# Intrinsic Risk Factors Associated with Patellofemoral Pain Syndrome

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# Declaration

I, Tracy Prowse (LNXTRA001), hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.



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(Signature)

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(Date)

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# List of Abbreviations

| | |
|---|---|
| ASIS | Anterior superior iliac crest |
| ICC | Intraclass correlation coefficient |
| ITB | Iliotibial band |
| MLA | Medial longitudinal arch |
| NH | Navicular height |
| PFP | Patelofemoral pain |
| PFPS | Patellofemoral pain syndrome |
| PFJRF | Patellofemoral joint reaction force |
| ROM | Range of movement |
| SD | Standard deviation |
| TFL | Tensor fascia lata |
| VAS | Visual analogue scale |
| VL | Vastus lateralis |
| VMO | Vastus medialis obliquus |

# Abstract


**Background**

Various authors have identified both extrinsic and intrinsic parameters as aetiologic factors associated with Patellofemoral Pain Syndrome (PFPS). However, due to the lack of strong well-conducted studies and the lack of standard inclusion and exclusion criteria, much of the evidence to support this association is either contradictory or inconclusive.

**Purpose**

This dissertation aimed to clarify which intrinsic risk factors are associated with PFPS. This was achieved firstly, in Chapter 2, by reviewing the evidence surrounding the intrinsic risk factors associated with PFPS and identifying the risk factors that needed further investigation. Secondly, in order to ensure repeatability in future research, most of the variables that were measured had been investigated in previous repeatability studies. However, the repeatability of the Modified Thomas Test and the Figure Four Test had been poorly investigated, therefore the purpose of Chapter 3 was to determine the repeatability of the Modified Thomas Test and the Figure Four Test. Finally, the aim of Chapter 4 was to investigate the association of lower limb malalignment and inflexibility, and PFPS. The intrinsic risk factors that were investigated had previously been inconclusively associated with PFPS and were possible to assess in the clinical setting and therefore applicable to physiotherapists in their standard daily practice.

**Methods**

Computerized bibliographic databases (MEDLINE, CINAHL, AMED, Journals@Ovid) were searched without language restrictions from the earliest date to July 2003 using a combination of keywords and MEDLINE subject headings. A review of the literature surrounding the contributing intrinsic and extrinsic factors increasing the risk of developing PFPS was discussed in chapter 2.

Repeatability of the Modified Thomas Test and the Figure Four Test was determined in chapter 3 by two therapists (raters) measuring the range of movement of 18 healthy subjects. The same rater measured each subject on the first and third day, and by the second rater on the second day. The Modified Thomas Test was measured in one week and the Figure Four Test the following week.

Seventeen PFPS subjects and 40 control subjects were assessed for the following intrinsic risk factors: genu varus/valgus, medial longitudinal arch of the foot, static rearfoot posture, iliopsoas, adductor, quadriceps, ITB, anterior hip and hamstring flexibility.

**Results**

One of the main findings in chapter 2 was the lack of clinical scientific evidence, such as well-conducted randomised controlled trials and prospective cohort studies, to support an association of risk factors with PFPS. Extrinsic risk factors associated with PFPS were competitive involvement in sports, running on hard surfaces or uneven terrain, overstretching and a sudden increase in weekly distance. Intrinsic risk factors associated with PFPS were a high medial longitudinal arch, gastrocnemius inflexibility, quadriceps inflexibility and a delayed onset to VMO activation. The influence of the rearfoot motion during gait needs to be investigated further.

The interrater intra-class correlation coefficient (ICC) and Pearsons' correlation coefficient (r) were ICC=0.71-0.84; r=0.71-0.9 for the Modified Thomas Test and both the ICC and r equalled 0.92 for the Figure Four Test. The intrarater ICC and Pearson's correlation coefficients were ICC=0.66-0.83; r=0.7-0.84 for the Thomas Test and both the ICC and r equalled 0.93 for the Figure Four Test. For the measurements of hip flexion, knee flexion and hip abduction in the Modified Thomas test, the limits of agreement demonstrated that two measurements would be within 7.9, 20.9 and 6.4 degrees of each other (respectively) in 95% of cases. The Figure Four Test measurements would be within 2.1 centimeters (cm) of each other in 95% of cases.

Chapter 4 demonstrated that the hip adductor flexibility (in cm) was significantly (p=0.022) decreased in the PFPS group (36.94cm +-14.39cm) than in the control group (44.95cm +-10.41cm). The hamstring flexibility (in cm) was significantly (p=0.006) decreased in the PFPS group (75.71cm +-12.7cm) than in the control group (90.3cm +-19.32cm). The anterior hip flexibility was significantly (p=0.029) restricted in the PFPS group (8.78cm +-2.7cm) than in the control group (7.37cm+-1.95cm).

**Conclusion**

Chapter 2 revealed that factors presented in the review of the literature were found to be documented with limited clinical scientific evidence. However, strong associations with PFPS were competitive involvement in sports, running on hard surfaces or uneven terrain, overstretching, a sudden increase in weekly distance timing of VMO activation, high medial longitudinal arch, gastrocnemius inflexibility and quadriceps inflexibility. The repeatability study in chapter 3 showed that both the Modified Thomas Test and the Figure Four Test were repeatable clinical tests. However, in future clinical settings, the limits of agreement for each measurement need to be considered in relation to the overall flexibility of each subject. These tests were easy to administer and provided a quick method of measuring aspects of hip and knee flexibility. Hamstring, adductor and anterior hip inflexibility were shown to be associated with PFPS in the research study presented in chapter 4. They need to be investigated further to determine cause and effect.

**Key Words**

Patellofemoral pain syndrome, extrinsic risk factors, intrinsic risk factors, flexibility, intrarater repeatability, interrater repeatability, Figure Four Test, Modified Thomas Test.

# Chapter 1 - Introduction and scope of the dissertation

Patellofemoral pain syndrome (PFPS) accounts for nearly one third of all complaints of knee pain in active female athletes [86] and is one of the most common clinical conditions encountered in the general population [99]. Patellofemoral Pain Syndrome (PFPS) can be defined as anterior or retropatellar pain in the absence of other knee pathology [3;12;88]. Symptoms are typically aggravated by activities such as prolonged sitting, ascending or descending stairs, kneeling, squatting and running [6]. It appears to be associated with intrinsic factors and extrinsic factors [85]. However, the interaction between these factors and the relationship with the development of PFPS is not known.

The management of PFPS often includes the use of anti-inflammatory and/or pain relieving modalities (cryotherapy, bracing, massage therapy, acupuncture), muscle flexibility training, quadriceps training, orthotics and the correction of biomechanical abnormalities or other potential causative factors identified during the subjective and objective assessment. Physiotherapists prescribe various treatment interventions based on the clinical findings during the assessment of the patient's flexibility, muscle strength or control and biomechanical status. This is done with the aim of correcting so-called "abnormalities", with the anticipated result being a reduction in symptoms. However, the strength of the scientific evidence to support the use of these physiotherapy interventions in the management of PFPS is limited [17]. It is suggested that the efficacy of these interventions needs to be investigated by designing scientifically rigorous trials and that it is only once this has been done, that the various factors that contribute to the development of PFPS can be confirmed [17].



However, before an intervention can be investigated, it is important to establish which risk factors (intrinsic and extrinsic) are associated with PFPS. This can be done by firstly searching the available literature to establish which factors have been confirmed as risk factors for PFPS and which factors need to be investigated further. Secondly, a case control and/or a prospective cohort study would need to be performed to confirm which intrinsic risk factors are associated with PFPS.

Therefore, the aim of Chapter 2 was to undertake a systematic review using evidence-based criteria of the intrinsic risk factors for PFPS. The aim of Chapter 3 was to establish

repeatability for flexibility measurements that had not been previously validated. The validation of assessment tools for the measurement of the various risk factors is essential prior to the commencement of a trial. This will ensure that the conclusions made are universal and applicable to the clinical setting [17]. The aim of Chapter 4 was to investigate all the intrinsic risk factors that had been found to be contradictory, anecdotal or poorly associated with PFPS.

The association of extrinsic risk factors and PFPS was not investigated in the present dissertation, since the assessment of equipment and training errors during a standard physiotherapy examination is not usually measured or quantified. Rather, the identification of extrinsic risk factors is based on the information given by the patient during the subjective examination.

# Chapter 2 - Risk factors associated with PFPS

Proposed submission to 'Physiotherapy' journal

## Introduction

Patellofemoral disorders are one of the most common knee pathologies encountered by orthopaedic and sports medicine clinicians [9;22;26;73;88;99]. Knee injuries accounts for 23% to 31% of injuries and complaints in the athletic population, where and pain related to the patellofemoral joint is the most common [9;20;52;72]. Patellofemoral Pain Syndrome (PFPS) is used as an umbrella term to encompass all anterior or retropatellar pain in the absence of other knee pathology [3;12;88]. However, since patients experience a variety of symptoms from the patellofemoral joint with different levels of pain and physical impairment, the term 'PFPS' is still widely discussed.

Anterior knee pain, chondromalacia patella, patellofemoral arthralgia, patellar pain and patellofemoral pain are often used synonymously with PFPS [76;88]. The term, 'anterior knee pain' is suggested to encompass all pain-related problems of the anterior knee. It includes pain due to intra-articular pathology, peripatellar tendonitis or bursitis, plica syndromes, Sinding-Larsen's disease, Osgood Schlatter's disease and other rare pathologies. It is suggested that by excluding these pathologies, the remaining patients with a clinical presentation of anterior knee pain can be diagnosed with PFPS [88]. Chondromalacia patella is a term used to define pathological changes of the retropatellar cartilage. It was used as a synonym for PFPS for half a century, however studies during the past three decades have shown a poor correlation between articular damage and the pain mechanism of PFPS [19;54;61]. There is a growing consensus concerning the terminology and inclusion criteria of PFPS and the literature generally describes PFPS as peripatellar or retropatellar pain, which is reproduced by any two of the following: the apprehension test (grinding the patella onto the PFJ), resisted knee extension or aggravating activities (squatting, ascending and descending stairs and prolonged sitting) [6;17;89]. These inclusion criteria were used in the present dissertation in order to ensure that PFPS was the primary pathology being investigated. There is a lack of a clear consensus about the aetiology and pathology associated with PFPS and there is a paucity of randomised controlled clinical trials regarding treatment [3;17].

Only once the efficacy of various treatment options for PFPS has been established in randomised controlled trials, can the various factors that cause the development of this syndrome be confirmed [17]. However, as with many physiotherapy approaches, the multifaceted programmes that are prescribed make it impossible to determine which component (or combination of components) is responsible for the changes in symptoms of individuals with PFPS [12]. Therefore, it is necessary to firstly define the possible associated risk factors by means of case controlled and prospective studies and then to address each factor by means of randomised controlled trials to determine whether or not it is causative to PFPS.

A number of extrinsic and intrinsic aetiological factors that may be associated with PFPS have been described [9;30;80;88;104;105]. Extrinsic factors are related to factors outside the human body such as excessive training, training errors, incorrect equipment used and environmental conditions [104]. Intrinsic factors relate to individual characteristics such as lower limb malalignment, leg length discrepancy, muscle imbalance and joint laxity [104]. There is general agreement on the classification of the risk factors associated with PFPS. It is the purpose of this paper to review the scientific evidence that exists to confirm which intrinsic and extrinsic factors are associated with PFPS. This will result in a better understanding of the causes of PFPS so that future randomised controlled trials can be devised to test appropriate treatment options.

Clinical neuromusculoskeletal medicine is seldom based on stable evidence-based criteria. It is the purpose of this review to assess the relevant risk factors, with reference to study design and inclusion and exclusion criteria in order to present a summary of the factors associated with PFPS and the strength of this association.

## Methodology

A systematic review was undertaken. Computerised bibliographic databases (MEDLINE, CINAHL, AMED, Journals@Ovid) were searched without language restrictions from the earliest date to July 2003 using the following combination of keywords and MEDLINE subject headings: patellofemoral pain syndrome, risk factors, anterior knee pain, Q-angle, training errors, flexibility, muscle strength, vastus medialis obliquus, medial longitudinal arch, rearfoot

asymmetry and genu valgus. The British Medical Association Library supplied the original articles that had been referenced in relevant articles, but which were not found on these databases. Eighty-five articles were retrieved for the review. All articles were included for discussion. Many of these studies did not use a standard list of inclusion and exclusion criteria, as recommended in previous literature [17]. This lead to an unclear picture as to whether these factors are associated with PFPS specifically or the umbrella term "anterior knee pain", which is defined by a number of knee pathologies. Therefore it was taken into account whether the studies met the inclusion and exclusion criteria for PFPS. The standard list of PFPS inclusion criteria were peripatellar or retropatellar pain, pain or crepitus on grinding of the patella, pain on aggravating activities and retropatellar pain on resisted knee extension [17]. The list of exclusion criteria were musculoskeletal conditions of the knee, the presence of a knee effusion, referred pain and previous corticosteroid injection to the knee [17].

The evidence was evaluated by following the grading system recommended by the Scottish Intercollegiate Guidelines Network (SIGN) [39]. Levels of evidence were based on the hierarchy of study types and the methodological quality of individual studies [39]. A similar modified grading system was used to evaluate the evidence in the present review. A table defining the terminology and grading of evidence used in the present review and as recommended by the SIGN is presented in Table 2-1. Factors well documented in controlled clinical trials were considered as "strong" evidence in the present review, factors documented with limited clinical scientific evidence (case control studies, prospective studies) were considered to be "limited" and postulated factors for which there is no scientific evidence (case series, anecdotal reports) were considered as "weak" evidence. The strength of evidence provided by a study is also influenced by how well the study was designed and carried out. Failure to give due attention to key aspects of study methods increases the risk of bias or confounding and thus reduces the study's reliability [39]. The methodological quality of the evidence was evaluated against defined criteria [39] and studies were considered to be "well-conducted" in the present review if they met these criteria (sample size, confounding factors, standard, valid and reliable measures, blinding, statistical analysis) [62].

**Table 2-1 A summary of the systems of determining levels of evidence**

| Strength of evidence | Present review | SIGN Grading System [39] |
|---|---|---|
| Strong | *: Factors well documented in high quality meta-analyses, systematic reviews or randomised controlled trials (RCTs) | 1++ High quality meta-analyses, systematic reviews of RCTs, or RCTs with a very low risk of bias<br>1+ Well-conducted meta-analyses, systematic reviews of RCTs, or RCTs with a low risk of bias<br>1- Meta-analyses, systematic reviews or RCTs, or RCTs with a high risk of bias |
| Limited | **: Factors documented with limited clinical scientific evidence (systematic reviews, case control studies, prospective cohort studies) | 2++ High quality systematic reviews of case-control or cohort studies or High quality case-control or cohort studies with a very low risk of confounding, bias, or chance and a high probability that the relationship is causal<br>2+ Well-conducted case-control or cohort studies with a low risk of confounding, bias, or chance and a moderate probability that the relationship is causal<br>2- Case-control or cohort studies with a high risk of confounding, bias, or chance and a significant risk that the relationship is not causal |
| Weak | #: Postulated factors for which there is no scientific evidence (case series, retrospective case series, anecdotal reports)<br>##: Contradictory evidence | 3 Non-analytic studies, e.g. case reports, case series<br>4 Expert opinion |

**Table 2-2 A summary of postulated evidence based factors associated with PFPS**

| Extrinsic Risk Factors | | | |
|---|---|---|---|
| **Factor** | **Study Design** | **Inclusion Criteria ***** | **Exclusion Criteria ****** |
| **Training Errors** | | | |
| Sudden increase in distance** | Retrospective; Prospective | 1; 1,2 | A; None |
| Competitive involvement in sports** | Retrospective; case control | 1; 1,3 | A; A-C |
| Overstretching** | Case control | 1,2 | A |
| Poor technique# | Expert opinion (review) | None | None |
| **Equipment** | | | |
| Incorrect shoes## | Retrospective; Prospective | 1; 1,2 | A; A,C |
| Cleat positioning# | Expert opinion (review) | None | None |
| Training surface# | Retrospective case series | 1 | A |

| Intrinsic Risk Factors | | | |
|---|---|---|---|
| **Factor** | **Study Design** | **Inclusion Criteria ***** | **Exclusion Criteria ****** |
| **Structural Intrinsic Risk Factors** | | | |
| *Patella alta*** | Prospective | 1-3 | A |
| Patella baja# | Expert opinion | 1-4 | A-D |
| *Patellar malalignment*** | Case control | 3 | A-D |
| *Femoral anteversion*** | Case control | 3 | None |
| Q-angle## | Case control/prospective cohort | 1,2; 1-4 | A; A |
| Genu valgus/varus## | Prospective/prospective cohort | 1-4;1,2 | A; A,C |
| Dynamic rearfoot motion** | Case control; case control | 1,2; 1,2 | A,B; A,B |
| *Static rearfoot angle*** | Single-session observational | 1,3 | A,B,D |
| High medial longitudinal arch** | Prospective; case control | None; 1,2 | A-D; A |
| *Leg length discrepancy*** | Prospective | 1-4 | A |
| **Dynamic Intrinsic Risk Factors** | | | |
| VMO/VL timing to activation* | Randomised controlled trials | 1-3; 1-3 | A; B,C |
| Weak pelvic & hip stabilisers# | Expert opinion | 1-4 | A-D |
| ITB inflexibility# | Case control; case series | 1-3; 1 | A; A |
| Gastrocnemius inflexibility** | Prospective cohort | 1-4 | A |
| Quadriceps inflexibility** | Prospective cohort | 1-4 | A |
| Hamstrings inflexibility# | Observational case series | 1 | A |
| Anterior hip inflexibility# | Expert opinion (textbook)) | 1-4 | A-D |
| Iliopsoas inflexibility## | Expert opinion / observational | None/None | None/None |

**: Factors well documented in controlled clinical trials*
***: Factors documented with limited clinical scientific evidence (case control studies, prospective studies)*
*#: Postulated factors for which there is no scientific evidence (case series, anecdotal reports)*
*##: Contradictory evidence*
*Italics: Factors that are not associated to PFPS*

******: PFPS Inclusion Criteria***
*1. Peripatellar or retropatellar pain*
*2. Pain/crepitus on grinding or apprehension test*
*3. Pain on aggravating activities*
*4. Retropatellar pain on resisted knee extension*

*******: PFPS Exclusion Criteria***
*A: Musculoskeletal conditions of the knee*
*B: Knee effusion*
*C: Referred pain*
*D: Previous corticosteroid injection*

## Extrinsic Risk Factors for PFPS

The relationship between extrinsic factors and PFPS has been investigated extensively. It appears that most of the extrinsic risk factors are related to the participation in a sporting activity, but no studies to date have demonstrated how any of these factors are associated with PFPS in the non-sporting population. Training errors and inappropriate equipment are broad terms used to describe a number of specific extrinsic risk factors.

