THE EFFECT OF A TARGETED FUNCTIONAL MOVEMENT RETRAINING INTERVENTION ON ANTERIOR KNEE PAIN AND ASSOCIATED BIOMECHANICAL MECHANISMS

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***Dissertation presented for the degree* of**
Doctor of Philosophy *in the Faculty of Medicine and Health Sciences at Stellenbosch University*

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March 2018

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Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Dominique Leibbrandt

March 2018

“This dissertation includes four original papers published in peer-reviewed journals or books and one unpublished publication. The development and writing of the papers (published and unpublished) were the principal responsibility of myself, for each of the cases where this is not the case, a declaration is included in the dissertation indicating the nature and extent of the contributions of co-authors.”

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Scientific products of this dissertation

The following articles were produced and submitted for publication. PDFs of the articles that have been published can be found attached as Appendix P.

<u>Accepted</u>

1. Leibbrandt, D., & Louw, Q. (2017). The Development of an Evidence-based Clinical Checklist for the Diagnosis of Anterior Knee Pain. *South African Journal of Physiotherapy,* in press.
2. Leibbrandt, D., & Louw, Q. (2017). Kinematic Factors Associated with Anterior Knee Pain during Common Aggravating Activities: A Systematic Review. *Physical Therapy Reviews*, 1-14.
3. Leibbrandt, D., & Louw, Q. (2017). The Test-Retest Reliability of Gait Outcomes in Subjects with Anterior Knee Pain. *Journal of Bodywork and Movement Therapies*, in press.
4. Leibbrandt, D., & Louw, Q. (2017). Targeted Functional Movement Retraining to Improve Pain, Function and Biomechanics in Subjects with Anterior Knee Pain: A Case Series. *Journal of Sports Rehabilitation*, in press.

<u>Submitted</u>

5. The Effect of an Individualised Functional Retraining Intervention on Pain, Function and Biomechanics in Subjects with Anterior Knee Pain: A series of n of 1 trial.
   Authors: D Leibbrandt & Q Louw
   Submitted to *Physical Therapy in Sport* on 20 September 2017.

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Abstract

Background

Anterior knee pain (AKP) frequently affects the knee joint and may limit an individual's ability to perform common activities of daily living (ADLs). It tends to become chronic, making it difficult to treat as the causes are not well understood. Individualised interventions are recommended due to the large variation of clinical presentations in subjects presenting with AKP.

Aims

The main aim of this research is to assess the effect of an individualised functional retraining intervention on kinematic contributing factors, pain, function and self-reported recovery in subjects with AKP.

The secondary aims are:

- To create an evidence-based checklist to assist with the diagnosis of AKP
- To create a decision-making algorithm for treating subjects with AKP based on their kinematic risk factors
- To establish the test-retest reliability of lower limb kinematics during gait

Summary of methods

Four study phases consisting of five studies with different methods were included in this dissertation. Each phase contributed towards a better understanding of the main theme, i.e. the treatment of biomechanical factors associated with AKP.

Phases A and B are preliminary research necessary to aid the conceptualisation of phase D (the main study). Phase A consisted of three studies. Study 1 was a systematic review to create an evidence-based checklist for the clinical diagnosis of AKP. Study 2 was a systematic review on kinematic risk factors for AKP in order to establish which factors clinicians should address first in treatment. Study 3 was a repeatability study to establish the test-retest reliability of our measurement procedures. Phase B was the pilot phase and consisted of one study. Study 4 was a case series to establish the feasibility of our decision-making framework and intervention procedures.

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Phase C was a planning phase where the preliminary research from previous phases were analysed and necessary changes were made in order to improve the execution of the main intervention component of the thesis (phase D).

Phase D was the main intervention study (Study 5). This was a series of n of 1 studies investigating the effect of an individualised functional retraining intervention on kinematic and clinical outcomes in 31 subjects with AKP.

Setting

The research was conducted at the Tygerberg CAF Motion Analysis Laboratory and the treatments done at the Tygerberg Physiotherapy Clinic of the University of Stellenbosch in Cape Town, South Africa.

Main results

Following a six-week individualised functional retraining intervention, 30 of the 31 subjects (96.8%) demonstrated improved pain levels (NPRS). All 31 participants (100%) demonstrated improved functional scores (AKPS) immediately post intervention. Nineteen of the 31 participants (61.3%) demonstrated a clinically significant improvement in their priority kinematic outcome post intervention. At six-month follow up, 15 participants (48.4%) rated themselves as fully recovered or pain-free on a 7-point Likert scale.

Conclusion

An individualised approach to exercise is recommended to improve pain, function, kinematics and self-reported recovery in subjects with AKP as the effects are greater than a standard intervention approach. Clinicians need to be educated on common biomechanical contributing factors and how to tailor treatment accordingly.

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Opsomming

Agtergrond

Anterior kniepyn (AKP) raak dikwels die kniegewrig en kan 'n individu se vermoë beperk om gewone daaglikse aktiwiteite uit te voer. Dit is geneig om tot 'n chroniese toestand te ontwikkel, wat dit moeilik maak om te behandel aangesien die oorsake nie goed verstaan word nie. Pasgemaakte intervensies vir AKP word aanbeveel weens die wye verskeidenheid kliniese vorme waarin dié toestand by subjekte voorkom.

Doelwitte

Die hoofdoel van hierdie navorsing is om te bepaal watter uitwerking 'n pasgemaakte funksionele herskolingsintervensie het op bewegingsfaktore, pyn, funksie en selfaangemelde herstel by subjekte met AKP.

Die sekondêre doelwitte is:

- om 'n bewysgegronde kontrolelys op te stel om AKP te help diagnoseer;
- om 'n besluitnemingsalgoritme vir die behandeling van subjekte met AKP te skep wat op hulle bewegingsrisikofaktore berus; en
- om die toets-hertoets-betroubaarheid van beweging in die onderste ledemaat in loopgang te bepaal.

Samevatting van metodes

Vir hierdie verhandeling is vier studiefases onderneem, wat uit vyf studies met verskillende metodes bestaan het. Elke fase het tot 'n beter begrip van die hooftema bygedra, naamlik die behandeling van die biomeganiese faktore wat met AKP verband hou.

Fase A en B was voorlopige navorsing wat nodig was vir die konseptualisasie van fase D (die hoofstudie). Fase A het uit drie studies bestaan. Studie 1 was 'n stelselmatige oorsig om 'n bewysgegronde kontrolelys vir die kliniese diagnose van AKP op te stel. Studie 2 was 'n stelselmatige oorsig van die bewegingsrisikofaktore vir AKP om te bepaal op watter faktore klinici eerste in behandeling behoort te konsentreer. Studie 3 was 'n herhaalbaarheidstudie om die toets-hertoets-betroubaarheid van die meetprosedures vas te stel. Fase B

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was die proeffase en het uit een studie (Studie 4) bestaan. Studie 4 was ’n gevallereeks om die uitvoerbaarheid van die besluitnemingsraamwerk en intervensieprosedures te bepaal.

Fase C was ’n beplanningsfase waarin die voorlopige navorsing van vorige fases ontleed en die nodige veranderinge aangebring is om die uitvoering van die hoofintervensiekomponent van die tesis (fase D) te verbeter.

Fase D was die hoofintervensiestudie (Studie 5). Dit het ’n reeks enkelpasiëntproewe behels wat ondersoek ingestel het na die uitwerking van ’n pasgemaakte funksionele herskolingsintervensie op die bewegings- en kliniese uitkomste by 31 subjekte met AKP.

Omgewing

Die navorsing is by die Bewegingsontledingslaboratorium van die Tygerbergse Sentrale Analitiese Fasiliteite onderneem, terwyl die behandeling by die Universiteit Stellenbosch se Tygerberg-fisioterapiekliniek in Kaapstad, Suid-Afrika, plaasgevind het.

Hoofresultate

Ná ’n ses weke lange pasgemaakte funksionele herskolingsintervensie het 30 van die 31 subjekte (96.8%) ’n verbetering in pynvlakke (NPRS) getoon. Ál 31 deelnemers (100%) het onmiddellik ná die intervensie beter funksionele tellings (AKPS) behaal. Negentien van die 31 deelnemers (61.3%) het na afloop van die intervensie ’n klinies beduidende verbetering in hulle prioriteitsbewegingsuitkoms ervaar. Gedurende ’n nasorgbesoek ses maande later het 15 deelnemers (48.4%) hulleself as ten volle herstel of pynvry op ’n sewepunt-Likertskaal beskryf.

Gevolgtrekking

In plaas van ’n standaardintervensiebenadering, word ’n pasgemaakte benadering tot oefening aanbeveel om ’n groter verbetering in pyn, funksie, beweging en selfaangemelde herstel by subjekte met AKP teweeg te bring. Klinici moet opleiding oor die algemene biomeganiese bydraende faktore ontvang, en oor hoe om behandeling dienooreenkomstig aan te pas.

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Acknowledgements

- I would firstly like to acknowledge my supervisor Prof Quinette Louw for the guidance, valuable feedback and support throughout the process of this dissertation.
- I would also like to express gratitude towards Stellenbosch University and the staff of the CAF Motion Analysis Laboratory, Language Centre and Biostatistics Unit for their assistance.
- I would like to thank Shirley Leibbrandt for assistance with proofreading and Melanie Murray for her assistance with delivering some of the physiotherapy interventions.
- I wish to acknowledge that this work is based on the research supported in part by the National Research Foundation (NRF) of South Africa (Grant number CSUR13090332637).

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List of Abbreviations

ACL	: anterior cruciate ligament
ADLs	: activities of daily living
AKP	: anterior knee pain
AKPS	: anterior knee pain syndrome
BMI	: body mass index
CAT	: clinical appraisal tool
CI	: confidence interval
CON	: control/control group
CT	: computerised tomography
FIQ	: functional index questionnaire
FMR	: functional movement retraining
FORM	: an Australian method for formulating and grading recommendations in evidence-based clinical guidelines
FPPA	: frontal plane projection angle
GRRAS	: guidelines for reporting reliability and agreement studies
GRF	: ground reaction force
HADS	: hospital anxiety and depression scale
ICC	: intra-correlation co-efficient
ITBS	: illiotibial band syndrome
LCL	: lateral collateral ligament
LEFS	: lower extremity functional scale
LR	: likelihood ratio
MCID	: minimal clinically important difference
MCL	: medial collateral ligament
MD	: mean difference
Mdn	: median
MDC	: minimal detectable change
MPFL	: medial patellofemoral ligament
MRI	: magnetic resonance imaging
NHMRC	: national health and medical research council
NPRS	: numeric pain rating scale
PCL	: posterior cruciate ligament
PCS	: pain catastrophising scale
PFJ	: patellofemoral joint
PFPS	: patellofemoral pain syndrome
PNF	: proprioceptive neuromuscular facilitation
PRISMA	: preferred reporting items for systematic reviews
PSFS	: patient specific functional scale
PV	: predictive value
RCT	: randomised-controlled trial
ROM	: range of movement
SD	: standard deviation
SEM	: standard error of measurement
SLS	: single leg squatting
SMD	: standard mean difference
SR	: systematic review
TIDieR	: template for intervention description and replication
TFJ	: tibiofemoral joint

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TIPPS : targeted interventions for patellofemoral pain syndrome
TSK : Tampa scale for kinesiophobia
VAS : visual analogue scale
VL : vastus lateralis
VMO : vastus medialis oblique
WHO : World Health Organisation

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Chapter 1: Introduction

1.1 Background

Anterior knee pain (AKP) is a common condition in adults and adolescents and may account for up to 17% of all knee-related complaints seen in primary care settings (Taunton et al., 2002). AKP is troublesome as it impairs functional ability and is persistent (Collins et al., 2013). It has been estimated that only a third of all patients diagnosed with AKP are pain-free one year later (Rathleff et al., 2014). In addition, the long-term prognosis is poor as approximately 40% of subjects presenting with the condition will experience an unfavourable self-reported recovery after 12 months despite receiving treatment (van Linschoten et al., 2009). As a result, AKP has a significant impact on time lost at work and in sports participation (Selfe et al., 2013). Early referral for physiotherapy has been suggested to improve prognosis (Collins et al., 2013; Rathleff, Roos, et al., 2015).

Subjects with AKP usually present with diffuse retropatellar or peripatellar pain of insidious onset that is aggravated by activities that load a flexed knee, such as stair climbing, running, jumping, squatting, lunging and prolonged sitting (Nunes et al., 2013). The term AKP is frequently used interchangeably with patellofemoral pain (PFP) to describe this type of pain in the absence of another pathology such as intra-articular pathology, age-related disorders (such as osteoarthritis and Osgood-Schlatter disease) and referred pain. AKP is an “umbrella term” or diagnosis of exclusion, therefore it encompasses a spectrum of disorders or pathologies. For the purpose of this thesis the term AKP was used synonymously with PFP and defined as “retropatellar or peripatellar pain, of more than three months’ duration, in the absence of intra-articular pathology, that is aggravated by activities that load a flexed knee joint” (Crossley et al., 2001; Harvie et al., 2011; Nunes et al., 2013).

The patella is a sesamoid bone located within the trochlear groove of the distal femur. The function of the patella is to protect the tibiofemoral joint (TFJ) and to improve the efficiency of knee extension. The attachment of the quadriceps tendon is at the superior pole of the patella and the patella tendon attaches to the inferior pole. Therefore, an important function of the patella is to act as a lever to improve the moment arm of the quadriceps thereby promoting the efficiency of

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the quadriceps extensor mechanism (Grelsamer et al., 1994). This extensor mechanism is vital for dynamic patellofemoral joint (PFJ) stability (Sherman et al., 2014).

Stability of the patella is also provided by the patella tendon, the medial patellofemoral ligament (MPFL), the medial reticulum, the vastus medialis oblique muscle (VMO) and the lateral retinaculum (Witvrouw et al., 2000). The VMO is the primary dynamic medial stabiliser of the knee, acting to restrain lateral translation from 0-15 degrees of knee flexion (Sakai et al., 2000). The MPFL provides passive restraint from 0-30 degrees of knee flexion. Lateral retinacula tightness has been associated with AKP as it may increase the forces between the lateral facet of the patella and lateral femoral trochlea (Sherman et al., 2014). This may result in degenerative pathology over time, possibly predisposing individuals to PFJ osteoarthritis (Sherman et al., 2014). Other local soft tissue structures that could contribute towards pain include the infrapatellar fat pad, bone marrow lesions, effusions and synovitis. However, the evidence supporting this is limited (Dragoo et al., 2012; Zhang et al., 2011). Bony local factors may also contribute towards AKP (Witvrouw et al., 2014). These bony factors may include joint geometry: shallow trochlear groove, patella alta and an increased sulcus angle (Amis, 2007).

AKP's aetiology is not well understood, posing treatment challenges for clinicians. As the exact causes are unknown, a multifactorial origin of symptoms has been proposed (Aminaka & Gribble, 2008). It has been suggested that the main cause of AKP involves excessive patellofemoral joint stress during dynamic activities that load a flexed knee (Chen & Powers, 2013). Abnormal anatomy and biomechanics are thought to be the main contributors to increased joint stress resulting in patellofemoral dysfunction (Sherman et al., 2014). However, a direct relationship between structural and biomechanical abnormalities and pain has not been established (Witvrouw et al., 2014). This is due to challenges in measuring muscle forces and tissue stress and uncertainties of whether these factors are related to the pain experienced (Besier et al., 2009). However, the ability to recognise these contributing factors is essential in order to improve the movement dysfunction that each patient presents with and obtain successful treatment outcomes (Sherman et al., 2014).

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There are many proposed contributing factors that have been associated with AKP and these factors can be classified as "extrinsic" or "intrinsic" (Halabchi et al., 2013). These "intrinsic" and "extrinsic" risk factors interact to make an individual more susceptible to injury (Meeuwisse et al., 2007). Intrinsic factors for AKP can be non-modifiable; for example, the shape and size of the patella (Waryasz & McDermott, 2008). Intrinsic factors associated with AKP can also be modifiable such as muscle weakness and tightness (Witvrouw et al., 2000). In this study will will be focusing on addressing intrinsic modifiable factors, specifically biomechanical factors associated with AKP.

Various modifiable intrinsic risk factors have been associated with AKP. These include hip muscle weakness (especially the abductors), quadriceps weakness, vastus lateralis (VL) and VMO activation co-ordination abnormalities, hamstring tightness and foot overpronation (Rogers et al., 2015; Halabchi et al., 2013). Imbalances of the quadriceps force vector, may result in an inability of the quadriceps to centralise the patellar in the trochlear groove. Some EMG studies have suggested that VMO is less active and that the VMO/ VL onset timing is altered in subjects with AKP (Cowan et al., 2001; Cowan et al., 2002). Other studies show no differences in quadriceps activation ratios and VMO activity between the pain group and controls (Keet et al., 2007).

In addition to muscle imbalances around the hip and knee, distal factors such as increased foot pronation and foot hypermobility have been associated with AKP (Barton et al., 2010). It has been suggested that these factors result in increased tibial internal rotation, thereby resulting in increased dynamic knee valgus and dynamic Q-angle. (Barton et al., 2012).

It has also been suggested that an abnormal Q-angle heightens the risk of developing AKP. A Q-angle of greater than 20 degrees is considered abnormal as it increases patellofemoral joint contact pressure and results in increased lateral displacement (Emami et al., 2007). The Q-angle can be influenced proximally by the motion of the femur or distally by the motion of the tibia (Powers, 2003). Hip abductor and external rotator weakness may result in an increased dynamic Q-angle during single support, resulting in an increased valgus force at the knee (Meira & Brumitt, 2011).

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Although many of the proposed causes and contributing factors related to AKP are biomechanical, it is important to consider that non-biomechanical mechanisms such as processing mechanisms may also play a role. Chronic AKP has been linked to processing alterations and modified pain sensation (Neal et al., 2016). These factors can influence the pain experience and be a barrier to recovery even in cases where structural and biomechanical findings seem clear (Sanchis-Alfonso et al., 2016). Therefore, psychosocial contributing factors should not be overlooked in the assessment and treatment of AKP.

1.2 Current treatment options

Conservative approaches are preferred over surgical and pharmacological options in the treatment of AKP (Collins et al., 2012; McCarthy & Strickland, 2013). Surgical options such as distal realignment of the extensor mechanism, lateral retinacula release or debridement are usually only considered as a last resort when conservative methods have failed (McCarthy & Strickland, 2013). Physiotherapy, is the mainstay of treatment for AKP (Keays et al., 2016).

The patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat in 2016 (Crossley et al., 2016) discussed conservative treatment options for the treatment of AKP. At this conference evidence-based recommendations were formed by an expert panel. Exercise therapy was recommended for the treatment of AKP to reduce pain in the short, medium and long term, and to improve function in the medium and long term. These exercise interventions should combine hip and knee exercises to replicate function instead of targeting the knee alone. Multimodal interventions were recommended for short- and medium-term pain relief and foot orthoses were recommended for pain relief in the short term. However, exercise therapy is currently the only recommendation as a long-term treatment approach (Crossley et al., 2016). There is prolific evidence on exercise in the treatment of AKP, however, the term “exercise therapy” is very broad and clinicians need specific recommendations on which approaches yield the best outcomes (van der Heijden et al., 2015).

Another recent study acquired opinion from 17 experts with at least five years of experience in AKP on current research and research priorities. The experts

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highlighted a need for future research to investigate and compare different exercise approaches and principles to improve patient outcomes. Individualised interventions have been recommended due to the large variation of clinical presentations in subjects presenting with AKP (Barton et al., 2015).

1.3 Brief chapter overview

Four study phases consisting of five studies with different methods will be included in this dissertation. Each study will contribute towards a better understanding of the main theme, i.e. the treatment of biomechanical factors associated with AKP. Each stage of the project will address a component or attempt to answer a question that will assist with the next phase. The different phases of the project, research questions and objectives are illustrated in Figure 1.

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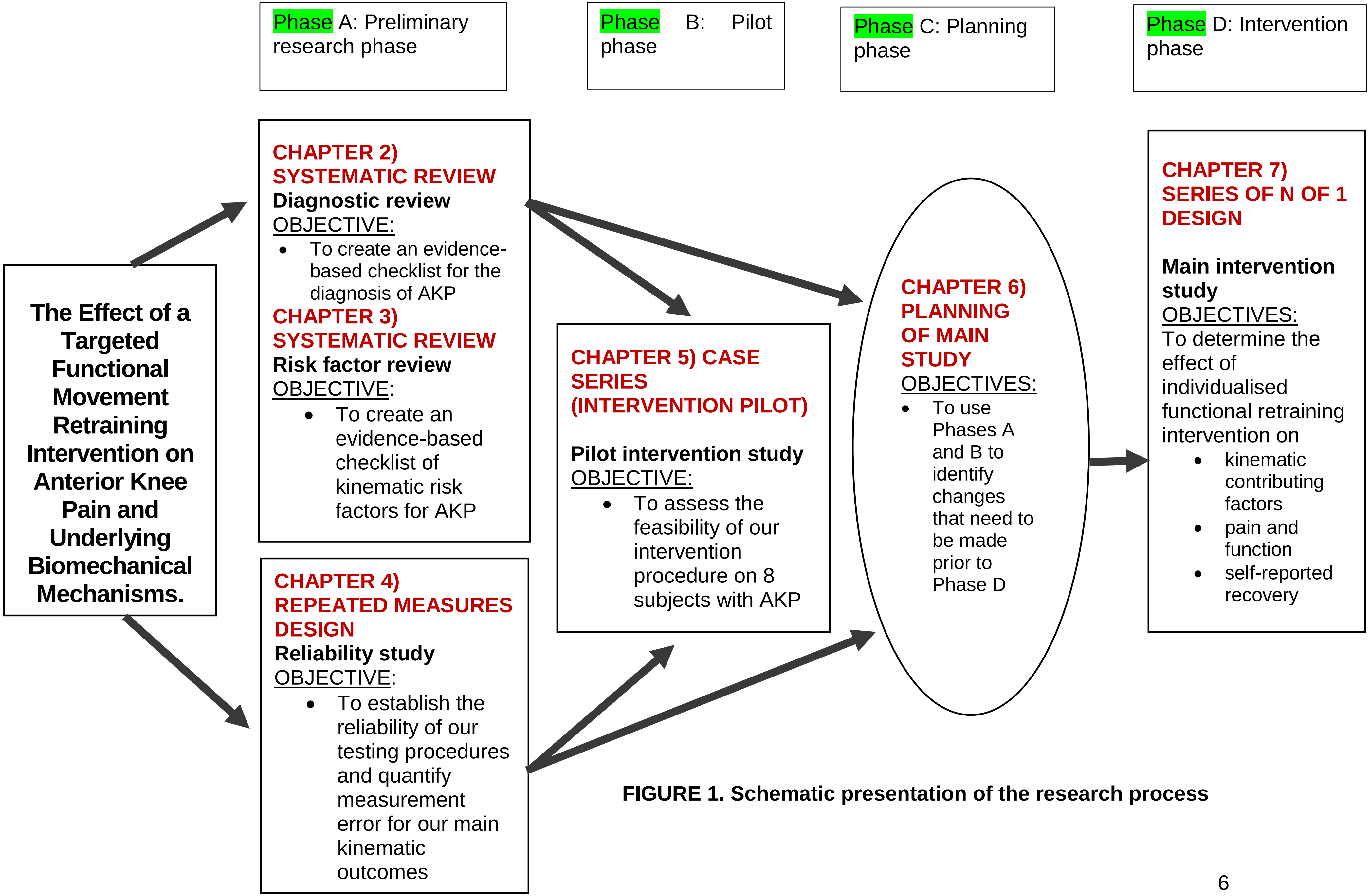

FIGURE 1. Schematic presentation of the research process

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The first phase is the preliminary research phase. This is preliminary research that was necessary to aid the conceptualisation of the main study. Phase A consisted of three studies. Study 1 (Chapter 2) was a systematic review done to create an evidence-based checklist for the diagnosis of AKP and exclusion of other pathologies. Study 2 (Chapter 3) was a systematic review to develop a decision-making algorithm based on a systematic review of evidence literature on kinematic risk factors for AKP. Study 3 (Chapter 4) was a repeatability study to establish the test-retest reliability of our measurement procedures. This was a laboratory-based study and participants were tested twice one week apart. The second phase (Study 4) was an intervention pilot for the main study. A case series of eight participants was conducted to establish the feasibility of the intervention study procedures. Following phases, A and B, changes were made to improve the quality of the research. These changes are described in phase C or the planning phase (Chapter 6).

The final phase (phase D) was the main intervention study (Chapter 7). A series of n of 1 design was used to investigate the effect of an individualised functional retraining intervention on 32 participants with AKP. Motion analysis procedures were assessed on three occasions. Participants received a six-week individualised functional retraining intervention. Pain and function were assessed throughout the treatment period and at 3- and 6-month follow up. Self-reported long-term recovery was also assessed at 6-month follow up. For this phase (Study 5), motion analysis procedures were repeated on three different occasions to increase the validly of the testing.

Subjects were recruited by advertisements placed in community, university and school-based newspapers and on sports club Facebook groups to attract a range of participants from a wide spectrum of activities, backgrounds, sports and ages. Advertisements/letters of invitation were sent to the clinics of all collaborators/sports groups. The study advert can be seen attached as Appendix A.

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1.4 Ethical considerations

Ethical approval for the project was obtained from the Health Research Council of the Stellenbosch University **(N13/05/078).** The letter of approval has been attached as Appendix B. Protocol amendments were submitted annually. Informed consent was obtained from each subject prior to the commencement of the study. Informed assent was obtained from parents/guardians for subjects under the age of 18 years. An example of informed consent documents is available as Appendix C. The study procedure, aims, requirements for participation, risks and benefits were clearly explained to each participant. Motion analysis procedures are low risk. However, there is a minor risk of skin irritation from the markers associated with motion analysis testing. Any unforeseen events will be covered by the Stellenbosch University indemnity policy. The participants were informed that they had the right to withdraw from the study at any point and they each received a copy of the informed consent document. All participants' personal information, test results, questionnaires and photographs were treated with confidentiality. Data remained anonymous by assigning codes to the participants. Data was stored in a Dropbox folder that only the research team was able to access and on the researcher's password protected laptop. Any hard copies of questionnaires were kept in a locked room on the Tygerberg 3D motion analysis laboratory. Data will be kept in a secure, locked and access-controlled room for five years.

1.5 Motivation

This PhD dissertation will provide new information on potential risk factors associated with AKP. We will quantify the repeatability of our procedures so that we can use these outcomes to establish the effect of an individualised functional retraining intervention. We will be able to correlate biomechanics to functional and clinical outcomes through long-term follow up.

To our knowledge no studies have assessed the effects of an individualised functional retraining intervention that targets specific biomechanical factors in subjects with AKP. In addition, our study design is novel as we are using a series of n of 1 design. By using subjects as their own controls, we are allowing for individual variation in aetiology and symptoms.

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1.6 Aims and objectives

The main aim of this research is to assess the effect of an individualised functional movement retraining intervention on kinematic contributing factors, pain, function and self-reported long-term recovery in subjects with AKP.

The secondary aims of this study are:

- To create an evidence-based checklist to assist with the diagnosis of AKP,
- To create a decision-making algorithm for treating subjects with AKP based on their kinematic risk factors, and
- To establish the test-retest reliability of lower limb kinematics during gait in subjects with AKP.

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Chapter 2: The development of an evidence-based clinical checklist for the diagnosis of anterior knee pain

ABSTRACT

Background

Anterior knee pain (AKP) or patellofemoral pain (PFP) is common and may limit an individual's ability to perform common activities of daily living (ADLs) such as stair climbing and prolonged sitting. The diagnosis is difficult as there are multiple definitions for this disorder and there are no accepted criteria for diagnosis. It is therefore most commonly a diagnosis that is made once other pathologies have been excluded.

Objectives

The aim of this study was to create an evidence-based checklist for researchers and clinicians to use for the diagnosis of anterior knee pain.

Methods

A systematic review was conducted in July 2016 and an evidence-based checklist was created based on the subjective and objective findings most commonly used to diagnose AKP. For the subjective factors, two or more of the systematic reviews needed to identify the factor as being important in the diagnosis of AKP.

Results

Two systematic reviews, consisting of nine different diagnostic studies were identified by our search methods. Diagnosis of AKP is based on the area of pain, age, duration of symptoms, common aggravating factors, manual palpation and exclusion of other pathologies. Of the functional tests, squatting demonstrated the highest sensitivity. Other useful tests include pain during stair climbing and prolonged sitting. The cluster of two out of three positive tests for squatting, isometric quadriceps contraction and palpation of the patella borders and the patella tilt test were also recommended as useful tests to include in the clinical assessment.

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Conclusion

A diagnostic checklist is useful as it provides a structured method for diagnosing AKP in a clinical setting. Research is needed to establish the causes of AKP is it is difficult to diagnose a condition with unknown aetiology.

2.1 Introduction

Knee pain affects about 70% of clients visiting the community health centres in the Western Cape (Parker & Jelsma, 2010). This alarming occurrence of knee problems is associated with moderate to high levels of disability. Anterior knee pain (AKP) or patellofemoral pain syndrome (PFPS) frequently affects the knee joint and impairs functional ability (Parker & Jelsma, 2010).

The international incidence has been reported to be 25% – 43% in sports injury clinics (Callaghan & Selfe, 2007; Witvrouw et al., 2000). AKP has a tendency to become chronic, and it has been estimated that 91% of subjects diagnosed with AKP still experience symptoms four years after its onset. AKP is particularly common in adolescents, between the ages of 12 and 17 years (Rathleff, Roos, Olesen, & Rasmussen, 2013), and may limit an individual's ability to perform common activities of daily living (ADLs) such as stair climbing and prolonged sitting (Nunes et al., 2013).

AKP is thought to be multifactorial in origin (Aminaka & Gribble, 2008). It also has the tendency to become chronic, especially in active individuals, adding an additional aspect of complexity to the treatment (Collins et al., 2012). There is agreement among recent reviews that conservative approaches are the preferred choice of treatment for AKP (Collins et al., 2012; McCarthy & Strickland, 2013). Surgical options such as distal realignment of the extensor mechanism, lateral retinacula release or debridement are generally only considered when conservative methods have failed or in the case of severe instability (McCarthy & Strickland, 2013).

The aetiology of AKP is not well understood. In addition, the aetiology may differ depending on whether symptoms are acute or chronic. There are a variety of pathways that could result in ongoing pain (psychological, pathophysiological, mechanical). However, the onset of the condition is hypothesised to involve excessive joint stress during activities that load the flexed knee joint. This

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patellofemoral joint stress is then transmitted through the cartilage, thereby exciting nociceptors in subchondral bone resulting in pain (Fulkerson, 2002). Over time, this joint stress may result in articular cartilage pathology (Powers et al., 2014).

There are many definitions and synonyms for AKP. It is often used as an umbrella term for pathologies that cannot be classified as anything else, and therefore can include a variety of different pathologies. The term has been used interchangeably with PFPS, chondromalacia patellae, runners knee, patellofemoral joint dysfunction and patella arthralgia (Collins et al., 2012; Cook et al., 2010; Lake & Wofford, 2011; Nunes et al., 2013). For the purpose of this article, we will be using the term "anterior knee pain".

Appendix D illustrates the range of definitions reported in systematic reviews. Some studies define AKP based on the area of pain and exclusion of other pathologies (Crossley et al., 2001; Prins & van der Wurff, 2009; Waryasz & McDermott, 2008). Other studies base the definition on the onset and duration of symptoms as well as aggravating factors (Lankhorst et al., 2012; Collins et al., 2012; Barton et al., 2008). The multiple definitions of AKP make accurate and standardised clinical diagnosis a challenging task for clinicians.

AKP is frequently defined as retropatellar or peripatellar pain, of more than three months' duration, in the absence of intra-articular pathology, that is aggravated by activities that load a flexed knee joint (Crossley et al., 2001; Harvie et al., 2011; Nunes et al., 2013; Prins & van der Wurff, 2009). The diagnosis of AKP is most commonly made based on the definition as well as the exclusion of other pathologies. However, this diagnostic procedure is vague and difficult to reproduce in a clinical setting. The aim of this study was to create an evidence-based checklist for researchers and clinicians to use for the diagnosis of AKP.

2.2 Methods

2.2.1 Study selection criteria

English-only studies reporting on the clinical diagnostic tests for AKP were considered for inclusion. Due to the abundance of literature on AKP, only systematic reviews were eligible for inclusion.

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Studies describing the subjective information used for the diagnosis of AKP such as the age of the subject, the duration of the symptoms, aggravating activities, previous history of trauma or other known knee injuries, were considered for inclusion. Studies describing objective clinical tests used for the diagnosis of AKP were included. Radiographic procedures such as MRIs were excluded as these procedures cannot form part of a physiotherapy clinical assessment. For the same reason, arthroscopic procedures were also excluded.

The subjects of the studies included both genders. Exclusions were for studies that may have incorporated diagnoses of Osgood-Schlatter and osteoarthritis in participants younger than 18 years or older than 40 years. In addition, studies portraying knee abnormalities such as patella subluxation or intra-articular pathology were also omitted.

2.2.2 Search strategy

Publications from inception to July 2016, located in PubMed, Ebscohost (MEDLINE, CINAHL, SportDiscuss), Scopus and Science Direct, were accessed in library databases at the Medical Library at Stellenbosch University during July 2016. The keywords used by the researcher (DL) in all the searches were: “anterior knee pain”, “patellofemoral pain syndrome”, “diagnosis”, “clinical tests” and “systematic reviews”. Searches were database-specific with MeSH terms for “patellofemoral pain syndrome” used in search engines such as PubMed.

PRISMA guidelines were followed with the reviewer (DL) screening the titles and abstracts of the first hits and consulting with the second reviewer (QL) as needed. Both reviewers retrieved all potential complete texts independently and used the same criteria to decide which ones were relevant for inclusion in the review after having considered possible discrepancies in the texts. The individual diagnostic studies within the included reviews were then analysed.

2.2.3. Methodological quality appraisal

A clinical appraisal tool (CAT) for systematic reviews was used for the appraisal of included studies. This CAT comprises ten questions assessing the methodological quality of the study and validity of the findings. This CAT, as well as a detailed explanation of the criteria, can be found on the BMJ website

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(http://clinicalevidence.bmj.com/x/set/static/ebm/toolbox/665052.html) and is presented in Appendix E.

