foot posture using clinical measures in a normal healthy population.	5.1 (114)
<b>METHODS</b>				
Study design	4	Present key elements of study design.	It was clear that the study was a cross-sectional design and employed a convenience / volunteer method.	5.2 (115)
Setting	5	Describe setting, location and dates, defining period of data collection.	A flow chart was used to clearly identify the period of data collection. All measures were collected in a clinical setting (cubicle and gait laboratory).	5.3 (124) 5.2 (115)
Participants	6	Give inclusion and exclusion criteria, sources and methods of selection of participants.	Participants were recruited in an acceptable manner, inclusion and exclusion criteria were clearly defined. Any participants who were unable to follow the instructions during data collection were not considered during data analysis. The FPI <sup>®</sup> (version 6) was used to categorise foot posture and acted as a screening tool. All participants were representative of a clear geographical location.	5.2 (115) 5.2 (115)
Variables of interest	7	List and clearly define all variables of interest which are seen as potential predictors.	PFJt alignment and foot measures were clearly defined. The former measures were employed to assess predictors of alignment in different foot postures. These reliability and validity of these measures were investigated in the preliminary phase of this thesis	5.2 (118 – 121) 4.1 – 4.3 (61 – 113)
Measurement	8	a) For each variable of interest give details of methods of assessment (measurement) b) If applicable, describe comparability of assessment	a) All of the measures performed including the FPI <sup>®</sup> method were clearly documented and referenced where applicable. Written information was supported by clear line drawings to aid clarity. All measures used were clinically based and all of these measures except the TS angle was obtained in a quasi-static position and was	5.2 (118 – 121) 5.2 (119 and 121) 4.1 (61 – 76)

Table 7.1: STROBE statement continued.

Section	Item #	Information required	Comment	Section (page number)
		method across all groups.	used to reflect functional alignment which was developed in preliminary study 1. A standardised protocol was followed, with the optimal method (ergonomically efficient for participant and researcher) clearly established in a pilot study before the study commenced.	5.2 (116 – 118)
Bias	9	Describe any measures taken to address potential sources of bias.	b) Not applicable. Due to the volume of measures taken, it is unlikely that recall bias would have played a role. At the end of each data collection session, all completed data sheets were placed in a sealed envelope and opened when data input commenced.	5.2 (121)
Sample size	10	Describe rationale for study size, including practical and statistical considerations.	The reliability and validity for all of the measures used (PFIt alignment and foot posture) were examined in a series of 3 preliminary studies and a pilot to the cross-sectional study.	4.1 – 4.3 (61 – 113) 5.2 (122 – 123)
Statistical methods	11	a) Describe all statistical methods including those to control for confounding. b) Describe how any design effects and missing data were addressed.	A power calculation was presented, but the target was not achieved. The approach to the sample size was clearly outlined and was not only based on statistical issues but pragmatic time restraint issues. a) and b) Statistical methods were clearly documented, with the <i>p</i> value set at 0.05. To ensure that independency was maintained only the dominant limb was analysed.	5.2 (123) 5.2 (122 – 123)
Quantitative variables	12	a) Explain how quantitative variables are analysed (e.g. which groupings are chosen, and why) b) Present results from continuous analyses as well as from grouped analyses, if appropriate.	a) The FPI <sup>®</sup> of the dominant limb for each participant determined the foot posture category – either the pronated, neutral or supinated group. The categorisation process was clearly documented and used the available range of potential FPI <sup>®</sup> scores. b) Initially, data was presented as a whole group and compared against the dominant and non-dominant limbs. Further comparative analysis was performed between groups (pronated, neutral and supinated) to determine differences in the measures performed.	5.2 (115 – 116) 5.3 (124 – 138)
Funding	13	Give source of funding and role of funder (s) for the study.	Not applicable.	–

Table 7.1: STROBE statement continued.

Section	Item #	Information required	Comment	Section (page number)
<b>Participants</b>	14	a) Report the number of individuals at each stage of the study b) Give reasons for non-participation c) A flow diagram is recommended. d) Report dates defining period of recruitment.	a) Flow chart was used to describe the flow of participants through the stages of the study. b) Reasons for non-participation were clearly stated. c) Flow diagram was used. d) The dates for data collection were presented in the flow chart.	5.3 (124)
<b>Descriptive data</b>	15	a) Give characteristics of study participants (e.g. demographic). b) Indicate for each variable of interest the completeness of the data.	a) and b) Demographic data was clearly presented, a table was used to present the mean, SD and range of this data (i.e. age, gender, weight). The distribution of FPI <sup>®</sup> values for the dominant and non-dominant limbs was also presented. Overall, a full set of descriptive and inferential statistics are presented.	5.3 (124 – 126) 5.3 (127 – 130)
<b>Outcome data</b>	16	Provide a summary of measures.	Summary of all measures were provided (i.e. dominant and non-dominant limbs). Tables were used in some cases to aid clarity.	5.3 (129 – 130)
<b>Main results</b>	17	For comparison using categories derived from quantitative variables, report the range of values or median value in each group.	The mean, SD and range of all measures (PFJt alignment and foot measures) for all groups (FPI <sup>®</sup> categories – pronated, neutral and supinated) for the dominant and non-dominant limbs. Graphs were used to illustrate the distribution of FPI <sup>®</sup> values for each of the 3 groups.	5.3 (127 – 130) 5.3 (127 – 128)
<b>Other analyses</b>	18	Report any other analysis performed (subgroup analyses and sensitivity analyses).	ROC analysis was used to provide/illustrate the ability of PFJt measures to discriminate between each categorised foot posture. Overall, the modified A angle and TFJt angle were the most sensitive measures at discriminating between different foot postures. This relationship is dependant on the PFJt measure used and theoretical/practical significance (validity) of the selected PFJt measures.	5.3 (136 – 137)
<b>DISCUSSION</b>				
<b>Key findings</b>	19	Summarise key results with reference to hypotheses.	The results show that there appears to be a relationship between PFJt alignment and foot posture. In addition, the results illustrate a trend in the	5.3 (138 – 139)

Table 7.1: STROBE statement continued.

Section	Item #	Information required	Comment	Section (page number)
<b>Limitations</b>	20	Discuss the limitations of the study, taking into account sources of potential bias or imprecision.	data indicating that PFJt alignment is increased with a pronated foot posture and decreases with a supinated foot posture.  Measures were static in nature but there was evidence of a dynamic significance using a quasi- static approach. Goniometers have been criticised for errors in measures and reduced reliability. This present study however demonstrated that the goniometer measures showed good-to-excellent reliability when a strict standardised protocol was used. This is further supported by the work conducted in the preliminary studies (chapter 4). The results however are still useful even with a conservative interpretation.	5.4 (146 – 147)
<b>Generalisability</b>	21	Discuss the generalisability of the study's findings.	Methods can be applied to population with PFJt pain as well as other musculoskeletal problems of the lower limb such as general knee pain and ankle pain. The quasi-static approach assists in providing a standardised and reliable approach to clinical assessment of patients with musculoskeletal dysfunction of the lower limb. Quick, simple to use clinical methods.	5.4 (140 – 148)
<b>Interpretation</b>	22	Give a cautious overall interpretation of the results in the context of current evidence and study limitations, paying attention to alternative interpretations.	The relationship between PFJt alignment and foot posture is complex. However the results of this study are believable and suggest an association type of relationship between PFJt alignment and foot posture. These normal ranges now require examination to determine their functional consequence (validity) and led into the final study of this thesis which used plantar pressure measurement. Whilst the foot posture categories (as determined by the FPI®) could be criticised for not being valid, if this was to be the case then functional assessment would show no differences between these groups.	5.4 (148)