### Training errors

Appropriate training is a constant balance between performing sufficient quality and quantity of work to maximise performance, but not so much that injury occurs [6]. Training errors are related to inappropriate quality and quantity of work, which can result in injury. The importance of training errors has been investigated in several studies. Training errors often result in overuse of the PFJ. Overuse of the PFJ relates to overloading of the PFJ over a prolonged period.

A sudden increase in weekly distance and a single high intensity session of training or competition, such as a 10km-race or a marathon has been shown to be associated with PFPS in both retrospective [9] and prospective [49] studies. Both studies were well-conducted, however the latter lacked any exclusion criteria, as is demonstrated in Table 2-2.

A competitive involvement in sport has been shown to be associated with the development of PFPS [9;89]. This was demonstrated in two well-conducted [39] retrospective and case controlled studies, which included at least two inclusion criteria [9;89].

Spending too much time stretching during a session is defined as overstretching. Overstretching was shown to be associated with PFPS. This was demonstrated in a case control study in which the PFPS subjects spent more time in minutes stretching per session than the control subjects ($p=0.042$) [22]. However, it is suggested that more information regarding the type and quality of stretches performed should be investigated before any definitive conclusions can be made.

In the case of cycling the poor technique of cyclists bringing their knees toward the crossbar of the bicycle frame in order to decrease wind resistance has been anecdotally identified as a risk factor [21]. However, there is insufficient evidence to justify this as a potential risk factor for PFPS, since it is cited as an author's opinion.

Most of the studies that investigated the relationship between PFPS and training errors have used at least two of the inclusion criteria listed in Table 2-2. However the presence of a knee effusion, previous corticosteriod injection or referred symptoms have frequently not been included which might interfere with the specific diagnosis of PFPS and might influence any variables measured or noted. The presence of an effusion might indicate intra-articular pathology and influence the intrinsic variables measured. However, it is unlikely that an effusion would influence the extrinsic variables, as it would most likely cause a subject to stop the aggravating activity rather than overload or increase the frequency of activity.

Therefore, it can be concluded that there is limited scientific evidence that a sudden increase in weekly distance, competitive involvement in sports and overstretching may be associated with PFPS (Table 2-2). Further clarification as to whether these factors cause PFPS (cause-effect relationship) would need to be investigated in a prospective cohort study or a randomised controlled trial. It has been suggested that if the load on the PFJ increases above a certain threshold, existing anthropometric and biomechanical abnormalities would then have sufficient time to interact and cause PFPS [22]. These anthropometric and biomechanical abnormalities are classified under intrinsic risk factors.



**Equipment**

A number of postulated aetiological factors relate to equipment errors. These include inappropriate shoes, incorrect equipment settings in cyclists and road surfaces. Inappropriate running shoes can have poor heel wedging; soft, loose-fitting heel counters; inflexible insoles under the metatarsal heads; narrow toe boxes; excessive lateral heel wear; improper application of sole repair material; and orthotics that have been removed or worn down [9].

In a retrospective survey of 1650 runners, the incidence of overuse injury within each major anatomical region was investigated. PFPS was found in 25.8% of the total population and 10% of PFPS sufferers were found to have inappropriate running shoes [9]. However, in a

prospective study of 390 military recruits, no statistically significant difference was demonstrated between recruits who had trained in modified basketball shoes and those who had worn standard lightweight infantry boots and the incidence of PFPS [70]. The retrospective case series study design is a weaker study design than the prospective study design according to the hierarchy of study types described previously and no statistical analysis was performed [39]. The latter should be regarded as stronger evidence. Despite the lack of statistical analysis in the retrospective study, both studies were well-conducted, and a specific diagnosis of PFPS was made. Both studies used exclusion criteria that were satisfactory (Table 2-2). At best, the current evidence that incorrect shoes are associated with PFPS is weak and contradictory (Table 2-2). Possible explanations for the contradictory findings are the differing populations (runners vs. army recruits) and therefore the differing aggravating activity (running vs. basic training regime) and the differences between running shoes and basketball shoes. Decreased shoe wear has been associated with PFPS, although it is suggested that this may be a result of the PFPS (runners stop running when they begin to feel PFP) rather than a possible cause [22].

PFPS in cyclists is more commonly attributed to incorrect equipment than in runners. Cleat positioning is important with regard to the angle of force at the foot-pedal interface [21] with patellar tracking being affected by medial or lateral rotation of the cleat. However, despite the evidence to support the theory that cleat positioning affects patellar tracking there are no studies to support the theory that it is a risk factor associated with PFPS (Table 2-2).

Hard road surfaces, road camber and uneven terrain have been suggested as possible risk factors in the development of PFPS [49]. In a retrospective survey of running injuries it was found that in 7% of the runners who developed PFPS there was an association with hard road surfaces, road camber and uneven terrain [9]. However, this can be considered as "weak" [39] evidence, since it is a weak study design (Table 2-1) and no statistical analysis was performed on the data. It is clear that to establish a cause and effect relationship between these factors and the development of patellofemoral pain further investigation is needed.

In summary, there is limited evidence that extrinsic factors such as competitive involvement in sports, overstretching and a sudden increase in mileage are risk factors associated with PFPS [9;22;49;89]. The cause-effect relationship between these factors and PFPS requires

further study using randomised controlled clinical trial study designs. The other postulated extrinsic risk factors for PFPS are not based on sound scientific evidence (Table 2-2).

## Intrinsic risk factors

Intrinsic risk factors comprise factors that are internal to the subject. There are structural and dynamic intrinsic risk factors. Structural factors refer to the alignment of the lower limb and dynamic factors refer to the strength, length and control of the muscles.

### Structural intrinsic risk factors

Malalignment of the lower extremity has been suggested as a predisposing factor to knee overuse injuries, including PFPS [58]. Malalignment factors that have been identified are the shape, size and position of the patella, excess femoral anteversion, increased Q-angle, genu varum or valgum, rearfoot varus/valgus, excessive subtalar joint pronation, patellofemoral joint alignment and leg-length discrepancy [4;58;66;88]. However, clinical studies have demonstrated contradictory findings in the various studies investigating patients with PFPS [8;26;47;53;68;89]. The scientific evidence to support the hypothesis that these factors cause PFPS will now be discussed.



#### The Patella

Abnormalities of the patella can cause abnormal patellofemoral tracking resulting in an increase in patellofemoral joint stress. The patella can vary in size (patella parva) and position (patella alta or patella baja). Patella alta, which is a "high-riding" patella might be unstable and prone to dislocation. Patella baja ("low-riding") is thought to cause knee pain due to the increased patellofemoral contact stress which occurs as a result of patellofemoral contact occurring earlier in knee flexion [67]. It has been shown that a clinical diagnosis of patella alta is unreliable [48] and can only be demonstrated by lateral X-rays [47]. This could possibly explain the conflicting evidence of whether a high riding patella is associated with PFPS or not [26;47] . It is also the reason behind not demonstrating the patella position as an intrinsic factor on Table 2-2. A retrospective study on 446 pupils found that patella alta was not associated with PFPS (although the term used was chondromalacia patella). However, lateral X-rays were not used, the only inclusion criteria was pain on aggravating activities, no

exclusion criteria were used and no control subjects were measured [26]. A prospective study in which arthrotomies were performed for 'chondromalacia patella' found that lateral X-ray showed patella alta in "some" of the knees, however no percentages or statistical analysis was performed to substantiate this statement. Moreover, the only musculoskeletal condition excluded was the possibility of an injury to the meniscus. No other exclusion criteria were used which, if present, could have interfered with the position of the patella. All inclusion criteria were used except for pain on resisted knee extension [47]. Therefore both studies have severe limitations; due to the poor study design and poor use of exclusion and inclusion criteria. Therefore, no conclusions can be made regarding the influence of the patella alta and PFPS.

Six fresh-frozen cadaver knee joints were used to study changes in retropatellar contact mechanics accompanying patella baja. The data indicated that patellofemoral contact stresses are not elevated appreciably in the cadaveric knees. It was concluded that the symptoms sometimes associated with patella baja may be due to factors other than local mechanical overload [69]. The diagnosis of PFPS was not mentioned in this study, therefore it cannot be concluded that there is no association of patella baja to PFPS, however no other evidence was found to support or negate the hypothesis that PFPS is associated with patella baja in the literature investigated. Patella baja is thus only anecdotally linked with PFPS [67].



**Patellar Alignment**

Patterns of patellofemoral joint malalignment have been described in the literature and include subluxation of the patella with tilting, subluxation without tilting and tilting without subluxation [32]. It is generally believed that individuals with PFPS typically have a patella that is laterally tilted and has decreased medial glide due to inflexibility of the soft tissue restraints of the lateral retinaculum [98]. However, reliability of measurements obtained with patellofemoral alignment tests have been shown to be poor or fair [27;92;98] and therefore these tests should not be used as a measurement tool or as a basis for treatment decisions. Rather, it is suggested that X-rays be used as the examination tool [98]. Moreover, no significant differences were found in congruence angle, patellar tilt and patellar subluxation between PFPS patients and the control group in a well-conducted case control study using radiographic examination [89]. These results are in contrast with those of Insall et al (1976), who stated that patellar malalignment alone could cause patellar pain. However, this

statement is based on the presence of either patella alta or an increased Q-angle, neither of which were classified under the patterns of patellar malalignment [32]. In addition this statement is not based on scientific evidence but rather clinical opinion. Therefore it is concluded that patellar malalignment is not associated to PFPS (Table 2-2). However, it is evident that further investigation is needed regarding patellar malalignment and its association to PFPS using radiographic examination.

The definition of patellar malalignment with regard to determining when alignment is considered normal or malaligned needs more investigation. It is argued that 60 to 80% of the normal population fall into the category generally classified as malaligned, which may overestimate the population at risk for developing PFPS and could result in conflicting evidence [76]. It is hypothesised in a review of the pathogenesis of PFPS that malalignment may not be directly associated with the onset of PFPS, but rather the cause may lie with neural damage and proprioceptive loss associated with overuse or trauma that precipitates the symptoms, coupled with underlying malalignment [80].

**Femoral Anteversion**

It has been suggested that femoral anteversion is a risk factor for PFPS. However, retrospective and case control studies have failed to show any relationship between knee symptoms and femoral neck anteversion [25;26]. Moreover, femoral anteversion can only be accurately measured using computed tomographic scanning as the gold standard, with magnetic resonance imaging being a reliable equivalent [91]. Yet, previous studies [25;26] have not used these techniques and therefore no definitive conclusion can be made about the association of femoral neck anteversion with PFPS, although the evidence to date (Table 2-2) shows that femoral anteversion is not associated to PFPS.

**Quadriceps (Q) angle**

The Q-angle is the angle formed by a line drawn from the anterior superior iliac spine (ASIS) to the central patella and a second line drawn from the central patella to the tibial tubercle. A large Q-angle is considered by some investigators to indicate severe patella malalignment [1;45]. It is proposed that PFPS, which is thought to be associated with a malalignment of the patella, is attributable to a large Q-angle [3;18;45;47]. The high incidence of PFPS in women has been attributed to gender differences in anatomic structure, in particular Q-angle [3]. The

normal Q-angle in men ranges from 8 to 14 degrees (average 7.5 degrees) and in women from 11 to 20 degrees (average 10.3 degrees) [18;47]. In a case control study investigating male and female runners with PFPS, injured runners were found to have a larger Q-angle (17.9 degrees) than the controls (11.1 degrees). The ratio of male to female runners was the same in both groups and no further analysis was performed on the gender of the runner [68]. Adequate inclusion criteria were used, however, the study did not exclude any possible confounding factors that could influence the measurement of the Q-angle, such as an effusion, referred pain or previous corticosteroid injections.

The importance of an increased Q-angle as a biomechanical factor in PFPS is not confirmed by any further studies [8;26;38;104]. The strongest evidence based study was a prospective cohort study of 282 students, which included all possible inclusion criteria and showed that Q-angle was not associated with PFPS ($p=0.394$) [104]. A case control study showed no association of the Q-angle to anterior knee pain ($p=0.07$) [8]. However, this study had no inclusion or exclusion criteria and no reference was made to PFPS specifically. The exclusion criteria for the former study did not include possible confounding factors, which may have influenced the outcome. However, it has been shown that both clinical estimation and instrumented measurement of the Q-angle has poor reliability ($r = 0.63$ and 0.23 for intra and inter-tester reliability respectively) [92] and varies continuously over time in the standing position (3.12 degrees over one minute) [100]. Therefore, any associations between Q-angle and PFPS cannot be made if a study uses clinical estimation only. Rather, it is suggested that radiographic examination should be used [92].

It has been shown that there are gender differences in patellofemoral contact areas and contact pressures [18]. The proposed explanation for this phenomenon suggests that the larger Q-angle leads to a valgus vector at the knee causing higher contact pressures. This theory is debatable due to measurement technique that was used and the fact that healthy cadaveric knees were used. Finally, it has been shown in two case control studies that it is not the Q-angle itself that is associated with PFPS, but rather the lack of variability of this angle in PFPS sufferers during a co-ordinated movement [38;43]. However, both these studies used clinical estimation to measure the Q-angle. The evidence suggests that Q-angle is not associated with PFPS, although, all of the studies that were reviewed regarding Q-angle used clinical estimation only; therefore no conclusions can be made regarding the

association of Q-angle to PFPS. Further research investigating the Q-angle should use radiographic examination.

**Genu Valgus/Varus**

It is proposed that either genu valgus or varus could increase the forces through the knee and the foot thereby affecting patella alignment and increasing the patellofemoral joint reaction force. It has been suggested that this could possibly lead to PFPS. However, there has only been one prospective study to substantiate this hypothesis [70]. In this study, adequate inclusion and exclusion criteria were used, and it was a well-conducted study (p=0.0001). In contrast, another prospective study which examined the intrinsic lower limb risk factors of 282 students, showed no significant difference in genu valgus or varus between subjects who developed PFPS and those who did not develop PFPS (P=0.96) [104]. Adequate inclusion criteria were used. However, the presence of an effusion, referred pain or previous corticosteroid injection did not exclude subjects from the study, which could account for the contradicting evidence. Assessment of knee alignment forms part of a standard physiotherapy biomechanical assessment, therefore more evidence to support the possible association of genu valgus/varus with PFPS is needed.

**Rearfoot Alignment**

Abnormal rearfoot alignment may change the lower extremity biomechanics, which can aggravate PFPS [90;97]. Forefoot varus with compensatory rearfoot valgus is thought to result in excessive pronation, which may affect the entire lower extremity kinetic chain [99]. The measurement of rearfoot alignment assesses the alignment of the rearfoot with respect to the lower leg. A valgus alignment is thought to be associated with pronation, which may lead to an increased valgus force through the knee [50]. This would cause abnormal tracking and an increase in the rotational stress through the knee [97]. Many researchers have suggested that this could be a potential cause for PFPS in long-distance running [23;67;94]. It has been suggested that excessive rearfoot movement causes PFPS [9;67]. However, no significant differences were found between the static rearfoot angles of a group of anterior knee pain sufferers and an asymptomatic group, nor between each group's left and right sides (p=0.31) [63]. This study was a single session observational study performed on 75 students and included all types of anterior knee pain that were increased by aggravating activities. Traumatic injuries of the ligaments, meniscus and intra-articular surface of the knee were

excluded, however symptoms arising from the growth plate, tendon, plica or fat pad were not excluded. Therefore the umbrella term, 'anterior knee pain' was used. Despite the lack of adequate inclusion and exclusion criteria, this was a well-conducted study that showed that static rearfoot alignment was not associated with anterior knee pain (Table 2-2).

In a case control study of 36 runners, the relationship between dynamic and static intrinsic risk factors and PFPS was investigated. It was shown that there was no difference between dynamic rearfoot motion in patients with PFPS and control [68]. However, because inadequate exclusion criteria were used it is possible that the biomechanical parameters measured could have been altered by factors as effusion, previous surgery, lumbar spine referred pain and previous corticosteroid injections. Moreover, no statistical differences were given to substantiate this statement. In contrast, it was demonstrated in a well-conducted case control study on 70 runners, which used adequate inclusion criteria, that PFPS sufferers have less pronation in the first 10% of the support phase in gait than control subjects (P=0.007) [22]. This is also in contrast with previous anecdotal and retrospective evidence that suggests that excessive pronation is associated with running injuries [9;31]. However, no statistical evidence is given in these references and no definition of the type of running injury that is associated with excessive pronation is given. Furthermore, it is not clear from the study methodology whether subjects, who had a previous corticosteroid injection or who suffered from pain referred from the lumbar spine, were excluded from the study which may alter the biomechanics of gait as previously mentioned. Therefore, it can be concluded that it is possibly the co-ordination of timing between the lower extremity joint actions that is associated with PFPS and not the quantity of rearfoot motion [37] (Table 2-2). However, further research using adequate exclusion criteria needs to be done in order to confirm the association of rearfoot motion and PFPS during the gait cycle.



**Medial Longitudinal Arch of the Foot**

The height of the arch of the foot can be determined by measuring the medial longitudinal arch of the foot (MLA) [34]. It is suggested that a collapsed arch may be associated with pronation and that it can affect the normal biomechanics of the lower limb [29]. It is proposed that deviations in the normal structure of the MLA produce functionally unstable and unbalanced conditions of the foot (pes planus) and consequently lower limb disorders [29]. It

is suggested that these structural deformities can be corrected through the use of various orthotic devices [24;57].