2.2.4. Development of a diagnostic checklist

An evidence-based checklist was created based on the subjective and objective findings. For the subjective factors, two or more of the systematic reviews were needed to identify the factor as being important in the diagnosis of AKP. For the objective factors, two of more of the reviews were needed to recommend the test based on either a sensitivity (more than 70%) or a positive likelihood ratio (more than 5). A positive likelihood ratio of between 2 and 5 is considered to generate small but clinically important changes in probability (Nijs et al., 2006). Clusters of tests found to improve diagnosis in any of the included reviews were also considered for the checklist.

2.3 Results

Two systematic reviews (Cook et al., 2012; Nunes et al., 2013), consisting of nine different diagnostic studies, were identified by our search methods. Of the nine diagnostic studies, four full texts were excluded as they used arthroscopic surgery for diagnosis and not clinical tests. A PRISMA flowchart is given in Figure 2.

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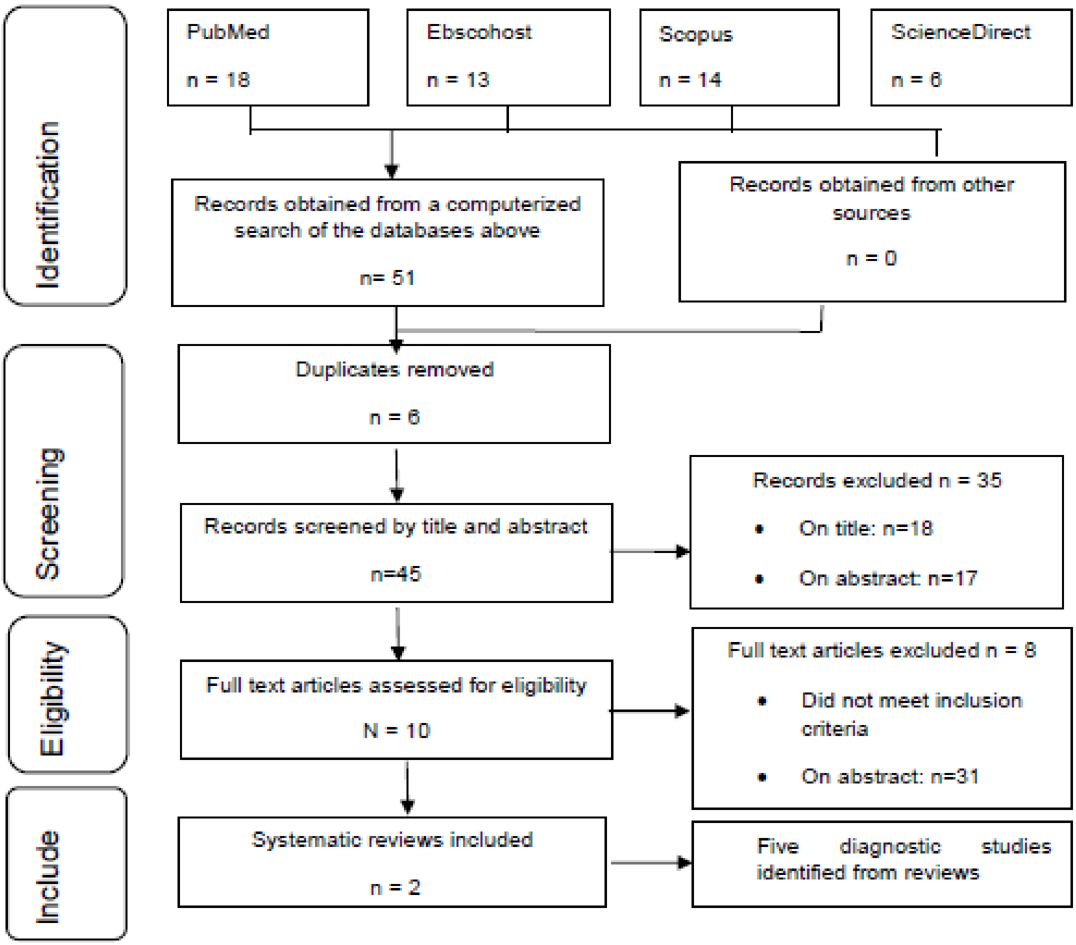

n: total number.

FIGURE 2. PRISMA flowchart of literature search.
Source: www.**prisma**-statement.org/**PRISMA**Statement/**FlowDiagram**.aspx

The final checklist is presented in Table 4 at the end of the chapter. Based on these studies, initial information that should be included in the subjective assessment includes age, area of pain, duration of symptoms, previous history of lower limb trauma or surgery and common aggravating factors. A flowchart of the diagnostic procedure is given in Figure 3

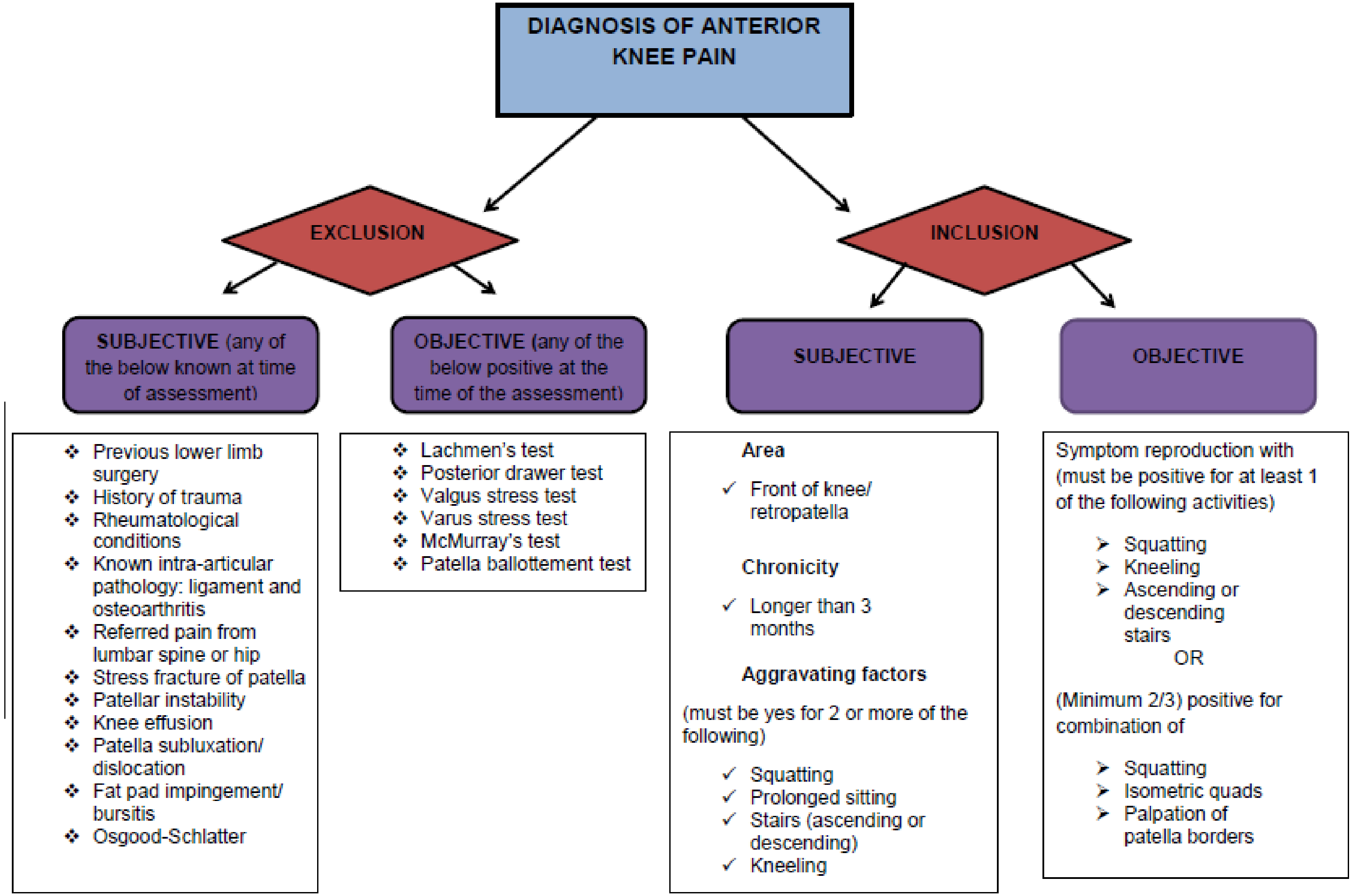

FIGURE 3. Flowchart demonstrating the process of diagnosis for anterior knee pain
Source: Cook et al., 2012; Nunes et al., 2013

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As AKP is still largely a diagnosis of exclusion, subjects should not be diagnosed with AKP if they are known to have any of the following pathologies: osteoarthritis; rheumatoid arthritis; patella fractures; patella subluxation and dislocation; fat pad impingement or bursitis; growth disorders such as Osgood-Schlatter; intra-articular pathology; patellar tendinitis; or referred pain from the lumbar spine or hip (Cook et al., 2010; Haim et al., 2006; Nijs et al., 2006; Sweitzer et al., 2010). Objective tests can be divided into functional clinical tests, manual tests and exclusion of intra-articular pathologies.

Table 1 summarises the accuracy of commonly used diagnostic tests for AKP. Clinical functional tests that most commonly reproduce symptoms in patients with AKP are squatting, kneeling, stair climbing and prolonged sitting. Squatting is the most accurate functional test with a sensitivity of 91%. Kneeling, stair ascent or descent and prolonged sitting follow with sensitivities of 84%, 75% and 72%, respectively (Cook et al., 2010; Haim et al., 2006; Näslund et al., 2006; Nijs et al., 2006; Sweitzer et al., 2010). It has been suggested that patients should present with pain in two or more of these activities in order to be diagnosed with AKP (Cook et al., 2012). Of the manual tests considered, only the patellar compression test (sensitivity of 83%) and the patellar tilt test (likelihood ratio = 5.4) can be recommended as diagnostic tests for AKP (Haim et al., 2006; Näslund et al., 2006; Sweitzer et al., 2010).

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TABLE 1: Accuracy of commonly used diagnostic tests for AKP

Test	Sensitivity	Specificity	LR+	LR–	PV+	PV–
Squatting	91	50	1.8	0.2	79	74
Kneeling	84	50	1.7	0.3	79	61
Stairs ascending and descending	75	43	1.3	0.6	73	46
Prolonged sitting	72	57	1.7	0.5	77	50
Patellar tilt test	43	92	5.4	0.6	93	40
Patellar compression test	83	18	1.0	1.0	63	38

LR: Likelihood ratio; PV: Predictive value

Source: Cook et al., 2010; Haim et al., 2006; Näslund et al., 2006; Nijs et al., 2006; Sweitzer et al., 2010

On clinical appraisal of the two included systematic reviews (Cook et al., 2012; Nunes et al., 2013), both studies achieved scores of 8/10, or 80%. Therefore, these reviews can be considered to be of high methodological quality. Table 2 shows the scoring according to the CAT.

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TABLE 2: Quality of evidence for diagnostic review

Study	**Cook et al., 2011**			**Nunes et al., 2013**		
SR quality criteria	**Yes**	**No**	**Can't tell**	**Yes**	**No**	**Can't tell**
1	×			×		
2		×			×	
3	×			×		
4	×			×		
5	×			×		
6	×			×		
7	×			×		
8	×			×		
9	×			×		
10		×			×	
Total	8/10			8/10		

Source: http://clinicalevidence.bmj.com/x/set/static/ebm/toolbox/665052.html
SR: Systematic review

2.4 Discussion

In this article, we created a standardised method for the diagnosis of AKP based on a systematic review of the evidence. Diagnosis of AKP is based on the area of pain, age, duration of symptoms, common aggravating factors, manual palpation, and exclusion of other pathologies. AKP can be defined as pain in the infrapatellar or retropatellar regions, in the absence of intra-articular pathology, that restricts activities of daily living that require knee flexion such as ascending or descending stairs, squatting and prolonged sitting (Cook et al., 2010; Haim et al., 2006; Näslund et al., 2006; Nijs et al., 2006; Sweitzer et al., 2010).

The subjective examination is important in the diagnosis of AKP. The interview should localise the pain, define the timing of onset and determine acute versus chronic versus overuse (Pećina & Bojanić, 1993). This information is important as it helps the clinician to rule out competing diagnoses. Extensor mechanism dysfunction is most commonly as a result of chronic repetitive trauma. AKP can also be patella subluxation or dislocation, ruptured patella or quad tendons. AKP during rest is often indicative of chondral lesions or dysfunctions (Post, 1999; Smith et al., 2010).

The search procedures yielded two systematic reviews (Nunes et al., 2013; Cook et al., 2012). From these two reviews we were able to identify five diagnostic

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studies (Cook et al., 2010; Haim et al., 2006; Näslund et al., 2006; Nijs et al., 2006; Sweitzer et al., 2010). The systematic review by Nunes et al. (2013) looked at five studies, that in total analysed 25 tests commonly used to diagnose AKP. The review concluded that there is no consistent evidence regarding the accuracy of commonly used diagnostic tests for AKP. However, the patellar tilt test (Haim et al., 2006) and the pain during squatting test (Cook et al., 2010) showed a strong tendency towards the PFPS diagnosis. The pain during squatting test demonstrated the highest sensitivity.

The other systematic review that was acquired through our search procedures (Cook et al., 2012) included nine studies; however, four were excluded as they made use of arthroscopy. The review included a variety of tests used to reproduce AKP including functional tests, patella mobility tests, special tests and the Q-angle test. Of these the functional tests, in particular, squatting, stair climbing and prolonged sitting demonstrated the highest accuracy.

Nijs et al. (2006) investigated the validity of five clinical tests for AKP, including the vastus medialis coordination test, the patellar apprehension test, Waldron's test, Clarke's test and the eccentric step test. In this study, the vastus medialis and patellar apprehension tests had a ratio of 2.26 and the eccentric step test scored 2.34. Waldron's test and Clarke's test both scored below 2, thus questioning their validity. Limitations of the study included inability to standardise the amount of force used, the tests were performed in isolation and in reality, these tests would be combined with other tests as part of a full subjective and objective clinical evaluation. The order of the tests also should have been standardised. Based on our criteria for inclusion, none of these tests are accurate enough to be considered for diagnosis.

Cook et al. (2010) explored the diagnostic accuracy of physical tests and functional activities commonly used to diagnose AKP. Clusters of functional findings and physical examination tests were also tabulated to determine combinations that improved diagnostic accuracy. Patients with intra-articular pathology were excluded. Measures used were manual compression of knee cap against femur (1) during rest and (2) during an isometric knee contraction, palpation of the posteriomedial and posteriolateral borders of the patella, resisted

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isometric quadriceps femoris muscle contraction, squatting, stair climbing, kneeling and prolonged sitting.

These measures were investigated as they are routinely used to measure AKP even though very few of these measures have been investigated for accuracy. The authors found that clusters may marginally improve accuracy. The cluster of two out of three positive tests for squatting, isometric quadriceps contraction and palpation of the patella borders scored the highest with a positive likelihood ratio of 4. The authors recommended the use of this cluster of tests to diagnose AKP in a clinical assessment. Individually, squatting, palpation, stepping down and the patella tilt test were recommended as useful tests to include in the clinical assessment.

Sweitzer et al. (2010) investigated the accuracy of patellar mobility tests including superior-inferior patellar mobility, medial-lateral patellar mobility, patellar tendon mobility and patellar inferior pole tilt. However, all of these tests demonstrated poor sensitivity (19% – 63%) as well as positive likelihood ratios (1.4–1.9) and have therefore not been included in our checklist.

In a study by Näslund et al. in 2006, a physiotherapist and an orthopaedic surgeon examined 80 patients clinically diagnosed with AKP and referred for physiotherapy. The examination included a case history and a clinical examination. The four tests used in the clinical examination were the patellar compression test, medial and lateral tenderness on extension, passive gliding of the patella and the Q-angle test. The results indicated that the compression test demonstrated the highest sensitivity (83%), but none of the tests could predict findings seen in radiographic examinations. The authors suggested that the Q-angle test can no longer be considered a reliable test in diagnosing AKP, as it shows great inter- and intra-observer variability. This is in agreement with a recent systematic review of prospective studies that demonstrated that the Q-angle is not a risk factor for AKP, thus questioning its relevance (Smith et al., 2008). The authors (Näslund et al., 2006) suggested the AKP is still ultimately a diagnosis of exclusion as it is a term used for knee pain that can be attributed to multiple causes. Therefore, more research on pathophysiology needs to be done.

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A very important aspect of diagnosis for AKP is the exclusion of intra-articular pathologies. These include ligaments such as ACL, PCL, MCL and LCL and the meniscii (medial and lateral). The most accurate tests to achieve this have been given in Table 3 (Benjaminse et al., 2006; Day et al., 2009; Malanga et al., 2003; Nijs et al., 2006). Based on this, we have chosen to include the anterior drawer test, the posterior drawer test, the valgus stress test, the varus stress test, McMurray's test and the patellar ballottement test in our checklist for the purpose of exclusion.

TABLE 3: Most accurate tests for exclusion of intra-articular pathology

Test	**Structure**	**Sensitivity (%)**	**Specificity (%)**
Lachman's	ACL	85	94
Anterior drawer	ACL	92	91
Posterior drawer	PCL	51–100	99
Valgus stress	MCL	86–96	Not reported
Varus stress	LCL	25	Not reported
Pivot shift	Meniscus	24	98
McMurray's	Meniscus	16–58	77–98
Apley's grind	Meniscus	13–16	80–90
Patellar ballottement	Effusion	32	100

Source: Benjaminse et al., 2006; Day et al., 2009; Malanga et al., 2003; Nijs et al., 2006

The two reviews used for the creation of our evidence-based checklist were both of high quality. The reviews evaluated the quality of the included studies and took this into consideration when making the recommendations. Consequently, we can be confident that the checklist is based on high-quality evidence. A limitation of this study is that search results were limited due to a lack of evidence on clinical tests used for the diagnosis of AKP. The checklist should be updated as more evidence becomes available. A systematic approach was used to ensure transparency of methods, minimise bias and produce reliable findings (Higgins & Green, 2011). However, due to the strict search criteria the search was limited.

In order to improve on the current evidence, it is necessary to establish possible causes of AKP. Causes are believed to be multifactorial, and diagnosis is still largely a diagnosis of exclusion in a specific population of younger active people. There may be subgroups of individuals with AKP and the aetiology may vary within these subgroups.

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2.5 Conclusion

AKP can be defined as retropatellar or peripatellar pain, of more than three months' duration, in the absence of intra-articular pathology, that is aggravated by activities that load a flexed knee joint (Crossley et al., 2001; Harvie et al., 2011; Nunes et al., 2013; Prins & van der Wurff, 2009). The diagnosis of AKP is made based on the definition as well as the exclusion of other pathologies. There are many clinical tests used to diagnose AKP; however, there is no standard method to diagnose AKP and many of the tests are not accurate. A diagnostic checklist is useful as it provides a structured method for diagnosing AKP in a clinical setting. Research is needed to establish the causes of AKP as it is difficult to diagnose a condition with unknown aetiology.

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TABLE 4: Evidence-based checklist for the diagnosis of AKP

SUBJECTIVE INFORMATION:

Age (must be yes)

	YES	NO
14-50[1,2,3,4,5]		

Area (must be yes)

	YES	NO
Front of knee or retropatellar[1,2,3,4,5]		

Chronicity

	YES	NO
Longer than 3 months[1,3,5]		

Aggravated by (must be yes for 2 or more of the following)

	YES	NO
Squatting[1,2,3,4,5]		
Prolonged sitting[1,2,3,4,5]		
Stairs (ascending or descending)[1,2,3,4,5]		
Kneeling[1,2,3,4,5]		

Excluded if any of the below known

	YES	NO
Previous lower limb surgery[1,3,5]		
History of trauma[1,3,5]		
Rheumatological conditions[1,3,5]		
Known intra-articular pathology: ligament and osteoarthritis[1,2,3,4,5]		
Patellar instability[1,4]		
Knee effusion[1,5]		
Patella subluxation/ dislocation[1,5]		
Fat pad impingement/ bursitis[3,5]		
Osgood-Schlatter[1,3]		

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OBJECTIVE TESTS:

Symptom reproduction with (must be positive for at least 1 of the following activities)

Squatting[1,2,3,4,5]		
Kneeling[1,2,3,4,5]		
Ascending or descending stairs[1,2,3,4,5]		

Positive for at least one of the following

Patellar compression test[1,4]		
Patellar tilt test[1,4]		

OR

(Minimum 2/3) positive for combination of

Squatting[3]		
Isometric quads[3]		
Palpation of patella borders[3]		

Excluded if positive for

Lachman's Test[6,7,8]	ACL		
Posterior Drawer Test[6,8]	PCL		
Valgus Stress Test[6,8]	MCL		
Varus Stress test[6,8]	LCL		
McMurray's Test[6,8]	MENISCUS		
Patellar Ballottement Test[5]	Effusion		

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Chapter 3: Kinematic factors associated with anterior knee pain during common aggravating activities: A systematic review

ABSTRACT

Background

AKP is a common condition with unknown aetiology. There are many proposed biomechanical factors associated with AKP, however it is unclear which factors are the most important and clinically relevant.

Objectives

To systematically review and summarise the literature on kinematic factors associated with AKP. The secondary objective was to create an evidence-based algorithm to be used by clinicians for screening purposes.

Method

A comprehensive search was conducted in November 2016 of all accessible electronic databases of published research available at Stellenbosch University library. The review was done according to PRISMA guidelines. Two reviewers screened the full-text articles for inclusion based on our criteria.

Results

Nineteen studies were included in this review, with a total sample of 734 subjects, 415 of which had been diagnosed with AKP. Subjects with AKP had significantly reduced peak hip internal rotation during gait (MD= -5.54; CI -7.54, -3.5); and significantly increased peak trunk ipsilateral lean (MD=2.76; CI: 0.96, 4.56), hip adduction (MD=4.51; CI: 1.98, 7.04) and knee valgus (MD=4.93; CI 2.06, 7.80) during single leg squatting compared to controls. No meta-analyses were possible for stair climbing outcomes due to study heterogeneity.

Conclusion

Clinicians should target the factors supported by the most evidence first in treatment. Gait and single leg squatting are currently the best activities to use for

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screening of abnormal biomechanics in subjects with AKP. Future research should focus on high-quality prospective studies to determine causality.

3.1 Introduction

Anterior knee pain (AKP) is prevalent in young, athletic populations (Rathleff, C.R., Roos et al., 2013). The incidence of AKP is estimated to be as high as 25-43% in sports injury clinics (Boling et al., 2010). The symptoms associated with AKP are also persistent, with an estimated 91% of patients diagnosed with AKP still experiencing symptoms four years after its onset (Collins et al., 2013; Rathleff, C.R., Roos et al., 2013). The duration of pain (pain for more than three months) is a consistent predicter of poor long-term prognosis, including poor outcome at 12 months (visual analogue scale, anterior knee pain scale, and functional index questionnaire). An anterior knee pain scale score of less than 70/100 is also a consistent poor prognostic factor. Therefore, early management may be important in enhancing prognosis (Collins et al., 2013).

The long-term impact of AKP may be significant as there is a proposed link between AKP and patellofemoral joint (PFJ) osteoarthritis later in life (Thomas et al., 2010). Persistent AKP may also have long-term implications for participation in daily and work tasks and well as sporting activities. It frequently hinders an individual's ability to perform common activities of daily living (ADLs) such as stair climbing and prolonged sitting, as well as sporting activities such as running and jumping (Nunes et al., 2013).

AKP is a poorly defined condition that is often used interchangeably with the term "patellofemoral pain syndrome" (Näslund et al., 2006). The definition is commonly based on the area of pain, the duration of symptoms, exclusion of intra-articular pathologies and the aggravating activities (Harvie et al., 2011; Nunes et al., 2013). Definitions have included AKP that is intensified by stairs, prolonged sitting and squatting (Nijs et. al., 2006); pain in and around the patella (Houghton, 2007); the insidious onset of retropatellar or anterior knee pain of greater than six weeks, provoked by selected activities (Collins et. al., 2008) and AKP related to dysfunction of the patellofemoral joint after other pathologies, have been excluded (Näslund et. al., 2006). For the purpose of this review AKP can be

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defined as retropatellar or peripatellar pain, that is aggravated by activities that load a flexed knee joint (Harvie et al., 2011; Nunes et al., 2013).

The onset of AKP is thought to involve excessive joint stress during activities that load the flexed knee joint. This patellofemoral joint stress is then transmitted through the cartilage thereby exciting nocioceptors in subchondral bone resulting in pain (Besier et al., 2011). Over time, this joint stress may result in articular cartilage pathology (Powers et al., 2014; Islam et al., 2015). However, the aetiological pathways are unknown (Islam et al., 2015). Their causes are thought to be multifactorial in origin, involving a variable combination of malalignment of the lower extremity, muscle imbalance around the hip and knee and overactivity (Rothermich et al., 2015; Lankhorst et al., 2012).

Abnormalities in kinematics and alignment that may contribute towards increased joint stress include an increased dynamic Q-angle, increased genu valgum, increased tibia varum, lateral displacement of the patella within the femoral trochlear and muscle imbalances (Lankhorst et al., 2012; MacIntyre et al., 2006). As AKP is most prevalent in a young active population, overactivity (in particular a sudden increase in training) should be considered a potential cause of the onset of pain (Ratleff et al., 2013; Milgrom et al., 1991).

Distal, proximal and local factors may contribute towards the development of AKP and therefore an understanding of the various contributing factors for AKP is essential to improve our understanding of the condition. Despite prolific information on factors associated with AKP, the findings remain inconclusive. An evidence synthesis from three systematic reviews (Lankhorst et al., 2012; Pappas, & Wong-Tom, 2012; Warryz, & McDermott, 2008) found that the only evidence-based factor that is strongly linked to AKP is decreased knee extensor strength. However, none of these reviews included primary studies into kinematic factors during functional activity. One systematic review has specifically investigated gait-related biomechanical contributing factors for AKP. Barton et al. (2009) evaluated gait-related kinematics in subjects with AKP during a variety of functional activities such as walking, running and stair and ramp ascent and descent.

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Twenty-four studies were included in this review. Twenty-three of these had case-control designs and one study was prospective (Hetsroni et al., 2006). Due to significant study heterogeneity, no effect size calculations or meta-analyses were possible. However, there were some potential trends that emerged. The review showed a trend towards reduced gait velocity during all activities tested in subjects with PFPS. In terms of kinematics, those results showed that individuals with AKP might have increased peak rear foot eversion at heel strike, delayed peak rear foot eversion during walking and running and reduced hip internal rotation during walking. There was limited evidence for reduced peak hip internal rotation, reduced peak knee flexion in the stance phase during walking; and greater knee external rotation at peak knee extensor moment during running. Findings of hip internal rotation parameters were inconsistent for walking and running. The findings of the review showed insufficient evidence for kinematic differences in any outcomes during stair and ramp climbing.

The authors concluded that due to the limited evidence for gait-related kinematics, more evidence is required to establish common biomechanical contributing factors for AKP. They recommended that prospective research should be conducted in future investigations to establish which factors may be predictive of pain. Due to the limited evidence found in 2009, an updated review is warranted.

An additional challenge is that the clinical implications of biomechanical factors are not always clear. Distinct recommendations for clinicians based on the best available evidence, are needed so that they know which features to address. Therefore, the aims of this review are to systematically review and summarise the body of evidence for kinematic risk factors in an AKP population and to create an evidence-based checklist for clinicians that highlights the most likely contributing factors for screening in order to facilitate rehabilitation.

3.2 Methods

The study protocol was approved by the Health Research Ethics Committee of Stellenbosch University in Cape Town, South Africa under ethics number N13/05/078. The authors certify that they have no affiliations with or financial

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involvement in any organisation or entity with a direct financial interest in the subject matter or materials discussed in the article.

3.2.1 Study selection criteria

Studies written in English reporting on the 3D kinematic factors associated with AKP were considered for inclusion. Studies were included if they were conducted to determine whether lower limb kinematic differences exist between subjects with or without AKP. Case-control, cross-sectional studies and prospective studies were eligible for inclusion. Qualitative research was excluded. The review included studies on any individuals diagnosed with AKP which could include any of the many synonyms associated with this condition (patellofemoral pain syndrome, patellofemoral joint dysfunction, retropatellar pain, patella malalignment syndrome, chondromalacia patella).

Males and females were included. Studies that included participants under the age of 18 or over the age of 40 were excluded in order to rule out Osgood-Schlatter and osteoarthritis as differential diagnoses. Studies that did not describe the diagnostic criteria used for the inclusion of participants were excluded. Studies that described other disorders of the knee such as osteoarthritis, patella subluxation or intra-articular pathology were excluded. Studies were included if they assessed kinematics during one of the following functional activities: walking, stair ascent or descent or single leg squatting.

The primary outcomes of interest for this review were the kinematic parameters of the lower extremity and trunk associated with AKP. Therefore, studies that used 3D motion analysis to acquire trunk, pelvic, hip, knee, ankle and foot joint kinematics, were included. For the purpose of this study, we only included tibiofemoral joint biomechanics for the knee joint, as advanced modelling is required to determine patellofemoral outcomes. Magnetic resonance imaging (MRI), computed tomography (CT) scan and x-ray studies were excluded as functional movement is not possible during these investigations.

3.2.2 Search strategy

A comprehensive search was conducted in November 2016 in all accessible library databases of published research reports available at the Stellenbosch

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University Medical Library. The following databases were searched from the inception of research to November 2016: PubMed, Ebscohost (MEDLINE, CINAHL, SportDiscuss), SCOPUS and Science Direct. A number of key words were applied to each database's search tool to narrow the search and to develop the most precise strategy for that database. Only English articles were included. The same key search terms were used for all databases with the appropriate truncation and Boolean operators (such as 'AND' and 'OR').

The following key words were used for the searches: "anterior knee pain", "patellofemoral pain syndrome", "biomechanics", "kinematics", "gait", "walking", "locomotion" OR "stairs" OR "squatting". The same approach was used for all searches and adapted as necessary according to specifics for that database. MeSH terms were used for "patellofemoral pain syndrome" in search engines, such as PubMed, that made use of that function. The searches were conducted by the researcher (DL) with experience in systematic review searches.

This review was done in accordance with the PRISMA guidelines. One reviewer (DL) screened the titles and abstracts of all initial hits. All potential full texts were downloaded and duplicates removed. A second reviewer (QL) was consulted when necessary. Both reviewers (DL and QL) retrieved the full texts of all potentially relevant articles and then screened them independently using the same criteria to determine the eligibility of the papers for inclusion in the review. The reviewers compared the full texts that had been accepted for inclusion and any discrepancies were discussed. A full search strategy for PubMed can be found attached as Appendix F. This strategy was adapted as necessary for each database.

3.2.3 Methodological quality appraisal

A clinical appraisal tool (CAT) used to assess quantitative studies was used to appraise the quality of the included papers (Law et al., 1998). The CAT consisted of 16 questions addressing three main issues: the results of the studies, the validity and whether the results are helpful (clinical significant). An answer of "yes" or "no" was required to answer the questions. Two randomly selected papers were screened by the second reviewer (QL) and discrepancies in the results were discussed. The following descriptive categories were used for interpretation of

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the methodological quality: a CAT score above 75% was considered good methodological quality; a score between 50% and 75% was considered moderate quality and a score lower than 50% was deemed to be of poor methodological quality (Law et al., 1998).

3.2.4 Evidence grading

Grading of evidence and subsequent recommendations for clinicians to isolate factors associated with AKP were obtained using the FORM framework, which was devised and scrutinised for an updated edition of the Australian NHMRC (National Health and Medical Research Council) standards (Hillier et al., 2011). In this study three components, namely level of evidence, consistency of evidence and the clinical impact are considered. The former pertains to the quality of evidence displayed by each biomechanical risk factor (Hillier et al., 2011), graded according to the NHMRC hierarchy for aetiology as reflected in Table 5.

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TABLE 5: NHMRC hierarchy of evidence for aetiology

Evidence level	Study design
I	Systematic review of prospective cohort studies
II	One prospective cohort study
III	One retrospective cohort study
IV	A case control study
V	A cross-sectional study or case series

The latter, clinical impact or effect size, refers to a subjective measure of the benefits that any research outcome would exert on a specific population (Hillier et al., 2011). Where there were noticeable differences between subjects with AKP and controls, effect size was determined by using the mean difference in angles.

3.2.5 Data extraction

Two customised excel spreadsheets, based on Cochrane forms, were used for data extraction. These spreadsheets extracted information regarding the sample demographics as well as the setting, study aims, study design, biomechanical outcomes of interest, functional activity assessed and results (p-values, means and standard deviations).

3.2.6 Data analysis or synthesis

Data was described narratively using tables or narrative summaries where appropriate. A random effects model in Revman version 5.3 was used to calculate mean differences and 95% confidence intervals (CI), provided that means and standard deviations (SD) were reported. Forest plots illustrating the mean difference and 95% CI were generated for graphic illustration. A meta-analysis was conducted for parameters which were reported in at least two studies, provided that homogeneity in the outcomes and samples were present.

3.2.7 Development of a clinical algorithm

The risk factors were classified according to their level of evidence. Grading the evidence allowed for a clinical algorithm to be developed for the screening/prevention and management AKP. The algorithm was originally developed by Aderem & Louw (2015) for identification of biomechanical factors associated with iliotibial band syndrome (ITBS). Three algorithms were created for

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the three activities considered in this review, namely walking (Figure 5), single leg squatting (Figure 6) and stair climbing (Figure 7)

These algorithms act as a guide for clinicians to screen for kinematic factors which may contribute towards the development or chronicity of a patient's AKP. The gender for each risk factor was specified. Findings were then classified into whether they were statistically significant or insignificant. Effect size was determined for statistically significant findings. Cross-sectional findings were classified within four categories which were based on whether the findings were "significant", "insignificant", "consistent" or "inconsistent". Effect sizes for the "must consider" and "maybe consider" categories were determined. An outcome was classified as "must consider" when there was supporting evidence based on at least two cross-sectional studies with significant and consistent findings. These are the priority contributing factors that clinicians should address first with treatment if a patient presents with them. An outcome was classified as "maybe consider" if there was supporting evidence based on a single study with significant findings. These factors should be considered if there are no "must consider" contributing factors present. Outcomes were classified as "do not consider" if there was conflicting evidence based on two or more studies and "not currently clinically relevant" if a single study yielded statistically insignificant findings. Factors in these two categories should not be addressed in treatment.