### *Clinical significance versus statistical significance*

In the cross-sectional study 3 groups were determined using the FPI<sup>®</sup> which identified high PFJt alignment angles for a pronated foot posture, central PFJt angles for a neutral foot posture and low PFJt angles for the a supinated foot posture. These findings suggest that the more foot posture changed (i.e. pronated through to supinated) the stronger the statistical significance, as expressed by a lower  $p$  value. This trend is also supported by the findings presented in the 3<sup>rd</sup> preliminary study (chapter 4.3) and final study (chapter 6). Whilst these results imply that significant differences occurred they must be viewed with caution because of the SEM associated with each of the measures. Therefore, for a variable to be different it has to make a difference. This is commonly referred to as 'clinical significance' or 'substantively important' (Landorf and Radford, 2008; Greenstein, 2003). It is used because 'statistical significance' only suggests that the associations between the variables tested did not occur by chance and that a significant  $p$  value is not absolute proof that there was a clinically important change (Petrie and Sabin, 2005). From the pilot (intrarater reliability) data presented in the cross-sectional study (page number) the SEM values ranged from 1.5° – 2.1° for the PFJt angles. For example, the Q angle had the largest SEM value of 2.1° which required a minimum of 2.2° for a true difference to occur and practically it would need to be much more than this (i.e. 3°). The pronated foot posture had a mean Q angle of 20.4° (SD 3.9), whilst the neutral and supinated foot posture groups had a mean Q angle of 14.9° (SD 2.0) and 13.2° (SD 2.3) respectively. Although significant differences were noted between all foot posture groups ( $p < 0.001$ ) for the Q angle inclusion of the SEM only indicates clinically significant differences and statistically significant differences between the pronated and supinated groups. These considerations (i.e. SEM) are important for determining the true meaning and value of measures within the clinical setting and small differences must be viewed with caution.

### *The relationship between PFJt alignment and foot posture*

The findings presented in the cross-sectional study suggest that PFJt alignment measures had a tendency to increase with a pronated foot posture and decrease with a supinated foot posture. The mean values for the neutral foot posture fell between these two sets of

foot postures. A number of mechanisms have been described that represent a plausible pathway where abnormal foot pronation can influence the mechanics and alignment of the PFJt and lower limb. These mechanisms were detailed in section 2.4.2 and illustrated in figure 2.20. In particular, the mechanism described by Tiberio (1987) suggests that abnormal foot pronation results in internal rotation of the tibia and femur, which in turn moves the patella in a medial direction increasing the Q angle. These factors can also be used to explain an increased valgus angle at the TFJt which is associated with abnormal foot pronation and an increased Q angle (McClay and Manal, 1998). These proximal (femur) and distal (tibia and foot) influences on the PFJt can however be described as variable (Powers, 2003). This is supported by the fact that whilst the knee is designed to absorb rotatory forces through transverse plane rotation (Bellchamber and van den Bogert, 2000), the extent of this rotation is dependant on muscles, ligaments and tendons which may absorb this motion (lag concept) (Nester, 2000).

These proximal and distal influences can be described further by recognising the influence of tibial rotation on the line of action of the vasti (i.e. VMO, VL) and the influence of femoral rotation on the line of action of the RF. However, because the patella is embedded within the quadriceps tendon (which is a continuation of the RF) it is not always forced to follow rotations of the femur (Powers *et al.*, 2003). This is particularly relevant when the quadriceps are contracted during weightbearing activities, and when the limb is extended and less reliant on static osseous stability. This could be of importance during clinical assessment of PFJt alignment creating an overall picture of PFJt alignment measures used in this thesis. This includes the modified A angle which provides an indication of the relationship between the tibial tubercle and patella; the TFJt angle which provides information on the relationship between the longitudinal axis of the tibia and femur and finally the Q angle which can provide information on the alignment from the ASIS to the PFJt. These proposed segmental rotations and the influence of PFJt alignment and foot posture patterns identified in the cross-sectional study are limited as they were conducted in a quasi-static nature. As a result the true dynamic effect of these alignment profiles cannot be appreciated. This was explored in the final study which



examined the functional consequences of these measures using plantar pressure measurement.

#### **7.4 Functional relationship between PFJt alignment, foot posture and foot function: the final study**

An important clinical issue for this thesis related to the functional significance of PFJt alignment measures examined in chapters 4 and 5 and how they could influence functional performance. This issue focussed on predictive validity of the PFJt alignment measures which were revisited in chapter 6. The data from the cross-sectional study (chapter 5) was used to define categories into which participants were placed into 3 groups which were predominantly defined by the PFJt measures and concomitant foot postures. These groups were described using an anatomical description. For example, a high Q, modified A and TFJt angle and a pronated foot posture were used to denote a position of internal limb rotation. Plantar pressure measurement data for each group were compared in section 6.5 and suggests that loading and the timing of loading are different. In particular, loading and time characteristics were lower and occurred for a longer duration for the group characterised with internal limb rotation and foot pronation. This is likely to have occurred because internal limb rotation and a pronated foot posture can attenuate the forces occurring at contact which result in delayed loading (Levinger and Gilleard, 2007; Levinger and Gilleard, 2005). In comparison, high loading and shorter timing characteristics for the group characterised with external limb rotation and supinated foot posture. This indicates that higher forces were applied more rapidly at contact and greater stability of the lower limb was achieved. Whilst this mechanism has been suggested previously (Crosbie and Burns, 2008; Burns *et al.*, 2005; Williams *et al.*, 2001) they have never been supported by objective data for different alignment profiles as is presented here. Moreover, the results provide some validity of the foot posture categorisation process (FPI<sup>®</sup>) used in chapters 5 and 6 since significant differences were noted between groups for the plantar pressure variables (chapter 6). Whilst this supports the recent work of Wong *et al.* (2008) further inquiry is needed. Overall, these findings however could have direct implications on the functional demands placed on the quadriceps muscles (and their antagonists the hamstrings) and could be reduced for

participants with internal limb rotation leading to atrophy of this muscle group which could contribute to further malalignment at the PFJt. These factors could provide an insight into one possible mechanism for a risk factor of PFJt pain.

#### *PFJt pain, PFJt alignment and foot function*

In many studies, the most reported example linking abnormal foot function and PFJt pain is abnormal pronation (Gross and Foxworth, 2003). Data from 20 patients with PFJt pain were also investigated during the final study. The PFJt alignment measures were very similar to that of the normal participants who were classified with internal limb rotation and a pronated foot posture. These findings are also supported by the fact that 80% of the PFJt pain group presented with a pronated foot posture. The plantar pressure measurement data indicated that the loading and timing characteristics were reduced and delayed compared to the normal groups. However, whilst similarities were noted with the group categorised with internal limb rotation and a pronated foot posture the loading and timing characteristics were delayed and longer. In addition to attenuation of forces associated with a pronated foot posture described previously is the preservation of eccentric contraction of the quadriceps during the early phase of stance (Powers *et al.*, 1997). This could be associated with pain avoidance and an indirect attempt to reduce the PFJt reaction force which has been disrupted by alignment at the PFJt and other factors (i.e. internal limb rotation and a pronated foot posture).

As discussed previously, the proximal (femur) and distal (tibia) effects of rotation on the PFJt can affect the line of action of the RF, for femoral rotation and the VMO and VL during tibial rotation. Whilst Powers *et al.* (2003) suggests that it is plausible for the femur to rotate without causing patella motion it is likely that the periarticular structures (which originate from the femoral epicondyles) can become overloaded (i.e. lateral) and under loaded (i.e. medial) which disrupts the static stabilisation. This could be particularly relevant in patients with PFJt pain who may also present with VMO weakness which can be influenced by tibial rotation and foot function.