The evidence surrounding the MLA and its association with PFPS focuses on two aspects of PFPS: firstly, the studies which investigate the possibility that a high arched foot is associated with PFPS and secondly, the studies which investigate the use of orthotics in the reduction of PFPS symptoms. A low arched foot can be corrected through the use of orthotics [23] and therefore it appears that these studies investigate the association between a low arched foot and PFPS. This has led to discrepancies in the literature regarding whether it is a high arched foot or low arched foot that is associated with PFPS.

It has been shown in a case control study on 70 runners, using adequate inclusion and exclusion criteria that the PFPS group had a lower arch index (higher arched feet) than control group [22]. However, the p-value for this finding was 0.05. This level of significance indicates that further research to support the relationship between a high MLA and PFPS is required. In a prospective study of 294 military recruits the association between lower limb malalignment and overuse injury was investigated. This study noted that recruits with higher arches had an increased risk of overuse injury [10] but this was not a study specific to PFPS and therefore no conclusions can be made regarding PFPS. However, it can be summarised that it is more likely to be a high arched foot that is associated with PFPS, rather than a low arched foot.

In a randomised controlled trial of 20 female patients with PFPS, the association between the use of soft shoe orthotics and the improvement in PFPS was investigated. Soft foot orthotics, which are proposed to correct the static position of forefoot varus and calcaneal valgus, resulted in a significant improvement in PFPS [23]. In this trial adequate inclusion and exclusion criteria were used, however there were low subject numbers (n=10) in both the control and patient groups. This finding is supported by a recent retrospective case series, which showed an improvement in PFPS symptoms in 76,5% of patients who wore soft shoe orthotics. However, this was a poorly designed study, as there was no control group and no exclusion criteria were used [81]. It is proposed that the improvement in pain is possibly due to the changes in transverse and frontal plane motion of the foot and knee during walking and running [24;96], although the only definitive conclusion that can be made from the studies

which have investigated this theory is that the orthotics improved PFPS. No conclusions can be made regarding the mechanism by which this occurs. This theory is further supported by a pre-post trial study of 12 asymptomatic female subjects, which investigated the changes in patellar alignment on radiographic examination before, during and after the use of orthotics. It demonstrated that subjects showed a statistically significant change in patellar positioning (medial glide) with the placement of posting material (orthotics) ($p=0.04$) [57]. However, the mechanism by which a reduction in PFPS symptoms is achieved is unknown. The calcaneal valgus support would appear to be more appropriate for the over-pronated foot, and not the high-arched foot that has been identified as a risk factor for PFPS. Therefore, it appears that another mechanism is responsible for the improvement in PFPS with soft shoe orthotics. It has been hypothesised that it is the proprioceptive effect that changes the symptoms of PFPS, rather than the mechanical change in foot position.

Despite this controversy surrounding the mechanism of orthotics, there remains a general agreement amongst clinicians that a low-arched foot is associated with PFPS [23;29;51;53]. However, the evidence weakly associates a high arched foot with PFPS [10;22] (Table 2-2). It appears that further case control and prospective studies should be performed in order to clarify whether it is a low or high medial longitudinal arch that is associated with PFPS.

**Leg-Length Discrepancy**

It is hypothesised that a lower extremity limb length discrepancy may have a significant effect on lower extremity biomechanics and the patellofemoral joint [99]. It is suggested that compensations for limb length discrepancies include excessive foot pronation, toeing-out (forefoot abduction) and a flexed knee gait and/or stance. All of these compensations can theoretically have an effect on patellofemoral tracking [99]. In a prospective study of 62 army recruits, the relationship between lower limb malalignment and knee exertion injuries was investigated [59]. A significant difference in leg length ($p=0.004$) was found between those army recruits who suffered knee exertion injuries and those who did not, in a prospective study [59]. However, the statistical analysis did not differentiate between PFPS and pain arising from other structures of the knee and therefore it cannot be concluded that a leg length discrepancy is associated with PFPS specifically. Moreover, the only exclusion criteria used was previous ligamentous knee traumas or fractures in the knee region. Therefore there

is a possibility that other musculoskeletal conditions of the knee could have confounded the results.

It has been shown in a recent well-conducted prospective cohort study of 282 students that there is no significant difference in leg-length discrepancy between subjects with PFPS and those without (p=0.355) [104]. Therefore a preliminary conclusion could be that leg-length discrepancy is not associated with PFPS and is a measurement that could be considered redundant in the biomechanical assessment of subjects with PFPS.

**Dynamic Intrinsic Risk Factors**

Strength and control of the muscles that stabilise the patella and the pelvis, as well as the range of movement of musculotendinous units of the lower limb are the main dynamic intrinsic factors that are postulated to affect patellar tracking [60]. These include vastus medialis obliquus strength and control, hip and pelvic stabiliser strength and control and musculotendinous range of movement.

**Vastus Medialis Obliquus strength and control**

Strengthening of the VMO muscle is considered one of the essential components of the non-operative approach to PFPS [12;67;84;104]. It was originally thought that a weak VMO resulted in an excessive lateral glide of the patella, due to the lack of restraint on the tight lateral structures, which in turn caused PFPS [67]. However, recent studies have highlighted the importance of the neural control system and have concluded that it is not only the strength of this muscle, but the timing of activation of VMO and vastus lateralis (VL) that is disturbed in patients with PFPS [11;14;104]. Furthermore, it has been shown in two recent randomised controlled clinical trials that physiotherapy, which included specific VMO training, resulted in a change in the onset of VMO relative to that of VL in PFPS sufferers and this was associated with a reduction in symptoms [12;15]. Adequate inclusion and exclusion criteria were used, (Table 2-2), however, a history of a previous corticosteroid injection was not included in the exclusion criteria listed in any of the studies. Despite the fact that a joint effusion was not specifically mentioned as an exclusion criterion, the signs or symptoms of other intra-articular pathology were deemed as exclusion criteria. This would have included pathologies which may produce a joint effusion. This is particularly relevant, since it has been shown that there

is a significant difference in VMO activation (p=0.0001) when an effusion is present [44]. Similarly, the anti-inflammatory effect of a corticosteroid injection would have the same result on VMO activation; therefore it should have been included in the exclusion criteria of these two studies.

Nevertheless, these studies have the strongest weighted evidence regarding the aetiology of PFPS and the inclusion and exclusion criteria used were superior to all other studies investigating the relationship between PFPS and associated risk factors (Table 2-2). However, due to the multifactorial nature of the physiotherapy interventions studied, it is not possible to isolate the factor responsible for the change in vasti timing. A number of possibilities exist including part or all of the treatment program (VMO retraining with biofeedback, home exercise program, PFJ taping, mobilisation of PFJ, gluteus medius retraining, or stretching of hamstrings) and further research is required to confirm which components are causative to PFPS.

Despite the growing evidence to support the theory that there is a delay in VMO activation in patients with PFPS, there is also evidence to show that timing differences between VMO and VL do not exist in PFPS sufferers (p<0.01) [74]. This was demonstrated in a case control study of 45 patients using fine-wire electromyography. However, no p values were given if no significant differences were found, which makes analysis of the results difficult. Moreover, there was a small sample size in the control sample (n=19), compared to the PFPS subjects (n=26). Therefore it is concluded that a reduced timing to activation of VMO is associated with PFPS and is possibly causative to PFPS.

**Hip and Pelvic-Muscle Stabilisers**

It has been suggested that patellar tracking can be affected by the alignment of the lower limb, specifically by an increase in the valgus force through the knee [78]. This would occur if there was a lateral tilt of the pelvis and hip complex on weight-bearing, which could result from a dysfunction of the pelvic, hip, and trunk-stabilisers, including the posterior fibres of gluteus medius [35;66;78]. Retraining of the gluteus medius muscle was included in the rehabilitation of previously mentioned randomised controlled trials [12;15] and therefore it could be suggested that dysfunction of this muscle might be associated with PFPS. However, this would need to be verified, firstly in case control studies or prospective studies in a similar

way to the previous VMO research [11;14;16] and then more controlled clinical trials would be necessary to verify it as a cause of PFPS.

**Musculotendinous range of movement**

A decrease in range of movement at the hip, knee and ankle joint has been associated with PFPS [40;83;99]. Flexibility can be defined as the range of motion available in a joint or in a group of joints that is influenced by muscles, tendons and bones [2]. For the purpose of this review, the term flexibility or inflexibility will be used to indicate an increase or decrease in joint range of motion. It is hypothesised that inflexibility of the iliotibial band (ITB), hamstrings, quadriceps, hamstrings, gastrocnemius, iliopsoas and the anterior hip structures can all potentially alter the tracking of the patella [35;66].

It is postulated that an inflexible lateral retinaculum can cause a lateral drift of the patella and PFPS [67]. The fibres of the ITB attach on to the lateral retinaculum. It is proposed that an inflexible ITB can pull the lateral retinaculum, thereby causing a lateral drift of the patella [67]. It is thought that an inflexible ITB can result in a lateral force vector on the patella during knee flexion [67]. There have been no well documented studies to relate ITB inflexibility to the development of PFPS, although two studies have investigated the hypothesis that ITB inflexibility may be a contributing factor to PFPS [75;101]. A case control study of 24 ballet dancers investigated the relationship between ITB inflexibility and PFPS. It was stated that there was an association between PFPS and ITB inflexibility, although no p values were recorded. Furthermore, the patient group had small subject numbers (n=12). Subjects were recruited from a group of 41 dancers if they met certain inclusion criteria. The only exclusion criterion was the presence of ligamentous laxity. Power analysis was not performed on the sample size. A second case series study was performed on 17 patients to investigate the association of ITB inflexibility and PFPS. It was found that 70% of the subjects had an inflexible ITB, however no control group was included. Therefore, this is a non-analytical study and the scientific relevance of this finding is graded low on the hierarchy scale which has been described previously [39]. Therefore, the evidence to suggest that ITB inflexibility is associated with PFPS is sparse and needs to be investigated further (Table 2-2).

It is thought that quadriceps inflexibility increases the patellofemoral joint reaction force (PFJRF), thereby increasing the stress through the PF joint. Hamstring inflexibility increases

the knee flexion of the knee during the stance phase. This may cause an increase in the PFJRF [102]. It is proposed that hamstring inflexibility could possibly result in an increase in the amount of dorsiflexion that is required at the ankle joint. If maximum dorsiflexion has already occurred at the talocrural joint, further dorsiflexion can only occur at the subtalar joint, which will then increase subtalar-joint pronation. It is suggested that increased subtalar joint pronation causes internal rotation of the tibia, resulting in an increase in the dynamic Q angle and therefore the valgus vector force on the patella increases [102]. However, the above-mentioned mechanisms by which inflexibility of the quadriceps and hamstrings are proposed to affect the forces on the patella are speculative and no research has been done to substantiate these theories.

Similarly, it is hypothesised that an inflexible gastrocnemius also results in a compensatory subtalar-joint pronation [56], because dorsiflexion of the talocrural joint is reduced. Gastrocnemius flexibility has been shown to be reduced in subjects with PFPS when compared to controls in a well-conducted prospective cohort study of 282 students which used adequate inclusion and exclusion criteria ($p=0.038$) [104]. However, further research is needed to strengthen the argument that gastrocnemius inflexibility is associated with PFPS.

Evidence to suggest that quadriceps and hamstrings inflexibility is associated with PFPS is controversial. Evidence of reduced flexibility of both quadriceps and gastrocnemius in subjects who developed PFPS compared to those who did not develop symptoms was demonstrated in a prospective study (n=480) (no significant different values given) [41]. A recent prospective cohort study showed an association between decreased quadriceps flexibility and PFPS ($p=0.028$), as) [104]. In contrast, a case control study of army conscripts showed that there is no association between knee extension injuries and hamstring or quadriceps flexibility [59]. However, this study was not specific to PFPS patients. Therefore, it can be concluded that there is an association of quadriceps inflexibility and PFPS (Table 2-2) although this could be confirmed with future case control or prospective studies.

An observational case series study on elite figure skaters investigated the association between hamstring inflexibility and PFPS. The results showed a significant difference in the hamstring flexibility of those skaters with knee pain and those without knee pain ($p<0.05$) [83]. However, this type of study design represents poor evidence. Further research is required to

confirm the association of hamstrings inflexibility with PFPS. An overriding factor in all the flexibility studies is that despite there being apparent contradictory findings, it is essential to ensure that the study defines the injury by means of at least two inclusion criteria and most, if not, all exclusion criteria. Most of the studies refer to knee pain or knee extension injuries, which could include a number of disorders. Therefore, it can be concluded, based on the above evidence (Table 2-2) that ITB, gastrocnemius, quadriceps and hamstrings inflexibility may be associated with PFPS [104], although further evidence is needed to confirm this.

It has been postulated that some patients with PFPS present with inflexible anterior hip structures, which could increase the valgus force through the knee, which in turn could increase the risk of patellofemoral pain [35]. However, there have been no studies to show an association between inflexible anterior hip structures and PFPS.

The Figure Four Test and Stretch is used to clinically assess whether patients have restricted anterior hip structures. It is also used as a means of stretching the anterior hip structures [35]. However, it is not indicated which anatomical structures specifically are stretched during the Figure Four Test. Possible anterior hip structures that could be stretched whilst performing this stretch are the hip adductors, the hip internal rotators, the hip flexors, the anterior hip capsule, the pubofemoral and iliofemoral ligaments. The Figure Four is a modified Faber's test, with the patient lying prone. This creates a more stable position for the pelvis and allows objective measurement of the hip inflexibility, that is, the distance from the anterior superior iliac spine to the floor. To date, there are no published repeatability or reliability studies that have been conducted to assess this test as a valid and repeatable measurement tool, nor have any studies been done to determine if inflexibility of the anterior hip is associated with PFPS.

Similarly, no studies have been conducted to assess if any of the components of the Figure Four Test are associated with PFPS. However, one factor that has been anecdotally linked to running related injuries of the lumbo-pelvic-hip complex is increased anterior pelvic tilt [33]. Inflexibility of the hip flexor musculature (iliopsoas, tensor fascia lata, rectus femoris, hip joint capsule and surrounding anterior hip ligamentous and fascial structures) may cause this anterior pelvic tilt and thus reduce hip extension flexibility. Clinicians continue to assess and treat inflexible iliopsoas muscles as part of the management of PFPS. However, recent

research has shown that hip extension and anterior pelvic tilt are coordinated movements during running biomechanics and the range of movement available to an athlete is not directly dependent on their flexibility [82]. Therefore, further research to investigate the possible association of inflexibility of the musculature of the hip (adductors, internal rotators, iliopsoas, tensor fascia lata, rectus femoris) with PFPS is needed to support or negate current management.

**Conclusion**

In Table 2-2 the various extrinsic and intrinsic risk factors that have a proposed association with PFPS are depicted. Many of the factors are documented with limited clinical scientific evidence (case control studies and prospective studies) or weak scientific evidence (case series and anecdotal evidence) (Table 2-1). There are no factors that have been well documented in controlled clinical trials, the only exception being the recent evidence regarding the timing of VMO activation in PFPS patients. However, due to the multifaceted treatment programmes used in these studies, no cause-effect pattern was established between PFPS and VMO timing. Controlled clinical trials are required to establish a cause and effect pattern between the development of PFPS and any particular risk factor. However, to date, there have been no such trials. Therefore, the only conclusions that can be made from the available evidence is that certain factors might be associated with PFPS.

Moreover, many of these studies do not use a standard list of inclusion and exclusion criteria (Table 2-2) consequently leading to an unclear picture as to whether these factors are associated with PFPS specifically or the umbrella term "anterior knee pain", which is defined by a number of knee pathologies [53;104]. Standardising the inclusion and exclusion criteria also ensures that there are no lower limb pathologies or disorders that might interfere with the kinetics or kinematics of knee motion [13]. There are no factors that have been well documented in prospective cohort studies and tested in controlled clinical trials. It is clear that prospective cohort studies are required to confirm or refute the various risk factors that contribute to the development of PFPS. To establish a cause and effect relationship between the development of PFPS and any particular risk factor, intervention trials are required to test the effect of risk factors. To date there have been no such trials, which have investigated one

risk factor, therefore the only conclusions that can be drawn from the available evidence is that certain factors might be associated with PFPS.

Extrinsic risk factors for PFPS such as competitive involvement in sports, inappropriate shoes in runners, overstretching and a sudden increase in distance have been documented in both prospective and case control studies [9;22;49;89]. These are factors that could easily be investigated in future clinical controlled trials with a view of establishing whether they are causal to the development of PFPS. Running on hard surfaces or uneven terrain was shown to be weakly associated with the development of PFPS, however this needs to be explored further in prospective studies and clinical trials.

Intrinsic risk factors for PFPS are patellar malalignment, femoral anteversion, leg length discrepancy and static rearfoot angle [26;89;104]. However, these studies lack a specific PFPS diagnosis, which could lead to contradicting evidence. Moreover, further investigation is needed regarding the definition of patellar malalignment. Therefore both patellar malalignment and femoral anteversion should be investigated with further case control studies and clinical trials. The association of genu valgus and/or varus needs to be investigated further, due to the contradicting evidence listed in Table 2-2 [70;104].

It has been shown that there is less dynamic subtalar pronation in the first 10% of the stance phase in PFPS sufferers [22] and that static rearfoot alignment is not associated with PFPS [63]. Therefore, it can be concluded that future clinical trials should aim at addressing the dynamic motion of the rearfoot in order to establish a cause and effect relationship between PFPS and rearfoot motion.

Factors that have been associated with PFPS (with limited evidence) are demonstrated in Table 2-3. They are a high MLA and inflexible gastrocnemii and quadriceps [22;41;104]. However, most of these factors have been associated with PFPS in only one study, therefore further research is required to confirm these findings. Inflexible ITB and hamstrings have been weakly associated with PFPS [75;83;101] and would need to be investigated further to establish an association. Furthermore, research is required, firstly, to confirm that it is a high MLA, rather than a low one, that is associated with PFPS, and secondly, to investigate the mechanism responsible for the improvement in PFPS with soft shoe orthotics. Once this is

achieved the appropriate intervention can be prescribed in a randomised controlled clinical trial. This will consequently provide information as to the contribution of the MLA to the development of PFPS.