3.3 Results

The initial search based on the keywords described above yielded a total of 309 hits. Duplicates were removed reducing the total number of potential studies for inclusion to 267. Following the application of the inclusion and exclusion criteria to the titles, 183 studies were excluded. The main reason for exclusion by title was that the studies were looking at conditions other than AKP. After abstracts were read, 57 studies were excluded. The primary reason for excluding these studies was that the risk factors investigated were not biomechanical (strength, flexibility, etc.). After reading the 27 full texts that were still eligible, the number of studies to be included in this systematic review was reduced to 19. The reason for excluding three of the full texts was that the activity used for the assessment

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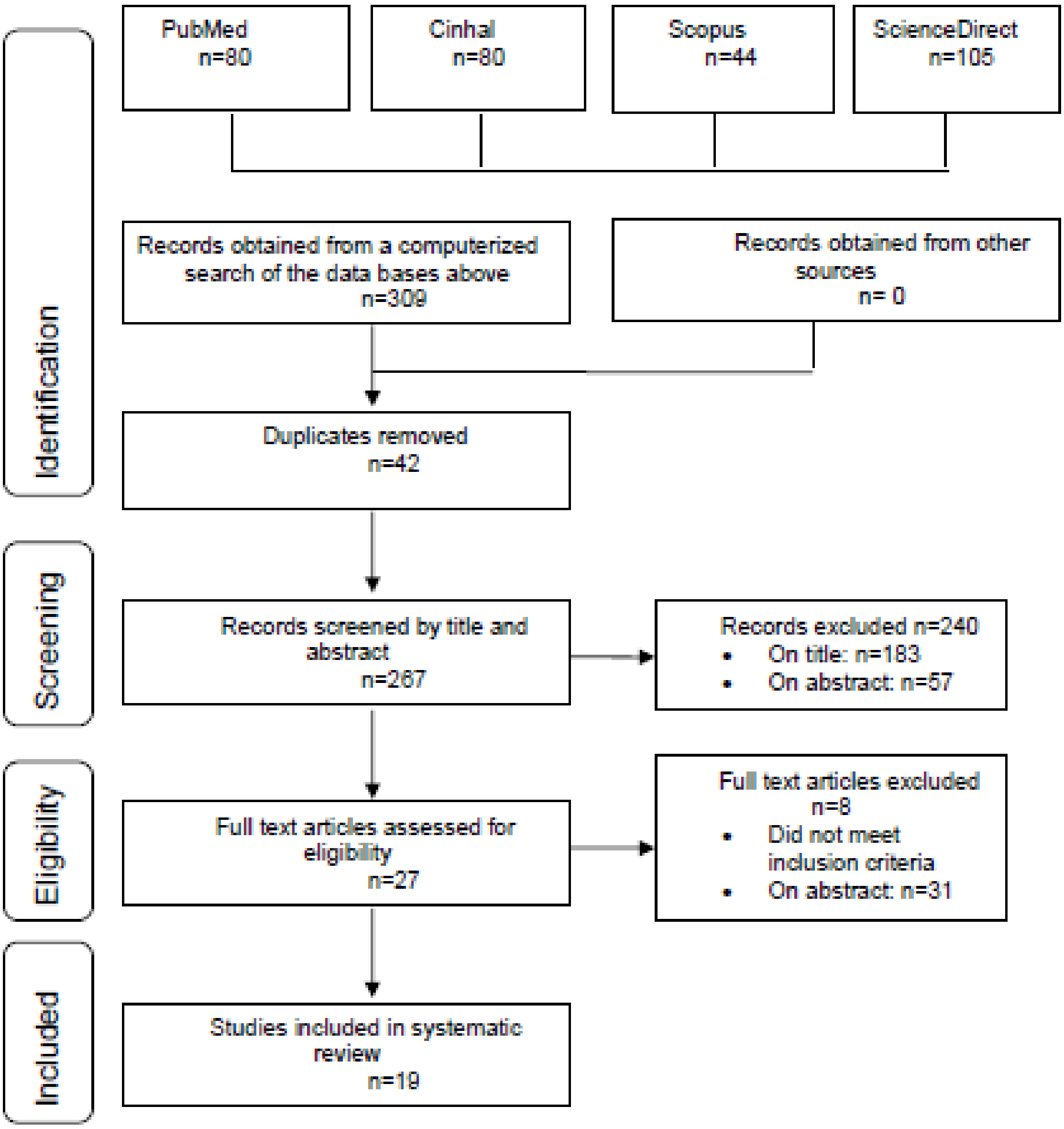
was not walking, stairs or squatting as outlined in the inclusion criteria. Results of the search strategy can be seen in Figure 4.



Abbreviations: n=total number

FIGURE 4. PRISMA flowchart for review on kinematic factors associated with AKP

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3.3.1 Sample description

The number of participants in each study varied from 10-80. The total sample was n=734. In the eligible studies, 415 subjects had AKP and the mean sample size was n=38.6. Twelve of the studies included females only (Salsich & Long-Rossi, 2010; de Oliveira Silva et al., 2015; McKenzie et al., 2010; Herrington, 2013; Willson & Davis; 2008; Grenholm et al., 2009; Levinger & Gilleard, 2005; Levinger & Gilleard, 2007; Powers et al., 1996; Powers et al., 1997; Powers et al., 1999; Powers et al., 2002). A sample description of the 19 eligible studies can be seen in Table 6. The ages of participants, anthropometrics and study settings appear similar.

3.3.2 Study design, aims and outcomes

The study design, aims and outcomes are summarised in Table 7. A common aim among all studies was to determine whether kinematic differences existed between groups with and without AKP. All the studies had cross-sectional designs and compared kinematics in an AKP population to pain-free controls. There was significant heterogeneity in terms of the functional activities that were used for assessment. Four studies investigated single leg squatting, three assessed gait biomechanics and two looked at stair climbing.

3.3.3 Methodological quality

All studies were cross-sectional with level 5 evidence. The methodological quality scores of the eligible studies can be seen in Table 8. The mean methodological score was 79.6% which, based on our criteria, can be considered moderate to good quality (80% considered good). All the included studies achieved moderate to good quality scores.

TABLE 6: Sample description of included studies for review of kinematic factors associated with AKP

	Sample size (n)			Gender (F/M)		Mean Age (yr) (SD)		Mass (kg) (SD)		Height (m) (SD)		Study setting
	Total	PFPS	CON	PFPS	CON	PFPS	CON	PFPS	CON	PFPS	CON	
Salsich, & Long-Rossi, 2010	40	20	20	0M 20F	0M 20F	25.6 (6.8)	24.0 (4.3)	62.3 (10.2)	66.1 (13.2)	1.7 (0.04)	1.7 (0.07)	Motion Analysis Laboratory Saint Louis University, USA
Barton et al., 2011	46	26	20	5M 21F	4M 16F	25.1 (4.6)	23.4 (2.3)	66.7 (12.8)	66.0 (15.4)	1.7 (0.08)	1.7 (0.08)	Motion Analysis Laboratory La Trobe University, Australia
Barton et al., 2012	46	26	20	5M 21F	4M 16F	25.1 (4.6)	23.4 (2.3)	66.7 (12.8)	66.0 (15.4)	1.7 (0.08)	1.7 (0.08)	Motion Analysis Laboratory La Trobe University, Australia
McKenzie et al., 2010	20	10	10	10F	10F	23.5 (3.4)	22.3 (2.4)	65.7 (13.8)	60.8 (9.4)	1.3 (0.09)	1.3 (0.07)	Motion Analysis Laboratory, McMaster University, Canada
Nakagawa et al., 2015	60	30	30	20F 10M	20F 10M	22.7 (3.4)	22.3 (3.0)	65.3 (10.3)	63.3 (9.8)	1.7 (0.1)	63.3 (9.8)	Motion Analysis Laboratory University of São Carlos, Brazil
Nakagawa et al., 2012	80	40	40	20M 20F	20M 20F	23.5 (3.8)	22.6 (3.2)	71.5 (8.5)	67.0 (8.2)	1.7 (0.55)	1.7 (0.7)	Motion Analysis Laboratory University of São Carlos, Brazil
Herrington 2013	42	12	30	12F	30F	24.0 (3.2)	20.0 (1.4)	66.9 (9.9)	63.9 (6.0)	1.6 (0.1)	1.7 (0.1)	Motion Analysis Laboratory University of Salford, Manchester, UK
Willson & Davis, 2008	40	20	20	20F	20F	23.3 (3.1)	23.7 (3.6)	61.7 (10.6)	61.1 (5.4)	1.7 (0.08)	1.7 (0.06)	Motion Analysis Laboratory at the University of Delaware.

de Oliveira Silva et al., 2015	54	29	25	29F	25F	21.5 (2.9)	22.01 (3.05)	63.25 (10.8)	62.12 (7.3)	1.65 (0.02)	1.64 (0.06)	Motion Analysis Laboratory at the University of Sao Paulo, Brazil
Brechter & Powers, 2002	20	10	10	5M 5F	5M 5F	38.2	32.0	70.8	67.9	1.6	1.6	Motion Analysis Laboratory at University of Southern California
Crossley, Cowan et al., 2004	66	48	18	17M 31F	9M 9F	28	35	69.5	66.3	1.7	1.7	Motion Analysis Laboratory at University of Melbourne
Grenholm et al., 2009	34	17	17	17F	17F	27.7	26	63	61	1.6	1.6	Motion Analysis Laboratory at University of Sweden
Levinger & Gilleard, 2007	37	13	14	13F	14F	38.4	25.1	70.6	61.3	1.7	1.7	Motion Analysis Laboratory at Southern Cross University, Australia
Levinger & Gilleard, 2005	35	11	14	11F	14F	36.3	25.1	64.9	61.3	1.7	1.7	Motion Analysis Laboratory at Southern Cross University, Australia
Nadeau et al., 1997	10	5	5	2M 3F	2M 3F	28.4	25.5	67.6	67.0	1.7	1.7	Motion Analysis Laboratory at University of Montreal, Canada
Powers et al., 1997	38	19	19	19F	19F	24.4	27.5	62.4	59.2	1.7	1.7	Motion Analysis Laboratory at University of Southern California
Powers et al., 1999	25	15	10	15F	10F	26.6	31.5	65.3	63.7	1.6	1.7	Motion Analysis Laboratory at University of Southern California
Powers et al., 2002	42	24	18	24F	18F	25.4	27.6	63.6	59.6	1.6	1.7	Motion Analysis Laboratory at University of Southern California

Powers et al., 1996	35	26	19	26F	19F	25.6	27.5	63.9	59.2	1.7	2.7	Motion Analysis Laboratory at University of Southern California

TABLE 7: Study characteristics of included studies for review of kinematic factors associated with AKP

Study	Study Aim	Design	Biomechanical outcome of interest	Functional activity
Salsich, & Long-Rossi, 2010	To determine if females with patellofemoral pain (PFP) have increased hip adduction, hip medial rotation, and knee valgus during the stance phase of gait.	Cross-sectional	Hip frontal and transverse plane angle and knee frontal plane angle at peak knee extensor moment and peak knee extension angle	Self-selected speed and fast speed walking
Barton et al., 2011	To compare kinematics at the knee, hip and foot/ankle in a group of individuals with PFPS to a group of asymptomatic controls.	Cross-sectional	Variables of interest included magnitude and timing of peak angles and ranges of motion during stance for: Fore foot dorsiflexion, abduction and supination; Rear foot dorsiflexion, internal rotation, and eversion; Knee flexion, abduction/valgus and internal rotation; Hip adduction and internal rotation.	Walking at self-selected speed
Barton et al., 2012	To establish the relationship of rearfoot eversion with tibial internal rotation and hip adduction during walking in individuals with and without patellofemoral pain syndrome.	Cross-sectional	Variables of interest included peak angles and ranges of motion during stance for: Rear foot eversion; Tibia transverse plane internal rotation; Hip frontal plane adduction.	Walking at self-selected speed
McKenzie et al., 2010	To compare the knee and hip motions (and their coordination) during stair stepping in female athletes with and without PFPS.	Cross-sectional	3D hip and knee joint angles at foot contact	Stair ascent and descent

Nakagawa et al., 2012	To determine whether there are any differences between the sexes in trunk, pelvis, hip, and knee kinematics, hip strength, and gluteal muscle activation during the performance of a single-leg squat in individuals with patellofemoral pain syndrome (PFPS) and control participants.	Cross-section al	Peak 3D trunk, pelvis, hip, and knee kinematics	Single leg squatting
Nakagawa et al., 2015	To compare trunk kinematics, strength and muscle activation between people with PFP and healthy participants during single leg squatting.	Cross-section al	Peak ipsilateral trunk lean, hip adduction, and knee abduction were angles	Single leg squatting
Herrington ,2013	To investigate the degree of knee valgus, assessed as 2D frontal plane projection angle (FPPA) during single leg squatting (SLS) in patients with PFP and compare their performance to controls and the uninjured limb.	Cross-section al	The average FPPA angle value for from the three trials was used for analysis.	Single leg squatting
Willson & Davis, 2008	To compare lower extremity kinematics in females with and without PFPS during the progressively demanding activities of single leg squats, running, and repetitive single leg jumps.	Cross-section al	Peak knee external rotation, hip internal rotation, and hip adduction angles and excursions	Single leg squatting
de Oliveira Silva et al., 2015	To investigate whether there is a decrease in knee flexion in adults with AKP compared to controls during stair ascent	Cross-section al	Peak knee flexion angle	Stair ascent
Brechter & Powers, 2002	To determine whether individuals with patellofemoral pain (PFP) demonstrate elevated patellofemoral joint (PFJ) stress	Cross-section al	Peak knee flexion	Self-selected speed and fast speed walking

	compared with pain-free controls during free and fast walking.			
Crossley, Cowan et al., 2004	To investigate the amount of stance-phase knee flexion in individuals with and without PFP during stair climbing	Cross-sectional	Peak stance phase knee flexion	Stair ascent and descent
Grenholm et al., 2009	To address whether lower extremity kinematics are altered in young women with PFP during stair descent.	Cross-sectional	3D mean hip adduction, knee flexion and ankle dorsiflexion	Stair descent
Levinger & Gilleard, 2007	To measure rear foot and tibia motion, and the ground reaction force (GRF) during the stance phase of walking in subjects with PFPS and compare them to healthy subjects.	Cross-sectional	Timing of peak rear foot eversion and peak ankle dorsiflexion	Walking at self-selected speed
Levinger & Gilleard, 2005	To compare the peak and timing of the heel strike transient force between subjects with PFPS and healthy controls.	Cross-sectional	Mean rear foot eversion/inversion pattern of motion relative to the tibia during the stance phase	Walking at self-selected speed
Nadeau et al., 1997	To examine the gait pattern of PFPS patients walking at a preferred speed in order to determine if they presented kinematic and kinetic alterations during gait.	Cross-sectional	Overall sagittal plane ROM hip, knee and ankle	Walking at self-selected speed
Powers et al., 1997	To determine the influence of pain and muscle weakness on gait variables in subjects with patellofemoral pain (PFP)	Cross-sectional	Mean stance phase sagittal plane motion of the ankle, knee, and hip joints was measured.	Self-selected speed and fast speed walking
Powers et al., 1999	To determine if subjects with patellofemoral pain demonstrate excessive lower limb loading during gait.	Cross-sectional	Knee flexion and heel strike Peak stance phase knee flexion	Self-selected speed and fast speed walking
Powers et al., 2002	To test the hypothesis that subjects with PFP would exhibit larger degrees of foot pronation, tibia internal rotation, and femoral internal rotation compared to individuals without PFP.	Cross-sectional	Three-dimensional kinematics of the foot, tibia, and femur segments	Walking at self-selected speed

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			Magnitude and timing of peak foot pronation and tibia rotation and femoral internal rotation	
Powers et al., 1996	To ascertain whether there were differences in the activity of the vastus muscles that would be suggestive of patellar instability in subjects with PFP.	Cross-sectional	Sagittal plane knee ROM throughout the gait cycle	Walking at self-selected speed

TABLE 8: Quality of included studies for review of kinematic factors associated with AKP

		Salsich & Long-Rossi, 2010	Barton et al., 2011	Barton et al., 2012	McKenzie et al., 2010	Nakagawa et al., 2012	Nakagawa et al., 2015	Herrington 2013	Willson & Davis, 2008	de Oliveira Silva et al., 2015
1	Was the purpose of the study clearly stated?	+	+	+	+	+	+	+	+	+
2	Was the study design appropriate?	+	+	+	+	+	+	+	+	+
3	Were the sample biases detected in the study?	+	-	-	+	-	-	+	+	+
4	Were the measurement biases detected in the study?	-	-	-	-	-	-	-	-	+
5	Was the sample size stated?	+	+	+	+	+	+	+	+	-
6	Was the sample described in detail?	+	+	+	+	+	+	+	+	+
7	Was the sample size justified?	+	-	+	-	-	-	-	+	+
8	Were the outcomes clearly stated and relevant to the study?	+	+	+	+	+	+	+	+	+
9	Was the method of measurement described sufficiently?	+	+	+	-	+	+	+	+	+
10	Were the measures reliable?	+	-	-	-	+	+	-	-	+
11	Were the measures valid?	+	-	-	-	-	-	-	-	+
12	Were the results reported in terms of statistical significance	+	+	+	+	+	+	+	+	-
13	Were the analysis methods appropriate?	+	+	+	+	+	+	+	+	+
14	Was clinical importance reported?	-	-	+	+	+	-	-	-	+
15	Was missing data reported where appropriate?	+	+	+	+	+	+	+	+	+

16	Were the conclusions relevant and appropriate given the methods and results of the study?	+	+	+	+	+	+	+	+	+
	Total CAT score /16	14	12	14	11	14	14	11	12	14
	Total CAT %	87.5%	75%	87.5%	68.75%	87.5%	87.5%	68.75%	75%	87.5%

		Brechter & Powers, 2002	Crossley, et al., 2004	Grenholm et al., 2009	Levinger &Gilleard 2007	Levinger & Gilleard, 2005	Nadeau et al., 1997	Powers et al., 1997	Powers et al., 1999	Powers et al., 2002	Powers et al., 1996
1	Was the purpose of the study clearly stated?	+	+	+	+	+	+	+	+	+	+
2	Was the study design appropriate?	+	+	+	+	+	+	+	+	+	+
3	Were the sample biases detected in the study?	+	+	-	-	-	+	-	-	-	-
4	Were the measurement biases detected in the study?	-	-	-	-	-	-	-	-	-	-
5	Was the sample size stated?	+	+	+	+	+	+	+	+	+	+
6	Was the sample described in detail?	+	+	+	+	+	+	+	+	+	+
7	Was the sample size justified?	-	-	-	+	-	-	-	-	-	-
8	Were the outcomes clearly stated and relevant to the study?	+	+	+	+	+	+	+	+	+	+
9	Was the method of measurement described sufficiently?	+	+	+	+	+	+	+	+	+	+

10	Were the measures reliable?	-	-	-	+	+	-	-	-	+	-
11	Were the measures valid?	-	-	-	+	+	-	-	-	+	-
12	Were the results reported in terms of statistical significance	+	+	+	+	+	+	+	+	+	+
13	Were the analysis methods appropriate?	+	+	+	+	+	+	+	+	+	+
14	Was clinical importance reported?	+	+	+	-	-	-	+	-	-	-
15	Was missing data reported where appropriate?	+	+	-	+	+	+	+	+	+	+
16	Were the conclusions relevant and appropriate given the methods and results of the study?	+	+	+	+	+	+	+	+	+	+
	Total CAT score /16	12	12	12	15	13	11	13	12	14	12
	Total CAT %	75%	75%	75%	93.75%	81.25%	68.75%	82.25%	75%	87.5%	75%

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3.3.4 Biomechanical results

3.3.4.1 Walking

A summary of the evidence for kinematics during gait can be seen in Figure 5. Evidence from the previous review (Barton et al., 2009) was included to create a comprehensive algorithm. This summarises the evidence based on significance and consistency of findings and provides recommendations on which factors should be considered first in treatment.

Two kinematic outcomes showed significant and consistent results from two or more studies: the peak hip rotation and timing of peak rear foot eversion. Pooling of data was possible for one outcome. Figure 8 illustrates the peak hip internal rotation angle during gait in subjects with AKP compared to controls. Data from two studies (Barton et al., 2011; Powers et al., 1997) was pooled showing consistent findings of a statistically significant reduction in hip internal rotation in subjects with AKP. There was no significant statistical heterogeneity amongst the studies (p=0.67), indicating that there was no significant clinical or methodological diversity among the studies. The overall effect was a statistically significant reduction in peak hip internal rotation during gait in subjects with AKP compared to controls (MD= -5.54; CI -7.54, -3.5).

Two studies found that subjects with AKP had delayed timing of peak rear foot eversion that was statistically significant (Levinger & Gilleard, 2007; Barton et al., 2011). However, pooling of data was not possible due to differences in measuring timing. Levinger et al. (2007), measured the percentage of time spent in stance phase (7% later in stance phase), whereas Barton et al. (2011) measured timing as the percentage of the gait cycle (5% later over the gait cycle).

Significant findings from single studies looking at hip kinematics indicated; earlier timing of peak hip internal rotation (Barton et al., 2011), increased peak hip adduction at peak knee extensor moment during walking at a self-selected speed (Salsich & Long-Rossi, 2010) and decreased peak hip adduction at peak knee extensor moment during fast walking (Salsich & Long-Rossi, 2010) in subjects with AKP compared to controls. Significant findings from single studies looking at knee kinematics indicated: increased peak knee extension (Salsich & Long-Rossi, 2010, decreased knee flexion

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at heel strike (Powers et al.,1999) and decreased knee flexion in early stance (Nadeau et al., 1997) in subjects with AKP compared to controls.

Significant findings from single studies looking at distal kinematics of the ankle and foot kinematics indicated: increased rear foot eversion at heel strike (Levinger & Gilleard, 2005), increased overall ankle range of movement (Barton et al., 2012), and increased peak ankle dorsiflexion during fast walking (Salsich & Long-Rossi, 2010) in subjects with AKP compared to controls. The findings for all other kinematic outcomes were either conflicting or insignificant.

3.3.4.2 Single leg squatting

A summary of the evidence for kinematics during single leg squatting can be seen in Figure 6. The previous review (Barton et al., 2009) did not include single leg squatting as an activity of interest. Pooling of data was possible for three outcomes. Figure 9 illustrates the peak knee valgus angle during single leg squatting in subjects with AKP compared to controls.

Data from three studies (Herrington, 2013; Nakagawa et al., 2012; Nakagawa et al., 2015) was pooled showing consistent findings of a statistically significant increase in knee valgus in subjects with AKP. There was no significant heterogeneity between the studies (p=0.07). The overall effect was a statistically significant increase in peak knee valgus in subjects with AKP compared to controls (MD=4.93; CI 2.06, 7.80).

Figure 10 illustrates the peak hip adduction angle during single leg squatting in subjects with AKP compared to controls. Data from two studies (Nakagawa et al., 2012; Nakagawa et al., 2015) was pooled showing consistent findings of a statistically significant increase in hip adduction in subjects with AKP. These two studies were conducted by the same authors but included different participants. There was no significant heterogeneity between the studies (p=0.77). The overall effect was a statistically significant increase in peak hip adduction in subjects with AKP compared to controls (MD=4.51; CI: 1.98, 7.04).

Figure 11 illustrates the peak ipsilateral trunk lean angle during single leg squatting in subjects with AKP compared to controls. Data from two studies (Nakagawa et al., 2012; Nakagawa et al., 2015) was pooled showing consistent findings of a statistically

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significant increase in ipsilateral trunk lean in subjects with AKP. There was no significant heterogeneity between the studies (p=0.87). The overall effect was a statistically significant increase in peak ipsilateral trunk lean in subjects with AKP compared to controls (MD=2.76; CI: 0.96, 4.56).

A significant finding from one study (Nakagawa et al., 2012) showed a statistically significant increase in contralateral pelvic drop during single leg squatting (p=0.003). The findings for all other biomechanical outcomes during single leg squatting were either inconsistent or insignificant.

3.3.4.3 Stair climbing

A summary of the evidence for stair ascent and descent can be seen in Figure 7. Pooling of data was not possible for any outcomes. Evidence from single studies found significant differences between subjects with AKP and controls for four outcomes; decreased knee flexion velocity at heel strike during stair descent (Crossley, Cowan et al., 2004), Increased peak hip adduction angle in females during stair descent (McKenzie et al., 2010), increased peak hip internal rotation in females during stair descent (Grenholm et al., 2009) and decreased peak knee flexion during stair ascent in females (Silva et al., 2015). There was inconsistent or insignificant evidence for all other outcomes

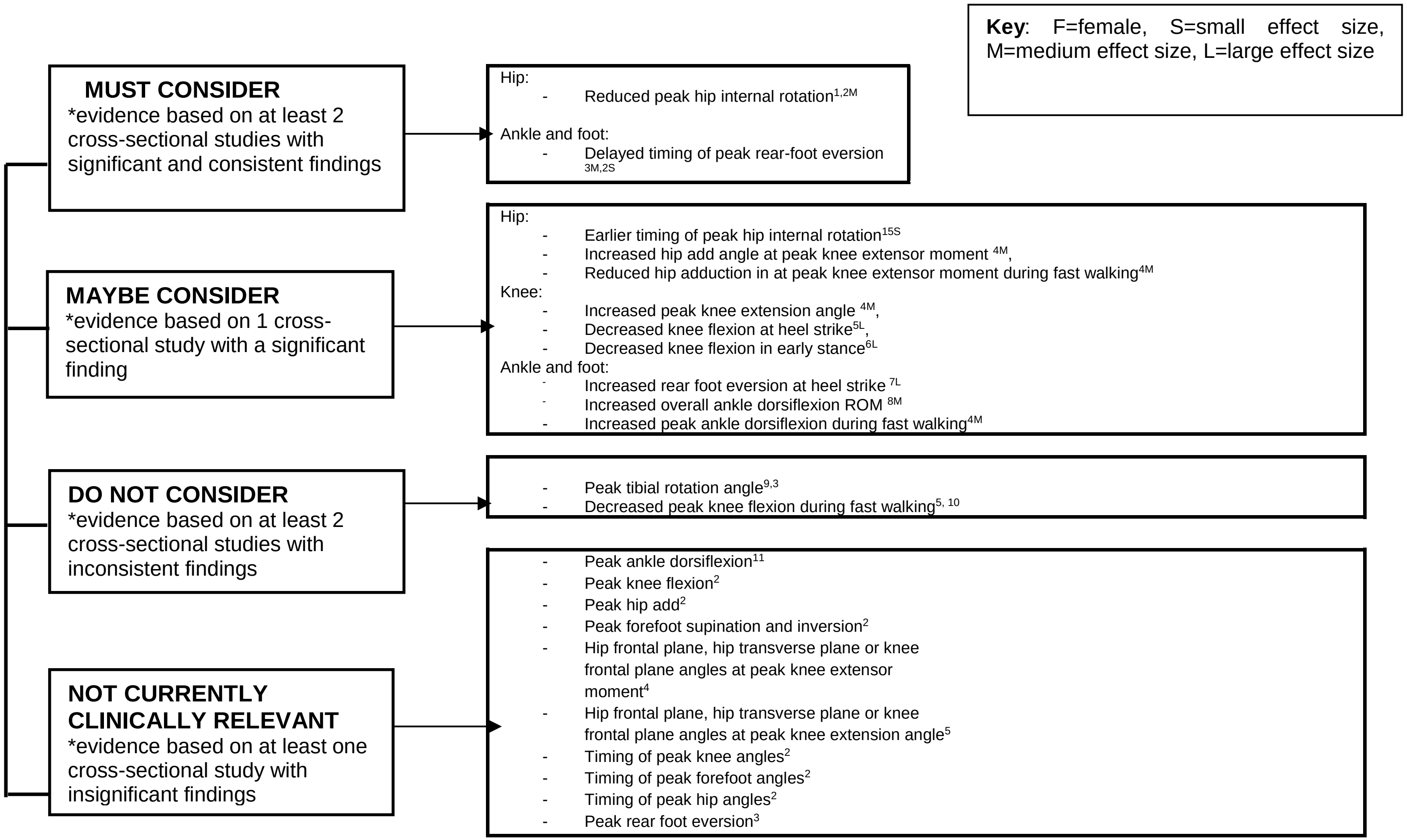

FIGURE 5. Algorithm for kinematic factors associated with AKP during walking

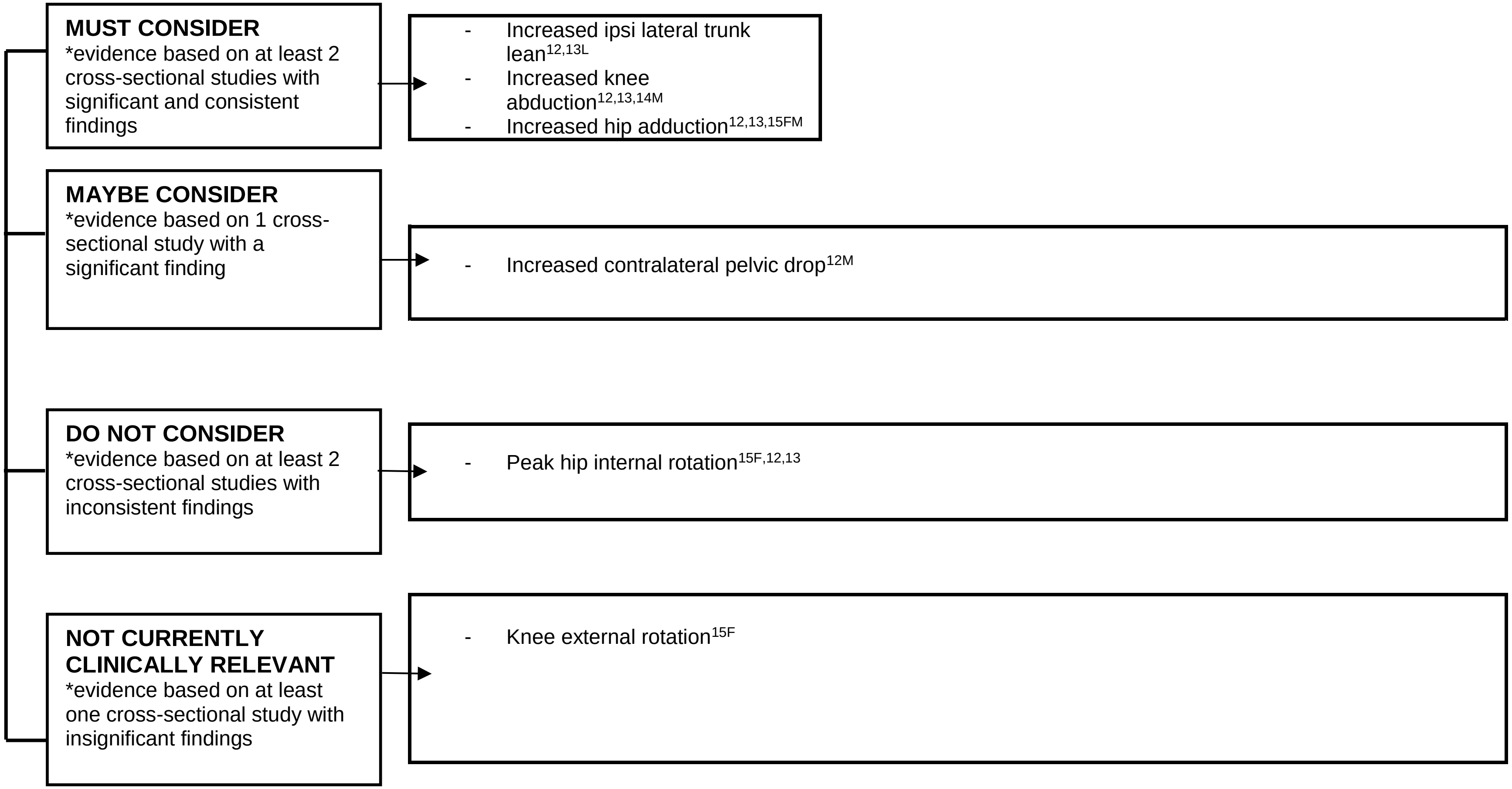

FIGURE 6. Algorithm for kinematic factors associated with AKP during single leg squatting

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MUST CONSIDER
*evidence based on at least 2 cross-sectional studies with significant and consistent findings

- None

MAYBE CONSIDER
*evidence based on 1 cross-sectional study with a significant finding

- Decreased knee flexion velocity at heel strike on descent[16M]
- Increased peak hip adduction on descent [17FM]
- Increased hip peak internal rotation on descent [17FS]

DO NOT CONSIDER
*evidence based on at least 2 cross-sectional studies with inconsistent findings

- Peak knee flexion[18, 19F]
- Knee flexion at heel strike[18,19F]
- Peak ankle dorsi flexion[18,17F]

NOT CURRENTLY CLINICALLY RELEVANT
*evidence based on at least one cross-sectional study with insignificant findings

- Peak hip flexion[18]
- Peak hip adduction at contralateral heel strike[16]
- Peak knee extension [17F]
- Peak hip extension [17F]
- Peak knee rotation [17F]
- Peak knee varus/valgus [17F]

FIGURE 7. Algorithm for kinematic factors associated with AKP during stair climbing

Study or Subgroup	AKP Mean [degrees]	AKP SD [degrees]	AKP Total	Control Mean [degrees]	Control SD [degrees]	Control Total	Weight	Mean Difference IV, Random, 95% CI [degrees]
Power et al 1997	-2.1	4.9	24	3.7	2.8	17	73.5%	-5.80 [-8.17, -3.43]
Barton et al 2011	7	6.6	26	11.8	6.9	20	26.5%	-4.80 [-8.75, -0.85]
Total (95% CI)			**50**			**37**	**100.0%**	**-5.54 [-7.57, -3.50]**

Heterogeneity: Tau² = 0.00; Chi² = 0.18, df = 1 (P = 0.67); I² = 0%
Test for overall effect: Z = 5.34 (P < 0.00001)

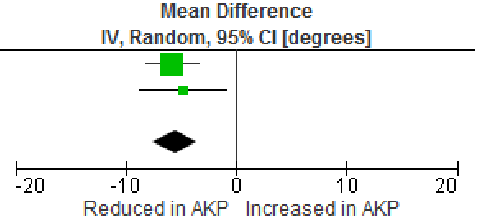

FIGURE 8. Forest plot of comparison: 1 Peak angles during walking, outcome: 1.1 Peak hip interval rotation [degrees]

Study or Subgroup	AKP Mean [degrees]	AKP SD [degrees]	AKP Total	Control Mean [degrees]	Control SD [degrees]	Control Total	Weight	Mean Difference IV, Random, 95% CI [degrees]
Herrington 2013	16.8	5.4	12	8.4	5.8	30	28.6%	8.40 [4.71, 12.09]
Nakagawa et al 2012	9.2	5	20	5.8	3.4	20	37.1%	3.40 [0.75, 6.05]
Nakagawa et al 2015	10.5	6.4	30	6.8	5.3	30	34.3%	3.70 [0.73, 6.67]
Total (95% CI)			**62**			**80**	**100.0%**	**4.93 [2.06, 7.80]**

Heterogeneity: Tau² = 3.94; Chi² = 5.21, df = 2 (P = 0.07); I² = 62%
Test for overall effect: Z = 3.37 (P = 0.0007)

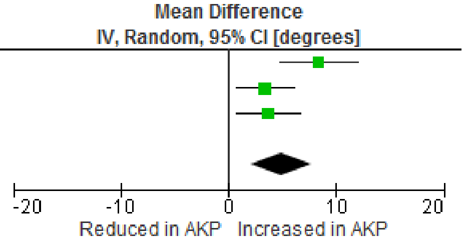

FIGURE 9. Forest plot of comparison: 2 Peak angles during single leg squatting, outcome: 2.1 Peak knee valgus [degrees]

Study or Subgroup	AKP Mean [degrees]	AKP SD [degrees]	AKP Total	Control Mean [degrees]	Control SD [degrees]	Control Total	Weight	Mean Difference IV, Random, 95% CI [degrees]
Nakagawa et al 2012	14.8	7.8	20	10.8	5.6	20	36.1%	4.00 [-0.21, 8.21]
Nakagawa et al 2015	24	6.5	30	19.2	6	30	63.9%	4.80 [1.63, 7.97]
Total (95% CI)			**50**			**50**	**100.0%**	**4.51 [1.98, 7.04]**

Heterogeneity: Tau² = 0.00; Chi² = 0.09, df = 1 (P = 0.77); I² = 0%
Test for overall effect: Z = 3.50 (P = 0.0005)

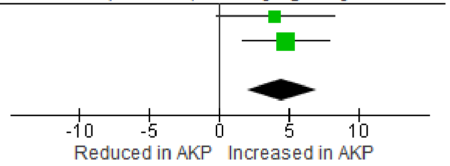

FIGURE 10. Forest plot of comparison: 2 Peak angles during single leg squatting, outcome: 2.2 Peak hip adduction [degrees]

Study or Subgroup	AKP Mean [degrees]	AKP SD [degrees]	AKP Total	Control Mean [degrees]	Control SD [degrees]	Control Total	Weight	Mean Difference IV, Random, 95% CI [degrees]
Nakagawa et al 2012	9.3	5.3	20	6.7	3	20	45.5%	2.60 [-0.07, 5.27]
Nakagawa et al 2015	9.8	5.2	30	6.9	4.4	30	54.5%	2.90 [0.46, 5.34]
Total (95% CI)			**50**			**50**	**100.0%**	**2.76 [0.96, 4.56]**

Heterogeneity: Tau² = 0.00; Chi² = 0.03, df = 1 (P = 0.87); I² = 0%
Test for overall effect: Z = 3.01 (P = 0.003)

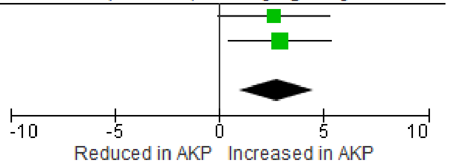

FIGURE 11. Forest plot of comparison: 2 Peak angles during single leg squatting, outcome: 2.3 Ipsilateral trunk lean [degrees]

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3.4 Discussion

Our review is the first to create a screening tool based on the best available evidence that clinicians can use to identify kinematic contributing factors for AKP during common aggravating activities. Our review findings showed additional evidence that delayed timing of peak rear foot eversion (occurs 7% of the gait cycle later in stance phase and 5% later over the entire gait cycle) and peak hip internal rotation (5 degrees less) during walking may be associated with AKP.