## 7.5 Clinical implications and interventions

PFJt pain is a complex and common problem resulting in a large socioeconomic impact worldwide (Callaghan and Selfe, 2007). The development of PFJt pain is thought to be associated with malalignment of the lower limb. In particular, abnormal foot pronation which has been speculatively linked with increased PFJt alignment angles (Q, modified A and TFJt angles) can be considered as a risk factor to PFJt pain. The disturbance in alignment is thought to cause an imbalance within the PFJt resulting in pain caused by damage to small nerves associated with the lateral and medial retinaculum. Consequently this may result in articular damage as local forces are increased and normal forces are decreased (Fulkerson *et al.*, 1992). Pain is often the prime reason why patients seek advice from a health professional and this can be associated with patients falling out of their EoF. This concept was presented in section 2.2.3 and is a useful guide which can provide an insight into etiological variances such as malalignment (i.e. abnormal foot pronation). This is supported by the findings presented in section 6.5 (final study) where participants who presented with internal limb rotation and foot pronation had sufficient stabilisation of the PFJt and operated within their EoF. Patients with PFJt pain however are likely to have had insufficient stabilisation (dynamic and static) causing microtrauma which exceeded their EoF.

The treatment for PFJt pain is multi-dimensional with no one clear treatment regimen outlined (Wilson, 2007). Conservative treatment using foot orthoses have been shown to be effective at reducing PFJt pain and is thought to be related to controlling the rotational forces at the TFJt (Eng and Pierrynowski, 1994) and a reduction in the Q angle (Huberti and Hayes, 1984). McConnell taping is also thought to realign the patella and was shown by Nyland *et al.* (2002) to influence foot function by directing peak forces anteriorly creating stability of the foot. As this thesis has shown the Q angle should never be used in isolation and a series of clinically relevant measures should be performed to allow for a pattern of true associations to be identified. These measures can also be supported by the use of plantar pressure measurement which can provide objective information on the mechanism of the relationship between foot function and PFJt alignment and pain. This can help clinicians to assess and monitor or screen individuals at risk of developing PFJt

malalignment induced pain. It is possible that, prophylactic attention to muscle strengthening, in conjunction with taping (i.e. McConnell) of the patella and foot orthoses, may facilitate the achievement of rehabilitation goals and reduce subsequent disability following pain. In terms of surgical intervention, the findings of the results presented in this thesis could help to provide guidance aimed at correcting malalignment and reducing for example the Q angle. These procedures may include distal realignment such as the Elmslie-Trillat or Fulkerson procedure which involves an antero-medial tibial tubercle transfer (Bellemans *et al.*, 1997).

## **7.6 Strengths and limitations of the thesis**

### *Strengths*

This thesis has a number of strengths and perhaps the most significant one relates to the clinical approach and clinical relevance of the findings presented throughout. In addition, a strict standardised protocol was performed for all of the studies conducted which is thought to have contributed to the improved reliability of the measures performed compared to previous studies (Tomsich *et al.*, 1996; Ehrat *et al.*, 1994). The findings of this thesis have good generalisability to a normal, healthy population which increases external validity. The battery of clinical measures used to evaluate PFJt alignment and foot posture were easy to perform, easy to learn and inexpensive which makes them appealing to the everyday clinical setting. Limited information exists in the literature on the relationship between foot posture and PFJt alignment and this thesis provides important information linking specific PFJt alignment and foot posture categories which did not previously exist. The sensitivity, specificity and predictive value of measures are thought to be enhanced when used collectively (Andersson and Deyo, 1996). This is supported by ROC analysis which was performed in section 5.7 (pages 136 - 138) and used for the first time to illustrate the ability of PFJt alignment measures to discriminate between foot postures. This demonstrates potential for use in further studies that employ measures associated with PFJt alignment and pain. More importantly however, are the findings presented in 6.5 which used the data from the cross-sectional study to establish the normal distribution of PFJt alignment angles creating an 'objective 3 group classification'. This allowed for the functional significance of PFJt alignment measures to

be examined and compared against patients with PFJt pain using plantar pressure measurement. Objectively quantifying the amount and timing of loading during the early part of stance not only provides new information on normal behaviour but provides further understanding of the relationship between PFJt alignment, PFJt pain and foot function.

### *Limitations*

This thesis has a number of limitations and the first comes from the potential for error of adhesive markers to the anatomical landmarks which may have influenced the results. The preliminary studies and a pilot study for the cross-sectional study however demonstrated that intrarater reliability of the measures and protocol used had sufficient reliability for clinical use. This is also related to the fact that one examiner had practiced and was motivated for all of the measures conducted. This information however does not apply to interrater reliability where motivation and practice could have differed between examiners. This therefore needs to be investigated in future studies. A second limitation is that all of the measures performed involved the use of a two-arm goniometer. Whilst the goniometer is inexpensive, portable, easy-to-use and is familiar to clinicians, it has certain limitations. These include the visual estimation required for the starting position and the visual estimation of the longitudinal axis of the limb, the size of the goniometer (Lea *et al.*, 1995) and the two-handed technique which leaves no hand to be free to stabilise a proximal or distal segment. These issues were addressed in this thesis and the errors were minimised. For example, a smaller goniometer was used to record the modified A angle. A larger goniometer was used for the TFJt angle, the proximal and arms of this goniometer allowed for a better visual estimation of the longitudinal axis. Despite these limitations, the results presented in this thesis are acceptable especially when the SEMs were calculated to inform the results and conclusions made.

### **7.7 Indications for further research**

This thesis has presented and identified a number of areas that require further inquiry to increase and develop knowledge and understanding of the relationship between foot

function and PFJt alignment. Whilst there are numerous possibilities, key areas that require further inquiry are:

- *Further development of PFJt alignment (clinical) measures*

Aimed at reducing the SEM. This would involve validation studies to record and compare PFJt alignment and foot posture measures obtained using imaging techniques (i.e. MRI, CT) and refinement of clinical measures in light of the results presented here.

- *EMG and plantar pressure measurement*

This would be aimed at establishing the true influence of quadriceps activity in participants with different alignment profiles (i.e. high PFJt alignment angles and pronated foot posture) and comparing this information with a cohort of patients with PFJt pain.

- *Randomised controlled study of conservative intervention*

This would involve obtaining baseline and follow-up information on clinical measures (PFJt and foot posture), levels and areas of pain and plantar pressure measurement following conservation intervention. This may include foot orthoses, McConnell taping and a strengthening program for the quadriceps (i.e. VMO). This would provide useful objective information over a period of time and allow the reporting of a specific treatment outcome.

## **7.8 Thesis conclusions**

This thesis was designed to investigate the relationship of PFJt alignment and foot posture using a battery of clinical measures and plantar pressure measurement. The studies presented have added to knowledge of the relationship between PFJt alignment, PFJt pain, foot posture and foot function. In particular, the cross-sectional study contributes to the literature by providing normal clinical reference values showing clear foot postures associated with PFJt alignment profiles. In addition, the data presented in

chapter 6 represents new objective information on the functional relationship of PFJt alignment and foot function. The main conclusions of this thesis are:

*The preliminary studies (chapter 4)*

*Development of a standardised clinical approach (section 4.1)*

- A quasi-static method was used to obtain and record a clinical technique for establishing the AOG and BOG. Assessment of these parameters proved to be reliable (ICC values 0.81 – 0.87) and was similar to that of a dynamic situation (linear regression of 57% for the AOG and 48% for the BOG). This approach provided a standardised reference point for clinical examination reducing an important source bias;

*Intrarater and interrater reliability: TS angle and the A angle (section 4.2)*

- The name of the 'A angle' was changed to the 'modified A angle' following a training session which focussed on selecting a consistent anatomical landmark and changing the measure to a standing weightbearing assessment. The intrarater reliability of both measures had ICCs between 0.59 and 0.92 whilst interrater reliability had ICCs between 0.65 and 0.71. Significant differences were noted between the TS angle and modified A angle ( $t = -30.220$ ,  $df 119$ ,  $p < 0.001$ ), with the latter producing a larger angle of 9.6°;

*Reliability and sensitivity of PFJt alignment measures to changes in foot posture and position (section 4.3)*

- The Q, modified A, and TFJt angles were able to respond to clinically discrete changes in foot posture and position. A change of 10° of rearfoot inversion (calcaneal motion) was required to produce statistically significant differences in the Q and TFJt angles, whilst 15° of inversion was needed for the modified A angle. For foot position, the Q, TFJt and modified A angle changed at 10° of abduction. This finding was also noted for an adducted position of 10° for the Q and TFJt angle, but 15° of adduction was needed to change the modified A angle.