The research to support the association of delayed activation of VMO with PFPS is, by far, the most extensively researched intrinsic risk factor. It has been shown that there is a delay of VMO activation in PFPS patients during functional activities, as well as during postural tasks [11;14;16], thus establishing an association with PFPS. However, the difficulty in establishing cause and effect was demonstrated by research which showed that there was an improvement in symptoms and an improvement in the VMO activation following a physiotherapy programme [12;15]. However, it is impossible to say which component of the physiotherapy programme caused the reduction in symptoms. Therefore, it can only be stated that a delayed VMO activation may cause PFPS. Future trials should investigate the individual components of the treatment programmes in an attempt to clarify if delayed VMO activation is causal to PFPS.

Factors that have been weakly associated with PFPS or where the evidence surrounding it is contradictory is detailed in Table 2-3. Future clinical research should aim to establish the association of Q-angle, genu valgus/varus, flexibility of ITB, iliopsoas, hamstrings, anterior hip and the role of the hip and pelvic stability in a case control or prospective study.

A previous case control study, which used adequate inclusion and exclusion criteria, but a small sample of subjects (n=10), assessed the differences in gait pattern of PFPS subjects and control subjects. No muscular compensations were depicted in any of the kinematic and kinetic parameters (knee flexion angle p=0.35). However, it was concluded based on the trends observed in the knee moment, hip moment compensations and ground reaction forces, that patients with PFPS adapt their gait to avoid loading the patellofemoral joint [71]. It is therefore hypothesised that inflexibility of the lower limb musculature could be a result of gait changes and/or delayed muscle activation of the antagonist muscles. Further research is required to establish the interaction effect between flexibility and muscle activation and the influence that each factor has on the development of PFPS.

It is suggested that PFPS may represent the end result of numerous pathophysiologic processes [64] and contributing risk factors, which on an accumulative basis, result in a level of patellofemoral pain (PFP) [35;58;85;88]. This suggestion could explain the contradicting evidence regarding PFPS, as well as the differences in results for different population groups. Therefore, it is essential that future research identifies a specific population group with similar exercise habits.

It is only when the risk factors for PFPS are accurately identified that appropriate treatments can be prescribed for patients [17]. Future studies should focus on defining PFPS using at least two of the inclusion criteria and all of the exclusion criteria described in Table 2-2. Exceptions to this recommendation would be if the measurement that was being investigated would not be affected by any one of the exclusion criteria. Standardising inclusion and exclusion criteria will ensure that the risk factors associated with PFPS specifically are investigated, rather than those associated with the broader term, 'anterior knee pain'. It is recommended that interventions and outcomes are measured in a standard, reliable and valid manner in order to identify specific risk factors [17]. The large number of outcome measurements currently used in clinical intervention trials reflects the absence of a "gold standard" assessment tool for PFPS. A recent systematic review summarised the visual analogue scale (VAS) as being the primary outcome measure used in all trials [17]. The VAS is reliable and valid in PFPS and therefore it is suggested that it be used as an outcome measure in future clinical trials. Lastly, it is recommended that the validation of assessment tools for measurement of the various risk factors is essential prior to the commencement of any trial. This will ensure that the conclusions made are universal and applicable to the clinical setting. Radiographic examination of patellar malalignment and femoral anteversion need to be investigated further in similar studies and the association of the extrinsic risk factors listed above need to be investigated further in randomised controlled clinical trials.

**Table 2-3 A summary of evidence based intrinsic risk factors associated and not associated with PFPS**

| Strength of evidence | Intrinsic Risk Factors Associated with PFPS | Intrinsic Risk Factors Not Associated with PFPS |
|---|---|---|
| **Strong** | VMO/VL timing to activation | |
| **Limited** | Dynamic rearfoot motion<br>High medial longitudinal arch<br>Quadriceps inflexibility<br>Gastrocnemius inflexibility | Patellar malalignment<br>Femoral anteversion<br>Static rearfoot angle<br>Leg length discrepancy<br>Patella alta |
| **Weak** | Q-angle<br>Genu valgus/varus<br>Weak pelvic & hip stabilisers<br>ITB inflexibility<br>Hamstrings inflexibility<br>Anterior hip inflexibility<br>Iliopsoas inflexibility<br>Patella baja | |

# Chapter 3 - Repeatability of flexibility measurements using the Modified Thomas Test and the Figure Four Test

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**Abstract**

Background

Clinical assessment of the range of movement and flexibility of the hip and knee is frequently performed using the Modified Thomas Test and Figure Four Test, yet the repeatability of these measurements has been poorly investigated.

Purpose

The aim of this study was to determine the intratester and intertester repeatability of the Modified Thomas Test and the Figure Four Test to allow therapists to use them with confidence in both clinical practice and future research.

Method

The range of movement of 18 healthy subjects was measured by 2 therapists (raters). Each subject was measured by the same rater on the first and third day (intra-rater), and by the second rater on the second day (inter-rater). The Modified Thomas Test was measured in one week and the Figure Four Test the following week. Statistical analysis of the data was performed using the Bland and Altman method and correlation coefficients.

Results

The interrater intra-class correlation coefficient (ICC) and Pearsons' correlation coefficient (r) were ICC=0.71-0.84; r=0.71-0.9 for the Modified Thomas Test and ICC=0.92 and r=0.92 for the Figure Four Test . The intrarater ICC and Pearson's correlation coefficients were ICC=0.66-0.83; r=0.7-0.84 for the Modified Thomas Test and ICC=0.93 and r =0.93 for the Figure Four Test. For the measurements of hip flexion in the Modified Thomas Test, the limits of agreement (6.5 degrees – 9.2 degrees) demonstrated that two measurements, taken according to the protocol described, would be within 7.9 degrees of each other in 95% of

cases. Similarly, measurements of knee flexion would be within 20.9 degrees of each other, hip abduction would be within 6.4 degrees of each other and the Figure Four Test measurements would be within 2.1 centimetres of each other in 95% of cases.

Conclusions
Both the Modified Thomas Test and the Figure Four Test are repeatable clinical tests. However, in a clinical setting, the limits of agreement for each measurement need to be considered in relation to the overall flexibility of each subject.

**Key Words**

Hip and knee range of movement, flexibility, intrarater reliability, interrater reliability, goniometric measurement, Figure Four Test, Modified Thomas Test

## Introduction

Flexibility can be defined as the range of motion available in a joint or in a group of joints that is influenced by muscles, tendons, ligaments and bones [2]. For the purpose of this study, the term flexibility or inflexibility is defined as an increase or decrease in joint range of motion. Flexibility measures are one of the components of a standard physiotherapy assessment of any overuse injury. Therefore, therapists regularly perform various measurements of the hip and knee when assessing flexibility and range of movement. Inflexibility at the hip, knee and ankle has been associated with lower limb overuse injuries [40;83;99;103] and therefore clinicians regularly assess the flexibility of patients to identify factors associated with the injury.

A test that is used to assess the flexibility of the anterior hip structures is the Figure Four Test [35;65;66]. This is measured with the patient in prone lying with the leg to be tested externally rotated in a modified Faber's test position [66]. It is postulated that some patients with PFPS have decreased flexibility of the anterior hip structures. It is thought that the inflexibility of the anterior hip is due to weakness of the inner range of the gluteus medius muscle, coupled with increased femoral internal rotation [35]. However, there are no studies to support this hypothesis. It is thought that the Figure Four test assesses the flexibility of the anterior hip structures and is also used to stretch these structures, if they are found to be restricted [35]. However, it is not indicated which anatomical structures specifically are stretched during the Figure Four Test. Possible anterior hip structures that could be stretched whilst performing this stretch are the adductors, the internal rotators, the hip flexors, the anterior hip capsule, the pubofemoral and iliofemoral ligaments. Further research is required to determine which anatomical components are involved during the Figure Four Test. No repeatability studies have been done for the Figure Four Test.

The flexibility of tensor fascia lata/iliotibial band (TFL/ITB), iliopsoas and quadriceps is measured using the Modified Thomas Test [42;55]. Inflexibility of these muscles have been identified as contributing factors to PFPS anecdotally [33], in an observational case series [75] and in a prospective cohort study [104]. However, there has been only one intrarater repeatability study performed on the Modified Thomas Test, using the same method as described in the present study [42]. Although excellent intrarater repeatability (ICC=0.91 to

0.94) was shown, interrater repeatability was not established. Therefore, interrater repeatability for the Modified Thomas Test needs to be further investigated.

The repeatability of a clinical test is defined as the extent to which a measurement procedure yields the same results on independent repeated trials for both one rater (intrarater) and different raters (interrater) under the same condition. The term reliability has been used by some authors to refer to either the repeatability or the validity (when a test is assessed against the gold standard) of a measurement procedure [87]. However, for the purpose of this study, the terms repeatability and validity have been used as the terminology of choice.

An intraclass coefficient (ICC) and Pearson's correlation coefficient (r), which reflects both systematic error and random differences in test scores, is accepted as the preferable method to assess repeatability [36]. This alone is not considered a precise measure of repeatability because it describes how two sets of scores vary together, not the extent of agreement between them [7]. However the Bland and Altman method (limits of agreement) considers measurement error and the strength of agreement between two measurements [5] and is used in this study.

The aim of this study was to determine the intratester and intertester repeatability of the Modified Thomas Test and the Figure Four Test through goniometric and vernier height gauge measurement respectively, using three different methods of statistical analysis.



**Methods**

Subjects:

Eighteen subjects (seven men and eleven women), aged between 22 to 40 years (mean age of 27.5 years) were enrolled in this study by convenience sampling. Subjects were recruited from the staff of the physiotherapy department at St George's Hospital. All subjects read and signed an informed consent form that was approved by the Wandsworth Local Research Ethics Committee and the University of Cape Town Ethics Committee prior to the onset of the study.

Volunteers were of various activity levels and were instructed not to participate in any form of unaccustomed activity (like stretching or exercise) during the two weeks that testing was taking place. This was to ensure that no confounding variables were introduced. The right limb of each subject was measured.

Assessors:
The three physiotherapists familiarised themselves with the measurement techniques over one hour. Each therapist had between 4 and 6 years clinical musculoskeletal physiotherapy experience.

Data collection equipment included a plastic goniometer (Jamar Goniometer, Jamar Technologies, 151 Keith Valley Road, Horsham, PA, USA, 19044) with a string attached to both ends and a vernier height gauge (Mitutoya Vernier Height Gauge, series 514, Mitutoyo UK Ltd, Heathcote Way, Heathcote Industrial Park, Warwick, Warwickshire, CV34 6TE). The goniometer had a 12.7cm moveable arm and a scale marked in one-degree increments and the vernier height gauge was marked in 1-mm increments.

**Modified Thomas Test Measurement**

Adhesive markers were placed on the following anatomical landmarks in standing: greater trochanter, mid patella, lateral malleolus, lateral femoral condyle and the anterior superior iliac spine (ASIS). The subject sat on the examination table with the hip joints positioned on the edge of the table while the thighs were positioned over the edge of the plinth. The therapist assisted the subject to roll into a supine position on the plinth with the hips and knees flexed on the trunk. The lumbar spine and sacrum were maintained in a flat position against the plinth and the lower extremity to be measured was gently lowered whilst keeping the contra-lateral limb flexed to the chest. The end of a subject's hip extension range of movement was defined as the point in the passive hip movement when the lumbar spine could no longer be maintained in the flattened position and began to move into hyperextension. The length of iliopsoas was determined by measuring the angle of hip flexion (positive value for hip flexion beyond neutral). The centre of the goniometer was placed on the greater trochanter and the moveable arm was directed towards the adhesive marker that was placed on the lateral femoral condyle. The static arm of the goniometer was directed in a line parallel to the trunk.

The ITB/TFL flexibility was measured by calculating the hip abduction angle of the femur relative to the cephalad line parallel to the trunk (positive value for abduction). The range of movement was measured in the same position that was defined by the end of hip extension described above. The centre of the goniometer was placed on the ASIS, the moveable arm was directed towards the mid patella marker and the static arm was directed along the cephalad line parallel to the trunk. Quadriceps flexibility was measured by determining the knee flexion angle obtained when the knee was passively flexed with the hip in the same position as described above. The measurement was taken in degrees at the point where the tester first felt resistance. The goniometer was placed on the lateral femoral condyle, the moveable arm was directed towards the lateral malleolus and the static arm was directed towards the greater trochanter (Figure 3-1).

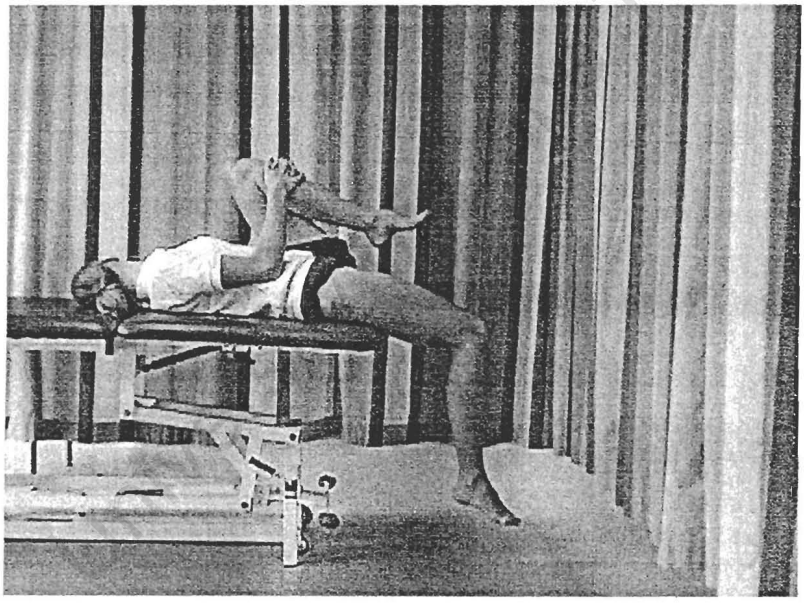

**Figure 3-1 The Modified Thomas Test**

**Figure Four Test Measurement**

The patient was positioned in prone lying with the leg to be tested externally rotated in a modified Faber's test position. The subjects were instructed to place the lateral malleolus on the tibial tubercle of the opposite leg (Figure 3-2). No rotation of the trunk occurred by ensuring that the trunk remained flattened in the prone position whilst the subject externally

rotated the leg. The tester measured the vertical distance (cm) from the lowest point of the ASIS to the floor, using a Vernier height gauge.

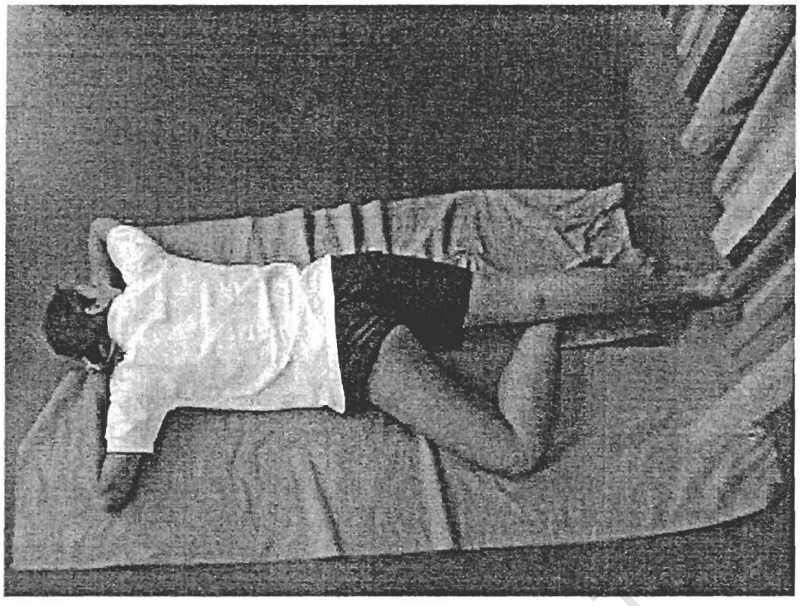

**Figure 3-2 The Figure Four Test and Stretch**



### Repeatability

The author and two additional therapists were assigned as rater one, two and three. Rater one and two performed a repeatability study for the Modified Thomas Test in the first week and then rater one and rater three performed a repeatability study for the Figure Four Test in the second week. Rater one measured the same subject at the same time of day on the first day and the third day for each measurement. Rater two or rater three measured the subjects in the same order on the second day with the subjects being instructed not to do any form of exercise or stretching in between testing. The raters took each measurement once and noted it on a separate sheet of paper to that of the other tester's measurements. The raters were blinded to each other's results.

### Statistical tests

All data were processed on a personal computer by using Microsoft Office software (Microsoft Corp., Redmond, Washington). The data were analysed with the SPSS 10.0 computer software program (SPSS Inc., Chicago, Illinois).

The correlation coefficients (ICC and Pearson's) indicate the proportional contribution of the between-subject variation as a result of the total variation [7]. The ICC is an attempt to overcome some of the limitations of the classic correlation coefficients. It reflects both degree of consistency and agreement among ratings [7].

The limits of agreement were calculated using the Bland and Altman (1986) method, which calculates the range within which the difference between two measurements will lie with a probability of 95%. Differences between the two measures were plotted against the mean of the repeated tests to check that the differences were reasonably uniform across the range of measurement. The advantages of this approach are that by using scatterplots, data can be visually interpreted fairly swiftly and any outliers, bias or relationships between variance in measures and size of mean can therefore be observed [7]. The limits of agreement provide a range of error that may relate to clinical acceptability, although this needs to be interpreted with reference to the raw data.



**Results**

The repeatability of the Modified Thomas Test and the Figure Four Test is depicted in Table 3-1. The Modified Thomas Test consisted of three measurements, namely iliopsoas flexibility, ITB/TFL flexibility and quadriceps flexibility.