Our review is the first to synthesise the evidence for biomechanical factors during single leg squatting in subjects with AKP. Single leg squatting was not included in a similar previous review (Barton et al., 2009), although it is commonly used in clinical practice. During single leg squatting, increased peak ipsilateral trunk lean, knee valgus/ abduction angle and peak hip adduction angle are the risk factors most strongly associated with AKP (Nakagawa et al., 2012; Nakagawa et al., 2015; Herrington, 2013; Willson & Davis, 2008). Nakagawa et al. (2015) proposed that these three factors may be linked and indicate an inability of the individual to stabilise the lower limb in the frontal plane. Both increased ipsilateral trunk lean and increased hip adduction may increase the valgus angle at the knee during single leg squatting as both features can increase the dynamic Q-angle of the affected limb (Powers, 2010). Increased valgus could then result in increased forces on the lateral patella facets and abnormal stresses on trochlear groove during loading and subsequently knee pain (Powers, 2010; Lee et al., 2003). Increased ipsilateral trunk lean and increased hip adduction may both be as a result of weak hip abductors (Salsich & Graci, 2015). Weakness and poor neuromuscular control of hip abductor muscles have been hypothesised to play a role in the development of AKP. Bolga et al. (2011) found that women with AKP demonstrated 26% less hip abduction strength ($p<0.001$) than similar age-matched controls. The authors suggested that the weakness of these muscle groups may result in an inability to resist external valgus and internal rotation moments during demanding activities such as single leg squatting and running.

Increased trunk lean might be an attempt to decrease the demand on the hip abductor muscles, however the compensatory effect might be an increase of the forces on the lateral patella due to the lateral weight shift of the body during

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loading on the affected side (Nakagawa et al., 2015). Another potential contributing factor could be decreased trunk lateral trunk strength, resulting in an increased knee abduction moment and consequently increased loading at the medial knee (Nakagawa et al., 2015).

Single leg squatting may be a useful activity to screen for kinematic factors associated with AKP in an athletic population with high functional demands. It may not be as relevant in less active subjects with AKP that do not to perform such demanding tasks on a regular basis. However, it should be interpreted with some caution as there is a lack of representative normative datasets based on healthy, pain-free subjects and there are variations in the position of the non-stance leg that may influence the lower extremity biomechanics of the performed task (Khuu et al., 2016).

Our review showed new evidence emerging from the current review links delayed timing of peak rear foot eversion and AKP (Barton et al., 2011). The potential link between rear foot eversion and AKP has been proposed to involve an increase in genu-valgus resulting in malalignment between the patella and femur. This might result in increased contact stress between the articulating surfaces (Hetsroni et al., 2006). Our review also demonstrated additional evidence for decreased peak hip internal rotation during gait in subjects with AKP (Barton et al., 2011). Powers et al. (2002) suggested that this could be a compensatory attempt to decreased PFJ loading, as increased hip internal rotation increases the dynamic Q-angle during loading thus increasing the stress on the medial knee. By limiting internal rotation subjects with AKP may limit this medial stress, but this compensation could shift stress to the lateral aspect of the knee. Levinger and Gilleard (2007) suggested that delayed timing of peak rear foot eversion may be an indication of prolonged subtalar pronation. This prolonged pronation would then in turn disrupt the temporal kinematic sequencing of the lower limb joint motion (Powers et al., 2002).

Our review demonstrates that proximal and distal kinematic factors are associated with AKP during gait. Barton et al. (2012) described an association between rear foot eversion and hip adduction during gait. The authors concluded that subjects with AKP that demonstrated greater hip adduction during gait also

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presented with increased rear foot eversion. However, this study (Barton et al., 2012) was cross-sectional and therefore the direction of this association could not be established.

It has been suggested that treatment approaches that targeted either proximal or distal factors could equally benefit symptoms at the knee (Barton et al., 2011). For example, prescribing orthotics would improve hip features and an approach aimed at the hip such as gluteal strengthening may decrease rear foot eversion. It is unclear whether one approach is more effective than the other and therefore clinicians should address and treat the most prominent feature in the individual patient first.

Stair climbing was investigated in the previous review (Barton et al., 2009) and the authors concluded there was no consistent evidence for altered kinematics during stair ascent or descent. In our review, no meta-analyses were possible for any outcomes. Results from single cross-sectional studies, indicate that decreased knee flexion velocity at heel strike on stair descent, increased peak hip flexion on stair ascent, increased peak hip internal rotation on descent and increased hip adduction on descent may be associated with AKP. Future research is needed to confirm these findings.

All the included studies ranked in the “moderate” to “high” categories based on critical appraisal of the methods. Although it is positive that the included studies are methodologically sound, the design of the included studies is a major limitation. Only cross-sectional studies were included as no prospective studies met our inclusion criteria. The implication of this is that no cause-and-effect relationship can be established between the parameters that we have highlighted and the development of AKP. We could establish associated factors, but causative or predictive risk factors for AKP need to be investigated in future prospective research.

A limitation of much of the literature in biomechanics and AKP is the inclusion of female participants only. In the current review, 12 of the included studies only investigated women. While literature suggests that the condition is twice as prevalent in women as in men (Boling et al., 2010) it occurs frequently in both genders. Future research should investigate men and women to reduce gender

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bias and establish potential differences in the biomechanical factors between men and women as the might differ (Besier et al., 2015).

A limitation of our review is that only English studies were included and this could introduce language bias. Another limitation that became apparent when the algorithm was created is that the evidence base for biomechanical risk factors for AKP is still small and more risk factors need to be investigated. In addition, there needs to be consistency in the way that kinematic outcomes are measured so that studies can be synthesised and compared. The search strategy and inclusion criteria for this study was strict and might have limited the results. The inclusion of more keywords might have broadened the search and should be considered when the checklist is updated in the future. Another limitation is that our procedures required motion analysis equipment which is not available in most clinics. Therefore, clinicians would need to refer patients for gait analysis, in order to screen for the kinematic factors presented in our algorithm.

As demonstrated by our review, gait analysis is currently the most appropriate activity to screen for biomechanical risk factors in individuals with AKP as it is a common ADL and there are well-established normative values for adults to which values can be compared to for screening purposes. Evidence for single leg squatting is limited but consistent. More evidence is needed to establish normative values and to standardise procedures before it can be strongly recommended as a clinical screening tool for subjects with AKP. Stair climbing needs more primary evidence before it can be considered a clinically useful tool for biomechanical screening. This is important as pain during stair climbing (in especially stair descent) is a common complaint in subjects presenting with AKP (Nunes et al., 2013). The presence of proximal, local and distal biomechanical factors for all three activities stresses the importance of considering biomechanics of the entire kinetic chain and not just structures around the knee.

3.5 Conclusion

Our review showed new evidence for kinematic factors associated with AKP during single leg squatting and additional evidence for delayed timing of peak rear foot eversion and decreased peak hip internal rotation during walking. Our evidence synthesis suggests that the most important kinematic factors

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associated with AKP to address during rehabilitation are: 1) reduced hip internal rotation and delayed timing of peak rear foot eversion during gait and 2) increased peak ipsilateral trunk lean, knee valgus/ abduction angle and peak hip adduction angle during single leg squatting. High-quality prospective studies are needed to determine which factors are risk factors predictive of AKP. Walking and single leg squatting are appropriate activities to use as biomechanical screening tools in a clinical setting as they have some factors that are supported by significant and consistent evidence. More research needs to be conducted investigating kinematic factors during stair climbing, particularly stair descent, as it is an activity that frequently aggravates AKP.

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Chapter 4: The test-retest reliability of gait outcomes in subjects with anterior knee pain

ABSTRACT

Introduction

Anterior knee pain (AKP) is a common condition frequently causing young, athletic patients to attend sports rehabilitation centres. Abnormal biomechanics are thought to contribute towards the development and chronicity of the condition. Gait analysis is commonly used to identify abnormal biomechanics in subjects with AKP; however, the reliability of these measurements is unknown. Therefore, the aim of this study was to quantify the test-retest reliability of hip, knee and ankle kinematics during gait in an AKP population so the true effects of an intervention can be established.

Methods

Thirty-one subjects with AKP attended the 3D Motion Analysis Laboratory at Tygerberg Medical Campus of Stellenbosch University in Cape Town, South Africa, for gait analysis. Participants returned seven days later at approximately the same time to repeat the gait analysis assessment from day one. The same assessor tested all subjects on both occasions. The intra-class correlation coefficients (ICC) and standard error of measurement (SEM) were calculated for hip, knee and ankle kinematic outcomes on the affected side and used for analysis.

Results

All outcomes obtained were acceptable to excellent test-retest reliability scores for both measures of relative reliability (ICC=0.78-0.9) and measures of absolute reliability (SEM= 0.94-4.21 degrees). Hip frontal plane and ankle sagittal plane outcomes were the most reliable and had the lowest measurement error. Hip transverse plane outcomes were least reliable and demonstrated the highest measurement error.

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Conclusion

Hip, knee and ankle kinematic factors that are commonly associated with AKP can be measured reliably using gait analysis. Daily and weekly variation in symptoms in an AKP population may influence the reliability of knee sagittal plane outcomes. Therefore, it is important to document factors that could influence the kinematics such as pain, activity levels and the use of pain medication.

4.1 Introduction

Anterior knee pain (AKP) is a common condition characterised by pain perceived at the anterior aspect of the knee during activities that load a flexed knee joint. The term “anterior knee pain” is often used interchangeably with “patellofemoral pain syndrome” and the diagnosis is most commonly made based on the area, aggravating activities, as well as the exclusion of other pathologies (Nunes et al., 2013). AKP is thought to be multifactorial in nature and the aetiology is not well understood (Aminaka & Gribble, 2008). Many studies have been done on the proposed mechanism of the condition yielding conflicting results and high intra-subject variability (Powers et.al., 2014).

Accurate objective measures for anterior knee pain are of paramount importance as without them the accurate diagnosis and monitoring of treatment cannot take place. Reliable measurement of kinematics is also critical for data analysis because it ensures that changes in a specific measurement represent a true change in performance (Nakagawa et al., 2013). This is particularly important in epidemiological analyses where clinical decisions are made (Sinclair et al., 2012).

Three-dimensional (3D) gait analysis is a recommended and reliable method of examining lower limb function. Clinical gait analysis aims to distinguish between “abnormal” gait associated with injury and normal gait that one would expect to find in an asymptomatic individual (Baker, 2006).

Variability in pre- versus post-intervention measurements may be due to the effects of the intervention, measurement error or both. Therefore, quantifying measurement error allows researchers to establish whether or not a treatment effect is clinically meaningful, and this limits the risk of overanalysing small differences.

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There are various factors that can result in measurement errors between sessions. These include marker placement errors, inconsistent anthropometric measurements, variations in walking speed, data processing errors and measurement equipment errors (Monaghan et al., 2007).

McGinley et al. (2009), did a systematic review investigating the reliability of gait related kinematics and kinetics of normal adults tested using 3D motion analysis systems. They looked at reliability within and between subjects, within and between sessions and within and between assessors. Based on this review, the highest reliability was found in the sagittal hip and knee kinematics, the lowest errors were found in transverse and frontal plane pelvis and hip frontal plane kinematics and the lowest reliability and highest error was found in the transverse plane hip and knee outcomes (McGinley et al., 2009). However, these results were for asymptomatic populations only and therefore the authors recommended that for future reliability studies, the sample recruited should be symptomatic or clinically diagnosed with the condition being investigated (i.e. AKP) as one cannot assume that the reliability of gait outcomes will be the same in healthy and symptomatic populations. An error of 2 degrees or less is considered to have good reliability, errors of 2-5 degrees can be considered acceptable but small changes may require some caution in data interpretation and errors of more than 5 degrees should raise concern as this could mislead clinical interpretation (McGinley et al., 2009).

The 3D gait analysis measurements are frequently used in clinical research on subjects with AKP for the objective measure of lower limb function. To date no studies have been done to establish the inter-session reliability of gait related kinematics for anterior knee pain. This means that the true result of gait analysis findings as well as treatment effects are unclear. Therefore, the aim of this study is to use a repeated measures design to establish the test-retest reliability of 3D hip, knee and ankle kinematics that have been shown to be associated with AKP during gait.

4.2 Methods

Ethics approval was obtained from the Health Research Council of the Stellenbosch University under ethics number **N13/05/078.** Informed consent was

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obtained from all participants over the age of 18 years and from parents/guardians for subjects under the age of 18 years. The study was reported according to GRRAS guidelines for reporting reliability and agreement studies (Kottner et al., 2011). The checklist can be found attached as Appendix H.

4.2.1 Population and sample

Thirty-one subjects (meeting the eligibility criteria) with AKP were included in this study. Our sample size was determined from a priori power analysis for an intervention study. This reliability study was a preliminary study for this intervention study to establish the reliability of the measurement procedures. Therefore, the same sample was used.

4.2.2 Diagnostic criteria

Subjects were recruited by advertisements placed in community, university and school-based newspapers in order to attract a range of participants from a wide spectrum of activities, backgrounds, sports and ages. Advertisements/ letters of invitation were also sent to the clinics of all collaborators/sports groups. All potential participants were screened using an evidence-based diagnostic checklist specifically developed for this study (Leibbrandt & Louw, 2017a) to ensure standardised diagnosis and exclusion of other pathologies. This checklist is based on an up-to-date evidence synthesis on systematic reviews and can be found attached in Table 4.

At the first testing session, a clinical assessment was done by the physiotherapist (DL) to confirm that the participant had AKP. This assessment comprised specific functional tests, a palpation, and special tests to exclude other pathologies (seen in Table 4). Once the subjects had met the criteria of the physical examination, they could proceed to the 3D motion analysis part of the assessment.

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4.2.3 Setting

The study was conducted at the FNB 3D Motion Analysis Laboratory at Tygerberg Medical Campus of Stellenbosch University in Cape Town South Africa. The same assessor tested all subjects on both occasions.

4.2.4 Measurement procedure

4.2.4.1 Instrumentation

A VICON Motion Analysis (Ltd) (Oxford, UK) 3D system was used to obtain the 3D movement analysis data. The VICON has demonstrated high accuracy and reliability (Ehara et al., 1997). The T10 is a motion-capturing system with a unique combination of high-speed accuracy and resolution. The system has a resolution of 1-mega pixels and captures 10-bit grey scale images using 1120 × 896 pixels, with the ability to capture speeds of up to 250 frames per second. Retro-reflective markers with a diameter of 9.5 mm were used. The standard plug-in gait model was used, as the model provided the angle output sought in the current study. VICON Nexus 1.8 software was used to filter and process data. VICON-specific anthropometric measurements that were obtained included: height; weight; leg length, knee and ankle diameter. All marker placements were done by the researcher, who has received training in marker placement and has two years' experience in marker placement. This serves to reduce marker bias.

4.2.4.2 Trial capture procedure

Participants were required to perform six barefoot walking trials at a self-selected speed, in a straight line, across a flat walk way in the motion analysis laboratory. Participants returned seven days later at approximately the same time, to repeat the full testing procedure from day one. This interval was chosen because it is long enough to avoid memory bias from the first occasion (Meldrum et al., 2014) and short enough to avoid a change in gait due to variation in symptoms (Whatman et al., 2013). Self-reported usual pain was also measured at both testing sessions using the numeric pain rating scale (NPRS).

4.2.4.3 Outcomes

The mean peak angles for hip transverse and frontal plane, knee sagittal plane at foot contact, peak knee sagittal plane, overall ankle sagittal plane ROM, ankle

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sagittal plane at foot contact and peak foot progression frontal plane obtained for the six trials were used for analysis. These outcomes were chosen as they are the factors most strongly associated with AKP based on a systematic review of the evidence (Leibbrandt & Louw, 2017b).

4.2.5 Data management and analysis

Data processing, preliminary marker reconstruction and labelling were performed using standard Vicon Nexus operations. Gap filling was performed using the standard Woltring filter supplied by Vicon. To determine test-retest reliability, intra-class correlation co-efficient (ICC) and standard error of measurements (SEM) were calculated using Stata version 13. ICCs were calculated using a consistency or relative reliability model. The 3D kinematic gait parameters in AKP patients were assessed using the means of the data obtained during the six trials of the first and of the second gait analysis sessions. The gait traces of all six trials were first checked for consistency. If the traces were consistent, the average (mean) of the six trials was used for analysis. The ICC provided a measure of relative reliability whereas the SEM provided an expression of the measurement error in the kinematic outcomes of interest in degrees (absolute reliability). The outcomes of this study ascertained the most reliable 3D kinematic outcomes. This will guide our choice of biomechanical outcomes to compare pre- and post-intervention. The SEM will assist us to determine whether the change in an outcome is a true effect attributable to the intervention.

The outcomes of this study will ascertain the most reliable 3D kinematic outcomes. This will guide our choice of biomechanical outcomes to compare pre- and post-intervention. The SEM will assist us to determine whether the change in an outcome is a true effect attributable to the intervention.

An outcome with an ICC of greater of than 0.8 was considered to have good reliability and a value of over 0.9 was considered excellent. An outcome with an ICC of 0.7-0.8 was considered to have acceptable reliability, whereas less than 0.7 was considered questionable and less than 0.6 poor (Rankin & Stokes, 1998).

4.3 Results

Thirty-one subjects (13 males, 18 females) with unilateral AKP (20 left sided, 11 right sided) were included in this study. The average age was 30 years (range 14-40; SD=8.42), height (mean=170.16 cm; SD=10.45 cm) and mass (mean=77.5 kg; SD=25.7 kg). Participant characteristics can be found below in Table 9.

TABLE 9: sample description for main study participants (affected side, age, gender, height and mass)

	Sample size (n)	Affected leg	Average age (years) Mean (SD)	Average height (cm) Mean (SD)	Average mass (kg) Mean (SD)	Average BMI (kg/m^2) Mean (SD)
Males with AKP	13	8 Left 5 Right	31.54 (8.65)	176.9 (8.18)	85.62 (24.19)	27.43 (6.03)
Females with AKP	18	12 Left 6 Right	29.22 (7.97)	165.3(11.60)	65.56 (23.98)	24.29 (6.13)
All subjects	31	20 Left 11 Right	30.19 (8.42)	170.16 (10.45)	77.50 (25.70)	26.79 (6.08)

4.3.1 Intra-class correlation co-efficient (ICC)

An analysis of kinematic data for all the included participants using ICC values revealed acceptable to excellent test-retest reliability (r=0.78-0.9) for all outcomes. The means of the six trials for both sessions were used for analysis. A summary of results can be found in Table 10.

TABLE 10: Between session reliability co-efficient (ICC) for all outcomes

Outcome	Peak hip transverse plane		Peak hip frontal plane (degrees)		Peak knee sagittal plane at foot contact (degrees)		Peak knee sagittal plane (degrees)		Average overall ROM ankle sagittal plane (degrees)		Peak ankle sagittal plane (degrees)		Peak foot progression (degrees)	
Session	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Mean	-0.17	-0.97	7.29	7.77	6.01	6.80	59.15	60.22	32.83	32.73	14.38	14.39	-2.97	-2.84
SEM		4.21		1.08		2.13		2.17		1.96		0.94		1.84
ICC (r)		0.78		0.92		0.79		0.78		0.88		0.90		0.88

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4.3.2 Standard error of measurement (SEM)

The SEM values of the same kinematic variable taking the mean values of sessions 1 and 2 for all participants were between 0.94 and 4.21 degrees for all included outcomes. All values were below 5 degrees of measurement error indicating that reliability was acceptable. However, one outcome (peak hip transverse plane) had a measurement error of above 2, indicating that although it is acceptable some caution should be taken when interpreting changes in this outcome due to an intervention. A summary of the SEM results can be found in Table 11.

TABLE 11: Standard error of measurement (SEM) between sessions for all outcomes

Outcome	Standard error of measurement (degrees)	Interpretation
Peak hip transverse plane	4.21	Acceptable but may require caution
Peak hip frontal plane	1.08	Good
Knee sagittal plane at foot contact	2.13	Good
Peak knee sagittal plane	2.17	Good
Average overall ankle sagittal plane ROM	1.90	Good
Ankle sagittal plane at foot contact	0.94	Good
Peak foot progression	1.84	Good

4.3.3 Subgroup differences in ICC and SEM

A summary of the ICC and SEM reliability values for male participants, female participants, adolescent participants (14-19 years) and adult participants (20-40 years) can be seen in Table 12.

TABLE 12: Subgroup differences for reality outcomes

	Males (n=13)		Females (n=18)		Adolescents (n=6)		Adults (n=25)	
Outcome	r	SEM	r	SEM	r	SEM	r	SEM
Peak hip transverse plane	0.84	2.80	0.77	5.24	0.82	3.93	0.79	4.27
Peak hip frontal plane	0.94	0.92	0.90	1.19	0.92	0.83	0.92	1.13
Knee sagittal plane at foot contact	0.75	2.14	0.83	2.17	0.68	2.76	0.82	1.95
Peak knee sagittal plane	0.93	2.09	0.70	2.28	0.68	2.63	0.81	2.05
Average overall ankle sagittal plane ROM	0.89	1.78	0.84	2.08	0.72	2.39	0.91	1.84
Ankle sagittal plane at foot contact	0.92	0.96	0.91	0.95	0.78	1.07	0.91	0.91
Peak foot progression	0.86	1.85	0.86	4.97	0.89	4.51	0.78	4.55

Although most outcomes were similar between subgroups some important differences should be noted. Most of the ICC values still demonstrated acceptable reliability co-efficient ($r>0.7$) with the exception of knee sagittal plane outcomes in adolescents ($r=0.68$). Ankle sagittal plane outcomes were also less reliable in adolescents compared to adults. Gender differences include a larger error (SEM) in hip transverse plane outcomes for females compared to males.

4.3.4 Usual pain levels (NPRS)

The average (mean) pain levels measured using the NPRS as well as the standard deviation (SD) for each participant at the two sessions can be seen below in Figure 12. The average NPRS for week 1 was 4.2/10 (SD=1.93) and week 2 was 3.97/10 (SD=1.82).

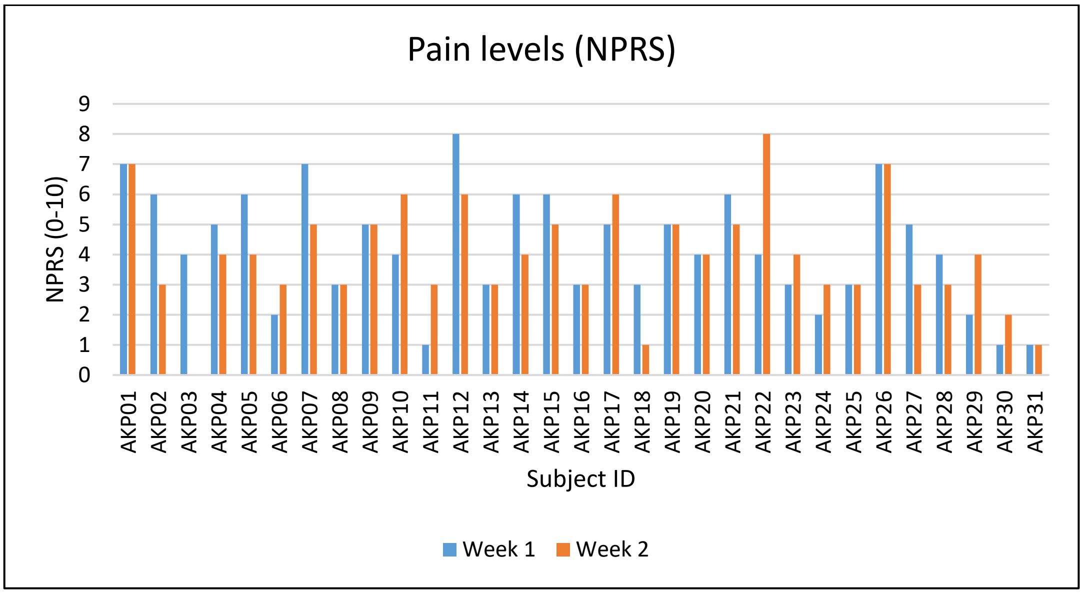

FIGURE 12. Participant pain ratings (NPRS) at session 1 compared to session 2

AKP: anterior knee pain (subject number)

4.4 Discussion

This is the first study to quantify test-retest reliability of 3D kinematic gait outcomes in an AKP population. The relative reliability (ICC) and absolute reliability (SEM) of all included outcomes were found to have acceptable to excellent reliability. The results showed that the hip frontal plane and ankle sagittal plane outcomes were the most reliable and had the lowest measurement error.

Hip transverse plane outcomes were least reliable and demonstrated the highest measurement error. This is in agreement with a previous systematic review on the reliability of gait outcomes in asymptomatic populations (McGinley et al., 2009). This may be related to the biomechanical model used to calculate the position of motion segments from markers placed on anatomical landmarks

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(Baker et al., 1999). Hip rotation angles are susceptible to errors related to misplaced thigh markers (Baker et al., 1999). It is therefore important to establish that it was possible to obtain acceptable levels of reliability and error. However, small changes (less than 5 degrees) in this outcome as a result of an intervention should be interpreted with caution.

The findings of our study showed that females with AKP demonstrated higher measurement in error in peak hip transverse plane kinematics (SEM=5.24 degrees) compared to men (SEM=2.8). This might be explained by gender differences in hip strength and kinematics between males and females with AKP. Females with AKP demonstrate a larger static Q-angle as well as increased dynamic hip internal rotation and decreased hip strength compared to males with AKP (Nakagawa et al., 2012; Boling et al., 2010). These differences might result in less consistency in hip rotation control during gait in females with AKP.

The most reliable outcomes determined in the systematic review by McGinley et al. (2009) were those of the hip and knee sagittal plane. Sagittal plane errors were typically less than 4 degrees. These findings on an asymptomatic population are consistent with the findings of the current study on an AKP population. However, the ICC value reported in McGinley et al. (2009) was 0.96, and the current study reported findings of 0.79 and 0.77. This suggests that knee sagittal plane outcomes are less reliable in an AKP population. One could argue that the reliability might be influenced by the unpredictable nature of the condition, causing variation in pain and symptoms. It has been suggested that some individuals may decrease knee flexion in stance phase and at foot contact during gait to try and avoid an increase in pain (Barton et al., 2009). Therefore, pain levels should be noted at the time of the assessment pre- and post-intervention as it could influence knee kinematics during gait.

Table 11 shows that the adolescent participants included in this study demonstrated less reliable measures of sagittal knee plane knee movement (r=0.68) than the adult participants (r=0.82). Previous research has suggested that adolescents with AKP between the ages of 12 and 16 may have a different aetiology of symptoms to adults and that abnormal movement patterns may play

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more of a role than decreased strength in this population group (Rathleff, R., Baird, et al., 2013).

In the current study, the average (mean) pain on a NPRS for week 1 was 4.2/10 and week 2 was 3.97/10 indicating that on average pain did not change between sessions. However, Figure 12 and the SD indicates that there was intra-subject variability in pain levels. This demonstrates the intermittent and highly variable nature of the condition. Pain levels should be taken into consideration when performing gait analysis as the symptoms on the day could influence the quality of movement.

Foot progression angle (foot frontal plane) is used to estimate peak rear foot eversion which is a key outcome associated with AKP. The results of this study showed good reliability (r=0.88) and low error (SEM=1.84 degrees) for these outcomes. Houck et al. (2008) found even higher ICC values of more than 0.9 and low SEM for rear foot eversion range of motion and static measurement in a standing position. However, the authors evaluated only asymptomatic individuals. In addition, Houck et al. (2008) used a multi-segment foot model whereas the current study used a standard plug-in gait model. Although the latter measurements are reliable, a multi-segment foot model would improve the validity of this outcome and would be recommended for a study focusing mainly on foot angles (Carson et al., 2001).

A limitation of this study is that it only quantifies test-retest reliability and not inter-rater reliability. Wilken et al. (2012) found that the addition of a second rater did not appreciably affect the reliability of kinematic or kinetic data. However, marker placement error may increase if the raters are not adequately skilled and trained in marker placement. Therefore, the skill of the rater is an important consideration for the consistency and accuracy of the outcomes in both research and clinical applications using motion analysis to obtain kinematic outcomes. The importance of providing clinical staff with adequate training in standardised protocols has been widely documented (Wilken et al., 2012; McGinley et al., 2009).

Table 9 demonstrates large standard deviations in anthropometrics in the included male and female participants. Male participants on average had a BMI of >25, which is classified as overweight. A recent study by Hart et al. (2016),

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showed that adults with AKP have a higher BMI than pain-free controls as it is hypothesised that the increased loading can contribute towards symptoms. This is also important because anthropometrics can influence the reliability of gait data as there may be soft tissue artefact due to the movement of markers and wands in participants with increased soft tissue or muscle bulk (Baker et al., 2009).

A challenge that clinicians are faced with when trying to quantify measurement error is that it is difficult to tell whether errors that do occur are more as a result of marker placement, data processing errors or subject-specific factors such as anthropometrics. However, if the errors are minimal and quantifiable this should not affect clinical outcomes.

Natural error should not be confused with measurement error (Schwartz et al., 2004). Therefore, clinicians should keep a careful record of potential subject specific confounding factors such as pain levels, activity levels and self-treatment strategies such as the use of pain medication when assessing changes in a participant's gait. These factors may vary for different pathological conditions and therefore researchers should consider doing repeated measures to calculate repeatability on a subsample of the study population in any study investigating the effect of a treatment strategy on a specific population.

4.5 Conclusion

Kinematic factors that commonly present in an AKP population can be measured accurately and reliably using 3D gait analysis. These outcomes all obtained acceptable to excellent reliability scores and acceptable to low measurement error between sessions. Therefore, these measurements may provide valuable information on the effects of an intervention. Compared to an asymptomatic population, knee sagittal plane outcomes in an AKP population may be slightly less reliable due to variation in pain and symptoms. In addition, hip transverse plane outcomes should be interpreted with caution if the changes are small as this outcome was the least reliable.