Intrarater reliability had ICCs that ranged between 0.81 and 0.89. These measures were taken forward to be included in the cross-sectional study;

*The cross-sectional study (chapter 5)*

- A total of 335 asymptomatic participants were examined. The FPI<sup>®</sup> (6-item version) was used to categorise the foot posture of the dominant limb of each participant ( $n = 110$  pronated group,  $n = 111$  neutral group,  $n = 114$  the supinated group). The battery of measures used in this study were, the TS angle, modified A angle, Q angle, TFJt angle, AOG, BOG and NH (NNH). Significant differences ( $p < 0.001$ ) were noted for the TS, modified A, Q and TFJt angles between all three groups suggesting that the values decrease with a supinated foot posture and increase with pronated posture. The modified A (0.87 – 0.95) and the TFJt (0.90 – 0.98) angles showed the greatest ability to discriminate between foot postures (ROC analysis).

*The functional relationship between PFJt alignment, PFJt pain and foot function (chapter 6)*

- The cross-sectional data was used to categorise 60 participants into 3 PFJt alignment groups ( $n = 20$  per group): high PFJt angles (= pronated), central PFJt angles (= neutral) and low PFJt angles (= supinated). A fourth group consisted of 20 patients with PFJt pain. The EMED<sup>®</sup>-m system showed that the rearfoot and midfoot loading characteristics were significantly different ( $p < 0.001$ ) between groups, with the pronated and PFJt pain groups demonstrating slower (CoP) and reduced loading patterns (MF) compared to neutral and supinated groups. This data indicates that foot posture, functional foot loading characteristics and PFJt alignment are related and suggests a mechanism by which PFJt and foot posture may be related to pathology. This provides a rationale for clinical interventions aimed at modifying foot and / or PFJt alignment which warrants further inquiry.



## Chapter 8

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## Chapter 9

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### Appendices

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## 9.1 Appendix 1.

UNIVERSITY OF WALES INSTITUTE CARDIFF

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SCHOOL OF HEALTH AND SOCIAL SCIENCES ETHICS PANEL

### Approval Form

#### Completion instructions:

- 1 Maximum number of words allowed altogether 550, including headings. Longer submissions will be returned without consideration.
- 2 Use font size 10-12.

Initial Submission Date : 8 <sup>th</sup> October 2003	Resubmission Date(s) :
Student : Sarah Curran	Course : MPhil/PhD
Supervisor 1 : Dr Dominic Upton	Supervisor 2 : Prof Ian Learmonth
Is this to be submitted to an LREC? <input type="checkbox"/> NO If Yes please name LREC :	Has a CRB check been sought? <input type="checkbox"/> YES

**Title of Project:** Identifying angle and base of gait: A comparative analysis using a clinical measurement, dynamic and static footprints.

**Background:** Footprint data has been employed since the early 19<sup>th</sup> century to assist in the recognition of abnormal and normal function (Wilkinson *et al.*, 1995). It is suggested that the angle and base of gait used during quiet standing is similar to that used in midstance (Perry, 1992). Previous research has shown reliability of a new technique in the analysis of dynamic footprints (Wilkinson and Menz, 1997). Whilst such data provides essential information dynamically no data exists in the use of static measures to assess the angle and base of gait.

#### Aim:

1. Determine the correlation of a clinical measurement, dynamic and static footprints using the angle and base of gait as parameters.
2. Establish reliability and validity between these measures.

**Sample Details:-**

A convenience sample of 20 – 25 university staff and students will be recruited. Each participant will meet the following criteria: 1. No reported history of lower limb surgery or trauma. 2. No gait or postural disturbance based on visual assessment.

**Method to be used :***Dynamic and static footprint data:*

A quiet walkway (clinic corridor) will be used. During dynamic assessment, participants will be asked to walk at their own selected cadence. For static footprints participants will be asked to walk on the spot at their own selected speed for a period of 30 seconds, and then asked to step into their angle / base of gait. All footprint data will be collected using a composite mixture of talcum powder and black powder paint.

*Clinical measurement:*

Participants will be asked to stand in their own relaxed base of gait, as previously described whilst the investigator draws (with a HB pencil) around the perimeters of both feet.

**Potential discomfort or inconvenience to respondent:** None – time only taken for recordings.

**Special points to note:** The study will be explained in detail to each participant and informed consent will be obtained from all participants. All data will be coded ensuring anonymity. Participants can withdraw at anytime.

**References:**

1. Perry, JE. (1992) *Gait analysis: normal and pathological function*. Slack Inc, Thorofare, NJ.
2. Wilkinson, MJ., Menz, HB and Raspovic, A. (1995) The measurement of gait parameters from footprints. *The Foot*, 5 (2), 84 – 90.
3. Wilkinson, MJ and Menz, HB. (1997) Measurement of gait parameters from footprints: a reliability study. *The Foot*, 7 (1), 19 – 23.

Student's signature \_\_\_\_\_

Date: \_\_\_\_\_

**(Supervisor signature required prior to submission)**

**I have checked this form and believe that all the necessary information is given.**

Supervisor's signature \_\_\_\_\_

To: Sarah Curran

# Memo

cc: Dominic Upton (Director of Studies)

From: SCHOOL ETHICS PANEL

Subject: MPhil / PhD

Our ref A1

Date: 23/10/03

Ethics Panel B: A. Murray.

Your proposal was amongst those considered at the most recent meeting of the School Ethics Panel.

- 1 [✓] Your proposal was approved subject to the conditions listed below.
- 2 [ ] Your proposal was approved in principle subject to the conditions listed below but the Panel request that you submit your questionnaire or interview schedule for scrutiny. This step is necessary as the subject of your research is potentially sensitive.
- 3 [ ] The information provided on the proposal is insufficient. You should submit a revised proposal after discussion with your supervisor. It is in your own interest to submit as soon as possible.
- 4 [ ] The Panel regrets it has reservations about your project and therefore cannot approve it in its present form. You are advised to submit a revised proposal for their further consideration. It is in your own interest to submit as soon as possible.

## Conditions of approval

- i) That any questionnaire and/or interview schedule which you intend to use, and any information or educational materials you intend to give to participants must be approved by your supervisor.
- ii) That you check with your supervisor that the project is technically feasible.
- iii) That your supervisor is satisfied that the measures that you intend to use are appropriate for you to use with intended sample
- iv) That the consent of each subject is sought and recorded as appropriate, and these records stored and available for examination, if required, by the Panel until publication of the results of the Examining Board at which your project is considered.
- v) That all raw data collected should be stored and be available for examination, if required, by the Panel until publication of the results of the Examining Board at which your project is considered. After this they should be destroyed unless prior consent has been obtained from all subjects for the data to be stored and used for teaching and research.
- vi) That should an external agency wish to see your findings you should first:
  - a) check this with your supervisor
  - b) make it clear to the agency that the project is undergraduate level**NB** No findings should be released until after the project has been examined.
- vii) That any substantive changes to the proposal as approved are referred to the Panel.
- viii) That any untoward incident which occurs in connection with this proposal should be reported back to the Panel **without delay**.

9.2 Appendix 2.



**COPY  
EXAMPLE**

Wales Centre for Podiatric Studies  
Western Avenue, Cardiff, CF5 2YB

**CONSENT FORM**

**Dynamic footprints, static footprints and a clinical technique  
for determining the angle and base of gait**

**Name of Researcher:** Sarah Curran

**Participant Identification Number for this Study:** \_\_\_\_\_

**Please tick box**

1. I confirm that I have read and understand the information sheet dated \_\_\_\_\_ (Version \_\_) for the above study and have had the opportunity to ask questions.

☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.