**Table 3-1 ICCs and Pearson's Correlation Coefficients for intratester and intertester reliability of the Modified Thomas test and Figure Four Test**

| Variable | Intratester | | Intertester | |
|---|---|---|---|---|
| | ICC | Pearson's | ICC | Pearson's |
| **Modified Thomas Test** | | | | |
| Iliopsoas flexibility (deg) | 0.83 | 0.84 | 0.82 | 0.90 |
| Quadriceps flexibility (deg) | 0.75 | 0.71 | 0.75 | 0.71 |
| ITB/TFL flexibility (deg) | 0.66 | 0.70 | 0.84 | 0.84 |
| **Figure Four Test** (cm) | 0.93 | 0.93 | 0.92 | 0.92 |

The limits of agreement were calculated and values are detailed in Table 3-2.

Examples of the Bland and Altman graphs are given in Figures 3-3, 3-4, 3-5 and 3-6. An impression of the repeatability can be gained by observing the deviation of the scatters (difference between the two measures) from zero. Ideally all the scatters would fall on the zero y-axis, thereby indicating no difference in any of the measures. The upper and lower bold lines represent the limits of agreement [5].

**Table 3-2 Limits of agreement and mean value measurements of the Modified Thomas test and Figure Four Test.**

| | Intratester | Extratester | Mean |
|---|---|---|---|
| Iliopsoas (deg) | 9.2 | 6.7 | 7.95 |
| Quadriceps (deg) | 20.9 | 21 | 20.95 |
| ITB/TFL (deg) | 6.19 | 6.6 | 6.4 |
| Figure Four (cm) | 2.4 | 1.8 | 2.1 |



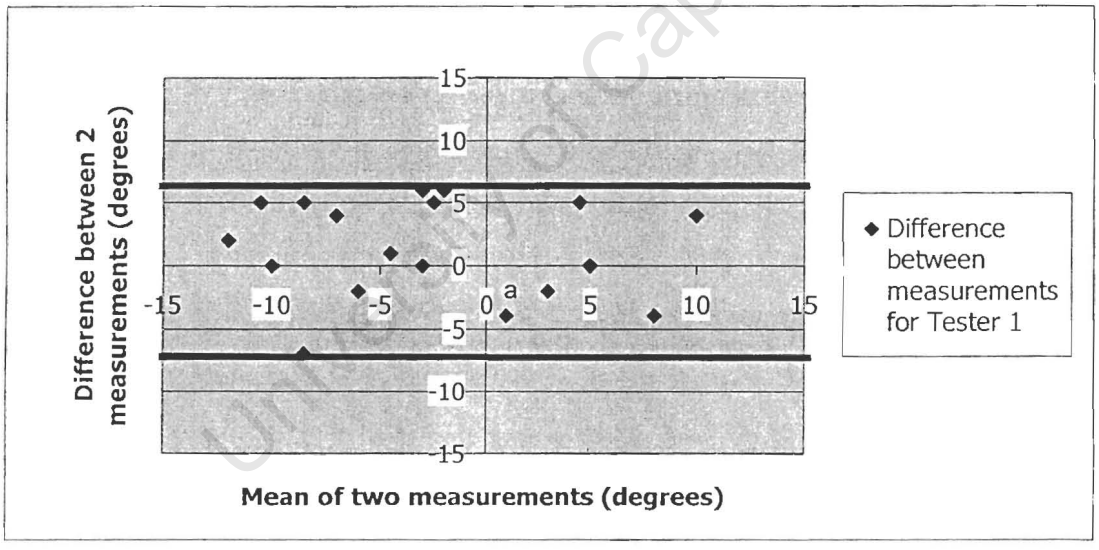


**Figure 3-3 Intra-tester repeatability for iliopsoas flexibility**

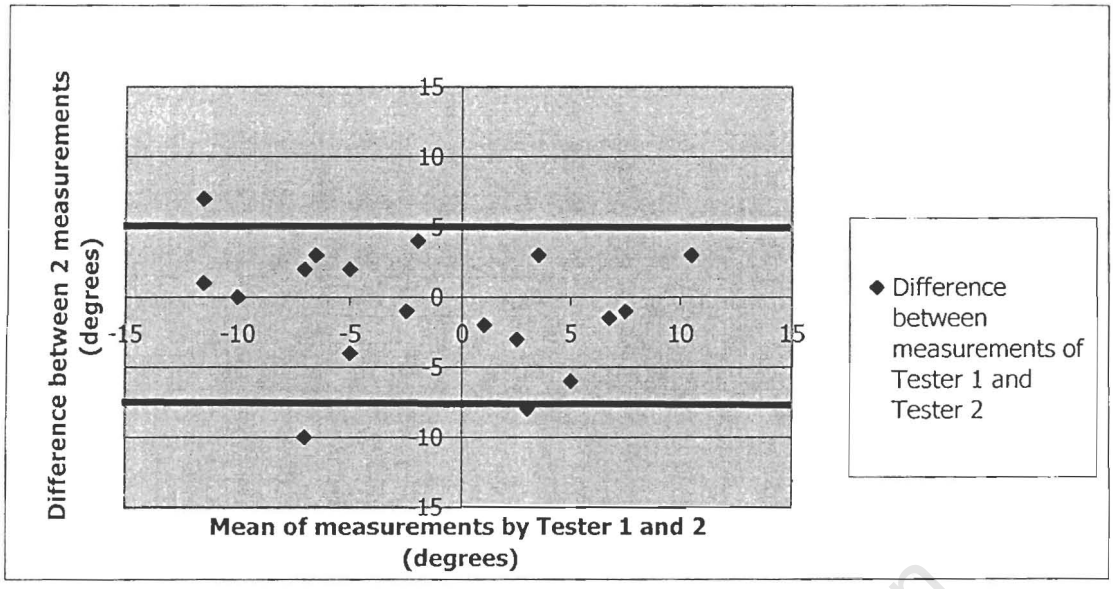


Figure 3-4 Inter-tester repeatability for Iliopsoas flexibility

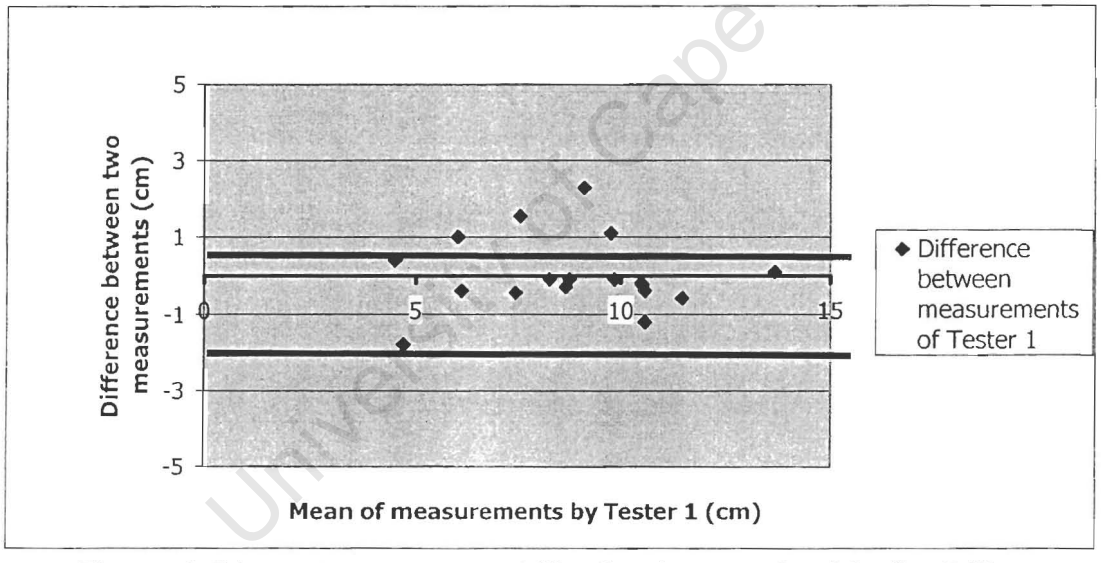


Figure 3-5 Intra-tester repeatability for the anterior hip flexibility

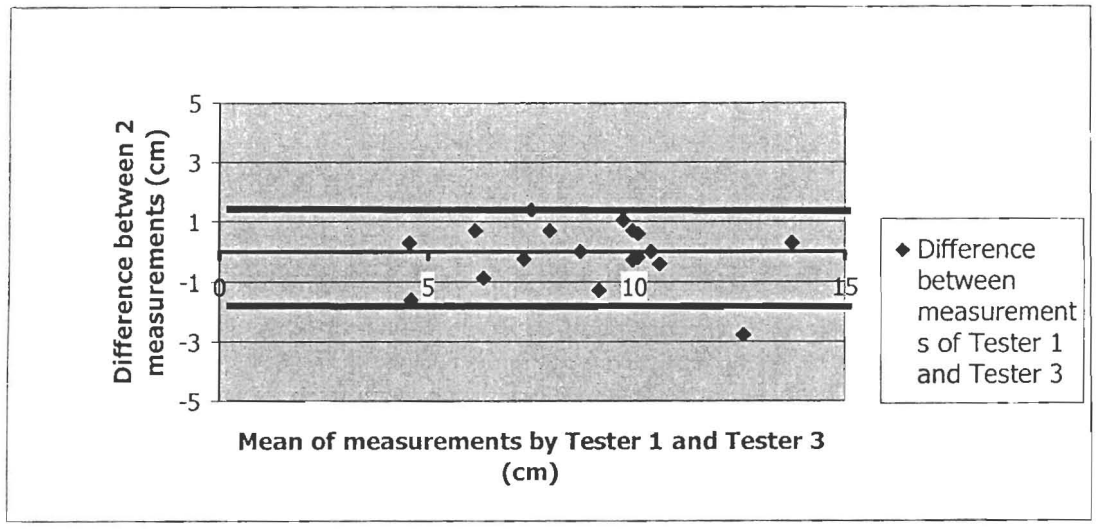


**Figure 3-6 Inter-tester repeatability for anterior hip flexibility**



## Discussion

The main findings of the study are that the Modified Thomas Test and the Figure Four Test are repeatable means of measuring ilopsoas, quadriceps, ITB/TFL and anterior hip structure flexibility. The ICC values for intratester repeatability of the Modified Thomas Test (ICC=0.66-0.83) are similar to those previously reported in a case series study (ICC=0.91-0.94) [42]. The interpretation of ICC values has been documented previously [28]. The ICC values below 0.4 were regarded as representing poor repeatability, ICC values between 0.4 and 0.75 were regarded as representing fair to good repeatability, and ICC values above 0.75 were regarded as representing high repeatability [28]. In contrast, it has been suggested that clinical acceptability of repeatability coefficients of measurement values should exceed 0.90, since the use of a measurement determines the minimally acceptable repeatability. In conclusion, there are no universally accepted standards of acceptable values for the ICC and therefore, it was decided to use three different forms of statistical analysis. The Pearson's correlation coefficient values were very similar to the ICC values, however no previous studies have measured the Pearson's correlation coefficient values for the Modified Thomas Test.

The limits of agreement values obtained by the Bland and Altman method suggest that, provided two measurements for the same subject show a difference of more than those mean values expressed in Table 3-2, then on 95% of occasions a real difference between

measurements exists. Therefore any differences in measurements greater than the values in Table 3-2 obtained in future research and during clinical examination would be greater than would be expected due to the error of the measurer.

No previous repeatability studies have been performed on the Figure Four Test. However, results of this study show it to be a highly repeatable test with narrow limits of agreement (2.1cm). The clinical relevance of this is that this test can be used in the clinical setting as a repeatable measurement tool. Therefore, if a difference in the values obtained from one occasion to the next is found, then that difference can be considered to be real and not due to error in measurement. However, the difference in measures obtained for the same subject needs to be greater than the limit of agreement (2.1cm).

The mean limit of agreement for both intratester and intertester repeatability for the quadriceps flexibility was 20.95 degrees, 7.95 degrees for iliopsoas flexibility and 6.4 degrees for ITB/TFL flexibility. This is extremely high when the average measurement for flexibility of the quadriceps, iliopsoas and ITB/TFL during the Thomas Test is considered. These measurements have been recorded as 52.5 degrees, -11.9 degrees and 15.6 degrees respectively [42]. Therefore, clinical examination and future studies need to ensure that two measurements for the same subject show a difference of more than the mean values shown in Table 4-2 in order to demonstrate a real difference between the measurements.

The current study uses a method of measuring the flexibility of iliopsoas, ITB/TFL and quadriceps based on the Modified Thomas Test described in a previous repeatability study [42]. However, a different version of the Modified Thomas Test has been described in an attempt to differentiate the influence of one- and two- joint muscles on the passive hip extension range of movement by changing the position of the knee angle [55]. Moreover, it has been demonstrated in a 2-group mixed design study of the Modified Thomas Test that a change in the knee joint angle in the sagittal plane during the Modified Thomas Test, resulted in repeatable differences in the passive hip extension range of movement ($p<0.001$) [93]. Intratester repeatability was established (ICC=0.7 to 0.96), although intertester repeatability and other statistical analysis was not conducted. Therefore, future studies should assess the intra- and intertester repeatability of the Modified Thomas Test using the method described in previous studies [55;93] and thereafter flexibility of the hip flexors and ITB/TFL could be

assessed using this modified method of measurement. More research is required to establish which angles the hip and knee joints need to be placed in, in order to obtain the correct measurements for the ITB and the hip flexors. This technique would not be suitable to measure the quadriceps flexibility. Therefore, it is suggested that an alternative method of measuring quadriceps flexibility is validated. It is suggested in chapter 4 that repeatability of quadriceps flexibility is assessed in a side lying position, in order to decrease the influence of the two-joint hip flexor muscles on quadriceps flexibility. This technique would need to be validated in a similar study to the present repeatability study.

**Conclusion**

This study shows that instrumented measurement of the flexibility of iliopsoas, ITB/TFL and the quadriceps using the Thomas Test is a repeatable clinical test when the repeatability ICC and Pearson's correlation coefficients are considered. Similiarly, the measurement of the flexibility of the anterior hip using the Figure Four Test is a repeatable clinical test.

However, in a clinical setting, the limits of agreement for each measurement need to be considered in relation to the overall flexibility of each subject, if any clinical decision is being made on the change of flexibility from one measurement to the next. These tests are easy to administer and provide a quick method of measuring aspects of hip and knee flexibility. Finally, further research is required to assess the repeatability of the Modified Thomas Test, in order that the influence of the one- and two- joint muscles on the range of movement of the hip extension range of movement can be differentiated.



**Acknowledgements**

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# Chapter 4 - Is lower limb malalignment and inflexibility associated with PFPS?

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Proposed submission to 'Physiotherapy' for publication

**Abstract**

Background

Various authors have identified both extrinsic and intrinsic parameters as aetiologic factors associated with Patellofemoral Pain Syndrome (PFPS). However, due to the lack of standard inclusion and exclusion criteria and the limited scientific evidence, much of the evidence is contradictory, inconclusive or weakly associated with PFPS.

Aim

The aim of this study is to investigate whether lower limb malalignment and inflexibility is associated with PFPS.

Methods

Seventeen subjects with clinically diagnosed PFPS and 40 non-injured control subjects were assessed for the following intrinsic risk factors: genu varus/valgus (degrees), medial longitudinal arch of the foot (cm), static rearfoot posture (degrees), quadriceps flexibility (degrees), ITB/TFL flexibility (degrees), iliopsoas flexibility (degrees), anterior hip flexibility (cm), adductor flexibility (degrees) and hamstring flexibility (degrees).

Results

The hip adductor flexibility (in cm) was significantly (p=0.022) decreased in the PFPS group (36.94cm +-14.39cm) than in the control group (44.95cm +-10.41cm). The hamstring flexibility (in cm) was significantly (p=0.006) decreased in the PFPS group (75.71cm +-12.7cm) than in the control group (90.3cm +-19.32cm). The anterior hip flexibility was significantly (p=0.029) restricted in the PFPS group (8.78cm +-2.7cm) than in the control group (7.37cm+-1.95cm).

Conclusion

Hamstring, adductor and anterior hip structure inflexibility is associated with PFPS and needs to be investigated further to determine cause and effect. The measurement of quadriceps flexibility needs to be standardised so that conclusive evidence can be established regarding its association with PFPS.

**Key Words**

Patellofemoral pain syndrome, intrinsic risk factors

## Introduction

Patellofemoral Pain Syndrome (PFPS) is defined as all anterior or retropatellar pain in the absence of other knee pathology [3;12;88]. PFPS is reported to affect 25% of the general population [67] and accounts for 25 -33% of all complaints of knee pain in active athletes [86]. PFPS is one of the most common clinical conditions of the lower limb treated in a clinical setting [6].

Both extrinsic and intrinsic aetiologic factors have been associated with PFPS [9;30;80;88;104;105]. Extrinsic factors are related to factors outside the human body such as training errors, incorrect equipment used and environmental conditions [104]. Intrinsic factors relate to individual characteristics such as lower limb malalignment, leg length discrepancy, muscle imbalance and joint laxity [104]. General agreement exists on this classification of the risk factors associated with PFPS.

Competitive involvement in sports, inappropriate shoes in runners, overstretching and a sudden increase in distance have been documented as extrinsic risk factors in prospective and case control studies [9;22;49;89]. These are factors that could easily be investigated in future clinical controlled trials with the view of establishing whether they are causal to the development of PFPS. Running on hard surfaces or uneven terrain was shown to be weakly associated with the development of PFPS. However, this needs to be explored further in case control studies, prospective studies and clinical trials.

In a clinical setting, the most effective management of PFPS is based on correcting the predisposing intrinsic factors to PFPS found during the initial evaluation of the patient [6]. Thereafter, appropriate and specific interventions are prescribed. A standard physiotherapy evaluation of a patient suffering from patellofemoral pain aims to establish which intrinsic risk factors are present. This evaluation will typically include an assessment of the flexibility of the muscles surrounding the knee, hip and ankle, patella alignment, strength and control of the VMO and pelvic stabilisers and a biomechanical evaluation (including patella position and shape, Q-angle measurement, leg length discrepancy measurement, rearfoot alignment,

medial longitudinal arch of the foot and genu varus/valgus measurement) [35;66]. However, the evidence to support the evaluation of these risk factors is sparse.