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Chapter 5 (phase B): Targeted functional movement retraining to improve pain, function and biomechanics in subjects with anterior knee pain: A case series

ABSTRACT

Context

Anterior knee pain (AKP) is a common condition, especially in a young active population. The clinical presentations of this condition vary considerably and therefore an individualised approach to treatment is needed.

Objective

The primary objective of this study was to investigate a novel targeted biomechanical intervention on subjects with AKP.

Design

A case series was conducted on eight participants with AKP.

Setting

The study was conducted at the Tygerberg Motion Analysis Laboratory and Tygerberg Physiotherapy Clinic in Cape Town, South Africa.

Participants

Eight subjects (five females; three males) diagnosed with AKP were included in this case series.

Intervention

Participants received a six-week, subject-specific functional movement retraining (FMR) intervention.

Main outcome measures

Three-dimensional hip, knee and ankle kinematics were used for analysis for each participant pre- and post-intervention. Pain was measured weekly using the numeric pain rating scale (NPRS). Two functional scales (lower extremity

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functional scale, and anterior knee pain scale), were used to assess pain and function in the pre- and post-intervention.

Results

All eight subjects demonstrated improved pain levels (NPRS), and functional outcomes (AKPS, LEFS). Seven of the eight participants (87.7%) demonstrated improvements in their main biomechanical outcome.

Conclusion

A subject-specific functional movement retraining intervention may be successful in the treatment of subjects with AKP presenting with biomechanical risk factors. Research on a larger sample is required to further investigate this approach.

5.1 Introduction

AKP affects up to half of young sports participants (Rathleff, C.R., Olesen et al., 2013). The condition impairs functional ability and is persistent. These symptoms hinder activities of daily living (ADLs) and sports participation (Nunes et al., 2013). Almost all (91%) of subjects diagnosed with AKP continue to experience symptoms four years after its onset (Collins et al., 2013; Rathleff, M.S., Roos et al., 2013).

AKP's aetiology is not well understood, posing treatment challenges for clinicians. A multifactorial origin of symptoms has been proposed (Aminaka & Gribble, 2008); the most common theory being that excessive joint stress during activities that load the flexed knee joint eventually results in articular cartilage pathology (Chen et al., 2014; Fulkerson, 2002). The exact cause of this increased joint stress is unknown, but it may arise from abnormal biomechanical and neuromuscular factors that cause mal-tracking of the patella within the femoral trochlea (Islam et al., 2015; Piva et al., 2006). Although this theory has been well cited in the literature, a cause-and-effect relationship has not been established due to challenges in measuring muscle forces and tissue stress and uncertainties of whether these factors are related to the pain experienced (Besier et al., 2009).

Conservative approaches are the preferred choice of treatment for AKP (Collins et al., 2012; McCarthy & Strickland, 2013) and surgical options such as distal realignment of the extensor mechanism, lateral retinacula release or debridement

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are considered as a last resort when conservative methods have failed (McCarthy & Strickland, 2013).

Functional movement retraining (FMR) is an approach to exercise based on the law of specificity that states “in order to achieve maximum training results, muscles should be conditioned in a manner similar to which they are to perform, including the exact pattern of movement” to improve neural recruitment patterns which are specific to the way in which the muscle is asked to contract (Swain & Leutholtz, 2002, p.19). FMR focuses on quality of movement or neuromuscular control and aims to improve sensorimotor control and achieve functional stability (Ageberg et al., 2010). It differs from strength training by correcting a dysfunctional movement pattern rather than targeting a specific muscle group. FMR has been used for rehabilitation following anterior cruciate ligament (ACL) injuries to improve active joint stabilisation, muscle imbalances and functional biomechanics (Risberg et al., 2004; Roddy et al., 2005; Ageberg, 2002). It is based on biomechanical and neuromuscular principles that can be applied to other knee injuries where abnormal biomechanics play a role such as AKP (Swain & Leutholtz, 2002).

The evidence on functional movement retraining on subjects with AKP is limited to case series research used to improve hip biomechanics during gait in runners (Willy et al., 2012; Noehren et al., 2010). In both of these studies, ten female runners with AKP completed eight sessions of a gait mirror retraining intervention using real-time kinematic feedback. The intervention focused on improving hip kinematics during running to within normal ranges. The subjects demonstrated significant and clinically meaningful changes in hip kinematics, pain on a visual analogue scale (VAS) and function on a lower extremity functional scale (LEFS) post two-week intervention. These improvements were maintained at one-month follow up (Willy et al.,2012; Noehren et al., 2010). The promising findings need to be tested on a larger scale to evaluate the effectiveness of this approach and to establish clinical approaches to facilitate movement pattern retraining. Furthermore, Functional movement retraining has not been used to correct movement patterns during other functional ADLs such as walking, squatting and stair negotiation. These are activities that often increase AKP (Nunes et al., 2013).

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To our knowledge no studies that assess the effects of a functional movement retraining approach during squatting, stair climbing and gait on subjects with AKP have been done. Based on the promising results from two previous laboratory-based studies on runners with AKP (Willy et al.,2012; Noehren et al., 2010), it will be beneficial to clinicians and researchers to further investigate this approach as it could have important clinical implications and change the way that clinicians prescribe exercise interventions for AKP. Therefore, the purpose of this case series was to investigate an individualised FMR approach on eight subjects with AKP using subjects' unaffected legs as a control to allow for individual variation in aetiology and symptoms.

5.2 Methods

5.2.1 Setting

The motion analysis was done at the 3D Motion Analysis Laboratory at Tygerberg Medical Campus of Stellenbosch University in Cape Town, South Africa and the interventions were done at the Tygerberg Medical Campus Physiotherapy Clinic at the same location.

5.2.2 Participants

The population comprised of males and females with AKP, between the ages of 18-40 years, residing in Cape Town, South Africa. This age range was chosen in order to limit the inclusion of participants with other age-related knee conditions such as Osgood-Schlatter and osteoarthritis. Eligible subjects reported anterior knee pain with at least two of the following activities: prolonged sitting, stairs, squatting, running, kneeling and lunging. On physical assessment, they presented with pain on patella palpation, pain when stepping down from 25-cm step and during a double leg deep squat (90 degrees).

All subjects were examined by a physiotherapist (DL) as it was important to exclude other underlying reasons which could present as anterior knee pain. Subjects were excluded if they had previous surgery involving the lower extremity of the affected limb, had a history of patella dislocation or subluxation, and had previous traumatic injuries to the menisci, cruciate or collateral ligaments in the asymptomatic or symptomatic limb.

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5.2.3 Sample description

Eight subjects with AKP (five females; three males; mean age= 27.75; age range= 18-37 years) were included. Subject-specific descriptions of the sample can be found below in Table 13. This includes descriptive information such as gender, age and affected side and anthropometric information such as height, mass and leg length.

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TABLE 13: Sample description for case series participants

Subject	Affected side	Gender (M/F)	Age (Years)	Height (m)	Mass (kg)	R leg length (mm)	L leg length (mm)
1	R	F	37	1.67	73.2	926	925
2	L	F	30	1.53	55.1	772	770
3	L	F	32	1.75	77.4	967	967
4	L	M	22	1.80	79.9	955	955
5	R	F	18	1.59	60.3	832	832
6	R	M	33	1.73	71.6	931	931
7	R	M	27	1.83	84.5	953	953
8	R	F	23	1.66	62.6	881	881
	5 R; 3 L	5 F, 3M	27.75	1.70	70.58	793.34	792.96

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5.2.4 Procedures

A VICON Motion Analysis (Ltd) (Oxford, UK) 3D system was used to obtain the 3D movement analysis data. The VICON has demonstrated high accuracy and reliability (Ehara et al., 1997). The standard plug-in gait model was used, as the model provides the angle output sought in the current study. VICON-specific anthropometric measurements obtained were: height; weight; leg length, knee and ankle diameter. All marker placements were done by the researcher (DL), who received training in marker placement and has two years' experience in marker placement. This served to reduce marker bias.

Participants were required to attend gait analysis sessions at week 1 and week 8 (pre- and post-intervention). Gait analysis was used to screen for kinematic contributing factors that could be targeted with treatment as there are well established normative values for these outcomes. The normative database used for comparison was gait data previously collected in the Tygerberg motion analysis laboratory on healthy, pain-free subjects. At these sessions, they were required to perform six successful barefoot walking trials at a self-selected speed. The pre-intervention gait analysis was done one week before the first treatment session and the post-intervention gait analysis assessment was done one week after the final treatment session. Therefore, the duration of the entire testing process was eight weeks. The functional outcomes, anterior knee pain scale (AKPS) and lower extremity functional scale (LEFS), were assessed pre- and post-intervention, on the day of the gait analysis assessment to assess the subjective impact of the treatment on the subjects' function and daily activities. The validity and reliability of these outcomes has been established in an AKP population (Watson et al., 2005). The questionnaires can be found attached as Appendix G**.**

The intervention was administered once a week for six weeks. The intervention has been described according to the template for intervention description and replication (TIDieR) checklist (Hoffmann et al., 2014), which can be found attached as Appendix H. The treatment sessions were done by a physiotherapist (DL) who was trained to administer the interventions and give specific treatment plans. The participants were instructed to do the exercises at home three times a week in addition to their weekly supervised treatment sessions. Participants were instructed to refrain from other treatment for their AKP during this time. The progress of the exercises was assessed weekly and adjusted as necessary. A spreadsheet of the exercises prescribed to each participant over the six-week period has been attached as Appendix J.

A progressive exercise database was created to assist with the choice of exercises focusing on the activity of which the patient complained. These exercises were chosen from a recent textbook on sport and area-specific functional rehabilitation (Liebenson, 2014). Two excel spreadsheets were created based on components of three functional activities used for screening; squatting, walking and stair climbing. Components of these activities were retrained emphasising the specific kinematic factor exhibited by the patient. In addition to being ranked according to task and area, the exercises were ranked according to three levels of difficulty. The level of difficulty was decided based on the following principles of progression: bilateral before unilateral, stable surface before unstable surface, and body weight before loading (Liebenson, 2014).

The least painful activity, (walking, squatting or stair-climbing), was addressed first. Three exercises were chosen from our exercise database for each session. An appropriate level of difficulty is one where the subject experiences no pain, but is unable to maintain good sensory motor control for three sets of ten repetitions (Swain & Leutholtz, 2002). Good sensorimotor control was determined by postural alignment of the trunk, hips knees and ankles (Ageberg et al., 2010). Verbal cues such as “don’t let the kneecaps pass over the front of the toes”, “keep the kneecaps facing forwards”, “keep the back straight”, “keep the hips and shoulders level” and “feel equal pressure through both feet” were used. Exercises were progressed when they were performed without pain, with good sensorimotor control for three sets of ten repetitions (by visual inspection from the therapist) and with minimal exertion from the subject’s perspective (Swain & Leutholtz, 2002). During the exercises, we enforced the “quality over quantity” principle.

5.2.5 Outcome measures and data analysis

Kinematics: The main contributing factor was identified for each participant based on decision-making algorithm using gait analysis as a screening tool. This

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algorithm is based on a systematic review of the evidence and can be found in Figures 5, 6 and 7 (Chapter 3). The identified feature was addressed during functional exercises based on the activity that the patient identified as being most problematic (walking, single leg squatting, lunging or stepping down). The primary outcomes, that included gait analysis and functional scales (AKPS, LEFS), were measured pre- and post-intervention (week 1 and week 8) and the painful side was used for analysis as all participants presented with unilateral symptoms. The average (mean) of six trials on the affected leg was used for analysis. Preliminary marker reconstruction and labelling were performed using Vicon Nexus 1.8 software. Lower extremity kinematics in the three different planes were performed in MATLAB (The Mathworks, Natrick, MA) using custom-built scripts.

Data was analysed narratively for each individual using tables or narrative summaries where appropriate.

Pain and function: The participants kept a weekly pain diary (NPRS) documenting usual pain during activity, on a scale of one to ten, weekly for 8 weeks on the same day each week. The AKPS and LEFS were also measured at the same time as the pre- and post-intervention motion analysis assessment (week 1 and week 8).

5.3 Results

5.3.1 Pain

The weekly pain diary using the NPRS showed that seven of the eight subjects (87.5%) demonstrated improved pain levels (NPRS) post-intervention. These seven participants were pain-free at the time of the reassessment. The average pain level at week 1 was 3.9/10 and post intervention it was 0.28/10. Figure 13 demonstrates the pain levels of the eight subjects throughout the treatment period. Only participant 8 (3/10) did not improve with a 3/10 pain rating pre- and post-intervention.

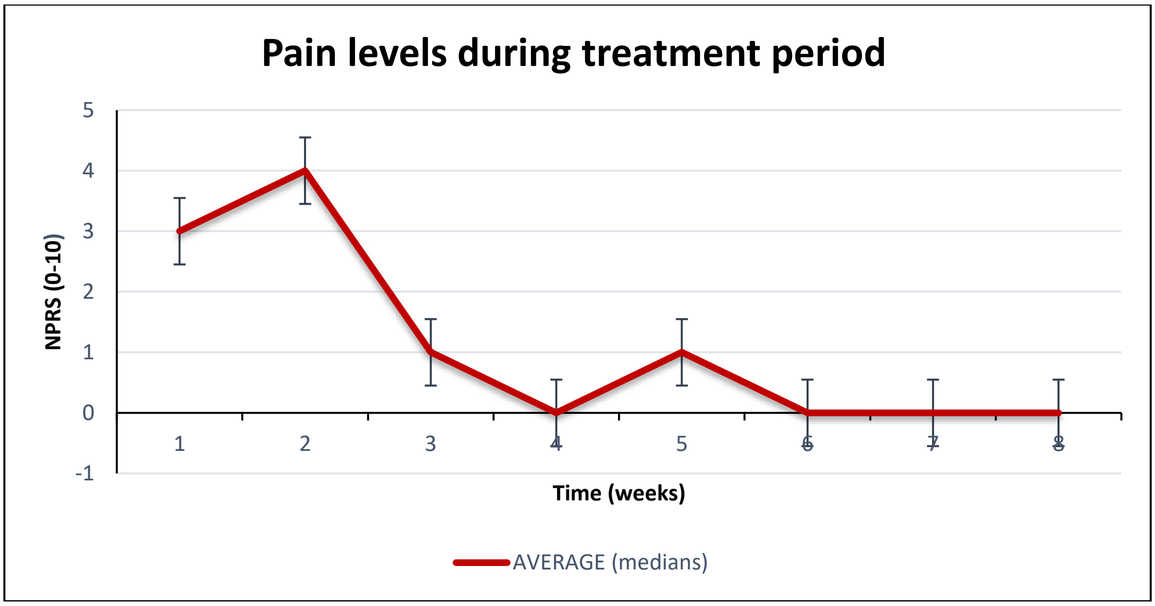

FIGURE 13. Weekly pain ratings (NPRS) for all patients throughout the treatment period (pain diary)

5.3.2 Function

All the included participants achieved improved functional scores (AKPS, LEFS) following the invention. However, not all of these improvements were clinically significant. The minimal detectable change (MDC) was 9 points and 8 points for the AKPS and LEFS respectively (Crossley, Bennell et al., 2004; Binkley et al., 1999). The minimal clinically important difference (MCID) was 10 points (Crossley et al., 2004) and 9 points (Binkley et al., 1999) for the AKPS and LEFS respectively. Based on this only two participants demonstrated clinically significant improvements in function. Participants experienced significant improvements. These were participant 1 (17%) and participant 6 (22.5%). With the LEFS, only participant 6 experienced a clinically significant change (22.5%). Functional scores can be seen in Table 14 (AKPS) and Figure 14 (LEFS).

TABLE 14: Functional scores (AKPS)pre- versus post-intervention for case series

Subject	Pre- intervention	Post- intervention	Difference
1	71	88	17
2	71	79	8
3	84	86	2
4	89	92	3
5	81	86	5
6	74	99	25
7	77	85	8
8	76	80	4

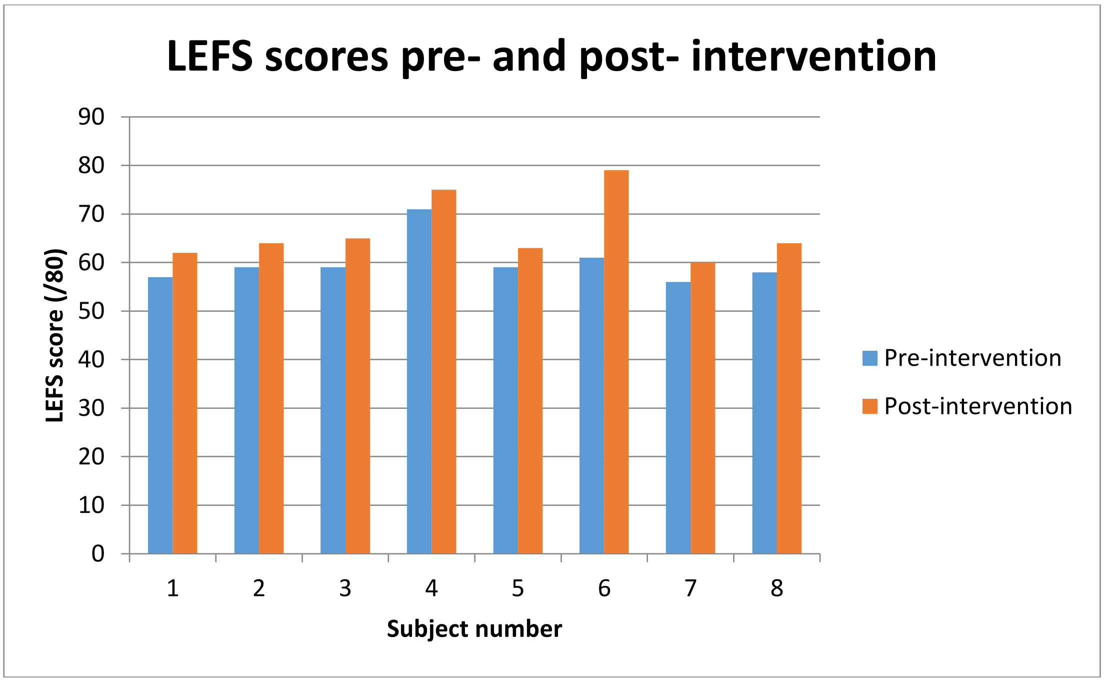

FIGURE 14. Lower Extremity functional scale (LEFS) scores pre- and post-intervention for case series

<u>5.3.3 Biomechanical results</u>

Table 15 summarises the individual results including the subject description, gait array of the priority kinematic contributing factor on the affected limb pre- and post-intervention, mean difference (in degrees) of main outcome pre- and post-intervention and whether or not the improvement can be considered clinically meaningful. Detailed case descriptions and individual results, including gait arrays can be found in Table 16 at the end of the chapter.

TABLE 15: Individual biomechanical results for case series participants pre- and post-intervention

Subject	Priority kinematic contributing factor	Pre-intervention (degrees) Mean (SD)	Post-intervention (degrees) Mean (SD)	Minimal detectable change (degrees)	Mean change (degrees)
1	Peak hip internal rotation	4.9 (0.4)	14.2 external (0.7)	1.6	19.3*
2	Decreased overall ankle sagittal plane ROM	23.1 (0.6)	27.2 (1.1)	3.7	4.1*
3	Average knee flexion in stance phase	8.7 (1.1)	13.7 (0.6)	3.6	5*
4	Average hip internal rotation	2.1 (0.4)	4.8 (0.3)	2.3	2.7*
5	Peak hip internal rotation	4.1 (0.9)	2.8 (0.3)	1.6	1.3
6	Peak rear foot eversion	11.6 (1.1)	12.4 (0.9)	Not available	0.8
7	Peak knee flexion throughout the gait cycle	53.9 (0.7)	59.6 (0.8)	5.3	5.7*
8	Knee flexion at heel strike	5.7 (1.6)	24.8 (1.6)	5.6	19.1*

(*=clinically meaningful change)

Identification of clinically meaningful changes were based on evidence for kinematic outcomes in healthy adults (Wilken et al., 2012). Intra-rater inter-session comparisons were used to identify these changes. A difference of less than 2 degrees is not considered clinically meaningful as this could be as a result of measurement error (Wilken et al., 2012). Clinically meaningful changes were noted in six of the eight participants (75%). Participants 5 and 6 did not demonstrate clinically meaningful improvements in their main biomechanical outcome. None of the participants got worse.

5.4 Discussion

This is the first study using a functional movement retraining intervention to address biomechanics in subjects with AKP during gait, single leg squatting and stair climbing. The intervention approach is novel as attempts have been made to target the treatment to the biomechanical contributing factors that each subject presents with.

Most of the participants presented with decreased pain at week 8 compared to week 1. However, Figure 13 clearly shows that participants experienced fluctuations in pain levels throughout the treatment period. This illustrates the intermittent nature of the disorder, which makes it more challenging to treat (Wilken et al., 2012). These participants all experienced AKP for longer than three months at the time of recruitment. It is therefore possible that central mechanisms were involved (Dye, 2005), as this can be classified as sub-acute going on chronic pain. Therefore, improved functional outcomes may be a better indication of treatment success than pain.

All the participants demonstrated improved functional outcomes post intervention. Although the changes were only significant in two participants, it still means that the participants could all perform at least one activity better than they could before the treatment. One possible reason for only two participants presenting with large changes is that this was overall a high-functioning group of participants at the baseline assessment regardless of their symptoms. It has been suggested that the LEFS as well as the AKPS might include some questions that are not often relevant to AKP such as questions about effusion and limping, and in the case of the LEFS non-weight bearing activities such as rolling over in bed (Watson et al., 2005). An additional limitation is that these questionnaires often require explanation due to medical terminology such as “atrophy” that some patients don’t understand (Watson et al., 2005).

All the participants showed some changes in their main biomechanical outcome as identified at the week 1 pre-intervention gait analysis. In addition, 75% of the participants showed clinically meaningful changes. Only participants 5 and 6 did not show clinically meaningful changes in their main outcomes. Participant 5 presented with increased peak hip rotation as her main biomechanical contributing factor. Although there was no significant change, she did demonstrate improvements in pain and function. Participant 6 presented with delayed timing of peak rear foot eversion (a distal factor) as his main contributing factor. It is possible that this was not the best treatment approach to address this specific contributing factor. However, his improvements in the functional scales were the most significant out of all eight participants (22.5% improvement for both). Perhaps his problem was structural and not biomechanical as he presented

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with increased rear foot eversion throughout the gait cycle. However, improved pain and function still indicate that the treatment was beneficial. Another factor that could explain why some participants did not improve, is that exercise compliance was not monitored. In future research participants should be required to keep an exercise compliance diary as well as a pain diary and this should be recorded weekly, at a similar time on the same day of the week.

There was an association between improved pain levels and improved biomechanics in 75% of the participants. However, we cannot establish the direction of causality. A cause-and-effect relationship has not been established due to challenges in measuring muscle forces and tissue stress and uncertainties of whether these factors are related to the pain experienced (Besier et al., 2009). High-quality prospective studies are needed, and the algorithm of risk factors used to make treatment designs should be updated continually.

Due to the large variety of clinical presentations in subjects with AKP, clinicians should consider a targeted treatment approach. The main contributing factor was not the same for each participant. Distal, local and proximal kinematic factors were identified. Regardless of the contributing factor, all improved in terms of functional scores. This is in agreement with previous literature suggesting that treatment approaches that targeted either proximal or distal factors could equally benefit symptoms at the knee (Barton et al., 2011). It is unclear whether a proximal or distal exercise intervention approach is more effective and therefore clinicians should first address whichever feature is the most prominent in the individual subject in treatment. The lack of standardisation to this approach may also make it more challenging for clinicians to reproduce in a clinical setting. However, this research offers some guidelines on how clinicians can approach treatment and attempt to tailor interventions for patients with AKP with different clinical presentations.

A limitation of functional movement retraining is that the approach is not relevant for subjects with AKP that do not present with biomechanical factors associated with AKP. Recent evidence has attempted to subgroup subjects with AKP according to which contributing factors for AKP they present with (Selfe et al, 2016). It would be interesting to establish whether there are biomechanical

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subgroups of subjects with AKP presenting with proximal, local or distal biomechanical contributing factors. Treatment approaches may need to be adapted for different subgroups and this motivates for the use of individualised treatment.

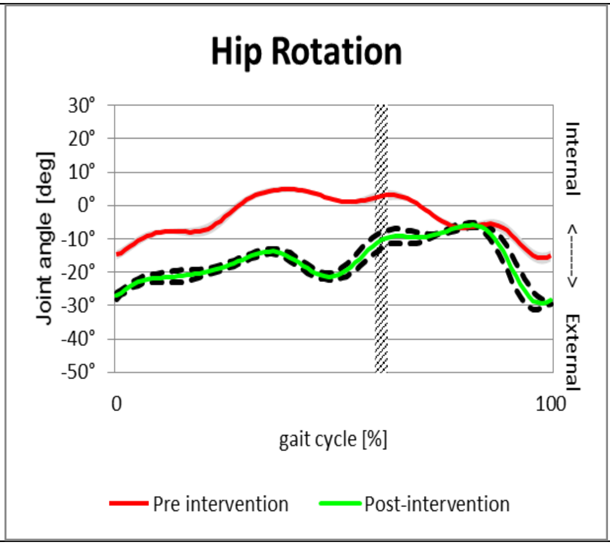
The small sample size limits our ability to extrapolate the findings to the general population. However, the positive results of this study justify the further investigation of this approach on a larger scale. Compliance of home exercises was not monitored. In the next stage of this research subjects will be required to keep an exercise compliance diary as well as a pain diary.

This case series is classified as level 5 evidence and therefore causality cannot be established, or strong recommendations made. However, the follow up study to this case series will be conducted using series of single-subject design (n of 1) on a larger sample (30 participants) with each subject acting as his or her own control and receiving more motion analysis assessments at regular intervals throughout the intervention period. McMaster University's hierarchy of evidence ranks this study design as level 1 evidence for treatment decisions (Guyatt et al., 2000; Elamin & Montori, 2012) as it accounts for intra-subject variability.

5.5 Conclusion

Functional movement might improve pain, function and biomechanics in individuals with AKP presenting with evidence-based biomechanical contributing factors. This needs to be investigated on a larger scale to establish its true efficacy. Single-subject designs are needed as this is the highest quality of evidence for treatment decisions. A one size fits all approach is unlikely to be successful when treating a multifactorial condition such as AKP where the aetiology is not well understood.

TABLE 16: Individual descriptions, results and gait arrays for case series participants

Subject number	Subject description	Main feature	Change pre- and post-treatment
1	37-year-old female with a 6-month history of **RIGHT** AKP. Her pain was aggravated by squatting, walking, going down the stairs and lunging. She experienced intermittent pain that she describes as a dull ache of approximately 5/10 intensity.		Session 1: Increased peak right hip internal rotation (4.9 degrees) Improvement of 19.3 degrees post intervention, putting her peak hip rotation within normal ranges

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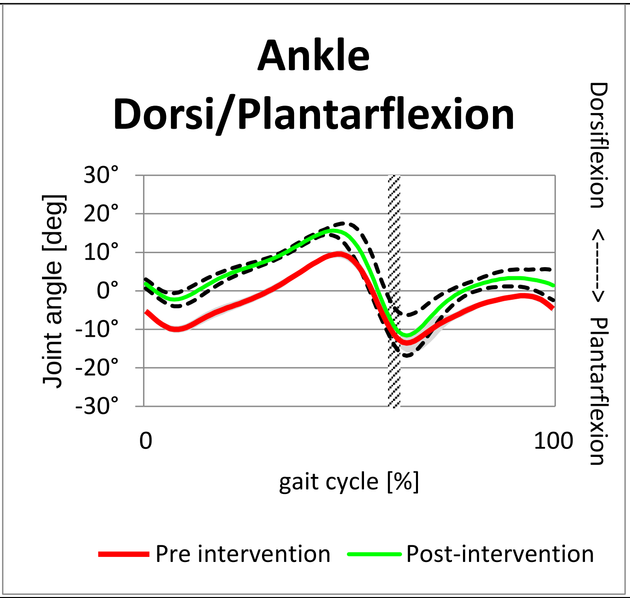
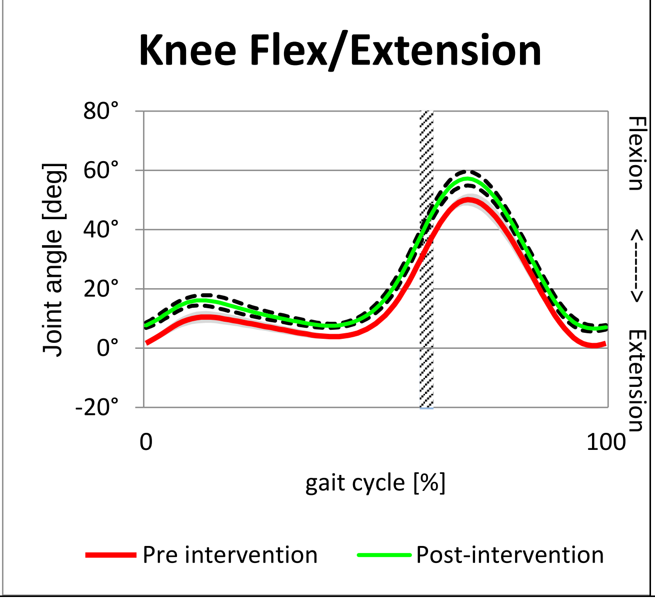
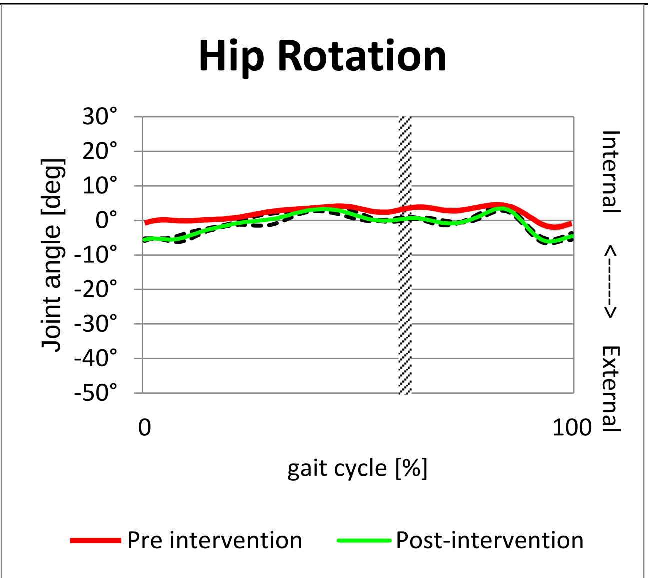
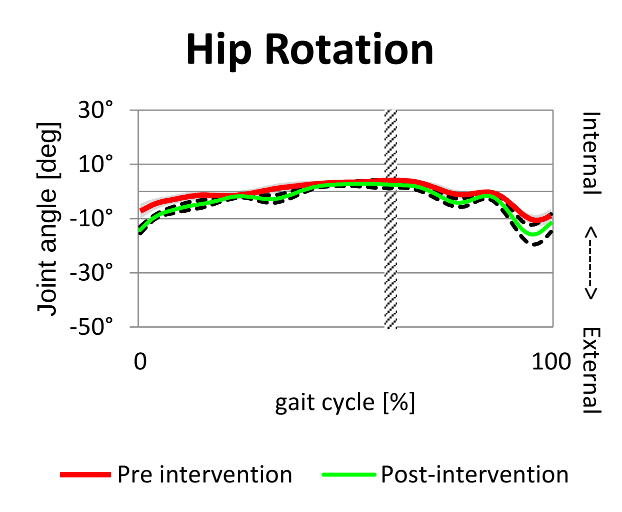
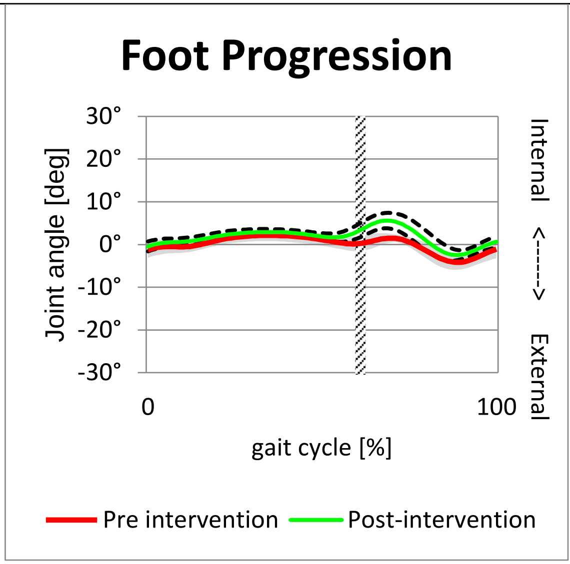
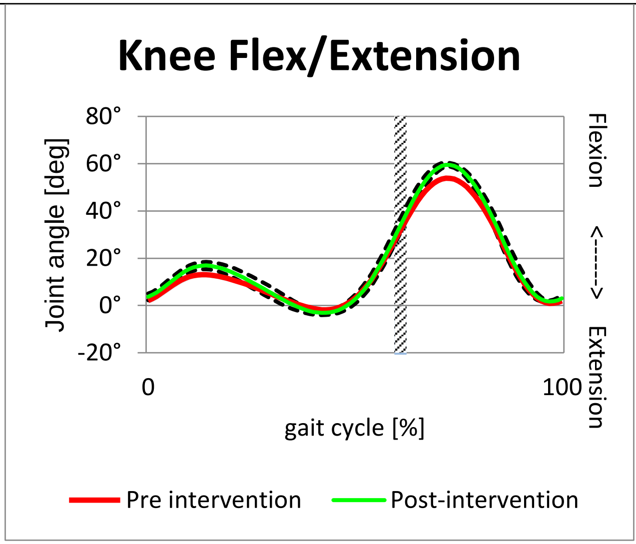
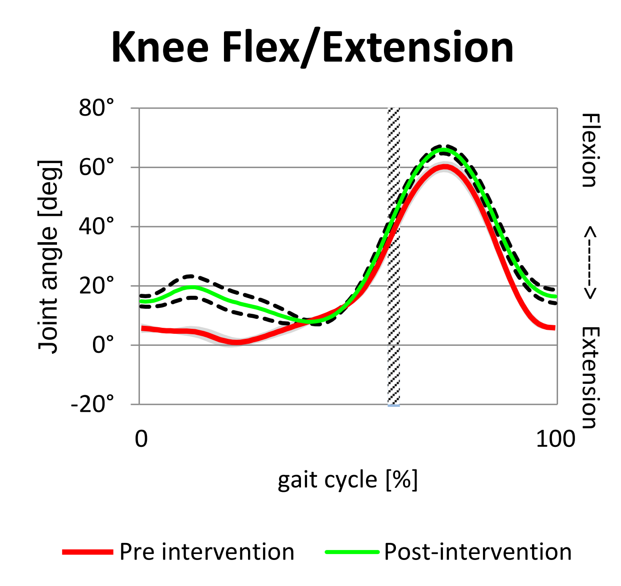
2	30-year-old female with a 3-month history of **LEFT** AKP. She experienced intermittently severe pain that she described as a sharp pain in front of and just below the knee cap. She experienced pain when performing an aggravating movement for a period of time (20-30 min)		<u>Session 1</u> Decreased overall ankle sagittal plane ROM (23.1 degrees) Improvement in overall ankle ROM of 4.1 degrees post intervention	Yes
3	32-year-old female with a two-year history of LEFT AKP. She was very active, cycling three times a week and going to 1-2 Pilates classes a week. She experienced an intermittent dull ache and her pain was in front of and sometimes on the lateral aspect of the patella.		<u>Session 1:</u> Decreased average knee flexion in stance phase (8.7 degrees) Improvement of stance phase knee flexion by 5.0 degrees post intervention	Yes

4	22-year-old male with a three-year history of LEFT AKP. He described his pain as a poorly localised dull ache of approximately 4/10 intensity, aggravated by jumping, kneeling, prolonged sitting (more than an hour), and after 15-20 km of running.		<u>Session 1</u> Increased average hip internal rotation throughout the gait cycle (2.1 degrees) Improvement of 2.7 degrees post intervention	Yes
5	18-year-old female with a 3-month history of RIGHT AKP. She described her pain as a sharp and nagging intermittent pain at the front of her knee cap and sometimes just below the knee cap.		<u>Session 1:</u> Increased peak hip internal rotation (4.1 degrees) Improved by 1.3 degrees post intervention (minor change)	No

6	35-year-old male with a two-year history of right AKP at the front of and behind the kneecap. He described the pain as being an intermittent nagging pain that is aggravated by lunging, prolonged sitting, running on uneven surfaces and jumping.		<u>Session 1:</u> Increased peak rear foot eversion throughout the gait cycle 11.6 (degrees) No change during stance phase. Minor improvement during swing phase (0.8 degrees)	No
7	27-year-old male with intermittent right AKP for 6 years. He described having pain around the kneecap during sitting stair climbing (up and down) and kneeling.		<u>Session 1:</u> Decreased average knee flexion throughout the gait cycle (53.9 degrees) Improvement of 5.7 degrees post intervention	Yes

8	23-year-old female with a 3-month history of right AKP. She described her pain as an occasion specific, sharp pain at the front of the knee cap. She experienced pain with dynamic activities only, specifically with squatting, stairs and lunging.		Session 1: Decreased knee flexion at heel strike (5.7 degrees) Improvement of 19.1 degrees post intervention	Yes

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Chapter 6 (phase C)

6.1 Introduction

This chapter aims to summarise the interpretation and application of the preliminary research studies described in Chapters 2 to 5. The chapter also summarises how the findings of the preliminary studies have assisted the planning, fine-tuning and procedures of the intervention study (phase D).