☐

3. I agree to take part in the above study.

☐

\_\_\_\_\_  
**Name of Participant**

\_\_\_\_\_  
**Date**

\_\_\_\_\_  
**Signature**

\_\_\_\_\_  
**Name of Person taking consent**  
(if different from researcher)

\_\_\_\_\_  
**Date**

\_\_\_\_\_  
**Signature**

Sarah Curran  
\_\_\_\_\_  
**Researcher**

\_\_\_\_\_  
**Date**

\_\_\_\_\_  
**Signature**

This consent form was a standard form that was used for all of the studies performed in this thesis. The title however was changed for each study.

### 9.3 Appendix 3.

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SCHOOL OF HEALTH AND SOCIAL SCIENCES ETHICS PANEL

#### Approval Form

##### **Completion instructions:**

- 1 Maximum number of words allowed altogether 550, including headings. Longer submissions will be returned without consideration.
- 2 Use font size 10-12.

<b>Initial Submission Date :</b> 12 <sup>th</sup> January 2004	<b>Resubmission Date(s) :</b>
<b>Student :</b> Sarah Curran	<b>Course :</b> MPhil / PhD
<b>Supervisor 1 :</b> Dr Dominic Upton	<b>Supervisor 2:</b> Prof Ian Learmonth
<b>Is this to be submitted to an LREC?</b> <input type="checkbox"/> NO <b>If Yes please name LREC :</b>	<b>Has a CRB check been sought?</b> <input type="checkbox"/> YES

**Title of Project:** The reliability of the A angle and tubercle sulcus angle.

**Background:** Pain associated with the patellofemoral joint is a common and complex phenomenon. It is thought to have a multifactorial aetiology that includes malalignment of the patella. Clinical patella alignment techniques involve measurement of frontal plane position of the patella and other osseous structures (Post *et al.*, 2002). Although the Q angle appears to be the most popular reported method for examining patella alignment, other clinical measures such as the 'A angle' (Arno, 1990) and the 'tubercle sulcus (TS) angle' have received limited attention. Both of these measures are thought to represent the relationship between the patella and tibial tuberosity but their accuracy, reliability and clinical value have been questioned (Tomisch *et al.*, 1996).

**Aim:** Determine the reliability of the A angle and TS angle.

##### **Sample Details:**

A convenience sample of 20 university student volunteers will be recruited. Participants will be included if they have no history of knee pain and are available for the training session (if required) and two measurement sessions. Three podiatrists (with at least 2 years experience postgraduate experience) will perform the measurements.

##### **Method to be used :**

The study will be divided into two parts, part 1 will involve a training session in order to establish optimal data collection methods for the A angle and TS angle. Information on these measurements will be provided to each of the three examiners before the training session. The 2<sup>nd</sup> part of the study will investigate the intra and interrater reliability of these measures.

All anatomical landmarks will be identified using 0.8mm adhesive circles. A small goniometer (standard size) will be used to measure each angle. Participants will be requested to wear shorts or loose thin trousers during the data collection sessions. All measurements will be repeated two weeks later.

**Potential discomfort or inconvenience to respondent:** If the front part of the participant's knees are hairy, they will be requested to shave this area (to allow for adhesive circles to remain in situ). Time taken for measurements.

**Special points to note:** Informed consent will be obtained from all participants and the nature and purpose of the study will be explained to each participant. To ensure anonymity, all data will be coded. Participants (including the examiners) can withdraw at anytime.

**References:**

1. Arno, S. (1990) The A angle: A quantitative measurement of patella alignment and realignment. *Journal of Orthopaedic Sports Physical Therapy*, **12** (3), 237 – 242.
2. Post, WR., Teitge, R and Amis, AA. (2002) Patellofemoral joint alignment: Looking beyond the viewbox. *Clinics in Sports Medicine*, **21** (3), 521 – 546.
3. Tomisch, DA., Nitz, AJ., Threlkeld, AJ and Shapiro, R. (1996) Patellofemoral alignment: Reliability. *Journal of Orthopaedic Sports Physical Therapy*, **23** (3), 200 – 208.

Student's signature \_\_\_\_\_

Date: \_\_\_\_\_

**(Supervisor signature required prior to submission)**

**I have checked this form and believe that all the necessary information is given.**

**Supervisor's signature** \_\_\_\_\_

To: Sarah Curran

cc: Dominic Upton (Director of Studies)

From: SCHOOL ETHICS PANEL

Subject: MPhil / PhD

# Memo

Our ref A1

Date: 22/01/04

Ethics Panel B: D. Heggs.

Your proposal was amongst those considered at the most recent meeting of the School Ethics Panel.

- 1 [✓] Your proposal was approved subject to the conditions listed below.
- 2 [ ] Your proposal was approved in principle subject to the conditions listed below but the Panel request that you submit your questionnaire or interview schedule for scrutiny. This step is necessary as the subject of your research is potentially sensitive.
- 3 [ ] The information provided on the proposal is insufficient. You should submit a revised proposal after discussion with your supervisor. It is in your own interest to submit as soon as possible.
- 4 [ ] The Panel regrets it has reservations about your project and therefore cannot approve it in its present form. You are advised to submit a revised proposal for their further consideration. It is in your own interest to submit as soon as possible.

## Conditions of approval

- ix) That any questionnaire and/or interview schedule which you intend to use, and any information or educational materials you intend to give to participants must be approved by your supervisor.
- x) That you check with your supervisor that the project is technically feasible.
- xi) That your supervisor is satisfied that the measures that you intend to use are appropriate for you to use with intended sample
- xii) That the consent of each subject is sought and recorded as appropriate, and these records stored and available for examination, if required, by the Panel until publication of the results of the Examining Board at which your project is considered.
- xiii) That all raw data collected should be stored and be available for examination, if required, by the Panel until publication of the results of the Examining Board at which your project is considered. After this they should be destroyed unless prior consent has been obtained from all subjects for the data to be stored and used for teaching and research.
- xiv) That should an external agency wish to see your findings you should first:
  - a) check this with your supervisor
  - b) make it clear to the agency that the project is undergraduate level**NB** No findings should be released until after the project has been examined.
- xv) That any substantive changes to the proposal as approved are referred to the Panel.
- xvi) That any untoward incident which occurs in connection with this proposal should be reported back to the Panel **without delay**.



## 9.4 Appendix 4.

### Reliability of the A angle and tubercle sulcus angle

#### Instruction sheet for examiners

##### Rationale for study

Pain associated with the patellofemoral joint (PFJt) is a common and complex phenomenon. It is thought to have a multifactorial aetiology that includes malalignment of the patella. Clinical patella alignment techniques involve measurement of frontal plane position of the patella and other osseous structures (Post *et al.*, 2002). Although the Q angle appears to be the most popular reported method for examining PFJt alignment, other clinical measures such as the 'A angle' and the 'tubercle sulcus (TS) angle' has received limited attention. Both of these measures are thought to represent the relationship between the patella and tibial tuberosity but their accuracy, reliability and clinical value have been questioned (Tomisch *et al.*, 1996).

The study will be divided into two parts. This 1<sup>st</sup> part of the study will involve a training session to establish optimal data collection methods for the A angle and TS angle. This session will allow you to practice both measures and outline any potential problems and identify improvements to the measures and their protocols. The session will last for approximately 90 minutes. The 2<sup>nd</sup> part of the study will investigate the intrarater and interrater reliability of the measures. Measurements will be performed two weeks apart.

*You will be provided with the following equipment:*

- 8mm circular stickers
- Small and large goniometer
- Pen, data sheets and envelopes

##### Please read carefully the protocol for each measure:

Each subject will be barefoot and wear shorts (or loose and thin fitting trousers) to expose the anterior aspect of the knee.

##### TS angle (after Hughston *et al.*, 1984)

###### Protocol and measurement

- Each participant will be seated on the edge of the examining couch with their knees flexed to 90° in a relaxed position and both feet firmly placed upon the ground. The examining couch may be adjusted as required for each individual.
- The examiner will be able to verify the position of 90° knee flexion using a large goniometer by aligning the arms with the lateral aspect of the distal femur and proximal aspect of the fibula.



**Clinical illustration of the TS angle.** Palpation of the medial and lateral perimeters of the patella allows the identification of the centre of the patella using a circular sticker (red). The tibial tubercle is palpated and identified in the same manner.