It is evident from the literature that further investigation is needed regarding patellar malalignment and its association to PFPS using radiographic examination [98]. The measurement of patella malignment should not take place in the clinical setting and should not be used as a basis for treatment decisions, because it has been shown that measurements are not repeatable or valid [27;92;98].

Biomechanical abnormalities that are commonly assessed in the clinical setting include patella position and shape, Q-angle, leg length discrepancy, rearfoot alignment, medial longitudinal arch of the foot and genu varus/valgus. The evidence to support the association of these factors with PFPS is limited. Moreover, it has been demonstrated that the reliability of the clinical measurements of the Q-angle and patella position is poor [48;92] and can only be demonstrated by lateral X-rays [47].

It has been shown in a well-conducted single session observational study that static rearfoot angle was not associated with anterior knee pain (p=0.31) [63]. However, this study was not specific to PFPS and therefore no conclusions can be made regarding the association of the static rearfoot angle and PFPS. No other studies have investigated the static rearfoot angle to PFPS and therefore further studies are required to clarify whether it should form part of a standard physiotherapy assessment. A high arched foot has been weakly associated with PFPS in a well-conducted case control study (p=0.050) [22] and a prospective study [10]. However, the latter study was not specific to PFPS and therefore no conclusions can be made from it regarding PFPS. However, it is more likely to be a high arched foot that is associated with PFPS, rather than a low arched foot, although further research is required to confirm this possibility. There is contradictory evidence regarding the association of PFPS and genu valgus or genu varus [104]. Assessment of knee alignment forms part of a standard physiotherapy biomechanical assessment, therefore more evidence to support the possible association with PFPS is needed.

A decrease in range of movement at the hip, knee and ankle joint has been associated with PFPS [40;83;99]. For the purpose of this study a reduction in range of movement is defined

as inflexibility. It is hypothesised that inflexibility of the iliotibial band (ITB), hamstrings, quadriceps, hamstrings, gastrocnemius, adductors, iliopsoas and the anterior hip structures can all potentially alter the tracking of the patella [35;66]. This is thought to lead to the development of PFPS. However, the evidence to support this hypothesis is limited and is based on studies with significant methodological limitations such as poor study design or small subject numbers. Moreover, inadequate inclusion and exclusion criteria were used.

There have been no well documented studies to relate ITB inflexibility to the development of PFPS, although two studies have investigated the hypothesis that ITB inflexibility may be a contributing factor to PFPS [75;101]. However, both studies had small subject numbers (n=12) and (n=17) and the latter had no control group. Therefore, the evidence to suggest that ITB inflexibility is associated with PFPS is sparse and needs to be investigated further. Gastrocnemius flexibility has been shown to be reduced in subjects with PFPS when compared to controls in a prospective cohort study ($p=0.038$) [104]. However, due to the sparse evidence, further research is needed to strengthen the argument that gastrocnemius inflexibility is associated with PFPS.

There is limited evidence to support the hypothesis that quadriceps and hamstring inflexibility is associated with PFPS. Evidence of reduced flexibility of the quadriceps in subjects who developed PFPS compared to those that did not develop symptoms was demonstrated in two prospective studies [41;104]. In contrast, a case control study of army conscripts showed that there is no association between knee extension injuries and hamstring or quadriceps flexibility [59]. This study, however, was not specific to PFPS patients and therefore it can be concluded, based on the quality and strength of the former studies that there is more likely to be an association of quadriceps inflexibility and PFPS although this should be confirmed with future case control or prospective studies. An observational case series study showed a significant difference in the hamstring flexibility of subjects with PFPS and those without PFPS ($p<0.05$) [83]. However, this type of study design represents poor evidence. Further research is required to confirm the association of hamstrings inflexibility with PFPS. It has been postulated that some patients with PFPS present with inflexible anterior hip structures, which could increase the valgus force through the knee, which in turn increases patellofemoral pain [35]. However, there have been no studies to show an association between inflexible anterior hip structures and PFPS. The Figure Four Test and Stretch is used

to assess whether patients have restricted anterior hip structure. It is also used as a means of stretching the anterior hip structures [35].

It is only when the risk factors for PFPS are accurately identified that appropriate treatments can be prescribed for patients. The validation of assessment tools for measurement of the various risk factors is essential prior to the commencement of a study or trial and standard inclusion and exclusion criteria should be used to define PFPS. This will ensure that the conclusions made are universal and applicable to the clinical setting. The aim of this study was to determine if lower limb alignment and flexibility measures were associated with PFPS. Each factor was measured using an assessment tool that has been shown to be reliable and valid. All the factors that were assessed were measured in a clinical setting and therefore, the results of this study are of clinical relevance to the standard practice of physiotherapists in their work place.

**Methods**

A case-controlled study design was used. Seventeen patients between the ages of 18 and 45 presenting with PFPS (unilateral or bilateral) to the Department of Physiotherapy at St George's NHS Healthcare Trust, Tooting, London, acted as subjects. This sample size was based on previous work [68;89] that had examined similar variables and which demonstrated power calculations of 0.9 [68] and 0.85 [89]. Forty control non-injured healthy subjects were recruited from the staff of the St George's Healthcare Trust. Controls were matched as a group to the injured subjects based on age and gender. Samples of convenience were used for both the subjects and controls. A comprehensive assessment to establish inclusion or exclusion was performed prior to accepting a patient into the study.



An orthopaedic consultant conducted a clinical assessment and made the diagnosis of PFPS based on at least two of the following clinical criteria: patella pain with manual compression of the patella against the femur with the knee in extension, patella tenderness to palpation of the postero-medial and/or postero-lateral borders of the patella, peri-patella pain during resisted dynamic knee extension, patella pain with manual compression of the patella against the femur during isometric knee extensor contraction (Clarke's compression test) or pain on going up or down stairs.

Patients were excluded from the study if they presented with any musculo-skeletal conditions of the knee (including ligamentous laxity, osteoarthritis, quadriceps muscle tear, synovial plica syndrome, Osgood-Schlatter's disease, patellar tendinopathy, quadriceps tendinopathy, bursitis, growth plate injury), previous or pending knee surgery, gross knee effusion, knee pain referred from the hip or spine, an upper or lower motor neuron lesion or previous corticosteroid injections to the knee. All subjects (controls and PFPS patients) had to be between the ages of 18 and 45 and had to participate in cardiovascular weight-bearing exercise twice or more a week in order to qualify for the study. Subjects were then referred for inclusion in the study.

Forty control non-injured healthy subjects were recruited from the staff of the St George's Healthcare Trust. Controls were matched as a group to the injured subjects based on age and gender.

All subjects were asked to read a patient information sheet (Appendices 1 and 2) prior to signing a consent form (Appendix 3). Permission to carry out the study was obtained from the Wandsworth Local Research Ethics Committee and the University of Cape Town Ethics Committee.

Lower limb alignment (genu/varus/valgus, the medial longitudinal arch, rearfoot alignment) and flexibility (anterior hip, quadriceps, iliopsoas, ITB, hamstrings and adductors) were measured using repeatable methods (Chapter 3).



**Measurement of lower limb alignment**

a) Genu Valgus/Varus

Genu valgus/varus was assessed by asking the subject to stand with the legs together with either the medial malleoli touching or the medial femoral condyles. Measurement of genu valgus or varus was taken as the distance between the most medial prominence of the medial malleolus (valgus) or medial femoral condyles (varus) using a vernier calliper. This distance was reported in centimeters (cm). Genu Varus was coded as a negative value. The repeatability of this measurement technique has been previously reported as (r= 0.93: intrarater repeatability; 0.95: interrater repeatability) [50].

b) Medial Longitudinal Arch

The medial longitudinal arch was assessed by measuring the navicular height (NH). The tester obtained the navicular height (NH) while the subject was standing on an elevated platform to allow accurate viewing of the navicular. In a relaxed calcaneal stance the navicular tubercle was palpated and the most prominent point marked on the skin. Using a Vernier height gauge the height of this mark from the supporting surface for both feet was then measured and the navicular height (NH) was reported in centimeters (cm). The repeatability of this technique has been established (r= 0.91: intrarater repeatability; r=0.7: interrater repeatability) [34].

c) Rearfoot alignment

Rearfoot alignment was measured with the patient standing on a bench with the feet together and the legs extended. The mid-point of the proximal calf bulk was marked with a cross. The point at which the muscle bulk inserts into the Achilles tendon was marked with a cross. The two crosses were connected with a drawn line. The next step was to mark a line bisecting the calcaneus. Lastly, the angle in degrees between the two lines was measured with a goniometer, with the one arm bisecting the calcaneus and the other arm on the line of pull of the calf muscle. The repeatability of this measurement has been established (r=0.88: intrarater repeatability; r=0.86 : interrater repeatability) [95].

**Lower limb flexibility measurements**

a) Anterior hip flexibility

The anterior hip flexibility was measured using the Figure Four Test (Figure 4-1). The patient was positioned in prone lying with the leg to be tested externally rotated in a modified Faber's test position. The patient placed the lateral malleolus on the tibial tubercle of the opposite leg. The tester measured the vertical distance from the lowest point of the anterior superior iliac crest (ASIS) to the floor. Measurement was in millimetres. A repeatability study for the Figure Four Test was conducted in chapter 3. The Pearson' correlation coefficient values for interrater repeatability were r = 0.92 and for intrarater repeatability r = 0.93 (chapter 3).

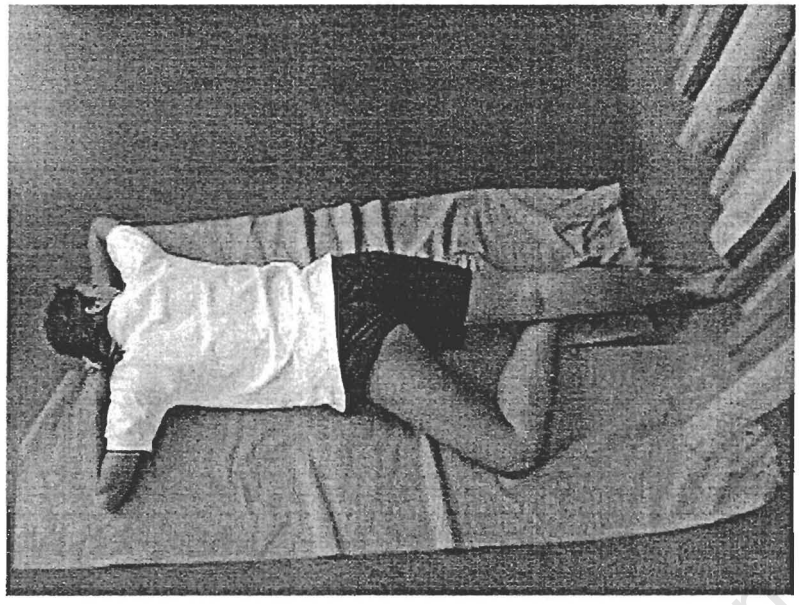

**Figure 4-1 The Figure Four Test**

b) The Modified Thomas Test

Quadriceps, Iliopsoas and ITB flexibility was measured using the modified Thomas Test (Figure 4-2). The flexibility of quadriceps has been measured in prone by flexing the knee to the end range of movement in previous studies [41;104]. This technique does not control for lumbar spine compensation, as a result of inflexible hip flexors and therefore was not chosen as a means of testing the quadriceps. However, future research should perhaps aim to define a gold standard of measuring quadriceps flexibility to avoid future contradictory evidence. Adhesive markers were placed on the following anatomical landmarks in standing: greater trochanter, mid-patella, lateral malleolus, lateral femoral condyle and the anterior superior iliac spine (ASIS). The subject sat on the examination table with the hip joints positioned on the edge of the table while the thighs were positioned over the edge of the plinth. The examiner assisted the subject to roll into a supine position on the plinth with the hips and knees flexed on the trunk. The lumbar spine and sacrum were maintained in a flat position against the plinth and the lower extremity to be measured was gently lowered whilst keeping the contra-lateral limb flexed to the chest. The end of a subject's hip extension range of movement was defined as the point in the passive hip movement when the lumbar spine could no longer be maintained in the flattened position and began to move into hyperextension. The length of iliopsoas was determined by measuring the angle of hip flexion (positive value for hip flexion). The center of the goniometer was placed on the greater trochanter and the moveable arm

was directed towards the adhesive marker that was placed on the lateral femoral condyle. The static arm of the goniometer was directed in a line parallel to the trunk.

The effect of ITB/TFL flexibility was measured by calculating the hip abduction angle of the femur relative to the cephalad line parallel to the trunk (positive value for abduction). The range was measured in the same position that was defined by the end of hip extension described above. The center of the goniometer was placed on the ASIS, the moveable arm was directed towards the mid patella marker and the static arm was directed along the cephalad line parallel to the trunk. Quadriceps flexibility was measured by determining the knee flexion angle obtained when the knee was passively flexed with the hip in the same position as described above. The measurement was taken in degrees at the point where the tester first felt resistance. The goniometer was placed on the lateral femoral condyle, the moveable arm was directed towards the lateral malleolus and the static arm was directed towards the greater trochanter.

A repeatability study for the Modified Thomas Test was conducted in chapter 3. The Pearson' correlation coefficient values for interrater repeatability were r = 0.71-0.91 and for intrarater repeatability r=0.7-0.84 (chapter 3).

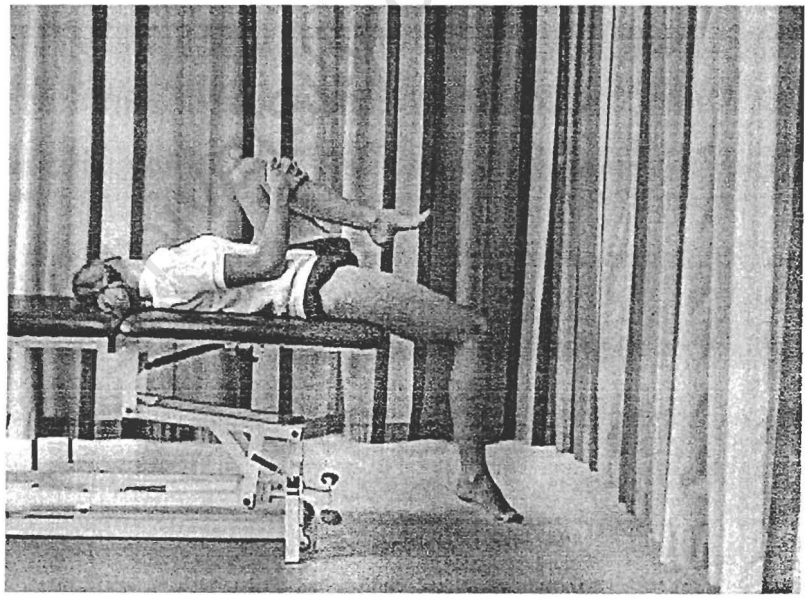

**Figure 4-2** The Modified Thomas Test

c) Hamstring flexibility

Hamstring flexibility was measured with the subject in supine lying with an inclinometer attached to the thigh. The pelvis was strapped down to avoid any excessive movement at the hips and lumbar spine. The measurement was taken in degrees at the point where the tester first felt resistance. The correlation coefficient for the tester determination of end feel was r=0.95 [46]. The repeatability of this measurement has been established (r=0.986: intrarater repeatability; r=0.971: interrater repeatability) [46].

d) Adductor flexibility

Hip abduction range of motion represented the hip adductor flexibility. The patient lay supine with the pelvis stabilized by hanging the contralateral lower leg over the table. The leg to be measured was maintained in neutral rotation with the foot perpendicular to the floor. It was then abducted passively in the frontal plane to the extreme of range, ensuring no movement took place in the trunk. Range of motion was measured in degrees with the stationary arm of the goniometer aligned between the ASIS and the vertical axis of the trunk and the moving arm along the axis of the abducted thigh between the ASIS and the midpatella. This measurement has been shown to have a high intra-observer reliability (r=0.96) [77].

**Statistical Analysis**

All data were processed on a personal computer by using Microsoft Office software (Microsoft Corp., Redmond, Washington). The data were analysed with the SPSS 10.0 computer software program (SPSS Inc., Chicago, Illinois).

The lower limb alignment variables (genu valgus/varus, medial longitudinal arch and rearfoot) and flexibility variables (anterior hip, quadriceps, iliopsoas, ITB, hamstrings, and adductors) were analysed to establish whether there were any significant differences between the control group and the PFPS subjects.

Statistical analysis to compare subject characteristics regarding weight, age, gender and physical activity for the control and PFPS groups was done using a two-tailed t-test. Significance for all t-tests was established at $p<0.05$. Differences in intrinsic characteristics between the painful (P) and non-painful (N) limb of the PFPS group were analysed using a

paired sample t-test. Similarly, differences in intrinsic characteristics between the dominant (D) and non-dominant (ND) limb of the control group were analysed using the same statistical method. Since 80% (14 of 17) of the injured subjects were symptomatic in their dominant knee and initial comparison of all the variables revealed no significant differences between the painful and non-painful sides, subsequent analyses between groups compared the dominant side of the control group to the painful side of the PFPS group. This method of statistical analysis was used in a previous well-conducted case control study [68]. An independent sample t-test was performed to determine differences between the intrinsic risk factors of the PFPS group and the control group. The painful side of the PFPS group (P) was compared to the dominant side of the control group (D).

Stepwise logistic regression was used to establish the probability of PFPS occurring in both groups. Stepwise logistic regression showed step 3 to be the most ideal model fitted. This was justified by the ANOVA results and the Hosmer and Lemeshow Test statistics. The latter statistics measure relative improvement achieved by addition of independent variables, with the high p-values indicating a good fit with no difference between the predicted and observed cases. Therefore step 3, which had a 0.88 p-value, was chosen.