The second aim of this chapter is to provide the reader with a practical overview of how the preliminary phase information was applied to an individual participant's physical assessment, screening, decision-making and intervention. For a practical overview, a single case description is presented. This participant (AKP27) has given informed consent to be used as an example and to have his photographs and videos used in this chapter. The decision-making framework for the intervention can be seen in Figure 15.

6.2 Interpretation and application of phases A and B

6.2.1 Clinical diagnosis of AKP

The primary aim of this dissertation was to assess the effect of an individualised functional retraining intervention on subjects with AKP. Therefore, the preliminary phase of the thesis was essential as each phase contributed towards the planning of the main study (phase D). In addition, the findings of each phase allowed the opportunity to make adaptations to improve the methodology, clarify the decision-making framework and the validity of the intervention applied in the main study (phase D).

The first step was to ensure that the target population was correctly identified and for this the accurate clinical diagnosis of AKP was key. In Chapter 2, an evidence-based checklist for the diagnosis of AKP was created. This was intended for clinical use and application in the main study (phase D) to clarify evidence-based inclusion and exclusion criteria. This allowed us to use the most important subjective and objective indicators to identify appropriate participants as well as to exclude participants likely to have other pathologies such as ligament sprains, meniscal injuries, patella subluxation and osteoarthritis.

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6.2.2 Identify kinematic factors associated with AKP

The second step in the preliminary phase was to identify the most important kinematic outcomes that are likely to be affected in an AKP population. These were the person-specific contributing factors that participants would be screened for to be addressed with an individualised functional retraining intervention in Chapter 7.

A systematic review was conducted in Chapter 3 to summarise the published literature on kinematic factors associated (as most of the studies included are cross-sectional) with AKP. This summary presents the best available evidence of kinematic factors associated with AKP. Based on this evidence synthesis, walking gait and single leg squatting are currently the best activities to use for screening kinematic factors in subjects with AKP. This is because kinematic factors with significant and consistent supporting evidence can be identified during these activities.

We have decided to use walking gait as our screening tool as this is the only activity with well-established normative values with which to compare values in subjects with AKP. It is also an activity that all subjects with AKP regardless of activity levels do daily.

The kinematic factors associated with AKP during walking gait are reduced peak hip internal rotation during gait; delayed timing of peak rear foot eversion (level 1) and earlier timing of peak hip internal rotation; increased peak hip adduction at peak knee extensor moment; increased peak knee extension and decreased knee flexion in early stance; increased rear foot eversion at heel strike; increased overall ankle range of movement and increased peak ankle dorsiflexion (level 2) in subjects with AKP compared to controls (see Chapter 3). The kinematic factors were classified according to their level of evidence based on significance and consistency of findings.

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6.2.3 Reliability of procedures

Following the kinematic review, Chapter 4 involved establishing the test-retest reliability of the measurement procedures and quantifying measurement error for the key outcomes identified in Chapter 3.

From this study, we identified that all the outcomes obtained were acceptable to excellent test-retest reliability scores for both measures of relative reliability (ICC=0.78-0.9) and measures of absolute reliability (SEM= 0.94 - 4.21 degrees). The peak hip transverse plane kinematic measurement should be interpreted with some caution as this was the least reliable. This reliability study added value by quantifying measurement error for the most important outcomes. This is very important to take into consideration when interpreting the effect of the intervention.

6.2.4 Feasibility assessment for the intervention (phase B)

A case series was done (Chapter 5) on eight subjects with unilateral AKP to assess the feasibility of the "clinical diagnosis" checklist and kinematic contributing factor screening tool and to pilot the intervention.

6.2.5 Lessons learnt (factors to be addressed in the main study)

The case series also highlighted some limitations to address in the main study:

1. Exercise compliance and activity levels were not monitored throughout the treatment period. This led to the inclusion of an exercise compliance diary that participants in the main study were required to complete weekly at their supervised treatment sessions. This is attached as Appendix L.
2. The kinematic outcomes changed slightly following the cases series as the kinematic review done in Chapter 3 was updated between the time of the case series and the main study, before being submitted for publication. Level 1 factors were addressed first in treatment and level 2 factors considered in the absence of level 1 factors. If a participant presented with two factors on the same level the factor which was the furthest (in degrees) from the normal values was addressed first.
3. Our exercise database was also updated following the case series to include warm-ups and some extra exercises prior to the main study. The

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exercises were divided into “proximal-focused”, “local-focused” and “distal-focused” exercises and each region was divided into three levels of difficulty. The focus area was chosen according to the participant’s risk factor. The exercises were changed at week 4 to progress to exercises that address components of squatting. This was done to make the exercises a bit more challenging and to prevent boredom.

4. In the main study, we conducted an extra motion analysis assessment so that the measurements were repeated three times instead of just pre- and post-intervention as done in the case series. The first two sessions were done one week apart at a similar time of the day with no treatment. These two tests were used for the reliability study done in Chapter 4. The third test was following the six-week intervention.
5. A second physiotherapist was included (MM) to test the decision-making framework and administer some of the interventions. She was able to follow the procedure, keep correct records of pain, exercise and compliance and prescribe appropriate exercises based on the framework.
6. In the case series, we only measured pain and function pre- and post-intervention with no long-term follow up post intervention. Due to the reoccurring and often chronic nature of AKP it is important to establish whether the effects that may be seen immediately after an intervention period are maintained. Therefore, the long-term follow up of pain and function was a very important component of phase D as long-term evidence is sparse in the research for exercise interventions to treat AKP. For phase D, pain and functional outcomes were followed up at three and six months post intervention in order to establish medium- and long-term effects of the intervention.
7. Additional outcomes were added to the long-term follow up. We added an exit interview (Appendix O) that included a measure of self-reported recovery. This was to allow participants to elaborate on their experience participating in the research, discuss changes (good or bad) that they experienced and rate how well-recovered they felt at the long-term follow up compared to session one (pre-intervention). We also removed an outcome. The LEFS was removed as we felt that it was not condition-specific and that some of the questions were about non-weight bearing

activities such as rolling over in bed that were irrelevant in an AKP population.

8. In the case series and previous chapters, the term “anterior knee pain” has been used to define our condition of interest. For the main study (Chapter 7), we have chosen to change this to “patellofemoral pain (PFP)” as this has recently been recommended as the preferred terminology in the 2016 PFP research retreat consensus statement (Crossley et al., 2016). This change has also been made for this Chapter for publication purposes so that the terminology used is consistent with other recent evidence.
9. The final change that was made prior to the main study was that we changed the terminology that defines the intervention from “functional movement retraining” to “individualised functional retraining”. The reason for this was that the focus of the intervention was about individualised exercise programming based on movement control. The definition functional movement retraining could have been misleading as it suggests that the main focus of the exercise was to improve functional neuromuscular control.

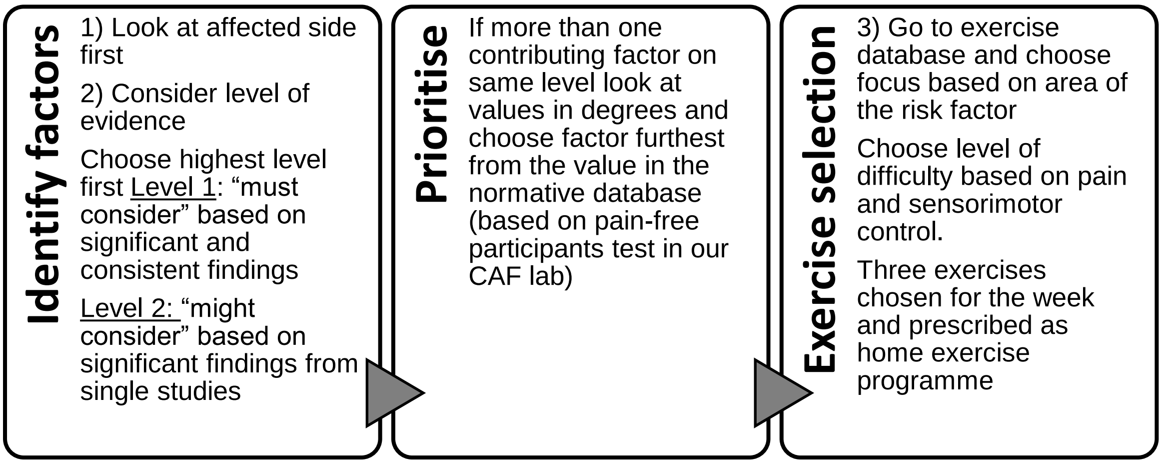

FIGURE 15. Decision-making frame work for intervention based on kinematic contributing factor identification

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6.3 Patient case description

An example of a patient case study to demonstrate the entire assessment and intervention process that each included participant went through is discussed below. This shows how phases A and B enabled us to make intervention decisions for the individual participant. This participant was part of phase D and therefore the process described here occurred after the changes discussed earlier in this chapter were made.

6.3.1 Clinical diagnosis (screening)

Participant number 27 (AKP27) was a 33-year-old male with a 7-year history of left-sided AKP. He reported pain with squatting, stair descent, downhill hiking and running and kneeling. He had no history of lower limb surgery or trauma. He had previously tried quadriceps stretching, taping and massage to treat his knee pain with no success. He volunteered for the study as he wanted to understand the cause of his long-term knee pain. His other main concern was to be able to enjoy hiking and running without being limited by his knee pain.

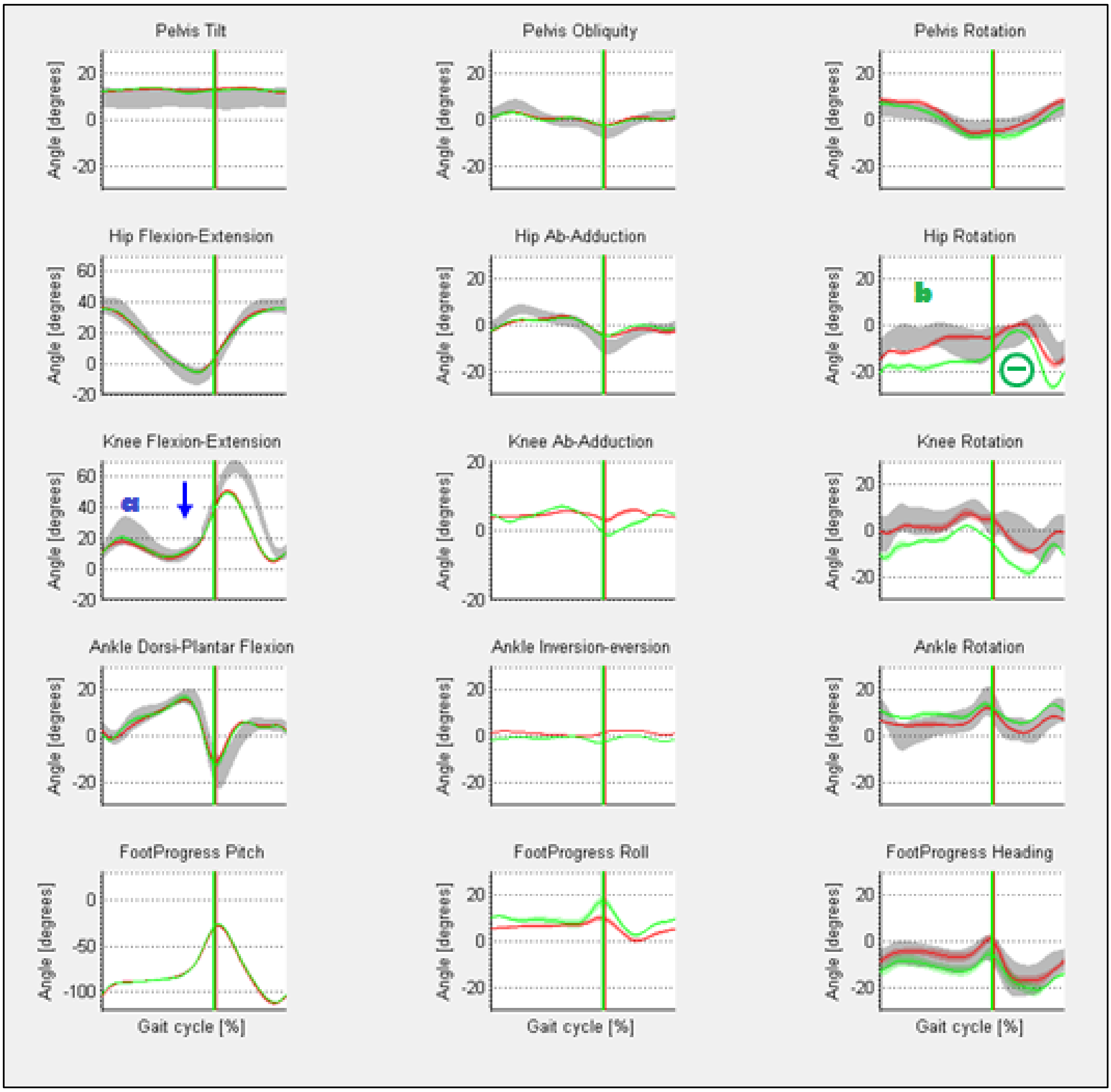
6.3.2 Session1: initial assessment

At his first assessment session, he reported 5/10 pain. We ruled out intra-articular pathology with special objective tests. His pain was reproduced by squatting, stepping down and isometric quadriceps contraction. He therefore qualified for the study and could proceed to the motion analysis. His initial functional score was 80/100 or 80% on the AKPS. This can be classified as a "minor functional impairment". On observation it was noted that he stood with a posterior pelvic tilt and hyperextension of both knees. Photographs can be seen below (anterior view, left lateral view, posterior view, right lateral view). Videos of the capture can be seen at https://www.dropbox.com/s/c29t5urmvss7rus/AKP27.zip?dl=0.

Figure 16. Photographs of marker placements

6.3.3 Kinematic feature identification

On his initial motion analysis, the priority feature that was identified was "increased bilateral knee extension throughout the gait cycle". This can be seen on his gait array below. One other feature that was identified was "decreased right hip internal rotation throughout the gait cycle". This was considered during treatment. However, it was not chosen as the priority feature to guide the choice of exercises as it is on the unaffected side and closer to the normal range than the knee feature. Therefore, the exercises were chosen from the local exercises functional database.



Key: red line- left leg; green line- right leg; grey band- normative database for CAF motion-analysis lab

Figure 17. Gait array for AKP27

In this participant, we were able to identify two kinematic factors. These were as follows:

- Increased bilateral knee extension throughout the gait cycle
- Decreased right hip internal rotation throughout the gait cycle

Increased bilateral knee extension throughout the gait cycle was identified as his priority factor as his affected side was the left side.

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Reasons

1) Left was affected side
2) Level of evidence (based on Chapter 3): No level 1 contributing factors (would be chosen first), one level 2 contributing factor. This was his only level 2 kinematic contributing factor.
3) Exercises selected from proximal factors database. Level 2 (intermediate difficulty)

6.3.4 Intervention planning: Exercise selection

Exercises for weeks 1-3 were chosen from the “exercises to address components of walking” database, whereas exercises for weeks 4-6 were progressed to the “exercises to correct components of squatting” database. His exercises were chosen from the “local factors” database and started at an “intermediate” level of difficulty (level 2). Each session started with a short warm up, followed by three functional exercises. Examples of exercises in the database can be found attached as Appendix J. The details of his 6-week exercise programme can be seen below in Table 17. Pictures and detailed descriptions of his exercises can be found attached in Appendix M.

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Table 17. Exercise prescription details for 6-week intervention period (AKP 27)

Week	AKP code	Exercises	Sets and reps	Progressions	Notes
1	AKP27	1) Step up knee up 2) Reverse lunge off step 3) Single leg squat foot on chair	1) 3 sets of 8 2) 3 sets of 5 3) 3 sets of 5		1) No weights 3) No weights but also no front support
2	AKP27	1) Step up knee up 2) Reverse lunge off step 3) Single leg squat foot on chair	1)3 sets of 8 2) 3 sets of 8 3) 3 sets of 8	1) Added 2 kg weight 2) Higher step 3) Added 2 kg weight	
3	AKP27	1) Step up knee up 2) Reverse lunge off step 3) Single leg squat foot on chair	3 sets of 10 for all	1) 5 kg weight 2) Increased reps 3) Increased reps	Patient doing very well, exercises getting easier
4	AKP27	1) Standing to sitting 2) Wall squats 3) Supported single leg squats	1) 3 sets of 10 2) 3 sets of 30 second holds 3) 3 sets of 5 reps	1) Lower chair 2) 90-degree knee bend 3) Holding onto chair	3) Don't let contra lateral pelvis drop

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5	AKP27	1) Standing to sitting 2) Wall squats 3) Supported single leg squats	1) sets of 8 2) 3 by 45 second holds 3) 3 sets of 10	1) single leg 2) Increased duration 3) No front support but foot on wall	
6	AKP27	1) Standing to sitting 2) Wall squats 3) Supported single leg squats	3 sets of 10 for 1) and 3) 60 second hold for 2)	Increased reps	

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6.4 Conclusion

This chapter has described the process of planning and implementing the intervention based on the preliminary research and pilot phases of this project. The necessary changes were made in preparation for the final phase (phase D) and the decision-making process was applied to an AKP patient case example. In the subsequent chapter (Chapter 7) the individualised decision-making process outlined in this chapter will be applied to 31 participants with AKP in the main intervention study (Study 5).

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Chapter 7 (phase D): The effect of an individualised functional retraining intervention on pain, function and biomechanics in subjects with patellofemoral pain: a series of n of 1 trial

ABSTRACT

Objectives

To determine the effect of an individualised functional retraining intervention on pain, functional outcomes and kinematics in subjects with PFP.

Study design

A series of n of 1 design

Setting

Tygerberg CAF 3D Motion Analysis Laboratory and Physiotherapy Clinic at the University of Stellenbosch Medical School in Cape Town, South Africa.

Participants

Thirty-one subjects with unilateral PFP between the ages of 14-40 were included.

Main outcome measures

Lower limb kinematics pre- and post-intervention, pain on a numeric pain rating scale (NPRS), function on an anterior knee pain scale (AKPS), Self-reported long-term recovery on a 7-point Likert scale.

Results

Thirty of the thirty-one subjects (96.8%) demonstrated improved pain levels (NPRS) post intervention. Participants demonstrated a statistically significant improvement in function (AKPS) immediately post intervention and continued to improve with greater functional scores at 6-month follow up. Fifteen participants (48.4%) rated themselves as fully recovered on a 7-point Likert scale at 6-month follow up. Nineteen of the 31 participants (61.3%) demonstrated a clinically significant improvement in their priority kinematic outcome post intervention.

Conclusion

Individualised functional retraining improves pain, function and kinematics in subjects with PFP presenting with kinematic contributing factors in the short term and pain, function and self-reported recovery in the long term. Clinicians need to be educated on common biomechanical contributing factors and how to tailor treatment accordingly.

7.1 Introduction

Patellofemoral pain (PFP) is characterised by retropatellar or peripatellar pain during activities such as squatting, stair climbing and prolonged sitting that load a flexed knee joint (Østerås et al., 2013). It has an estimated prevalence of 19-31% in a young athletic population (Rathleff, M.S., Roos et al., 2013). The causes of PFP are multifactorial and biomechanical factors may play an important role in its development (Witvrouw et al., 2014). Many of the proposed causes of PFP are likely to be associated with patient biomechanical dysfunction or poor dynamic stability during weight-bearing activities (Rabelo et al., 2014). The impact of PFP is considerable as it hinders participation in sport, physical activity, work, and school (Lankhorst et al., 2015). In addition, it has the tendency to become chronic. As many as 50% of subjects with PFP will still experience symptoms after 5-8 years (Collins et al., 2013).

Conservative approaches, primarily physiotherapy, are preferred for the treatment of PFP (Witvrouw et al., 2005). Surgical options such as lateral retinacular release, chondroplasties, proximal realignments and distal realignments should be considered a last resort thereafter (McCarthy & Strickland, 2013). In addition, surgery should only be considered when there are specific indications and the pathology is clearly defined (Post & Dye, 2017). At the recent Patellofemoral Pain Research Retreat in 2016, a document of current evidence-based treatment guidelines was created (Crossley et al., 2016). According to this, current recommended treatment options include exercise therapy in the short, medium and long term; multimodal interventions in the short and medium term; and foot orthoses in the short term. The authors concluded that exercise should be considered the first choice of treatment due to the large body of evidence supporting it (Crossley et al., 2016). This recommendation is supported by a high-quality systematic review that investigated the effect of

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exercise in the treatment of PFP (van der Heijden et al., 2015). The main outcomes included short- and long-term pain, function, and long-term self-reported recovery. Based on a meta-analysis of RCTs, there is low quality but consistent evidence that exercise results in clinically meaningful reductions and pain and improvements in function in the short term. Despite the tendency of PFP to become chronic, the review showed that long-term evidence was limited. Three studies followed up on pain and functional outcomes 4-12 months post intervention (Clark et al., 2000; Moyano et al., 2013; van Linschoten et al., 2009). Of these, only one study (van Linschoten et al., 2009) measured self-reported long-term recovery at 12-month follow up. In this study, the exercise group was no more recovered than a control group that had not received an exercise intervention. It is unclear why exercise appears to improve pain and function in the short term, but recovery in the long term remains challenging. To improve long-term recovery, it is necessary to establish which subgroups of patients with PFP, benefit from which type of intervention (van Heidjen et al., 2015). There is evidence that suggests that an individually tailored approach to exercise interventions improves patient outcomes in subjects with other musculoskeletal conditions such as lower back pain (Hodges & Falla, 2017). Therefore, further investigation of this approach in an PFP population is needed.

Since the 2015 Cochrane review, a prospective cohort study investigated the long-term effects of a multimodal individualised intervention for PFP (Keays et al., 2016). Thirty-seven subjects with AKP received four treatments over a 4-week period, namely local interventions which focused on stretching the quadriceps; fourteen days of taping; fourteen more days of specialised lower limb movement and postural correction; followed by continued self-management. Subsequently a 3-year follow up yielded positive results with 73% pain-free and 27% having less pain than previously. Moreover, 82% returned to their sporting activities, while 54% took up new sports. Only 7% experienced a recurrence of PFP. The inclusion criteria for this study only required that patients had a 1-month duration of symptoms. Therefore, treatment success can be ascribed to early interventions and the effect of this intervention on persistent PFP remains unknown. In addition, the study by Keays et al. (2016) reported on the effect of treatment tailored to subgroups (i.e. hypermobile stance, hypomobile and faulty movement pattern

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subgroups). The effect of an individually tailored exercise intervention on an individual's presentation can be complex and may span across more than one subgroup.

According to McMaster University's hierarchy of evidence (http://fhs.mcmaster.ca/medicine/residency/halfday_ebm.htm) and the Oxford Centre for Evidence-Based Medicine (http://www.cebm.net/index.aspx?o=5653), a n of 1 design can be regarded as level 1 evidence for treatment decisions as it enables the assessment of the intervention for a specific person (Elamin & Montori, 2000; Guyatt et al., 2000). Greenhalgh (2017) acknowledges the difficulty in applying the mean response (as assessed in a RCT) to a specific person. The selected methodological design attempts to address this problem by facilitating the translation of evidence into practice. In addition, a series of n of 1 design is well suited for conditions with multiple anatomical and biomechanical risk factors and it is impossible to control for all known confounding variables between subjects. Using subjects as their own control eliminates this problem and allows the application of an individually tailored treatment approach in a person-specific manner. Individualised approaches are well aligned with a person-centred approach to healthcare which is currently promoted by the World Health Organisation.

This study reports on the short- and long-term effect of an individualised exercise intervention. To our knowledge this is the first research into PFP which uses a series n of 1 design using subjects as their own controls. We hypothesise that an exercise intervention tailored to the individual can improve pain, function and kinematics in subjects with PFP post-intervention compared to pre-intervention. The aims of this study are to determine the effect of an individualised functional retraining intervention on 1) lower limb kinematics and 2) short- and long-term pain and functional outcomes in 31 subjects with PFP.

7.2 Methods

7.2.1 Study design

The study was conducted using a series of single-subject design with each subject acting as his or her own control.

7.2.2 Population and sample size

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The population comprised 31 subjects between the ages of 14-40 with unilateral PFP, residing in the Cape Metropolitan. Our sample size was determined from a priori power analysis for a single-group pre-test post-test design and the effect size using pilot data on a sub-sample of eight participants. A two-tailed Wilcoxon-signed rank test was used as the data was abnormally distributed. Assuming that alpha=0.05, power=0.95 and effect size=0.75, we needed a sample size of n=27. We recruited 31 participants to allow for drop out.

7.2.3 Inclusion criteria

An evidence-based screening tool was developed specifically for this study (Leibbrandt & Louw, 2017a) to ensure standardised diagnosis and exclusion of other pathologies. This checklist is based on an up-to-date evidence synthesis on systematic reviews. An initial screening was done at recruitment. Potential participants were asked to complete a short, screening questionnaire via email, containing the subjective indicators required for the diagnosis of PFP. Participants were considered based on age, area of pain, duration of pain, aggravating factors and previous medical history. Sixty-seven participants inquired and of these 31 met the subjective criteria. The most common reason for exclusion was age (>40 years old).

Individuals who met the criteria in the preliminary screening were booked for a testing session at the 3D CAF Motion Analysis Laboratory at the Tygerberg campus of Stellenbosch University. At the first session written informed consent was obtained and all participants were screened based on the objective criteria described in the evidence-based diagnostic checklist. All 31 participants met the criteria and could therefore proceed to the 3D motion analysis assessment. VICON-specific anthropometric measurements that were obtained prior to the motion analysis included: height, mass, leg length, knee diameter and ankle diameter.

7.2.4 Instrumentation

A fast, accurate, reliable and high-resolution motion-capturing 3D device, the T10 VICON Analysis (LTD) (Oxford, UK) T10 system (Ehara et al., 1997) was used to obtain the 3D movement analysis data. Retro-reflective markers with a diameter of 9.5 mm were applied. The standard plug-in gait model was used, providing the

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angle output sought in the current study. Nexus 1.8 software was used for preliminary marker reconstruction, labelling and processing of data. All marker placements were done by an experienced researcher (DL), to reduce marker bias. Gap filling was performed using the standard Woltring filter supplied by Vicon. Segment and joint kinematics were calculated using the PIG-model and filtered with a 4th-order Butterworth filter at a 34 10Hz cut-off frequency. Data was exported to MATLAB to extract the joint kinematics of the lower limbs.

7.2.5 Testing procedure

Participants were required to attend gait analysis sessions at week 1, week 2, and week 8. Gait analysis was used to screen for kinematic factors associated with PFP that could be targeted with treatment, as there are well-established normative values for these outcomes. The normative dataset is based on gait data from healthy, pain-free subjects walking at a self-selected speed tested in the Tygerberg motion analysis laboratory. An example of a gait array used for screening can be seen below in Figure 18.

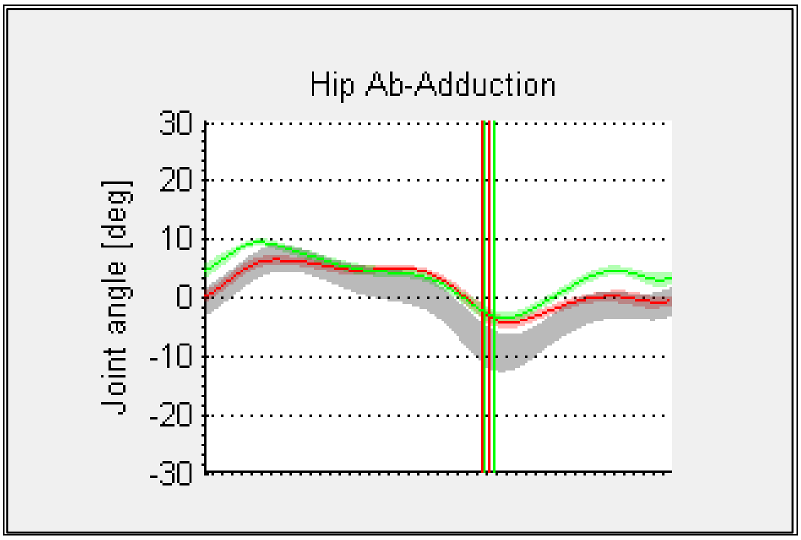

FIGURE 18. Example of risk factor identification on gait array for screening purposes

Testing was repeated on three occasions. Sessions 1 and 2 were to establish the test-retest reliability of the kinematic outcomes and to quantify measurement error. Session 3 was done post intervention to determine the effects of the intervention. Therefore, the duration of the entire testing period was eight weeks.

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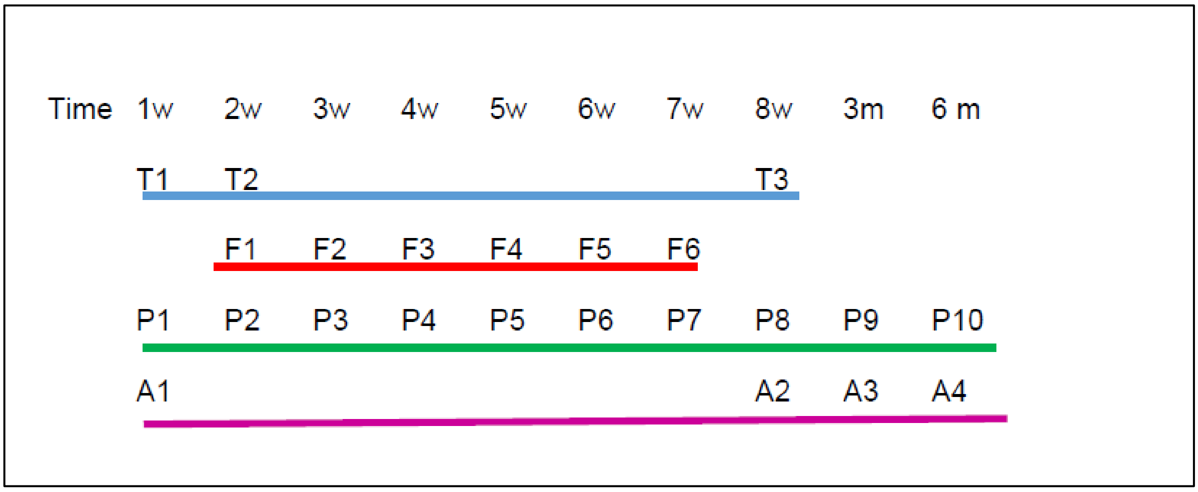
Function was measured using the anterior knee pain scale (AKPS) and was assessed pre- and post-intervention on the same day as the gait analysis assessment to evaluate the subjective impact of the treatment on the patient's function and daily activities. The validity and reliability of the AKPS has been established in an PFP population (Watson et al., 2005). The AKPS was followed up at three months, one month after the end of the intervention period, and again at six months. The AKPS can be found attached as Appendix G**.** The timing of the outcome measures and intervention period is outlined in Figure 19.