- During the relaxed position assumed by the participant the examiner will palpate the lateral and medial perimeters of the patella and identify the centre of the patella by appropriately affixing an 8mm sticker.
- The tibial tubercle will then be palpated and marked in the same way previously highlighted. A small goniometer will then be used to assess the TS angle. The proximal arm of the goniometer should be aligned with the circle positioned on the centre of the patella and the distal arm should be aligned with the tibial tubercle.

**A angle** (after DiVeta and Vogelbach, 1992; Arno, 1990)

*Protocol and measurement*

- This measurement is currently performed with the participant in a supine position. Each participant should be asked not to contract their quadriceps or hamstrings. The examining couch may be adjusted as required for each individual.
- During the relaxed position assumed by the participant the examiner will palpate and mark with an adhesive circle the inferior pole of the patella and the tibial tubercle.
- The patella was bisected with the proximal arm (fixed) of the goniometer whilst the distal arm (moving) bisected the tibial tubercle.



**Clinical illustrations of the A angle.** The photo on the left shows the outline of the patella and tibial tubercle. The axis of the goniometer is positioned over the inferior pole of the patella (X). The patella was bisected with the proximal arm (fixed) of the goniometer whilst the distal arm (moving) bisected the tibial tubercle.

Please use the table below to indicate any limitations of either measure and highlight how they could be improved (continue on a separate sheet if necessary).

TS angle	A angle

## 9.5 Appendix 5

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### SCHOOL OF HEALTH AND SOCIAL SCIENCES ETHICS PANEL

#### Approval Form

##### Completion instructions:

- 1 Maximum number of words allowed altogether 550, including headings. Longer submissions will be returned without consideration.
- 2 Use font size 10-12.

<b>Initial Submission Date :</b> 14 <sup>th</sup> March 2004	<b>Resubmission Date(s) :</b>
<b>Student :</b> Sarah Curran	<b>Course :</b> PhD
<b>Supervisor 1:</b> Dr Dominic Upton	<b>Supervisor 2:</b> Prof Ian Learmonth
<b>Is this to be submitted to an LREC?</b> <input type="checkbox"/> NO <b>If Yes please name LREC :</b>	<b>Has a CRB check been sought?</b> <input type="checkbox"/> YES

**Title of Project:** The influence of foot posture on patella alignment: a cross sectional study.

**Background:** Pain associated with the patellofemoral joint (PFJt) is a complex and worldwide problem (Post *et al.*, 2002; Thomee *et al.*, 1995). Over the years a number of authors have speculated that abnormal foot function contributes to PFJt pain (Gross and Foxworth, 2003; Tiberio, 1987). Whilst these reports seem conceivable, clinicians have little objective basis for making such judgements. Although radiographs (x-rays) and magnetic resonance imaging (MRI) are useful these methods are limited because of (Powers, 1998) ethical, financial and pragmatic constraints. In contrast, clinical assessment of patella alignment such as the Q angle, tubercle sulcus (TS) angle and modified A angle are appealing due to their low cost and simplicity. These measures also have the capability of being performed in studies which recruit large numbers of participants, such as those used in observational inquiry (i.e. cross sectional studies). Before a study can be undertaken on the clinical relationship between foot posture and PFJt alignment, the identification of the optimal measures of PFJt alignment which are responsive to changes in foot posture/position must be established.

##### Aim:

1. Investigate the intrarater reliability and predictive validity of selected measures of PFJt alignment to changes in foot posture and position.
2. Use the identified optimal measures to establish normal values in a cross sectional study of a healthy participants linking foot posture and PFJt alignment.

##### Sample details:

##### First part of the study

A convenience sample of 20 university students will be recruited. Each participant will meet the following inclusion criteria: No history of gait or balance disturbance based on visual inspection; No history of a systemic illness that may influence gait; no history of trauma or injury to the lower extremities; no apparent limited motion of the subtalar based on clinical assessment.

The measures of PFJt alignment to be investigated will be the modified A angle and the Q angle. The TFJt angle will also be investigated and will act as benchmark for lower limb alignment. All measures will be repeated three times and will be repeated two weeks later to determine reliability.

**Sample Details:**

Second part of the study

Subject to evidence of suitable intrarater reliability and predictive validity of the measures investigated in section 1, further measurements will be from a convenience sample of staff and student volunteers from UWIC (Llandaff campus). Before data will be collected, a power calculation will be performed to identify the estimated sample size for the study. All participants will satisfy the previously mentioned criteria.

**Method to be used:**

Prior to the measures age, gender, height, weight and limb dominance (identified by kicking a ball) will be obtained. The Foot Posture Index<sup>®</sup> will be used to categorise individuals into one of three categories (pronated [low arch], neutral or supinated [high arch]). A standardised quasi-static (one-step, weight-bearing) approach will be used for each of the measures performed. As well as PFJt alignment measures, the angle and base of gait and height of the navicular will also be obtained (foot measures). A goniometer (large and small) and ruler will be used to obtain all measures. One examiner will take all of the measurements.

**Potential discomfort or inconvenience to respondent:** If the front part of the participant's knees is hairy, they will be requested to shave this area (to allow for adhesive circles to remain in situ). Time taken for measurements.

**Special points to note:** Informed consent will be obtained from all participants. Anonymity will be guaranteed for all participants. Any participant can withdraw at anytime. All participants will be provided with an explanation of the nature and purpose of the study. This information however will also be written for the 2<sup>nd</sup> part of the study.

**References:**

1. Gross, MT and Foxworth, JL. (2003) The role of foot orthoses as an intervention for patellofemoral pain. *Journal of Orthopedic Sports Physical Therapy*, **33** (11), 661 - 70.
2. Post, WR., Teitge, R and Amis, AA. (2002) Patellofemoral joint alignment: Looking beyond the viewbox. *Clinics in Sports Medicine*, **21** (3), 521 - 546.
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5. Thomee, R, Renstrom, P, Karlsson, J and Grimby, G. (1995) Patellofemoral pain syndrome in young women. II. Muscle function in patients and healthy controls. *Scandinavian Journal of Medicine and Science in Sports*, **5** (4), 245 - 251.

Student's signature \_\_\_\_\_

Date: \_\_\_\_\_

**(Supervisor signature required prior to submission)**

**I have checked this form and believe that all the necessary information is given.**

Supervisor's signature \_\_\_\_\_

# Memo

To: Sarah Curran

cc: Dominic Upton (Director of Studies)

From: SCHOOL ETHICS PANEL

Subject: PhD

Our ref A1  
Date: 29/04/05

Ethics Panel B: D. Heggs.

Your proposal was amongst those considered at the most recent meeting of the School Ethics Panel.

- 1 [✓] Your proposal was approved subject to the conditions listed below.
- 2 [ ] Your proposal was approved in principle subject to the conditions listed below but the Panel request that you submit your questionnaire or interview schedule for scrutiny. This step is necessary as the subject of your research is potentially sensitive.
- 3 [ ] The information provided on the proposal is insufficient. You should submit a revised proposal after discussion with your supervisor. It is in your own interest to submit as soon as possible.
- 4 [ ] The Panel regrets it has reservations about your project and therefore cannot approve it in its present form. You are advised to submit a revised proposal for their further consideration. It is in your own interest to submit as soon as possible.

## Conditions of approval

- xvii) That any questionnaire and/or interview schedule which you intend to use, and any information or educational materials you intend to give to participants must be approved by your supervisor.
- xviii) That you check with your supervisor that the project is technically feasible.
- xix) That your supervisor is satisfied that the measures that you intend to use are appropriate for you to use with intended sample
- xx) That the consent of each subject is sought and recorded as appropriate, and these records stored and available for examination, if required, by the Panel until publication of the results of the Examining Board at which your project is considered.
- xxi) That all raw data collected should be stored and be available for examination, if required, by the Panel until publication of the results of the Examining Board at which your project is considered. After this they should be destroyed unless prior consent has been obtained from all subjects for the data to be stored and used for teaching and research.
- xxii) That should an external agency wish to see your findings you should first:
  - a) check this with your supervisor
  - b) make it clear to the agency that the project is undergraduate level**NB** No findings should be released until after the project has been examined.
- xxiii) That any substantive changes to the proposal as approved are referred to the Panel.
- xxiv) That any untoward incident which occurs in connection with this proposal should be reported back to the Panel **without delay**.