The original sample size for this study was based on previous work [68;89] that had examined some of the variables measured. However, due to the number and variety of variables measured in the present study, the author chose to analyse the power statistics for each variable measured in this study. These will be presented in the results section.



## Results

### Physical Characteristics and Gender

The physical characteristics (age and weight), gender and physical activity of the control and PFPS group are depicted in Table 4-1. There were no significant differences between the groups for these variables.

### Lower Limb Alignment

The comparison of the lower limb alignment variables between the PFPS group and the control group is depicted in Table 4-4. There were no significant differences for any of the alignment variables between the PFPS group and the control group. However, the odds ratios

for all variables were greatest for arch height (4.22) and rearfoot valgus (1.2) (Table 4-7). The odds ratio was determined using logistic regression in order to establish what the chances (odds) were of the control subjects being potential PFPS sufferers when certain intrinsic risk factors were either present or absent. No significant differences were found between the left and right sides of the PFPS group, as depicted in Table 4-2, although, there were significant differences for the arch height (p=0.0005) and rearfoot valgus (p=0.007) in the control group (Table 4-3).

**Flexibility**

The comparison of the flexibility variables between the PFPS group and the control group is depicted in Table 4-4. The hip adductor flexibility (in cm) was significantly (p=0.022) decreased in the PFPS group (36.94cm +-14.39cm) than in the control group (44.95cm +-10.41cm). The hamstring flexibility (in cm) was significantly (p=0.006) decreased in the PFPS group (75.71cm +-12.7cm) than in the control group (90.3cm +-19.32cm). The anterior hip flexibility was significantly (p=0.029) restricted in the PFPS group (8.78cm +-2.7cm) than in the control group (7.37cm+-1.95cm). Moreover, the odds ratio for the anterior hip flexibility (1.2) was the greatest for any of the flexibility variables, as depicted in Table 4-7. No significant differences were found between the left and right sides of either groups, as depicted in Table 4-2 and Table 4-3, except for the anterior hip flexibility in the control group (p=0.001).

**Power Calculations**

Table 4-8 shows the effect size and power calculations for the significantly different variables. The final column shows the number of subjects needed in order for the power to be 0.8. This will ensure that future studies use an adequate sample size when measuring each variable.

**Table 4-1 Comparison of age,weight, gender and physical activity characteristics**

| Variable | Control (n=40) Mean (SD) | PFPS (n=17) Mean (SD) | p-value | C.I. (upper / Lower limit) |
|---|---|---|---|---|
| **Age (years)** | 69.13 (13.57) | 65.12 (13.25) | 0.309 | 67.93+/-3.5 |
| **Weight (kg)** | 28.48 (4.15) | 28.65 (5.33) | 0.896 | 28.5+/-1.17 |
| **Gender (M/F)** | 12/28 | 6/11 | 0.35 | |
| **Physical activity (hrs/week)** | 1.89 (0.98) | 2.32 (1.16) | 0.158 | 2.02+/-0.27 |

**Table 4-2 Comparison of the intrinsic variables of the painful (P) and non- painful (NP) limb of the PFPS group**

| Variable | Painful (n=17) Mean (SD) | Non-painful (n=17) Mean (SD) | p-value | C.I. (upper / lower limit) |
|---|---|---|---|---|
| **Alignment** | | | | |
| Arch height (cm) | 2.16 (0.55) | 2.38 (0.45) | 0.063 | -0.45 / 0.01 |
| Rearfoot (degrees) | 9.35 (7.22) | 6 (4.67) | 0.071 | -0.32 / 7.02 |
| **Flexibility** | | | | |
| Quads (degrees) | 57 (9.12) | 57.53 (10.97) | 0.846 | -6.2 / 5.14 |
| Iliopsoas (degrees) | -0.71 (4.7) | -1.29 (7.5) | 0.687 | -2.45 / 3.62 |
| ITB (degrees) | -0.16 (4.24) | -2 (3) | 0.482 | -1.83 / 3.71 |
| Adductors(degrees) | 36.94 (14.39) | 39.53 (13.83) | 0.232 | -7 / 1.83 |
| Hamstrings(degrees) | 75.71 (12.7) | 74.47 (13.04) | 0.364 | -1.57 / 4.03 |
| Anterior hip (cm) | 8.78 (2.7) | 9.31 (1.77) | 0.128 | -1.23 / 0.17 |

**: Indicates significant differences between groups (p<0.05)*
*Rearfoot valgus indicated by a positive value; iliopsoas flexibility and ITB flexibility indicated by a negative value*

**Table 4-3 Comparison of the intrinsic variables of the dominant (D) and non-dominant (ND) limb in the control group**

| Variable | Dominant (n=40) Mean (SD) | Non-dominant (n=40) Mean (SD) | p-value | C.I. (upper / lower limit) |
|---|---|---|---|---|
| **Alignment** | | | | |
| Arch height (cm) | 1.97 (0.45) | 2.2 (0.44) | 0.0005* | -0.33 / 0.13 |
| Rearfoot (degrees) | 6.3 (5.68) | 4.6 (4.76) | 0.007* | 0.5 / 2.9 |
| **Flexibility** | | | | |
| Quads (degrees) | 62.83 (12.69) | 60.83 (12.94) | 0.186 | -1 / 5 |
| Iliopsoas (degrees) | -0.3.5 (7.34) | -2.53 (7.88) | 0.171 | -2.4 / 0.44 |
| ITB (degrees) | -1 (3.39) | -1.43 (3.31) | 0.483 | -0.79 / 1.64 |
| Adductors(degrees) | 44.95 (10.41) | 44.05 (12.68) | 0.465 | -1.57 / 3.37 |
| Hamstrings(degrees) | 90.3 (19.32) | 89.53 (19.37) | 0.571 | -1.97 / 3.52 |
| Anterior hip (cm) | 7.37 (1.95) | 8.33 (1.94) | 0.0005* | -1.48 / -0.46 |

**: Indicates significant differences between groups (p<0.05)*
*Rearfoot valgus indicated by a positive value; iliopsoas flexibility and ITB flexibility indicated by a negative value*

**Table 4-4 Comparison of the intrinsic variables of the PFPS group (P) and the control group (D)**

| Variable | Painful (n=17) Mean (SD) | Dominant (n=40) Mean (SD) | p-value | C.I. (upper / lower limit) |
|---|---|---|---|---|
| **Alignment** | | | | |
| Arch height (cm) | 2.16 (0.55) | 1.97 (0.44) | 0.178 | -0.09 / 0.47 |
| Rearfoot (degrees) | 9.35 (7.22) | 6.3 (5.68) | 0.93 | -0.53 / 6.63 |
| Genu varus (cm) | -1.36 (2.17) | -0.18 (2.34) | 0.081 | -2.51 / 0.15 |
| **Flexibility** | | | | |
| Quads (degrees) | 57 (9.11) | 62.83 (12.69) | 0.93 | -12.65 / 0.99 |
| Iliopsoas (degrees) | -0.71 (4.7) | -3.5 (7.34) | 0.155 | -1.09 / 6.68 |
| ITB (degrees) | -1.06 (4.24) | -1 (3.39) | 0.956 | -2.18 / 2.07 |
| Adductors(degrees) | 36.94 (14.39) | 44.95 (10.41) | 0.022* | -14.8 / -1.22 |
| Hamstrings(degrees) | 75.71 (12.7) | 90.3 (19.32) | 0.006* | -24.84 / -4.35 |
| Anterior hip (cm) | 8.78 (2.7) | 7.37 (1.95) | 0.029* | 0.15 / 2.69 |

**: Indicates significant differences between groups ($p<0.05$)*
*Rearfoot valgus indicated by a positive value, genu varus indicated by a negative value; iliopsoas flexibility and ITB flexibility indicated by a negative value*

**Table 4-5 Analysis of Variance (ANOVA) results for the independent variables**

| Variable | Step 1 | Step 2 | Step 3 | Step 4 | Step 5 |
|---|---|---|---|---|---|
| ITB | 0.58 | | | | |
| Iliopsoas | 0.5 | 0.51 | | | |
| Hamstrings | 0.3 | 0.38 | 0.36 | | |
| Figure 4 | 0.37 | 0.35 | 0.26 | 0.26 | 0.004 |
| Genu varus | 0.08 | 0.09 | 0.1 | 0.11 | 0.08 |
| Arch height | 0.02 | 0.18 | 0.15 | 0.12 | 0.06 |
| Rearfoot | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 |
| Quads | 0.14 | 0.14 | 0.12 | 0.09 | 0.1 |
| Adductors | 0.07 | 0.05 | 0.06 | 0.01 | 0.004 |

**Table 4-6 Hosmer and Lemeshow test**

| Step | p-Value |
|---|---|
| 1 | 0.92 |
| 2 | 0.4 |
| 3 | 0.88 |
| 4 | 0.87 |
| 5 | 0.83 |

**Table 4-7 The odds ratios for the independent variables in step 3**

| Variable | Odds Ratio |
|---|---|
| **Alignment** | |
| Arch height | 4.22 |
| Rearfoot valgus | 1.2 |
| Genu varus | 0.74 |
| **Flexibility** | |
| Quadriceps | 0.93 |
| Adductors | 0.91 |
| Hamstrings | 0.98 |
| Anterior Hip | 1.2 |

**Table 4-8 Effect size and power calculations**

| Variable | Effect Size | Power | No. of subjects required |
|---|---|---|---|
| **Alignment** | | | |
| Arch height | 0.34 | 0.25 | 135 |
| Rearfoot | 0.64 | 0.6 | 40 |
| Genu varus | 0.54 | 0.4 | 55 |
| **Flexibility** | | | |
| Quadriceps | 0.43 | 0.2 | 75 |
| Iliopsoas | 0.6 | 0.55 | 45 |
| ITB | 0.14 | 0 | 1000 |
| Adductors | 0.56 | 0.5 | 55 |
| Hamstrings | 1.15 | 0.95 | 9 |
| Anterior hip | 0.53 | 0.5 | 58 |



## Discussion

The aim of this study was to determine if lower limb alignment and flexibility measures were associated with PFPS. The main findings of this study were that no differences between the control group and the PFPS group were found in lower limb alignment measures, but that inflexible anterior hip structures, inflexible hamstrings and inflexible hip adductors were associated with PFPS.

In this study there was no association between genu varus or valgus and PFPS, although most of the subjects in both groups presented with genu varus. The association between genu varus or valgus and PFPS was not clear from previous studies. The results of this study

are in agreement with a prospective study that showed no significant difference in genu valgus or varus between subjects with PFPS and those without (p=0.96) [104]. In contrast, a well-conducted prospective study, using adequate inclusion and exclusion criteria found an association between PFPS and genu varus (p=0.0001) [70]. This contradictory finding could be due to confounding variables such as an effusion or referred pain, since these factors were not excluded in the latter study. The results of the present study, however, further substantiate the hypothesis that there is no association between genu varus or valgus and PFPS.

The present study did not find an association between the static rearfoot alignment and PFPS. This is in agreement with a previous well-conducted single observational study which showed that static rearfoot alignment was not associated with PFPS (p=0.31) [63]. However, it was shown in the previous study that there were no significant differences between the left and right sides of either group. In this study the non-dominant side (4.6cm+-4.76cm) was less than the dominant side (6.3cm+-5.68cm) of the control group (p=0.007). However, it was noted in the previous study that by using standard statistical methods, which calculated the means of the data, the differences that existed on an individual basis were not shown. Therefore, it was suggested that future investigations of the rearfoot should not only use bilateral measurement, but investigators should recognize that averaging data for the purposes of analyzing data may be inappropriate. This study had not been published prior to the onset of the present study. Therefore, a limitation of the present study is that the rearfoot data was averaged and only the dominant side of the control group was compared to the painful side of the PFPS group. This method of analysis was based on a previous case control study [68]. It is concluded that static rearfoot alignment is not associated with PFPS, although the data of the present study suggests that future studies should analyse the lower limb alignment data so that the differences between the left and right sides of the subjects can be taken into account.

The findings of this study did not demonstrate any significant differences between the medial longitudinal arch (MLA) of the PFPS and the control group. However, the mean MLA height for the painful (2.16cm+-0.55cm) and non-painful (2.38cm+-0.45cm) sides of the PFPS group was higher than the mean values of the dominant (1.97cm+-0.45cm) and non-dominant (2.2cm+-0.44cm) limbs of the control group. The odds ratios for all variables were greatest for

an increased arch height (4.22). The results of this study are in agreement with the results of a previous case control study and prospective study, which showed that PFPS sufferers tend to have a higher arched foot than control subjects. The case control study demonstrated that PFPS sufferers have a higher arched foot than control subjects (p=0.050) [22]. This finding was supported by a prospective study which noted that recruits with higher arches had an increased risk of overuse injury [10]. This was not a study specific to PFPS and therefore no conclusions can be made regarding PFPS. It is concluded that a high arched foot is associated with PFPS, rather than a low arched foot, despite the present study not finding any significant differences between the PFPS group and the control group. It is therefore hypothesised that the reported improvement in PFPS as a result of soft foot orthotics use [23] could be due to the cushioning effect on the high arched foot, rather than a structural change in alignment.

The main findings of this study were that inflexibility of the hamstrings, anterior hip and hip adductors were associated with PFPS. This study found that hamstring flexibility of the PFPS group (75.71cm+-12.7cm) was less than the control group's flexibility (90.3cm+-19.32cm) (p=0.006). This is in agreement with a previous observational case series study on skaters, which showed that hamstring flexibility of those skaters with knee pain were more inflexible than those without knee pain (p<0.05) [83]. Therefore, it is concluded that hamstrings inflexibility is associated with PFPS. However, the mechanism by which hamstring inflexibility could cause PFPS is unknown. It is suggested in previous anecdotal literature that hamstring inflexibility could affect the valgus force on the patella [102]. The present study design does not indicate a cause and effect relationship. It could be hypothesised that the PFPS could cause hamstring inflexibility, due to the gait changes that have been reported to occur in PFPS subjects [71;79]. Therefore, future research should investigate the cause and effect relationship between hamstring inflexibility and PFPS in a randomised controlled trial.

The present study found that anterior hip inflexibility was associated with PFPS using the Figure Four Test. No previous studies have measured the relationship between anterior hip flexibility and PFPS. It is proposed that inflexibility of the anterior hip structures increases the valgus force through the knee, which in turn increases the risk for developing patellofemoral pain [35], although this has not been demonstrated scientifically. The limitations of the Figure Four Test is that no studies have been performed to investigate which structures of the

anterior hip are involved during the test [35]. The hip adductors, the hip internal rotators, the hip flexors, the anterior hip capsule, the pubofemoral and iliofemoral ligaments are possible anatomical structures which could be stretched during the test. The present study found that the hip adductor flexibility of the PFPS group (36.94cm+-14.39) was less than the control group (44.95cm+-10.41cm) (p=0.022). Therefore, it is suggested in the present study, that adductor inflexibility may contribute to anterior hip inflexibility during the Figure Four Test, although future studies could investigate this further to establish which structures specifically are restricted when a subject presents with a restricted Figure Four Test. No studies have investigated the association of hip adductor inflexibility with PFPS to date, therefore it can be concluded that inflexibility of the hip might be associated with PFPS. It has been hypothesised in previous studies that a lack of control or strength of the hip and pelvic stabilisers (posterior fibres of gluteus medius) could be associated with PFPS [35;66;78]. It is hypothesised in the present study that inflexibility of the hip musculature could be associated with a lack of control and strength of the hip stabilisers. Further research would need to investigate these hypotheses further.

Additional findings of this study were that quadriceps inflexibility and ITB inflexibility was not associated with PFPS. These findings are in contrast to previous evidence [41;75;101;104]. Evidence of reduced flexibility of both quadriceps and gastrocnemius in subjects who developed PFPS compared to those that did not develop symptoms was demonstrated in a prospective study (n=480) (no significant different values given) [41]. A prospective cohort study showed an association between decreased quadriceps flexibility and PFPS (p=0.028) [104].

The contradictory findings of the present study could be due to the difference in measurement technique, since the previous studies measured quadriceps flexibility in prone by flexing the knee to the end range of movement. This technique does not control for lumbar flexion, however, the technique used in the present study does not account for the effect that the hip flexors have on knee flexion angle. Another explanation for this contradictory finding is that in order for the power of this variable to be 0.8, 75 subjects would be required. Since there were only 17 subjects with PFPS there is a chance that there were some missed findings (type 2 error) for quadriceps flexibility. Therefore, future research should firstly, aim to define a gold standard of measuring quadriceps flexibility to avoid future contradictory evidence; secondly,

assess repeatability of the gold standard; and thirdly, use a minimum of 75 subjects. Until these studies are performed, no further conclusions can be made regarding the association of quadriceps flexibility and PFPS.

No association between ITB flexibility and PFPS was found in the present study, which is in contrast to previous evidence. A case controlled study which investigated the association of ITB inflexibility and PFPS showed an association between ITB inflexibility and PFPS, although small subject numbers (n=12) were used and no p values were recorded [75]. A case series study showed anecdotally that ITB inflexibility was associated with PFPS, however, no control group was included [101]. The contradictory findings could be due to the low subject numbers in the present study and previous studies, since it has been demonstrated in the present study that 1000 subjects would be needed to ensure a powerful result when investigating ITB flexibility. This would be an unrealistic expectation of a case control study design, but could be possible if a prospective cohort study design were used in future research. Therefore no conclusions should be made regarding ITB inflexibility.

The main findings of this study were that inflexible anterior hip structures, inflexible hamstrings and inflexible adductors were associated with PFPS. These results are in agreement with previous postulated hypotheses and studies of limited scientific evidence [35;83]. It is clear that prospective cohort studies are required to confirm or refute the various risk factors that contribute to the development of PFPS. To establish a cause and effect relationship between the development of PFPS and any particular risk factor, intervention trials are required to adequately test the effect of risk factors. To date there have been no such trials, which have investigated one risk factor, therefore the only conclusions that can be drawn from the available evidence is that anterior hip, hamstring and hip adductor inflexibility might be associated with PFPS.