Key

T= Gait analysis tests

F= Functional movement retraining intervention

P= Pain measurements (NPRS)

A= Anterior knee pain scale (functional measurements)

w=weeks, m= months

FIGURE 19. Timeline for measurement procedure for study outcomes

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7.2.6 Intervention description

The intervention has been described according to the template for intervention description and replication (TIDieR) checklist (Hoffmann et al., 2014), which can be found attached as Appendix H. Individualised functional retraining is an approach to exercise that targets subject-specific biomechanical risk factors by focusing on correcting a dysfunctional movement pattern rather than addressing a specific muscle group. Experts in the field (Barton et al., 2015) recommend incorporating movement pattern retraining as part of the exercise plan for subjects with PFP, as it is unclear whether specific muscle group strengthening translates to improved movement performance (Wouters et al., 2012). A progressive exercise database**,** adapted from a recent textbook on functional rehabilitation (Liebenson, 2014) was created to assist with the choice of exercises. Two exercise database spreadsheets were created. The first focused on components of walking and was used to choose exercises for weeks 1-3. The second focused on components of squatting and was used to choose exercises for weeks 4-6. Functional retraining during these exercises focused on the specific kinematic factor exhibited by the patient. The exercises were ranked according to three levels of difficulty within task and area. Exercises were progressed according to the following principles: bilateral before unilateral, stable surface before unstable surface, and body weight before loading (Liebenson, 2014). Examples of proximal and local focused exercises at different levels of difficulty from the database can be seen in Appendix J.

Participants were required to exclusively attend the Tygerberg Physiotherapy Gym weekly for six weeks for individual supervised treatment sessions. The progress of the exercises was assessed weekly and adjusted as needed. Appendix K lists examples of the individually tailored exercises over the 6-week period.

Exercise sessions lasted 20-30 minutes. At the first session, the findings of the gait analysis were explained to the patient. Each exercise session started with 10 minutes of gait retraining in front of a mirror focusing on the feature that was identified during the pre-intervention motion analysis. Thereafter, three exercises were chosen from our exercise database for each session, with an appropriate

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level of difficulty where the subject experiences no pain, but is unable to maintain good sensory motor control for three sets of ten repetitions (Swain & Leutholtz, 2002). The therapist's verbal feedback and visual feedback from a mirror (Barton et al., 2015) encouraged quality and correction. Good sensorimotor control was determined by postural alignment of the trunk, hips knees and ankles (Ageberg et al., 2010). Verbal cues such as "don't let the kneecaps pass over the front of the toes"; "keep the kneecaps facing forwards"; "keep the back straight"; "keep the hips and shoulders level"; and "feel equal pressure through both feet", were used. Exercises were progressed when performed without pain, with good sensorimotor control (by visual inspection from the therapist) for three sets of 10 repetitions (Ageberg et al., 2010).

The participants were required to do the exercises at home three times a week apart from their weekly supervised treatment sessions because published reports suggest that supervision is beneficial in the early phases of rehabilitation to monitor technique. However, subjects should be motivated to independency as quickly as possible (Papadopoulos et al., 2015).

The clinician asked patients to complete a weekly pain monitoring and exercise compliance diary at each treatment session (see Appendix L). The diary documented pain intensity, nature, aggravating and easing factors and any other possible influencing factors on the symptoms. The number of days per week that the patient completed the exercises was also recorded. The treatment sessions were administered by one of two experienced musculoskeletal physiotherapists (DL and MM).

7.2.7 Data management and analysis

The data was initially analysed for each individual subject by describing measures of central tendency (means) and variation expressed (standard deviations) of pelvis, hip, knee and ankle kinematics, at baseline and post-intervention. The 2-standard deviation (SD) band method was used to determine which participants obtained clinically meaningful improvements in their priority kinematic factor (Logan et al., 2008). This method has been previously used to analyse single-subject design data as it accounts for individual variability (Jones et al., 2009; Nourbakhsh & Ottenbacher, 1994).

The pain and functional outcome scores were used to determine who improved, whose condition was unchanged or whose worsened. The data was categorised according to severity of pain and level of functional impairment. A Pearson Chi Square test established categorical changes following treatment and at 3- and 6-month follow up. A paired t-test established significant group differences and confidence intervals and the mean difference (MD) to calculate the effect sizes of pain and functional scores.

Subgroup data was analysed using a 2-tailed Wilcoxon-signed rank test as the kinematic data was abnormally distributed. With assistance from the Biostatistics Unit of the Faculty of Health Sciences at Stellenbosch University, Stata version 13 was used for data analysis.

7.2.8 Outcomes

7.2.8.1 Primary outcomes

- Priority kinematic factor was identified for each participant based on decision-making algorithm using gait analysis as a screening tool (Figure 5). This algorithm was developed specifically for the study and is based on a systematic review of the evidence (Leibbrandt & Louw, 2017a),
- Pain ratings using the numeric pain rating scale (NPRS) over the 8-week testing period and 3- and 6-month follow up (post-intervention period),
- Functional scores using the AKPS at week 1, week 8 and 3-month and 6-month follow up (post-intervention period), and
- Long-term recovery on a 7-point Likert scale at 6-month follow up (post-intervention period).

7.2.8.2 Secondary outcomes

- Reliability of kinematic outcomes with the inter-class correlation co-efficient (ICC) and standard error of measurements (SEM) calculated in a separate study (Leibbrandt & Louw, 2017d). The means of data acquired during the six trials of the first and second gait analysis sessions, were used to assess the 3D kinematic gait parameters, and
- Exercise compliance over 6-week period measured as the number of times per week that the exercises were completed.

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7.3 Results

7.3.1 Sample characteristics

Thirty-one subjects (13 males, 18 females) with unilateral PFP (20 left-sided, 11 right-sided) were included in this study. The average age was 30 (range 14-40; SD=8.4), height (mean=170.1 cm; SD=10.4 cm) and weight (mean=77.5 kg; SD=25.7 kg). The average duration of symptoms was 16.5 months and 64% of the participants had tried previous treatment such as massage, taping, pain medication and strength training. Participant characteristics are depicted in Table 9 which can be seen in Chapter 4 of the thesis.

7.3.2 Pain

The weekly pain diary using the NPRS showed that 30 of the 31 subjects (96.8%) demonstrated improved pain levels (NPRS) post-intervention (8 weeks). The average pain level at week 1 was 4.93 /10 and post-intervention it was 1.79/10. This group change is statistically significant ($p<0.0001$) with a mean difference (MD) of -3.03 (95% confidence interval [95% CI] =-3.65, -2.41) as seen in Table 18. At the 3-month follow up the treatment effect improved to a MD of -3.16 (95% CI=-3.84, -2.48), with subjects reporting an average pain level of 1.06/10. This effect was maintained at the long-term follow up done six months post intervention MD of -3.23 (95% CI=-3.87, -2.59).

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TABLE 18: Average group pain (NPRS) and functional scores (AKPS) pre- and post-intervention

Analysis	Outcome	Mean (SD) Baseline	Mean (SD) Follow up	95% CI	Effect size (MD)
Short-term usual pain	NPRS	4.23 (1.93)	1.19 (1.62)	-3.65, -2.41	-3.03
Usual pain at 3-month follow up	NPRS	4.93 (1.93)	1.06 (1.41)	-3.84, -2.48	-3.16
Usual pain at 6-month follow up	NPRS	4.93 (1.93)	1.0 (1.5)	-3.87, -2.59	-3.23
Short-term function	AKPS	73.7 (8.42)	86.94 (9.34)	10.72, 15.73	13.23
Function at 3-month follow up	AKPS	73.7 (8.42)	91.23 (7.4)	14.76, 20.28	17.52
Function at 6-month follow up	AKPS	73.7 (8.42)	92.68 (7.65)	15.77, 22.17	18.97

Table 19 shows the changes in pain severity based on NPRS scores throughout the follow-up period. The percentage of participants in each category differed significantly pre- versus post-intervention $X^2(4, N= 31) = 12.37$, $p= 0.015$. These positive changes reflected a significantly greater percentage of participants in the "pain-free" and "mild" pain categories post-intervention.

There were no significant changes between pain categories post-intervention (8 weeks) compared to the 3-month follow up $X^2(4, N=31) = 8.06$, $p=0.89$ and 6-month follow up indicating that the effects were maintained without improvement. The same applied at the 6-month follow up compared to the post-intervention showing that the treatment effects were maintained in the long term $X^2(4, N=31) = 3.7$, $p=0.44$. Pain diary results for each participant throughout the treatment period are in Table 21.

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TABLE 19. Proportion of participants in different categories of pain severity (NPRS) throughout the follow-up period

Categories	Actual scores (NPRS)	Pre-intervention	Post-intervention	3-month follow up	6-month follow up
0	0 (pain-free)	0 (0%)	18 (50.1%)	18 (50.1%)	18 (50.1%)
1	1-3 (mild)	12(38.7%)	10 (32.3%)	12(38.7%)	11 (35.5%)
2	4-6 (moderate)	15 (48.4%)	3(9.6%)	1(3.2%)	2 (6.5%)
3	7-9 (severe)	4 (12.9%)	0(0%)	0 (0%)	0 (0%)

7.3.3 Function

Table 18 shows a statistically significant improvement in function on the AKPS immediately post intervention ($p<0.00001$) with an effect size (MD) of 13.23 (95%CI=10.72, 15.23). The effect size of the intervention was larger at the 3-month follow up with a MD of 17.52 (95% CI=14.76, 20.28) indicating that on average patients continued to improve even one month after the supervised treatment. At the long-term follow up, participants showed a greater effect size compared to the 3-month (medium term) follow up with a MD of 18.97 (95% CI=15.77, 22.17) showing that the effects were not only maintained in the long term but slightly improved. The mean group functional scores can be seen in Figure 20. Individual AKPS scores for each participant throughout the treatment period and at 3- and 6-month follow up are in Table 22.

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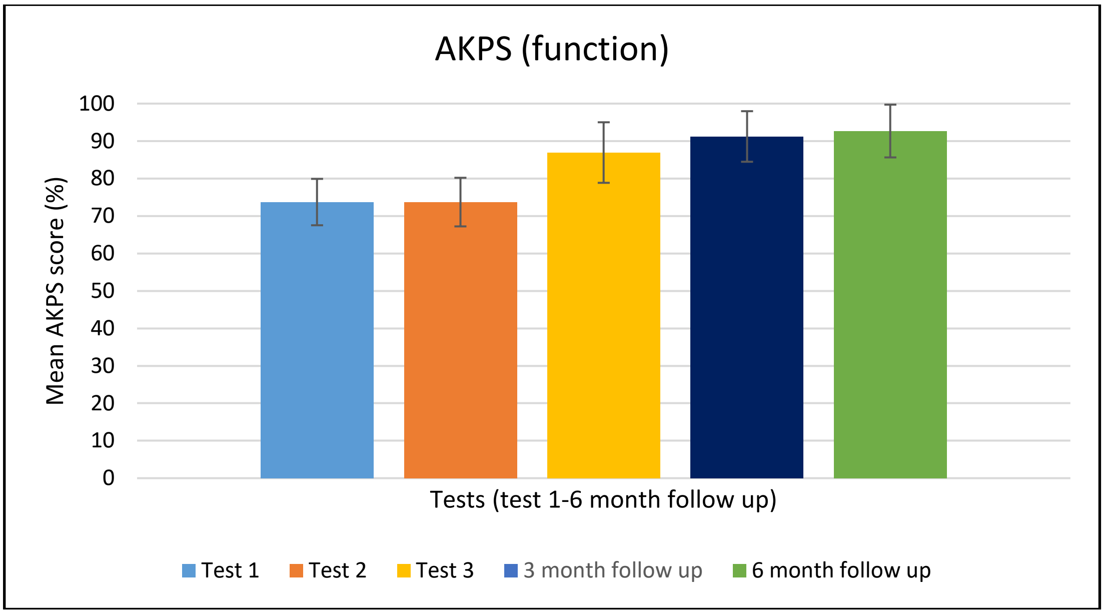

FIGURE 20. Functional scores (AKPS) throughout the treatment period and at 3-and 6-month follow up

Table 20 shows the changes in functional impairment based on AKPS follow-up scores. The percentage of participants in each category differed significantly pre- versus post-intervention $X^2(4, N= 31) = 10.83$, $p= 0.029$. These changes were positive with a significantly greater percentage of participants in the minor disability categories following the intervention.

There were no significant changes between pain categories post-intervention (8 weeks) compared to the 3-month follow up $X^2(4, N=31) = 6.33$, $p=0.18$ indicating that the effects were maintained but not improved. The same applied at the 6-month follow up compared to the post-intervention showing that the treatment effects were maintained in the long term $X^2(4, N=31) = 2.76$, $p=0.6$.

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TABLE 20: Proportion of participants in different categories of functional impairment (AKPS) throughout the follow-up period.

Categories	Actual scores AKPS (100)	Pre-intervention	Post-intervention	3-month follow up	6-month follow up
1	<60 (severe functional impairment)	2 (6.5%)	0 (0%)	0 (0%)	0 (0%)
2	60-79 (moderate functional impairment)	21 (67.7%)	6 (19.4%)	4 (12.9%)	3 (9.7%)
3	80-99 (minor functional impairment)	8 (25.8%)	24 (77.4%)	20 (64.5%)	19 (61.3%)
4	100 (No functional impairment)	0 (0 %)	1 (3.2%)	7 (22.6%)	9 (29%)

7.3.4 Compliance

Average participant compliance over the 6-week intervention period was thrice a week. This ranged from 1.5- 5.2 times that the subjects completed their weekly exercises over the 6-week intervention period. Individual compliance results over the 6-week treatment period are in Table 23.

7.3.5 Long-term self-reported recovery

Self-reported long-term recovery was measured on a 7-point Likert scale at the 6-month follow up as seen below in Figure 21 (van Linschoten et al., 2009). The measurements ranged from fully recovered to worse than before. If subjects regarded themselves as having recovered well or having recovered completely, they were classified as "recovered". Those who were "not recovered", identified as worse than before or as minimally recovered (van Linschoten et al., 2009; Rathleff et al., 2015). Fifteen participants (48.4%) rated themselves as fully recovered, whereas only one participant (AKP12) rated herself as not recovered. The remaining 48.4% reported being "partially recovered" with scores of between 3 and 5.

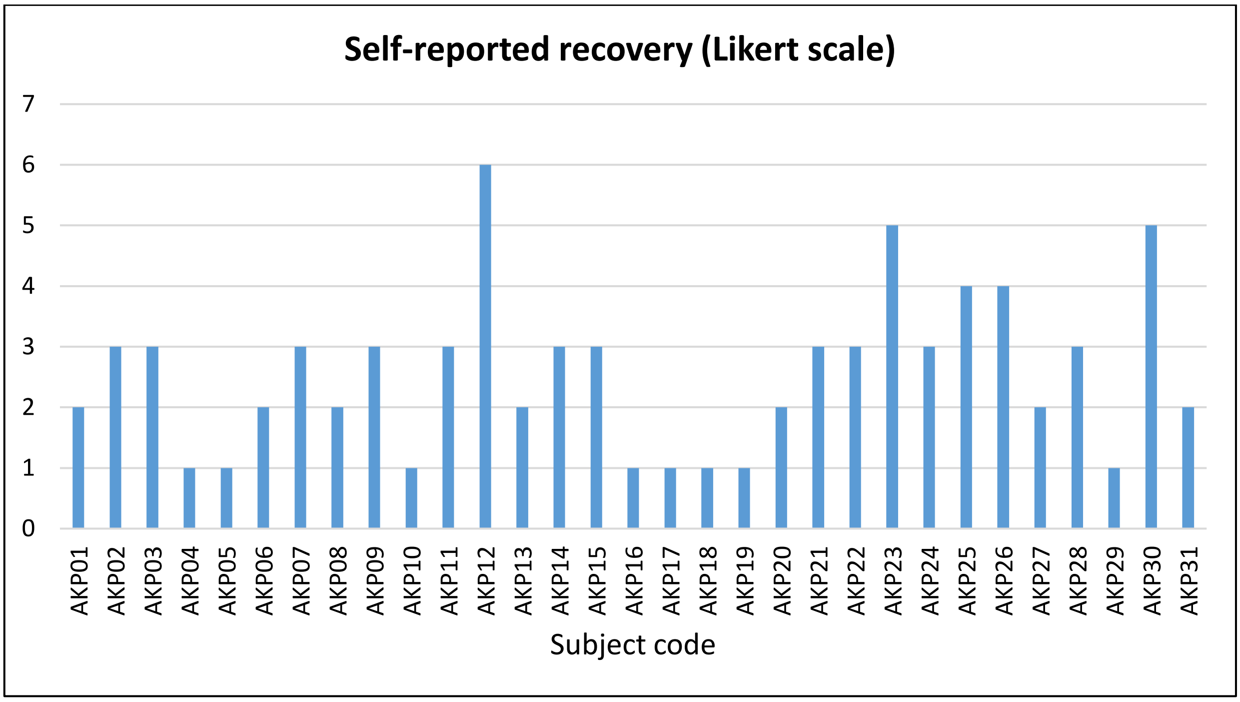

FIGURE 21. Self-reported recovery for all participants on a Likert scale at 6 months post intervention

7.3.6 Biomechanical results

7.3.6.1 Reliability of priority outcomes

A comparison of session 1 and 2 kinematic data, tested one week apart with no intervention in between revealed that all outcomes obtained were acceptable to excellent test-retest reliability scores for both measures of relative reliability (ICC=0.78-0.9) and measures of absolute reliability (SEM= 0.94 – 4.21 degrees). Hip frontal plane and ankle sagittal plane outcomes were the most reliable with the lowest measurement error. Hip transverse plane outcomes were least reliable and demonstrated the highest measurement error.

7.3.6.2 Temporal-spatial parameters (TSPs)

The pre- and post-intervention means and standard deviations for speed, step length and cadence were calculated. There were no differences between the pre- and post-intervention values; speed = 0.4 m.s (0.05), step length= 0.73 m (0.6), cadence=0.56 spm (0.06).

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7.3.6.3 Individual results for priority kinematic factor

Individual results for each participant's priority kinematic factor is summarised in Table 24. The results were analysed using the 2SD band method to identify clinically significant changes for each participant based on individual variation.

Of the 31 participants, 20 (64.5%) showed clinically significant changes post-intervention compared to pre-intervention. Of these 19 (61.3%) improved (positive change) and one (3.2%) worsened (negative change). Ten participants (32.3%) showed no significant change in their priority kinematic factor following treatment. There were no significant differences between genders with 11/18 (61%) of females and 8/13 (61%) of males showing clinically meaningful improvements. The 25 adult participants aged 20-40 did slightly better than the six adolescents, with 64% and 50% improving respectively. However, a bigger adolescent group is required to draw further conclusions.

From the individual results, four main subgroups were identified based on priority kinematic factors. These were decreased knee flexion in stance (n=5), decreased peak knee flexion throughout the gait cycle (n=10), increased peak hip adduction (n=8) and decreased peak hip internal rotation (n=8).

7.3.6.4 Subgroup results

Subgroup data was analysed using the Wilcoxon-signed rank test as the data was abnormally distributed. The results are summarised in Table 25. There was no change in the median post-test ranks (Mdn=5.78) compared to the median pre-test ranks (Mdn=5.39) for the decreased knee flexion in stance phase group (z=-1.75, p=0.08).

There were three positive biomechanical improvements:

The median post-test ranks for the increased peak knee extension throughout the gait cycle group (Mdn=21.9) were significantly higher than the median pre-test ranks (Mdn=18.13, z=-2.17, p=0.03).

The median post-test ranks for the increased peak hip adduction group (Mdn=8.98) were significantly lower than the median pre-test ranks (Mdn=7.31, z=-1.96, p=0.05).

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The median post-test ranks for the decreased hip internal rotation group (Mdn=-6.64) were significantly higher than the median pre-test ranks (Mdn=-4.88, z=2.1, p=0.03).

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TABLE 21: Individual results for pain diary (NPRS)

Subject ID	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
AKP01	7	7	6	2	4	0	0	3
AKP02	6	3	5	5	3	4	0	0
AKP03	4	0	4	3	0	0	6	0
AKP04	5	4	3	1	1	1	4	2
AKP05	6	4	2	0	8	7	4	5
AKP06	2	3	3	1	3	1	2	0
AKP07	7	5	3	7	8	7.5	2	0
AKP08	3	3	2	3.5	3	3	3	3
AKP09	5	5	0	1	4	3	2	2
AKP10	4	6	5	6	2	4	3	0
AKP11	1	3	4	3	1	2	4	0
AKP12	8	6	5	3	3	4	6	4
AKP13	3	3	1	2	0	0	3	0
AKP14	6	4	5	6	4	2	2	2
AKP15	6	5	0	0	7	5	4	0
AKP16	3	3	9	5	0	0	0	0
AKP17	5	6	2	3.5	3	5	1	2
AKP18	3	1	1	0.5	1	0	0	0

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AKP19	5	5	4	3	0	0	0	0
AKP20	4	4	5	3	3	3	3	3
AKP21	6	5	4	3	8	3	3	3
AKP22	4	8	3	2	2	2	2	0
AKP23	3	4	5	2	2	2	3	0
AKP24	2	3	1	3	3	0	2	1
AKP25	3	3	3	0	0	0	0	0
AKP26	7	7	4	3	4	0	7	5
AKP27	5	3	2	3	2	0	0	0
AKP28	4	3	4	2	4	2	0	2
AKP29	2	4	5	4	0	2	0	0
AKP30	1	2	2	2	1	0	1	0
AKP31	1	1	1	1	0	0	1	0
Mean	4.23	3.97	3.32	2.74	2.71	2.02	2.19	1.19
SD	1.93	1.82	1.96	1.80	2.42	2.15	1.97	1.62

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TABLE 22: Individual results for anterior knee pain scale (AKPS)

Subject ID	Pre-intervention	Post-intervention	3-month follow up	6-month follow up
AKP01	59	63	85	85
AKP02	79	86	94	94
AKP03	76	94	95	95
AKP04	71	78	93	100
AKP05	83	94	100	100
AKP06	84	90	100	90
AKP07	54	70	90	93
AKP08	71	85	93	96
AKP09	72	84	84	88
AKP10	69	94	96	100
AKP11	72	86	89	89
AKP12	68	77	77	68
AKP13	71	88	88	91
AKP14	74	82	88	96
AKP15	74	82	84	91
AKP16	69	90	100	100
AKP17	70	91	79	95
AKP18	90	98	100	100
AKP19	73	100	100	100
AKP20	86	93	96	96
AKP21	68	84	86	86
AKP22	75	85	85	87
AKP23	66	95	91	91
AKP24	69	77	77	79
AKP25	82	93	93	93
AKP26	61	69	78	78
AKP27	80	94	96	98
AKP28	76	86	100	100
AKP29	69	95	97	100
AKP30	83	94	94	94
AKP31	91	98	100	100
MEAN	73.71	86.94	91.23	92.68
SD	8.42	9.31	7.41	7.65

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TABLE 23: Individual results for exercise compliance

Subject ID	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
AKP01	3	2	3	2	3	2
AKP02	5	4	4	4	4	4
AKP03	3	4	3	3	3	3
AKP04	3	3	2	2	2	3
AKP05	2	2	2	2	2	2
AKP06	3	3	2	3	3	3
AKP07	5	3	3	5	5	4
AKP08	3	3	2	0	3	3
AKP09	3	1	0	3	1	1
AKP10	5	4	5	4	6	2
AKP11	3	3	2	3	5	3
AKP12	3	2	3	3	3	2
AKP13	2	4	4	5	3	3
AKP14	2	4	4	2	5	2
AKP15	1	3	3	3	3	3
AKP16	2	2	3	3	3	2
AKP17	3	3	2	2	2	2
AKP18	3	1	3	3	2	2
AKP19	2	3	2	2	4	2
AKP20	3	3	3	3	3	3
AKP21	1	3	3	3	2	2
AKP22	3	3	2	3	2	3
AKP23	2.5	4	3	3	2	3
AKP24	3	3	3	3	3	3
AKP25	3	3	4	4	4	4
AKP26	5	4	5	4	2	2
AKP27	6	6	5	5	5	4
AKP28	3	3	3	3	3	3
AKP29	2.5	2	4	2.5	3	3
AKP30	5	5	5	4	5	4
AKP31	4	3	3	3	3	3
MEAN	3.17	3.10	3.06	3.07	3.19	2.74
SD	1.23	1.04	1.12	1.05	1.19	0.77

TABLE 24: Individual results for priority kinematic factor

Subject ID	Age	Gender	Priority kinematic factor	Pre-intervention (degrees)	SD	2SD	Post-intervention (degrees)	Mean change (degrees)	Clinically meaningful
AKP01	38	F	Decreased L knee flexion in stance	-0.20	1.02	2.04	0.41	0.60	No
AKP02	18	F	Increased bilateral peak hip adduction	8.33	0.69	1.40	7.31	-1.02	No
AKP03	39	F	Decreased bilateral knee flexion in stance	6.43	1.30	2.60	9.28	2.85	Yes+
AKP04	29	M	Decreased R peak hip internal rotation	-7.00	1.23	2.46	-8.10	1.10	No
AKP05	31	M	Decreased L peak hip internal rotation	-7.20	1.94	3.88	-1.30	5.90	Yes +
AKP06	37	M	Increased R peak hip adduction	14.45	0.42	0.84	8.65	-5.80	Yes+
AKP07	15	F	Decreased bilateral knee flexion in stance	13.72	1.56	3.12	14.06	0.34	No
AKP08	40	M	Increased bilateral peak hip adduction	6.04	0.76	1.52	6.57	0.53	No
AKP09	18	M	Decreased bilateral knee flexion in stance	5.01	0.92	1.84	4.89	0.12	No
AKP10	14	F	Increased bilateral knee extension throughout the gait cycle	13.26	0.86	1.72	18.00	4.74	Yes+
AKP11	37	F	Decreased L peak hip internal rotation	-6.28	0.92	1.83	-5.18	1.10	Yes+
AKP12	17	F	Increased R peak hip adduction	11.57	0.51	1.02	9.22	-2.35	Yes+
AKP13	14	F	Increased R peak hip adduction	9.62	0.31	0.62	5.67	-3.95	Yes+
AKP14	39	F	Decreased L peak hip internal rotation	-8.73	1.07	2.14	-5.24	3.49	Yes+
AKP15	31	M	Increased bilateral peak knee extension throughout the gait cycle	19.4	0.40	0.80	22.78	3.38	Yes+

AKP16	40	F	Decreased bilateral knee flexion in stance	5.39	1.77	3.54	5.78	0.39	No
AKP17	40	M	Decreased R peak hip internal rotation	0.48	0.36	0.72	3.78	3.3	Yes+
AKP18	25	M	Increased bilateral peak knee extension throughout the gait cycle	20.0	0.82	1.64	17.1	2.9	Yes -
AKP19	25	F	Increased R peak hip adduction	10.39	0.39	1.78	8.37	-2.02	Yes +
AKP20	29	F	Increased bilateral knee extension throughout the gait cycle	17.67	0.20	0.40	19.41	1.74	Yes+
AKP21	34	F	Increased R knee extension throughout the gait cycle	26.89	1.14	2.28	24.84	-2.05	No
AKP22	33	F	Decreased L hip internal rotation	-4.96	2.30	4.60	-3.56	1.40	No
AKP23	31	M	Increased L peak hip adduction	7.4	1.23	2.46	2.55	-4.85	Yes+
AKP24	40	F	Increased bilateral knee extension throughout the gait cycle	18.35	0.26	0.52	23.44	5.09	Yes+
AKP25	27	M	Increased L knee extension throughout the gait cycle	17.9	1.21	2.42	20.50	2.60	Yes+
AKP26	31	F	Decreased L peak hip internal rotation	-24.99	2.42	4.84	-13.38	11.61	Yes+
AKP27	33	M	Increased bilateral knee extension throughout the gait cycle	13.61	0.23	0.46	23.29	9.68	Yes+
AKP28	27	F	Increased bilateral knee extension throughout the gait cycle	8.24	1.70	3.40	20.95	12.71	Yes+
AKP29	37	F	Increased bilateral peak hip adduction	6.69	0.64	1.28	7.97	1.28	No
AKP30	36	M	Decreased L hip internal rotation	-5.37	0.46	0.92	-4.57	0.80	No

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AKP31	32	M	Increased L knee extension throughout the gait cycle	21.59	0.20	0.40	27.17	5.58	Yes+

+ Positive change (kinematics improved); - Negative change (kinematics got worse)

TABLE 25: Subgroup results for priority kinematic factor

Subgroup	Number of subjects (n)	Median (SD) pre	Median (SD) post	w-value	P-value	If significant, positive or negative change?	z-value
Decreased knee flexion in stance	5	5.39 (4.5)	5.78 (5.10)	N/A (sample size < 6)	0.08	N/A, no change	-1.75
Increased peak knee extension throughout the gait cycle	10	18.13 (5.1)	21.90 (3.10)	8	0.03*	Positive	-2.17
Increased peak hip adduction	8	8.98 (2.8)	7.31 (2.15)	8	0.05*	Positive	-1.96
Decreased peak hip internal rotation	8	-6.64 (7.39)	-4.88 (4.96)	4	0.03*	Positive	2.10

*=statistically significant change

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7.4 Discussion

The results of this study showed that most participants demonstrated improvements in self-reported pain and function following an individualised functional retraining intervention. The effect of the intervention on average pain levels had improved one month later (3-month follow up). As had the average functional scores (AKPS) with 96.8% of the participants reporting clinically significant improvements in function. Given that the participants had all experienced PFP for longer than three months at the time of recruitment, it is possible that central mechanisms were involved (Rathleff et al., 2013). This can be classified as sub-acute going on chronic pain. Therefore, function could be a more important indicator of treatment success than pain.

These findings concur with a recent high-quality systematic review (van der Heijden et al., 2015) that exercise is effective in improving short-term pain and function. In the current study, the subjects demonstrated improved pain levels in the medium term at 3 months following completion of the intervention and these were maintained in the long term at 6-month follow up. In terms of functional outcomes, the subjects showed improved functional scores at 3 months and they reported that their functional scores had continued to improve at 6-month follow up.

There is limited and low quality long-term evidence for the effect of exercise in the treatment of PFP (Witvrouw et al., 2005). Moyano et al., (2013) found that proprioceptive neuromuscular facilitation (PNF) and aerobic exercise interventions resulted in significantly reduced pain and significant improvements in function in subjects with PFP at 4 months post intervention. The effects of these two intervention groups were equal and demonstrated greater improvements in all outcomes than a third group that only received stretching. However, this was not followed up at 6 or 12 months post intervention. Another study (Clark et al, 2000) did a long-term follow up for four different treatment groups 1) exercise, taping and education, 2) exercise and education, 3) taping and education and 4) education only. The exercise intervention focused on eccentric strengthening of the lower limb extensors and participants received 6 sessions over a 3-week period. At 12-month follow up, the exercise groups showed significantly greater improvements in pain compared to the other groups. However, the long-term functional scores where equal. This shows that reductions in pain do not necessarily result in improvements in function. The reasons for this are unclear, however it is possible that a 3-week intervention period was insufficient to address functional impairment in the participants. It is also possible that subjects did not continue with self-management after the treatment period especially if pain had decreased. The findings of the current study showed improvements in pain and function at a 6-month follow up; however, it is unclear how this compares to other exercise interventions and if the effects would be maintained at 12 months or even a few years later. These limitations should be addressed in future research.

A major challenge in the treatment of PFP is that participants tend to improve with exercise but don't recover fully (van Linschoten et al., 2009). The 6-month follow up showed that half of the participants (48.6%) recovered fully and half reported being partially recovered. This is similar to findings from a previous exercise intervention study that found that 43% had recovered at 3-month follow up and 62% at 12-month follow up (van Linschoten et al., 2009). Exercise interventions need to prevent reoccurrence; therefore, one needs to ascertain what inhibits full recovery. In the current study, one of these factors could be compliance with continued self-management after the 6-week supervised exercise period, as this was not measured.

Several recent studies have established which patients are most likely to experience favourable outcomes with different conservative treatment approaches (Lack et al., 2014; Lankhorst et al., 2016; Matthews et al., 2016). A longer duration of symptoms (>4 months) will most likely result in a poor outcome. Other prognostic factors include older age, greater usual pain severity and lower baseline AKPS score (Matthews et al., 2016). One study (Lankhorst et al., 2016) found that females respond better than males to exercise therapy. Kinematic differences may exist between genders (Nakagawa et al., 2012). These factors include increased dynamic measures of knee valgus angle, hip internal rotation angle and decreased dynamic measures of knee flexion angle compared to males (Boling et al., 2010). Females may have decreased hip strength compared to pain-free controls (Prins & van der Wurff, 2009) and thus exercise that strengthens hip muscles might be more beneficial for women than for men. We identified males and females with hip kinematic risk factors and found no significant differences between the genders with both benefiting equally from hip-focused interventions.

Nineteen participants showed clinically significant changes in their priority kinematic factor, targeted with functional exercises. Eleven demonstrated no significant change and one participant (AKP18) worsening of his main kinematic factor identified in session 1. The reason for this is unclear as the subject reported a full recovery, with no pain (0/10 on the AKPS) and full function (100% on AKPS) at the 6-month follow up. The subject was a trail runner and reported decreasing his training load during the intervention period and gradually progressing again once his pain had subsided. This suggests that training factors such as medication or load and intensity may have contributed to his symptoms.

It is estimated that 60% of overuse running-related injuries stem from training errors, including rapid increases in running distance and intensity (Hreljac & Ferber, 2006). It is impossible to control for all factors and accurate monitoring of training variables (such as a weekly exercise diary) is essential. A recent study by Esculier et al. (2017), conducted an RCT on 69 subjects with PFP. Participants were randomised to one of three groups: 1) education on activity modification alone, 2) education and strength exercises and 3) education and gait retraining. The authors unexpectedly found that all groups improved equally after the 8-week intervention period and at 3-month follow up suggesting that exercise and gait retraining provided no additional benefit to education on activity modification alone. This not only highlighted the importance of education and activity modification, but also challenged the recommendation that exercise should be the cornerstone of treatment for subjects with PFP (Keays et al., 2016) by suggesting that activity modification should be the central component of treatment in runners with PFP. It would be interesting to see if the results were the same if the participants were followed up at 6 to 12 months post intervention. It is unclear if an individualised exercise approach might influence the findings. However, it is clear that targeting kinematics is just one component of individualised treatment. Activity modification and load management is vital and should be included in an individualised treatment plan.