## 9.6 Appendix 6.



Wales Centre for Podiatric Studies  
Western Avenue, Cardiff, CF5 2YB

### Participant Information Sheet

Version 1 (2<sup>nd</sup> May 2006)

## Relationship between foot posture on patellofemoral joint alignment: A cross-sectional study

*You have been invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what will be involved. Please take your time to read the following information carefully and discuss it with others if you wish. Please ask if there is anything is not clear or if you would like more information. Take time to decide if you wish to take part. Thank you for reading this.*

### Problematic knee pain

Pain in and around the front part of the knee is one of the most common complaints worldwide. The front part of your knee consists of the patellofemoral joint (PFJt), which is the knee cap (patella) and lower front part of your thigh bone (distal anterior aspect of femur). Understanding how this joint functions and aligns is an important consideration when treating patients with pain in the front part of their knee. Foot posture has been regarded as a major determinant of disrupting the mechanics and alignment of the PFJt but little is known on the effects of various foot postures (low arched foot/high arched foot). Although complex equipment (magnetic resonance imaging [MRI], computed tomography [CT]) can provide valuable information on the joint, causative factors and treatment outcomes, their clinical use is often limited due to time and financial constraints. In response to these limitations, there is a need to develop simple reliable, and easy to use cost-effective clinical techniques. Of particular interest is the need to identify suitable methods of measuring the alignment of the PFJt and the influence of foot posture.

### What do I have to do?

This study involves a series of measures of the front part of your knee's and the inner part of your feet. You will be asked to step onto a piece of paper (1 metre by 1 metre) and asked to stand for a couple of minute whilst the examiner palpates and identifies anatomical landmarks on your knee and completes the series of measures. This process will be repeated three times.

You will be asked to remain in this position whilst the examiner performs a further measure on your feet. The examiner will again identify anatomical landmarks and place a circular sticker on the inner part of your arch. Once this is complete you will then be instructed to sit on a chair with your knees flexed to 90° and your feet firmly placed on the ground. The whole process should take no longer than 15 minutes.

*Thank you for taking part in this study.*

Sarah Curran (Wales Centre for Podiatric Studies, UWIC, 029 2041 7221).



## 9.7 Appendix 7.



### APPLICATION FOR ETHICS APPROVAL

Please read the **UREC GUIDELINES** before completing this form

Name	Sarah Curran		
School/Centre	Cardiff School of Health Sciences		
Type of Researcher	Member of Staff		
Programme enrolled on	PhD		
Other researcher(s) working on project	N/A		
Does your project require ethical approval from an LREC or other body?			No
If yes, please name the LREC or other body			
Has a CRB check been sought?	Yes	Does your project use Human Tissue?	No

Title of Project:	Influence of knee alignment on plantar pressure distribution: comparisons of high, normal and low angles in healthy participants and patients with patellofemoral joint pain.
Expected Start Date:	November 2007
Approximate Duration:	4 weeks
Funding Body (if applicable):	N/A

<b>DECLARATION</b>	
I confirm that the information contained in this form is correct Signature of Principal Investigator:	Date: 25/09/07
Briefly give experience in research involving human participants Undertaken a series of preliminary studies investigating the reliability and validity of clinical measures of the knee (patella alignment). This contributed to the development of a cross-sectional study of 335 healthy participants to establish normal knee alignment (patellofemoral joint [PFJt] and tibiofemoral joint [TFJt]) values for different types of foot posture. Co-ordinated a randomised controlled trial on two different types of knee replacement (tibial components) (University of Bristol).	
<b>FOR STUDENT PROJECTS ONLY</b>	
I confirm that I have read and agreed the information contained in this form	
Name of Supervisor: Ian Mathieson	Date: 25/09/07
Briefly give Supervisor's experience in research involving human participants Series of preliminary studies investigating the reliability and validity of foot type measures. A case controlled study (foot type as a risk marker for lower back pain).	
Signature of Supervisor:	

<b>School Research Ethics Committee / UREC use only</b>	
Decision reached:	Project approved <input type="checkbox"/> Project approved in principle <input type="checkbox"/> Decision deferred <input type="checkbox"/> Project not approved <input type="checkbox"/> Project rejected <input type="checkbox"/>
Name:	Date:
Signature:	

<b>SECTION A – PROJECT DETAILS</b>
<b>Briefly describe the rationale behind your project</b>
<p>PFJt pain is a common problem worldwide and affects people of all ages, especially those who participate in sport (Callaghan and Selfe, 2007). Many factors are considered to influence its development, including acute trauma, muscle weakness and malalignment of the patella (Wilson, 2007). Abnormal foot postures, for example excessive pronation, are thought to be related to malalignment of the patella (Gross and Foxworth, 2003) but the exact nature of the relationship is poorly understood. Clinical techniques for assessing patella alignment and foot posture provide a simple, quick and cost effective way of examining the relationship between the two. This is supported by a previous cross-sectional study which identified a strong relationship between knee alignment and foot posture. Clinical techniques however offer little insight into the functional consequences of alignment variations. For example, it is not known if different knee alignments result in different dynamic gait function. Plantar pressure measurements provide a good indication of how the foot contacts the ground and transfers load during the stance phase of gait (Orlin and McPoil, 2000) and this may be important in the development of musculoskeletal pathology and PFJt pain. Systems such as the EMED-m platform (Novel, Munich, GmbH, Germany) record plantar loading transitions at high data acquisition rates (50 – 60 Hz) and therefore permit investigation of rapid movement characteristics of the foot and lower limb. Establishing the effect of differing knee alignment values on foot function using parameters such as maximum force, force time integrals and the centre of pressure will help to understand the nature of the relationship between PFJt alignment, PFJt pain and foot posture.</p>
<b>What are the aims of the research?</b>
<p>The aim of the study is to determine the functional significance of PFJt alignment using plantar pressure measurement in healthy individuals and patients with PFJt pain.</p> <p>Null hypothesis: The velocity and direction of the maximum force, force time integrals and the centre of pressure will not be different in healthy individuals with high, central and low angular knee measures and patients with PFJt pain.</p>
<b>What methods of data collection and analysis will you adopt?</b>
<p>Static clinical measures:</p> <p>Foot posture - Foot Posture Index, navicular height, angle and base of gait.</p> <p>Patella/knee alignment - modified A angle, Q angle, TFJt angle.</p> <p>Patient group only - a visual analogue scale will be used to record the levels of pain. A knee pain drawing (front part of the knee only to replicate the PFJt) will also be used and each patient will be asked if they have pain in the shaded area. This approach is similar to that used by Birrell et al (2005) for hip pain drawings.</p> <p>Plantar pressure measurement:</p> <p>A 2 step protocol will be used to obtain the recordings from the EMED-m platform (Novel, GmbH, Munich, Germany) which is embedded within its own customised walkway.</p> <p>All measures will be taken with participants barefoot. All techniques are non-invasive and cause no discomfort or pain.</p>
<b>What remuneration (if any) will be offered to participants?</b>
None - N/A
<b>Provide sample details including (as appropriate)</b>
<ul style="list-style-type: none"> <li>• Age of participants</li> <li>• Details of how many participants will be involved</li> <li>• Description of sampling method and criteria</li> <li>• Description of where and how the sample will be recruited</li> <li>• Details of the initial contact method</li> </ul>
<p>Data from 60 healthy volunteers will be collected from undergraduate Podiatry students based at the Wales Centre for Podiatric Studies, UWIC. Each participant will be recruited into 1 of 3 groups using a criteria based on 'low', 'central' and 'high' patella/knee alignment values. Recruitment will be continued until a total of 20 participants are achieved for each</p>

Ethics approval – version 4 March 07



## UWIC

group. A patient group will also be recruited and will consist of 20 patients presenting with PFJt pain who attend the clinics based at the Wales Centre for Podiatric Studies, UWIC (total sample n = 80). A participant information sheet will be provided and all participants will provide written informed consent (see attached sheets).