### Limitations

The sample size of the present study was not adequate to ensure powerful results. Future studies should perhaps assess a limited number of variables at a time using different sample sizes according to the table presented in Table 4-8.

The data of the present study suggests that future studies should analyse the lower limb alignment data so that the differences between the left and right sides of the subjects can be taken into account. A limitation of the present study is that the rearfoot data was averaged and only the dominant side of the control group was compared to the painful side of the PFPS group.

The measurement technique of quadriceps was not ideal in either the present study, or in previous studies. The present study suggests that future clinical measurement and research of quadriceps flexibility should perhaps be performed in a side lying position. This position enables the tester to ensure that the hip angle is maintained at zero degrees, to counteract the effect that the hip flexors have on the knee flexion angle. Moreover, lumbar spine movement can be limited by flexing the opposite limb to the chest. The Modified Thomas Test should therefore be used only to measure iliopsoas and ITB flexibility. Future studies should assess the repeatability of measuring quadriceps flexibility in a side lying position and thereafter, further case control, prospective and randomised control trials can be performed using this measurement technique.



**Conclusion**

The current study found inflexibility of the anterior hip, hamstrings and adductors to be associated with PFPS. This is in agreement with previous research.

Future research should aim at establishing the mechanism by which these variables are associated with PFPS. This could be achieved by allocating a specific stretch programme to subjects in a randomised controlled trial. However, it is hypothesised that inflexibility of the lower limb might be a result of poor activation of the posterior fibres of gluteus medius and perhaps the altered gait which occurs in PFPS patients. Therefore, it is suggested that further studies should also investigate the association of the timing to activation/strength of gluteus medius. Thereafter, a randomised controlled trial should be performed to determine whether it is the muscle activation/strength or the inflexibility that causes PFPS.

Despite the lack of association of quadriceps flexibility to PFPS in the current study, it is suggested that a gold standard of measuring quadriceps flexibility be investigated further.

Thereafter, the association of PFPS and inflexibility of the quadriceps needs to be investigated further.

The clinical implications of the findings of the present study are that clinicians should include the measurement of these factors in the initial clinical assessment of a patient presenting with PFPS.

## Summary and Conclusion

The ultimate goal of research in physiotherapy is to improve clinical practice based on the most recent available evidence. The purpose of this dissertation was to add to the body of evidence regarding the aetiological factors that may be associated with PFPS. Intrinsic and extrinsic risk factors have been associated with the development of PFPS. However, a review of the literature revealed that there is little scientific evidence to support a cause and effect relationship between factors and the development of PFPS. There is some evidence to support a possible association of various factors to PFPS but many of the studies were limited by not including standard inclusion and exclusion criteria, and were not strong study designs, such as in randomised controlled trial or prospective cohorts. This in turn has led to contradictory results.

It can be concluded from chapter 2 that the evidence to support the hypothesis that extrinsic factors are associated with PFPS is stronger than that of the intrinsic factors. Competitive involvement in sports, running on hard surfaces or uneven terrain, overstretching and a sudden increase in mileage have been well documented as risk factors for PFPS in prospective and case control studies [9;22;49;89]. These are factors that could easily be investigated in future clinical controlled trials with a view to establishing whether they are causal to the development of PFPS.

The association between intrinsic factors and PFPS appears to be based on weaker evidence (anecdotal, case series, hypotheses). Some of the case control and prospective studies are limited by the lack of standardization of inclusion criteria. This has resulted in contradictory findings for the association of factors such as iliopsoas inflexibility, the increased Q-angle and genu valgus/varus with PFPS. It has been documented in one case controlled study and one prospective study that a high medial arch is associated with PFPS. However, there was a lack of standard inclusion criteria in both studies. Inflexibility of the gastrocnemii and quadriceps and a delayed onset to activation in the VMO have all been associated with PFPS in well-conducted case control studies [11;14;22;41;104].

There is either limited or no evidence to support the association of the remaining postulated intrinsic risk factors to PFPS (flexibility of the ITB, hamstrings, hip adductors and the anterior hip structures). Further investigation is needed regarding the definition and investigation of patellar malalignment and femoral anteversion in order to support the evidence that exists, which negates their association to PFPS.

The study in chapter 3 showed that both the Modified Thomas Test and the Figure Four Test are repeatable clinical tests. However, in a clinical setting, the limits of agreement for each measurement need to be considered in relation to the overall flexibility of each subject.

The aim of the study in chapter 4 was to determine if lower limb alignment and flexibility measures were associated with PFPS. This was done using standard inclusion and exclusion criteria and it was ensured that all measurements performed were repeatable. The main findings of this study were that hamstring, hip adductor and anterior hip structure inflexibility was shown to be associated with PFPS. However, further studies need to be performed to determine if they are causative to the development of PFPS. It is hypothesised in the present dissertation that inflexibility may be a result of inadequate activation of the muscle stabilisers at the hip and knee joint (VMO and posterior fibres of gluteus medius), which may or may not be related to the changes in gait pattern that is observed in PFPS sufferers. Thus, further investigation is required to confirm or refute this possibility. The influence of foot biomechanics on the development of PFPS needs to be investigated further, with special attention to the dynamics of the foot during the gait cycle. The measurement of quadriceps flexibility needs to be standardized so that conclusive evidence can be established regarding its association to PFPS.



Future research needs to determine which intrinsic risk factors are related to PFPS. These would include quadriceps flexibility, ITB flexibility, weak pelvic and hip stabilisers, the influence of foot biomechanics during gait, patella malalignment and femoral angle. This can be studied using case control and prospective study designs.

Randomised controlled clinical trials need to be performed to determine which of the intrinsic factors found to be associated in this dissertation are causative of PFPS: hamstring, adductor and anterior hip inflexibility and the timing of VMO activation. Similarly, the extrinsic factors

found to be associated with PFPS (competitive involvement in sports, running on hard surfaces or uneven terrain, overstretching and a sudden increase in mileage) need to be investigated further.

Table 5-1 summarises the factors that should be measured in a clinical setting, based on the evidence presented in the present dissertation. These are factors that have been shown to be repeatably and appropriately measured in the clinical setting. They have been shown to be: strongly associated with PFPS, such as in randomised controlled trials, associated with PFPS with limited evidence, such as in case control studies or prospective cohorts; weakly associated with PFPS, such as in anecdotal reports or case series; or contradictory, therefore needing further assessment.

**Table 5-1 Factors to be measured during clinical assessment of patient with PFPS**

| Factor to be measured | Strength of evidence |
|---|---|
| **Subjective Assessment** | |
| Sudden increase in distance | Limited |
| Competitive involvement in sports | Limited |
| Overstretching | Limited |
| Inappropriate shoes | Contradictory |
| Training surface | Weak |
| **Objective Assessment** | |
| VMO activation | Strong |
| Gluteus medius activation | Weak |
| Gastrocnemius flexibility | Limited |
| Anterior hip flexibility | Limited |
| Hamstring flexibility | Limited |
| ITB flexibility | Contradictory |
| Adductor flexibility | Limited |
| Quadriceps flexibility | Contradictory |
| Medial longitudinal arch of foot | Contradictory |
| Timing of rearfoot motion during gait | Limited |

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# Appendices

Appendix 16 - Patient information sheet

**Physiotherapy Department**
**St James Wing**

St George's Healthcare NHS
NHS Trust

*Appointments & Enquiries:*
**Tel No: 020 8725 1360**
**Fax: 020 8725 2432**
**Direct Line: 020 8725 3008**

Our Ref:

Date:

**1. Study Title**

An investigation into the association between dynamic intrinsic risk factors for **patellofemoral pain.**

**2. Invitation paragraph**

You are being 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 it will involve. Please take the time to read through the following information carefully and feel free to ask if anything is unclear. Thank you for reading this.

Consumers for Ethics in Research (CERES) publish a leaflet entitled 'Medical Research and You'. This leaflet gives more information about medical research and looks at some questions you may want to ask. A copy may be obtained from CERES, P0 Box 1365, London N16 OBW. Thank you for reading this information sheet

**3. What is the purpose of the study?**
We want to identify certain factors that are possibly related to your and other patient's knee pain. Once this has been done it will give physiotherapists a better idea of what kind of exercises are useful in the treatment of the type of knee pain that you are suffering from.

**4. Why have I been chosen?**
You have seen your GP or orthopaedic consultant with signs and symptoms of patellofemoral pain (a type of knee pain) and your condition makes you suitable for this study.

**5. Do I have to take part?**
It is up to you to decide to take part or not. If you decide to take part you will be given an information sheet to keep and asked to sign a consent form. If you decide to take part you are free to withdraw at any time and without giving a reason. This will not affect the standard of care you receive.

**6. What do I have to do?**
If you agree to participate you will be asked to answer some general questions about the history to your injury, health and some personal details like your height and weight. A series of measurements will then be taken of the flexibilty of your hip and knee muscles and the height of your foot arch. That will be the end of your involvement. The whole process should take about 45 minutes.

**7. What are the possible disadvantages and risks of taking part?**
The assessment techniques used in this study are the same ones used in a normal physiotherapy examination. These techniques are documented in literature and physiotherapy textbooks and are of no risk to you.

**8. What are the possible benefits of taking part?**
Should the researcher discover any differences in your flexibility or foot posture compared to the normal values that have been described in research before, you will be given a rehabilitation programme as well as shoe insoles that will address these issues and possibly help in reducing the amount of knee pain you get. However, this cannot be guaranteed, since further research will need to be done to determine if the things we find different in people with knee pain are directly related to the knee pain itself. The information we get from this study may help us to treat patients with knee pain better in the future.

**9. What happens when the research study stops?**
Your participation in the study will only be for one physiotherapy consultation. Your treatment thereafter will continue as it would do normally.

**10. What happens if something goes wrong?**
If taking part in this research project harms you, there are no special compensation arrangements. If you are harmed due to someone's negligence, then you may have grounds for a legal action but you may have to pay for it. Regardless of this, if you wish to complain about any aspect of the way you have been approached or treated during the course of this study, the normal National Health Service complaints mechanisms may be available to you.

**11. Will my taking part in this study be kept strictly confidential?**
All information collected about you during the course of the research will be kept strictly confidential. Any information about you which leaves the hospital/surgery will have your name and address removed so that you cannot be recognised from it. Your own GP will be notified of your participation in the trial.

**12. What will happen to the results of the research study?**
The results of the research may be published in a research journal, however you will not be identified in any report or publication.

**13. Who is organising and funding this research?**
This research is being organised by the researcher who is based at the Physiotherapy out patients department St George's Hospital, Tooting. The researcher is undertaking this study as part of the completion of a Masters degree in Sports Physiotherapy. This research is supported by the Chartered Society of Physiotherapy.

**14. Who has reviewed this study?**

This study has been reviewed by the Wandsworth Local Research Ethics Committee and the University of Cape Town Ethics Committee.

Thank you for taking part in this study

**Contact for further information**
If you have any further questions regarding this study, you can contact the researcher, Tracy Lane at:

Physiotherapy Outpatients Department
St George's Hospital
Ground Floor, St James Wing
Blackshaw Road
Tooting
SW17OQT
Tel: 0208-7251360

**You will be given a copy of the information sheet and a signed consent form to keep.**

**Physiotherapy Department**
**St James Wing**

St George's Healthcare NHS
NHS Trust

*Appointments & Enquiries:*
**Tel No: 020 8725 1360**
**Fax: 020 8725 2432**
**Direct Line: 020 8725 3008**

Our Ref:

Date:

**Study title**
**An investigation into the association between dynamic intrinsic risk factors forpatellofemoral pain.**

**Invitation paragraph**
You are being 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 it will involve. Please take the time to read through the following information carefully and feel free to ask if anything is unclear. Thank you for reading this.

Consumers for Ethics in Research (CERES) publish a leaflet entitled 'Medical Research and You'. This leaflet gives more information about medical research and looks at some questions you may want to ask. A copy may be obtained from CERES, P0 Box 1365, London N16 OBW. Thank you for reading this information sheet

**What is the purpose of the study?**
We want to identify certain factors that are possibly related to patient's knee pain, in particular patellofemoral pain (PFP). Once this has been done it will give physiotherapists a better idea of what kind of exercises are useful in the treatment of PFP.

**Do I have to take part?**
It is up to you to decide to take part or not. If you decide to take part you will be given an information sheet to keep and asked to sign a consent form. If you decide to take part you are free to withdraw at any time and without giving a reason.

**What do I have to do?**
If you agree to participate you will be asked to answer some general questions about your health and some personal details like your height and weight. A series of measurements will then be taken of the flexibilty of your hip and knee muscles, the height of your foot. That will be the end of your involvement. The whole process should take about 45 minutes.

**What are the possible disadvantages and risks of taking part?**
The assessment techniques used in this study are the same ones used in a normal physiotherapy examination. These techniques are documented in literature and physiotherapy textbooks and are of no risk to you.

**What are the possible benefits of taking part?**

The information we get from this study may help us to treat future patients with knee pain better.

**What happens if something goes wrong?**
If taking part in this research project harms you, there are no special compensation arrangements. If you are harmed due to someone's negligence, then you may have grounds for a legal action but you may have to pay for it. Regardless of this, if you wish to complain about any aspect of the way you have been approached or treated during the course of this study, the normal National Health Service complaints mechanisms may be available to you.

**Will my taking part in this study be kept strictly confidential**
All information collected about you during the course of the research will be kept strictly confidential. Any information about you which leaves the hospital/surgery will have your name and address removed so that you cannot be recognised from it.

**What will happen to the results of the research study?**
The results of the research may be published in a research journal, however you will not be identified in any report or publication.

**Who is organising and funding this research?**
This research is being organised by the researcher who is based at the Physiotherapy out patients department St George's Hospital, Tooting. The researcher is undertaking this study as part of the completion of a Masters degree in Sports Physiotherapy. This research is supported by the Chartered Society of Physiotherapy.

**Who has reviewed this study?**
This study has been reviewed by the Wandsworth Local Research Ethics Committee.

**Thank you for taking part in this study**

**Contact for further information**
If you have any further questions regarding this study, you can contact the researcher, Tracy Lane at:

Physiotherapy Outpatients Department
St George's Hospital
Ground Floor, St James Wing
Blackshaw Road
Tooting
SW17OQT
Tel: 0208-7251360

**You will be given a copy of the information sheet and a signed consent form to keep.**

**Physiotherapy Department**

St George's Healthcare NHS
NHS Trust

**St James Wing**

*Appointments & Enquiries:*
**Tel No: 020 8725 1360**
**Fax: 020 8725 2432**
**Direct Line: 020 8725 3008**

Our Ref:
Date:

**Title of project:** An investigation into the association between dynamic intrinsic risk factors for patellofemoral pain.

**Name of researcher:** Tracy Lane

Please initial box

1. I confirm that I have read and understood the information sheet for the above study and that I have had the opportunity to ask questions ☐

2. I understand that participation in this study involves no risks ☐

3. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected ☐

4. I agree to take part in the above study ☐

| Name of patient | Date | Signature |
|---|---|---|
| Researcher | Date | Signature |

Appendix 4- Data collection form

St George's Healthcare NHS
NHS Trust

Patient identification number:
Control subjects ID number:
Subject participate in exercise twice or more a week?

| Variable | Unit of Measure | Value on painful side * Left/Right or Dominant/Non | Value on non-painful * Left/Right or Dominant/Non |
|---|---|---|---|
| Age | Years | | |
| Gender | Male / Female | | |
| Weight | Kilograms | | |
| Knee alignment: Valgus / Varus | Millimetres | | |
| Rearfoot alignment: Valgus / Varus | Degrees | | |
| Medial longitudinal arch of the foot | Millimetres | | |
| Quadriceps flexibility | Degrees | | |
| Iliopsoas flexibility | | | |
| Tensor fascia lata/iliotibial band | | | |
| Hip abduction range of movement | Degrees | | |
| Hamstrings flexibility | Degrees | | |
| Flexibility of the anterior hip structure | Millimetres | | |

Control subjects: use right side as painful side and left as non-painful side

**VAS rating**

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|

**No pain** ⟶

**Physiotherapy Department**
**St James Wing**

St George's Healthcare NHS
NHS Trust

*Appointments & Enquiries:* Tel No: 020 8725 1360
Fax: 020 8725 2432
Direct Line: 020 8725 1357

Date:

Dear Mr Fairbank, Mr Calvert, Mr Bircher, Nadya German, Stephen Jones, Katie Knapton and Susie Durrell

Re: **Research into the association between dynamic intrinsic risk factors for patellofemoral pain (PFP)**

I am writing to inform you of the above study that I am doing for the completion of my masters degree in Sports Physiotherapy.

Patients who agree to participating in this study will undergo a biomechanical assessment, including flexibility, alignment (Q angle; Genu Valgus/Varus) and foot posture. The inclusion criteria are (at least two of the following):
patellar pain with manual compression of the patella against the femur
patellar tenderness with palpation of the postero-medial and postero-lateral borders of the patella
patellar pain during resisted dynamic knee extension
patellar pain with manual compression of the patella against the femur during isometric knee extensor contraction (Clarke's compression test)
pain going up or down stairs.
Patients must be between the ages of 18 and 45
**Exclusion criteria:**
musculo-skeletal conditions of the knee (including ligamentous laxity, osteoarthritis, quadriceps muscle tear, synovial plica syndrome, Osgood-Schlatter's disease, patellar tendinopathy, quadriceps tendinopathy, bursitis, growth plate injury)
previous or pending knee surgery
gross knee effusion
knee pain referred from the hip or spine
upper or lower motor neuron lesion
previous steroid injections to the knee.

Should you feel you have a suitable patient that needs physiotherapy and meets the criteria, I would appreciate it if you wrote my name (TRACY LANE) as well as the wording "KNEE STUDY" at the top of the referral. I will inform you in writing if they are going to participate in the study as well as a report of their treatment outcome on discharge. If you would like any further information about this study, please contact me at:

Physiotherapy Outpatients Department (Gym)
St George's Hospital
Ground Floor, St James Wing
Blackshaw Road, Tooting, SW17OQT

Thank you

Yours sincerely,

Tracy Lane
Senior II Physiotherapist
MCSP, SRP