The age range for all participants will be 19 - 50 and each will have their gender, age, height, weight and foot size (length and width) recorded. The inclusion criteria for the healthy participants will be as follows: No obvious foot or gait abnormalities and no history of foot or lower limb pathology within a 12-month period.

The patients will have signs and symptoms associated with the PFJt of sufficient severity for them to seek advice and treatment. The specific inclusion criteria for this group will be as follows: patella pain that is aggravated during walking, running, squatting, kneeling, ascending and descending stairs (Fulkerson, 2002). Patients will have a positive apprehension test and will have not received treatment before data collection. Patients will be excluded if they have signs and symptoms that indicated other types of knee conditions these will include clicking, locking giving way and swelling of the knee. Patients will also be excluded if they have a positive response to the following: anterior and posterior draw test, McMurray's test and valgus/varus stress tests. Patients who report a traumatic injury or surgery to the TFJt and PFJt will also be excluded.

### SECTION B – POTENTIAL RISKS

What potential discomfort or inconvenience to the participants do you foresee?

None

How do you propose to deal with the potential risks?

N/A

What potential risks to the interests of the researchers do you foresee?

None

How will you deal with these potential risks?

N/A

### SECTION C – CONSENT

Will informed consent be sought from the participants? Yes

IF NO

Explain why informed consent will not be sought

N/A

IF YES

Describe how informed consent will be obtained and attach copies of relevant documents

Written informed consent will be obtained after the nature of the study has been explained to all participants (see attached sheets). All participants will have the right to withdraw at anytime and patients will be made fully aware that their treatment will not be affected should they decide to take or not take part in the study.

If there are doubts about participants' abilities to give informed consent, what steps have you taken to ensure that they are willing to participate?

N/A

If participants are aged 18 or under describe how you will seek informed consent

N/A

How will consent be recorded?

A tick box will be used on each data collection sheet to confirm that consent has been obtained.

<b>SECTION D – OTHER DETAILS</b>	
Will participants be informed of the right to withdraw without penalty?	Yes
If no, please detail the reasons	
How will you ensure participants' confidentiality and anonymity?	
Details will be coded.	
How will issues of data storage be addressed?	
Only the principal researcher will have access to the data which will be destroyed upon completion of the study.	
Are there any further points you wish to make with regard to the proposed research?	
N/A	
<p>References</p> <p>Birrell, F, Lunt, M, Macfarlane, GJ and Silman, AJ (2005) Defining hip pain in population studies. <i>Annals of Rheumatological Disease</i>, 64, 95 - 98.</p> <p>Callaghan, MJ and Selfe, J (2007) Has the incidence or prevalence of patellofemoral pain in the general population in the United Kingdom been properly evaluated? <i>Physical Therapy in Sport</i>, 8, 37-43.</p> <p>Fulkerson, JP (2002) Diagnosis and treatment of patients with patellofemoral pain. <i>American Journal of Sports Medicine</i>, 30, 447 - 456.</p> <p>Gross, MT and Foxworth, JL (2003) The role of foot orthoses as an intervention for patellofemoral pain. <i>Journal of Orthopedic Sports Physical Therapy</i>, 33, 661 - 70.</p> <p>Orlin, MN and McPoil, TG (2000) Plantar pressure measurement <i>Physical Therapy</i>, 80, 399 - 409.</p> <p>Wilson, T (2007) The Measurement of Patellar Alignment in Patellofemoral Pain Syndrome: Are We Confusing Assumptions With Evidence? <i>Journal of Orthopaedic Sports Physical Therapy</i>, 37, 330-341.</p>	

15 October 2007  
cshs/als/ethics/app

Curran, Sarah  
Staff Research  
Cardiff School of Health Sciences  
Llandaf Campus  
Western Avenue  
Cardiff CF5 2YB

Dear Applicant

**Re: Application for Ethical Approval**

**Influence of knee alignment on plantar pressure distribution: comparisons of high, normal and low angles in healthy participants and patients with patellofemoral joint pain.**

Your research project proposal, as shown above, was amongst those considered at the meeting of the School Research Ethics Committee on 10/3/2007.

I am pleased to inform you that your application for ethical approval was **APPROVED** subject to the conditions listed below – please read carefully.

**Conditions of approval**

That any changes in connection to the proposal as approved, are referred to the Panel.

That any untoward incident which occurs in connection with this proposal should be reported back to the Panel **without delay**.

Yours sincerely



**Prof K Jones**  
**Chair of Department of Applied Life Sciences Ethics Panel**  
Cardiff School of Health Sciences  
Llandaf Campus  
Western Avenue  
Cardiff CF5 2YB

Tel : 029 20416896  
E-mail : [kpjones@uwic.ac.uk](mailto:kpjones@uwic.ac.uk)

Cc:

**PLEASE RETAIN THIS LETTER FOR REFERENCE**

PO Box 377 Western Avenue Cardiff CF5 2YB UK  
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Cardiff's **metropolitan** university

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prifysgol **metropolitan** Caerdydd

## 9.8 Appendix 8.



Wales Centre for Podiatric Studies  
Western Avenue, Cardiff, CF5 2YB

### Participant and Patient Information Sheet

Version 1 (20<sup>th</sup> September 2007)

#### **Influence of different knee alignment angles on pressures under the foot: comparisons between healthy participants and patients with patellofemoral joint pain**

*You have been invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what will be involved. Please take your time to read the following information carefully and discuss it with others if you wish. Please ask if there is anything not clear or if you would like more information. Take time to decide if you wish to take part. Thank you for reading this.*

#### **Problematic knee pain**

Pain in and around the front part of the knee is one of the most common complaints worldwide. The front part of your knee comprises the patellofemoral joint (PFJt), which is the knee cap (patella) and lower front part of your thigh bone (distal anterior aspect of femur). Understanding how this joint functions and aligns is an important when treating patients with pain in the front part of their knee. Foot posture (and function) is thought to play a role in disrupting the function and alignment of the PFJt but little is known on the effects of various foot postures (low arched foot and high arched foot).

Although there are a small range of complex equipment (Magnetic resonance Imaging, Computed Tomography) which provides detailed information on the joint their clinical use is often limited due to time and financial constraints. In response to these limitations, there is a need to develop simple, reliable, and easy to use cost-effective clinical techniques. Of particular interest is the need to identify suitable methods of measuring the alignment of the PFJt and the influence of foot posture.

#### **What do I have to do?**

This study involves two sets of data collection the first involves a series of clinical measures of your dominant knee and foot which will be identified by asking you to

kick a ball. Patients with pain in one knee will have data collected from that limb only. The second set of data collection will involve you walking across a pressure platform which is embedded within a 3-metre walkway. Your gender, age, height, weight and shoe size (foot length) will be recorded and all measures will be obtained barefoot. If you are suffering with PFJt pain you will be asked to complete a visual analogue scale (VAS) to determine pain levels. You will also be asked to shade in the area of pain on a lined diagram of the knee to indicate where the pain occurs.

The whole process should take no longer than 20 minutes. If you have any questions please ask and **if you are a patient attending the Wales Centre for Podiatric Studies your treatment will not be affected should you choose to take or not to take part in this study.** All information is confidential and only the named researcher will have access to the data. All raw data will be destroyed upon completion of the study.

*Thank you for taking part in this study.*

---

**Name of researcher:** Sarah Curran

**Contact address:** Wales Centre for Podiatric Studies  
University of Wales Institute, Cardiff  
Western Avenue  
CF5 2YB

Direct line: 029 2041 7221

Email: [scurran@uwic.ac.uk](mailto:scurran@uwic.ac.uk)