Another potential confounder in biomechanical research is gait speed. An increase in peak sagittal plane outcomes, especially increased peak knee flexion during stance, occurs with an increase in gait speed (Lelas et al., 2003). Changes in speed could explain changes in kinematics that might not be because of the intervention. In this study, the average gait speed did not change pre- versus post-intervention. This improves the validity of our findings as gait speed was not a factor responsible for kinematic changes.

It is not obvious which patients benefit from specific interventions. A recent cross-sectional observation study (Selfe et al., 2016) explored subgrouping of subjects with PFP based on clinical assessment findings. The authors identified three clinical subgroups in a sample of 130 subjects with PFP. These were 1) a “strong” subgroup with good hip abductor and quadriceps strength and rectus femoris flexibility; 2) a “weak and tight” subgroup with poor quadriceps and hip abductor strength and poor flexibility; and 3) a “pronated foot” subgroup with the highest foot pronation index and patella mobility. Recognition of different biomechanical subgroups would be useful in identifying who benefits from early exercise intervention.

Four biomechanical subgroups based on the priority kinematic factors were identified in this study. Three of these subgroups demonstrated significant improvements post intervention on a Wilcoxon-signed rank test, thereby endorsing an individualised functional exercise approach when addressing local and proximal factors. It is unclear whether this approach would be useful for distal kinematic factors such as timing of peak rear foot eversion. In the current study, the gait analysis was done barefoot, and this might have influenced the foot kinematics. Future research should perform a shod gait analysis as this better replicates subject’s everyday gait pattern and might result in the identification of more distal factors. Future research, with a larger sample for the accurate identification of biomechanical subgroups should establish which benefits most from individualised functional exercise intervention.

Our results suggest that an individualised approach to exercise may be beneficial in reducing short-term pain and improving short-, medium- and long-term function in subjects with PFP. Kinematics during gait may also improve in patients

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presenting with kinematic contributing factors. In order to provide individualised interventions more research needs to be done using n of 1 designs. However, it is important to remember that a limitation of this design is that the results cannot be generalised to all subjects with PFP. However, it provides clinically relevant guidelines that can be used for subjects with PFP presenting with similar kinematic contributing factors. As this approach is novel it needs to be tested on a larger sample and compared to other exercise interventions such as standard strength training of the hip and knee before it can be recommended as an effective intervention for subjects with PFP.

A limitation of the current study is that the gait analysis re-assessment was only done immediately post intervention. Future research should include a biomechanical reassessment at the long-term follow up to establish whether the biomechanical results were maintained or improved and how this relates to long-term pain and function. Another limitation is that the kinematic factors that were identified are based on cross-sectional studies and therefore we cannot establish if they are factors predictive of PFP or rather effects of the pain.

7.5 Conclusion

Most participants (64.5%) demonstrated clinically meaningful improvements in their priority kinematic outcome post intervention. The effects of the intervention were maintained in the long term and half of the participants reported that they had recovered fully at 6 months post intervention. Future research should investigate factors preventing individuals with PFP from full long-term recovery.

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Chapter 8: Discussion and conclusion

8.1 Introduction to chapter

The overall aim of this dissertation was to assess the effect of an individualised functional retraining intervention on AKP and associated biomechanical mechanisms. To achieve this aim four study phases consisting of five interlinked studies were conducted. A schematic presentation of the research process can be seen in Figure 1.

Phase A was the preliminary research phase and it consisted of two systematic reviews and a reliability study. These studies are presented in Chapters 2, 3 and 4 and are based on published research articles. These studies aimed to answer questions that would aid the conceptualisation of the main intervention study (phase D). In this phase, we established a standardised method for diagnosing AKP, identified the most important evidence-based kinematic outcomes that needed to be measured, and established the test-retest reliability of our motion analysis measurement procedures.

Phase B was the pilot phase where we took the information from phase A and used it to pilot the intervention. This was done as a case series on eight subjects with AKP (Study 4) and can be seen in Chapter 5. The intention was to assess the feasibility of the planned intervention procedures so that necessary changes could be made prior to the main study.

Phase C was the planning phase. This was not a published article or study but rather a “linking chapter” (see Chapter 6) to integrate what we had learnt from phases A and B and to discuss how it influenced the planning of phase D. This chapter also included a patient case example to demonstrate the decision-making process used to determine each participant’s individualised intervention.

Phase D or the intervention phase was the main intervention study (Study 5) and is presented in Chapter 7. This series of n of 1 design study investigated the effect of an individualised functional retraining intervention on short-term pain, function and kinematic outcomes and long-term pain, function and self-reported recovery in 31 subjects with AKP.

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The purpose of this chapter is to discuss and highlight the main findings and contributions of this project to the diagnosis of AKP, the biomechanical aetiology of AKP, the use of outcome measures in AKP and the long-term effects of exercise interventions in an AKP population.

This study is novel, as an applied individualised approach correlates with the WHO's policy framework for person-centred healthcare (2007). According to these guidelines, person-centred healthcare should be prioritised so that individuals, families and communities have access to a trusted healthcare system that meets their needs (Yardley et al., 2015). This approach promotes collaboration between individuals, clinicians and healthcare organisations to improve the quality and responsiveness of the provided healthcare. It serves to empower patients by including them in the decision-making regarding their health.

Healthcare workers need to provide evidence-based healthcare that is tailored to the individual (Grol & Grimshaw, 2003). The services should address the individual's requirements, preferences and expectations satisfactorily. Clinicians should be encouraged to develop communication skills, build trust and focus interventions around patients. In addition, clinicians should integrate patient education, family involvement and self-management wherever possible (Yardley et al., 2015). To achieve these aims, clinicians need to focus on implementing innovative treatment approaches and interventions through research and guideline development. Ongoing assessment is necessary to monitor and evaluate the developing health system (Saunders et al., 2005).

There are many potential benefits for both patients and healthcare providers in shifting towards a patient-centred approach. Patients and their families will be more compliant, experience better healthcare and have a higher quality of life. Healthcare providers are likely to have improved job satisfaction and gain trust and respect from patients, resulting in good public reputation, affordability and improved sustainability to secure the future existence of the healthcare system (http://www.wpro.who.int/health_services/people_at_the_centre_of_care/documents/ENG-PCIPolicyFramework.pdf).

8.2 An evidence-based design for treatment decisions

An individualised person-centred approach is recommended in clinical practice, yet most research for AKP focuses on RCTs with all participants receiving the same intervention (Keays et al., 2016). For the main intervention study (Chapter 7), a series of n of 1 study design was used. To our knowledge this is the first time that such an approach has been applied on subjects with AKP in clinical research. The design was appropriate as we were assessing individual interventions and not the effect of the same intervention on the average outcomes of a group. This enabled subjects to act as their own controls, which is useful in a condition such as AKP where there are multiple potential causes and contributing factors, and it is difficult to account for all confounding variables. Subject-specific variables such as natural history of the disorder, placebo effects as well as patient and health worker expectations can cause confusion for clinicians. This is because other study designs require clinicians to generalise results from treatment strategies tested on other people with their own patients. In addition, analysing a group may mask the performance and interesting findings of individuals. The single-subject design allows one to draw strong conclusions regarding the factors controlling the dependent variable without using random assignment.

According to McMaster University's hierarchy of evidence (http://fhs.mcmaster.ca/medicine/residency/halfday_ebm.htm), this type of design is currently regarded as level 1 evidence for treatment decisions (Elamin & Montori, 2012). Therefore, this project provides experimental evidence that an individualised functional retraining intervention that is individually tailored to target kinematic contributing factors is effective in the treatment of AKP when the subjects are compared to themselves.

In a clinical physiotherapy practice, treatment sessions are usually one-on-one consultations with a patient, and the clinician should be able to tailor the treatment appropriately to optimise the individual's outcomes. This study design results in a more pragmatic trial. Having said that this method is not appropriate if a clinician is looking to treat a group using an identical method on a daily basis. Moreover, it is often impractical to use this approach on a large sample size as heavy time demands are required to carefully monitor change as well as confounding variables in individual subjects over time. Another limitation is that the lack of a control group as this makes it hard to exclude the natural progression and healing of the condition as a reason for improvement. However, considering that all included participants had pain for three months and many for years this explanation is unlikely.

A single-subject approach is often confused with a case series design as seen in our intervention pilot (Chapter 5). However, it is different as it relies on multiple precise measures of main outcomes and experimental control to establish the true effect of an intervention on an individual's outcomes. As researchers, we need to consider that evidence-based clinical decision-making should include elements beyond critical evaluation of the treatment design. These include evidence with clinical judgement, expert opinion and consideration of the unique circumstances of each participant. Before definitive evidence-based guidelines can be made, they need to be implemented in a context that includes clinical judgement and patient preferences (Logan et al., 2008). Future research on interventions for AKP should consider single-subject study designs as this allows for individualised treatment using subjects as their own controls.

8.3 Contribution towards the diagnosis of AKP

AKP is a complex multifactorial condition with possible proximal, local and distal contributing factors (Davis & Powers, 2010). Treatment is particularly challenging as the tendency to become chronic adds an additional dimension of complexity to its treatment. In the current study, the average duration of symptoms was over a year: 16.5 months (Chapter 7), indicating that symptoms were chronic in most of the participants. Chronic AKP may affect a patient not only physically, but also psychologically and this can be an additional barrier to recovery (Sanchis-Alfonso et al., 2016). Even if structural and biomechanical findings are clear, psychological factors may modify pain sensation and response to treatment (Domenech et al., 2014). The systematic review of evidence that was done in Chapter 2 showed that it was a diagnostic requirement that the subjects with AKP had at least a 3-month duration of symptoms (Nunes et al., 2013; Cook et al., 2012). Therefore, by definition, subjects with AKP are in a sub-acute going on chronic stage of healing and this makes the response to treatment more unpredictable.

AKP has multiple aetiological pathways (Näslund, 2011; Noehren et al., 2013). A complete history is required for diagnosis and this should include information on the onset, aggravating factors, duration of symptoms and previous treatment (Nunes et al., 2013, Cook et al., 2012). The onset of AKP is usually gradual and non-traumatic. This is indicative of an overuse condition or underlying malalignment (Sanchis-Alfonso et al., 2016). The absence of clear causes contributes towards the complexity of reaching a diagnosis. AKP is primarily a diagnosis of exclusion as there is currently a lack of standardised methods for diagnosis of AKP in research and practice (Cook et al., 2012).

This research project presents the initial steps towards standardising the diagnosis of AKP (Chapter 2). By using RCTs and systematic reviews in a logical, transparent process, we developed a standardised diagnostic checklist. This is important, as it allows for clearer descriptions of the sample, presents a way of including more homogeneous people, enables comparisons between studies and allows for intervention studies to be replicated in other settings. There are many similar attempts in the literature related to other musculoskeletal and sports injuries, for example standardisation of diagnostic criteria for concussions (McCrory et al., 2005), groin pain (Bradshaw et al., 2008) and rotator cuff injures in the shoulder (van Kampen et al., 2014).

A diagnostic checklist such as the one created in Chapter 2 provides a structured method for diagnosing AKP in a clinical setting. The evidence-based diagnostic checklist (Table 4, pp.23-24) is a time-saving tool that clinicians could use to improve the accuracy of diagnosis by prioritising the most important clinical tests in suspected AKP cases. However, as the aetiology of symptoms may vary in different subgroups of individuals with AKP, the diagnostic checklist should be updated as more evidence becomes available.

8.4 Contribution towards outcome measurement for AKP

There is a need for standardisation of outcome measures so that the effects of different interventions for AKP can be compared (van Heijden et al., 2015). Two outcomes, the VAS and the NPRS, are recommended to measure pain in AKP

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research (van Heidjen et al., 2015). These outcome measures have proved to be reliable and valid in chronic musculoskeletal pain (Williamson & Hoggart, 2005). In the current project, the NPRS was utilised as it is user friendly and can be administered verbally (Hawker et al., 2011). This was necessary for our 3- and 6-month follow ups that were done telephonically.

Two of the standard outcomes used to measure function in an AKP population are the AKPS and LEFS (Crossley et al., 2004). In Chapter 5 (the intervention pilot) both outcomes were used. However, for Chapter 7 only the AKPS was used as it has the highest validity and reliability in subjects with AKP (Crossey et al., 2004). The LEFS was removed as it is not specific to AKP and some of the questions were about non-weight bearing activities such as rolling over in bed that were irrelevant in a AKP population (refer to Chapter 6). It is important to measure the AKPS, as a score of less than 70/100 is also a consistent poor prognostic factor (Collins et al., 2013).

Although the AKPS is the standard outcome measure for functional ability in AKP research there are various limitations that should be considered. Some of the questions are related to activities such as running and jumping that more sedentary individuals with AKP might not do. Therefore, it might be more appropriate for active individuals or sport-related AKP cases. In the current study, we did not only include runners or sports people with AKP but also cases of AKP with every day activities such as stair-climbing and prolonged sitting.

Outcome measures that are person-centred to assess the individual need remain a challenge in clinical research because this cannot always be standardised. As the focus of this project is individualised assessment and treatment we would recommend the inclusion of the patient-specific functional scale (PSFS) as a complementary outcome measure to be used in combination with the AKPS in future AKP research. With the PSFS, patients are asked to rate five functional activities which they are having difficulty with and their functional limitation associated with each (Sterling & Brentnall, 2007). They can then repeat this post intervention to see if the activities that concern them the most are improved.

The other concern about using the standard outcome measures is that these outcomes often do not consider the context of the study population, limiting our

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ability to apply results to the clinical population. In this study a South African sample was used, yet none of these AKP outcome measures have been validated within the South African context.

8.5 Contribution towards understanding biomechanical aetiological factors associated with AKP

There is reasonable support from the published literature that indicates that biomechanical factors are associated with AKP development and chronicity of AKP (Sherman et al., 2014; Lankhorst et al., 2012; Rothermich et al., 2015). Biomechanical studies have described patella mal-tracking and functional malalignment as causes of AKP (Petersen et al., 2014). Measures of dynamic or functional malalignment are more relevant in an AKP population than static measures, as pain typically occurs during dynamic activities (Crossley et al., 2011; Petersen et al., 2014). The combination of overload of the patellofemoral joint for repetitive aggravating activities such as high intensity exercise and dynamic malalignment may lead to overload of structures of the patellofemoral joint resulting in pain (MacIntyre et al., 2006).

One systematic review (Barton et al., 2009) has evaluated gait-related kinematics in subjects with AKP during a variety of functional activities such as walking, running and stair and ramp ascent and descent. The results showed that individuals with AKP might have increased peak rear foot eversion at heel strike, delayed peak rear foot eversion during walking and running and reduced hip internal rotation during walking. An update of this review (in Chapter 3) showed that gait-related factors were similar with additional evidence for delayed timing of peak rear foot eversion and decreased peak hip internal rotation during walking. Gait analysis was identified as the most appropriate activity to screen for kinematic risk factors in individuals with AKP as it is a common ADL and there are well-established normative values for adults with which values can be compared to for screening purposes (Benedetti et al., 2008; Bovi et al., 2011). Therefore, it might be worthwhile to refer subjects with AKP that present with pain during gait-related activities for a gait analysis to confirm findings of movement pattern dysfunction from visual analysis. In these cases, it might be useful to use gait analysis as a measure of treatment success following an intervention period

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to establish if these factors improve post intervention and if the changes in gait are related to improvements in pain and function (Petersen et al., 2014).

It has been suggested that long-term results in the treatment of AKP will not be achieved unless the underlying impairments are addressed. Treatment should therefore focus on individuals and subgroups based on presenting impairments (Davis & Powers, 2010). There have been efforts in recent AKP research to establish subgroups of subjects with AKP. One study investigated the individualised assessment and subsequently subgrouping of subjects AKP based on clinical outcomes (Selfe et al., 2016). The study suggested that there are three clinical subgroups of subjects with AKP. These subgroups were identified as a “strong” subgroup, a “weak and tight” subgroup and a “weak and pronated” foot subgroup. It is unclear if these underlying impairments influence the way that the subjects with AKP move (biomechanics) during common aggravating activities and the effect is of this subgrouping on treatment outcomes is unclear. Only clinical tests were used in this method of subgrouping and biomechanical analysis was not included in the study methods.

In Chapter 7, the results suggested that there might be biomechanical subgroups of individuals with AKP. Four kinematic subgroups of subjects with AKP were identified. These were decreased knee flexion in stance (n=5), decreased peak knee flexion throughout the gait cycle (n=10), Increased peak hip adduction (n=8) and decreased peak hip internal rotation (n=8). Although these subgroups were small they assisted the individualised decision-making process and were based on the best available evidence (Chapter 3). Recognition of different biomechanical subgroups has clinical implications as it could be useful in identifying who benefits from early exercise intervention and save time and resources as clinicians would know what to address first in treatment. These factors were in line with previous evidence for kinematic contributing factors during gait (Barton et al., 2009; Chapter 3). However, none of the included participants presented with distal kinematic factors such as delayed timing of peak rear foot eversion, despite the fact that this was identified in Chapter 3 as a common evidence-based factor associated with AKP. Findings from this project indicate that focus should be on addressing proximal and local factors with exercise interventions. It is difficult to correct rear-foot control with exercise and therefore orthotics might more effective in this risk factor group, however this is only advocated in the short term (Barton et al., 2010). In addition, it has been suggested that treatment approaches that targeted either proximal or distal factors could equally benefit symptoms at the knee as the kinetic chain effects might be similar (Barton et al., 2011). The knee hyperextension and hip rotation subgroups had greatest treatment success (p=0.03). This concurs with previous literature indicating that there are no significant differences in pain and functional outcomes with hip or knee focused interventions but functional exercises that combine some of both elements are recommended (van Heijden et al., 2015; Fukudu et al., 2010).

8.6 Contribution towards understanding the effect of exercise on biomechanical factors

This was the first study that attempted to individualise treatment to target each participant's kinematic contributing factors. It has been recommended that the non-operative management of AKP should depend on examination findings and aim to improve patella tracking and optimise lower extremity mechanics (Sanchis-Alfonso et al., 2016). Assuming that these factors are found during assessment and specifically addressed in treatment, this should decrease the patients' symptoms and minimise reoccurrence (Sanchis-Alfonso et al., 2016). However, there is currently no validation that these outcomes can be influenced by exercise.

A systematic review on targeted exercise interventions for runners with AKP (Neal et al., 2016) found that exercise resulted in short-term improvements in pain and function but resulted in no significant kinematic changes post intervention. This was based on the results of two 8-week targeted biomechanical intervention studies (Ferber et al., 2011; Earl et al., 2011). The authors suggested that benefits were derived by other non-biomechanical mechanisms such as limb stiffness changes or nociceptive input processing alterations (Neal et al., 2016).

The results of the current study (Chapter 7) revealed that (64.5%) of all included participants showed clinically significant changes in their priority kinematic factor post-intervention compared to pre-intervention. Compared to the other evidence (Neal et al., 2016) this seems like a large success rate for an approach that

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targets kinematic mechanisms. An explanation for this is that the kinematic outcomes measured in Chapter 7 were subject-specific and analysed individually for each participant. In RCTs such as Ferber et al., (2011) and Earl et al., (2011), using a group average (mean) for all kinematic outcomes might not have reflected the treatment success of individual participants.

To conclude that the kinematic improvements are as a result of the intervention we need to rule out potential confounding factors. One potential confounder is gait speed, as this can influence knee kinematics. A comparison of average spatiotemporal parameters pre- and post-intervention showed that there were no differences in average gait speed for all participants. Therefore, this can be ruled out as a confounding factor.

Intra-subject variability can also influence the confidence that we have in the effect of an intervention. Due to the study design using subjects as their own controls these factors can be accounted for. Reliability of outcomes, equipment and the assessor could influence the effect of an intervention. In Chapter 4, we established that all kinematic outcomes had acceptable to good test-retest reliability (measurement procedure and equipment). Moreover, one assessor was used for all motion analysis assessments which decreased the risk of inconsistency in marker placement.

Additional factors that could influence intervention outcomes include compliance, motivation and training factors. While it is impossible to control for all of these factors, careful records were kept in the pain and exercise compliance diaries (Appendix L) so that changes in training and poor compliance could be monitored. Overall the compliance report by participants was good (3 times a week). Most participants kept a consistent level of activity throughout the treatment period as they were encouraged to continue with normal activities respecting pain as they would have done if not in the study. Taking all factors into consideration, efforts were made to control for confounding factors. However, future studies using an n of 1 design should include multiple baseline measurements to improve our confidence that the changes in kinematics observed were as a result of the intervention.

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8.7 Contribution towards understanding the long-term effect of exercise

There is evidence that exercise is effective for treating AKP (van Heijden et al., 2015). A major shortcoming of previous research in AKP is the limited evidence for long-term follow up (Keays et al, 2016; van Linschoten et al., 2009). Exercise interventions if prescribed correctly should improve long-term outcomes by improving the tissues capacity to sustain a mechanical load (Rathleff et al., 2015). Exercises aimed at improving movement control should also be beneficial in the long run as one would think that a more efficient movement pattern would decrease the risk of re-injury.

We addressed this by including a long-term follow up to ensure that treatment effects were maintained. This is essential as this condition often becomes chronic. Self- reported recovery at 6 months post intervention showed that in our study half of the participants reported a full recovery. However, this means that the other half improved but did not recover fully. Therefore, future research needs to establish the factors that are preventing a full recovery and strategies to prevent reoccurrence. In the current study, we gave advice for continued exercises and self-management after the supervised intervention period, this was not monitored. Some participants might have discontinued with the exercises. This would be particularly problematic in the 30% of cases that did not demonstrate kinematic improvements after 8 weeks of doing the individualised exercises. These participants might have needed longer than 8 weeks to experience the full effects of the exercise programme.

Another factor to consider is that there might be a subgroup of subjects with AKP with central pain mechanisms that need to be managed differently. Current evidence suggests that there might a subgroup of female adults with AKP presenting with altered central pain processing mechanisms (Rathleff et al., 2016). Female adolescents with AKP have been found to have lower pressure pain thresholds, indicating both localised and distal hyperalgesia compared to pain-free controls (Rathleff et al., 2013). It is unclear if these mechanisms would also be apparent in males with AKP. Further investigation into the chronic pain aspect of AKP is warranted in further research. These factors should ideally be considered as part of a biopsychosocial individualised intervention approach. In addition, future research needs to establish the contribution of chronic pain mechanisms and how to address these.

Three studies have shown that duration of symptoms is a consistent predictor of poor prognosis (Lack et al., 2014; Lankhorst et al., 2015; Matthews et al., 2016). The average duration of symptoms in the included participants at the time of recruitment was over a year (16.5 months), indicating that most of them had chronic symptoms. While early exercise interventions increase the chance of treatment success, participants with chronic symptoms should be encouraged that they too can improve with an appropriate individualised intervention. Clinicians should educate patients about the factors that are contributing to their ongoing AKP. If patients understand what the exercises are trying to correct they might be more motivated to do them, thereby aiding exercise compliance. Exercise compliance is likely to improve the chance of long-term recovery (Rathleff et al., 2015).

The included participants completed an exit interview at the 6-month follow up. This interview was done via email. The participants were asked about their history of knee symptoms, previous treatment strategies that they had tried, what they wanted to achieve by participating in the research and if expectations were met. This exit interview can be found attached as Appendix O. These interviews revealed that 64.5% of the included participants had tried previous treatment including pain medication, strength training, massage and taping with no success. In addition, 42% had specifically tried physiotherapy including manual therapy, taping, shock-wave therapy and strengthening exercises with no long-term success. This might be because the treatment was not individually tailored to the patient based on examination findings.

8.8 Limitations

A limitation of the current study and possible reason that some participants might not have improved was the timing of the motion analysis reassessment. Unfortunately, time restrictions and the availability of funding limited the intervention period to eight weeks. Further research should include a motion analysis reassessment in the long-term follow up to establish whether the biomechanical results were maintained or improved and how this relates to long-

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term pain and function. This might allow more time for the treatment effects to translate into unconscious kinematic changes that could manifest as improvements on motion analysis outcomes. Another limitation of this study is that it was not possible to blind the therapist who administered the intervention as they had to know the results of the motion analysis assessment in order to make individualised treatment decisions.

The identification of biomechanical subgroups was not a primary aim of this dissertation. A larger sample would allow for more accurate identification of biomechanical subgroups. This would also allow for further subgrouping based on factors such as age and gender to enable us to see which of these groups of patients respond best to an individualised functional retraining approach.

With regards to our inclusion and exclusion criteria, we did not exclude participants with a high BMI. Five of the included participants had a body mass index (BMI) that could be classified as obese (BMI>30). Excess soft tissue also influences the reliability of the motion analysis as it can cause movement of the markers and wands during motion capture procedures. Another possible factor is that the extra weight itself could have been a contributing factor in the development and chronicity of the knee symptoms due to the increased loading of the knee joint. The participants were advised to try and reduce body weight as a long-term strategy to reduce knee symptoms. It might be useful to exclude obese participants with a BMI of more than 30 to control for this.

Current evidence for kinematic risk factors for AKP are based mainly on cross-sectional studies. The major disadvantage of this is that it is unclear whether these factors are causes of AKP or pain avoidance or compensatory strategies that attempt to reduce PFJ contact stress. Therefore, clinicians should be cautious when attempting to correct these factors that patients don't "over-correct" but rather aim to achieve neutral or normal ranges of the targeted movements (for example neutral hip rotation rather than encouraging excessive internal or external rotation). The decision-making algorithms presented in Chapter 3 can be improved when better quality evidence becomes available. However, regardless of the direction of causality if an intervention addressing these factors improves AKP and functional outcomes the intervention can still be recommended.

Walking was identified as the most appropriate kinematic screening tool for subjects with AKP in this project (Chapter 3). However, this is a limitation as some participants might not exhibit the same impairments during the functional exercises as they did during gait analysis and they may not experience pain with walking. As more evidence becomes available functional activities that more commonly aggravate pain such as squatting, lunging and stairs might be more relevant as these activities are more functionally demanding. Additional activities should also be added as more evidence becomes available.

The current intervention is only relevant for subjects with AKP presenting with kinematic risk factors and cannot be generalised to all subjects with AKP. In the decision-making framework, we focused on kinematic risk factor identification of the affected side as all participants had unilateral AKP. However, it was noted that some participants presented with kinematic features associated with AKP on the unaffected side. This could be important to address after the affected side has been treated as AKP often becomes bilateral (Dixit et al., 2007). Symmetry of movement control should be promoted.

8.9 Future research directions

If we are trying to achieve a holistic person-centred approach to treatment, an individually tailored treatment approach based only on biomechanics is insufficient as it only addresses one aspect of the biopsychosocial model of treatment. Future research should develop ways to tailor treatment to the individual taking into consideration the interplay of physical, biological, psychological and social factors (Falla & Hodges, 2017).

Regarding outcome measures, it would be beneficial for future studies to include a relevant psychological outcome measure as patients with AKP often experience anxiety, depression, fear of movement and catastrophising (Domenach et al., 2014). This would add value to a biopsychosocial individualised assessment for AKP. An outcome that has been validated in South Africa such as the South African pain catastrophizing scale (Morris et al., 2012) might be useful. However, this outcome measure first needs to be validated in an AKP population.

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The current study suggested possible biomechanical subgrouping based on the kinematic contributing factors that subjects presented with. However, it is unclear if subgrouping based on biomechanics is appropriate or will improve patient outcomes. It is also unclear how this method of subgrouping compares to clinical subgrouping methods such as Selfe et al. (2016) or if the how the two methods of subgrouping might be integrated. Future research needs to establish if subgrouping improves treatment outcomes and which methods are most valid. This is important as subgrouping is resource intensive and costly.

The results of this study showed encouraging improvements in pain, function and biomechanics in the included study. However, as this approach is novel further research on a larger sample is warranted before it can be recommended. As this approach is resource intensive, clinician involvement and participant education and self-management can make the approach more sustainable in the long term.

Current evidence for kinematic factors associated with AKP are mainly based on cross-sectional evidence, as seen in Chapter 3. Due to the cross-sectional study design we cannot say that the factors are causes or predictors of AKP. According to Joubert et. al., (2007, pp. 15-16), criteria required to establish a causal relationship include that following: “1) temporality - the occurrence of the disease should proceed the outcome; 2) strength of association - the occurrence of AKP should be significantly greater in one risk factor group compared to a group that does not present with that risk factor; 3) biological plausibility - the risk factor should be biologically plausible and supported by high quality laboratory evidence; and 4) consistency - there should be similar findings in a variety of other studies with no conflicting evidence.” This highlights the need for high-quality prospective cohort studies to establish biomechanical risk factors that are predictive of AKP and can be addressed early in treatment or as preventative measures in high-risk subjects.

Future research is also needed to establish how this biomechanical intervention compares to other intervention approaches such as specific muscle group strengthening that might not result in improved biomechanics. The current intervention needs to be compared to other interventions before conclusions can be drawn about its effect. In order to compare the “effect” of this intervention to

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other interventions, addition research using an n of 1 design is needed. In addition, long-term follow up and biomechanical reassessment (at least a year post intervention) should be done in future research to see if treatment effects can be maintained after discharge with ongoing self-management and how this relates to long-term recovery.

8.10 Conclusions

AKP is a common and complex condition. The diagnosis and causal mechanisms are not well understood and therefore long-term prognosis tends to be poor. Due to the multifactorial aetiology of symptoms and various potential contributing factors recent studies have suggested that there are subgroups of subjects with AKP. Yet most of the research on AKP participants still relies on a "one size fits all" approach whereby participants receive identical interventions. This study showed that an exercise intervention can be improve pain, function and biomechanics targeted towards kinematic deficits that the individual presents with. The effects were maintained 6-months post intervention, and these positive findings should be substantiated by further research. However, addressing kinematics is just one component of a comprehensive individualised treatment approach. Future research on the psychological contributing factors should be investigated as these need to be included in the holistic individualised management of this complex condition.

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Appendices

Appendix A: Advert for Study

Are you EXPERIENCING PAIN IN FRONT OF YOUR KNEE??

Participants will be assessed and treated for Anterior Knee Pain by the physiotherapist at the FNB-3D Movement Analysis Clinic.

(Assessment and treatment costs will be paid for by research funding)

Volunteers may email kneepainsu@gmail.com for further enquiries regarding the study.

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Appendix B: Letter of ethical approval

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Ethics Letter

28-Feb-2017
Louw, Quinette QA

Ethics Reference #: N13/05/078
Title: The effect of physiotherapy on anterior knee pain and underlying mechanisms

Dear Prof Quinette Louw

The Health Research Ethics Committee (HREC) approved the following progress report by expedited review process:

Progress Report dated: 10 January 2017

The approval of this project is extended for a further year

Approval date: 28 February 2017

Expiry date: 27 February 2018

Where to submit any documentation
Kindly submit **ONE HARD COPY** to Elvira Rohland, RDSD, Room 5007, Teaching Building, and **ONE ELECTRONIC COPY** to ethics@sun.ac.za

Please remember to use your **protocol number** **(N13/05/078)** on any documents or correspondence with the HREC concerning your research protocol.

Federal Wide Assurance Number: 00001372
Institutional Review Board (IRB) Number: IRB0005240 for HREC1
Institutional Review Board (IRB) Number: IRB0005239 for HREC2

The Health Research Ethics Committee complies with the SA National Health Act No.61 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Good Clinical Pracices Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

Sincerely,
Ashleen Fortuin
REC Coordinator
Health Research Ethics Committee 1

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Appendix C: Informed consent and assent forms

TITLE OF THE RESEARCH PROJECT: The effect of physiotherapy on anterior knee pain and underlying mechanisms

REFERENCE NUMBER:
PRINCIPAL INVESTIGATOR: Prof QA Louw/Dr JH Muller
ADDRESS: Faculty of Medicine & Health Sciences, Division of Physiotherapy, Stellenbosch University, 4th floor, Teaching Building, Tygerberg, 7505
CONTACT NUMBER: 021 938 9667

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff or doctor any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Health Research Ethics Committee at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

What is this research study all about?

Anterior knee pain commonly affects adolescents and young adults causing them to be less physically active. The aim of this study is to gain greater insight to the causes of anterior knee pain and to assess the effect of physiotherapy on the knee joint and muscle function.

This study will take place at the FNB-3D Movement Analysis Clinic, Stellenbosch University, Tygerberg Campus and Magnetic Resonance Imaging (MRI) will be done at Panorama Mediclinic. This project will include 45 individuals, aged between 14 and 40 years who experience anterior knee pain.

Participants will be assessed and treated for anterior knee pain by the senior physiotherapist at the FNB-3D Movement Analysis Clinic. The treatment will include strengthening exercises based on your motion analysis assessment. Your treatment will be individually tailored and not the same as anybody else’s.

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You will also undergo tests to measure your knee biomechanics. This will involve electromyography (measurement of muscle function) and 3D movement analysis (to measure lower limb joint angles). All these procedures will involve the placement of electrodes or reflective markers on your muscles or bony landmarks on your body. We will also measure your height, weight, leg length and other body dimensions. All these procedures are non-invasive. The biomechanical testing will be done at the FNB-3D Movement Analysis Clinic, Stellenbosch University, Tygerberg Campus. The duration will be about 60 minutes and you will be requested to walk down a walkway in the laboratory and perform a step-down task from a 25cm step and a squat. The biomechanical and MRI data will be used to calculate the risk factors of the patella that may be related to your anterior knee pain.

We will also measure the intensity of your knee pain and functional problems using questionnaires. These will be administered before the physiotherapy treatment, immediately thereafter and again 3 months post the treatment.

Why have you been invited to participate?

You have been invited to participate in this the study because you experience anterior knee pain and responded to our invitations or advertisements.

What will your responsibilities be?

You will be required to visit the FNB-3D Movement Analysis Clinic for biomechanical testing. These tests will be conducted before the physiotherapy treatment and again immediately after the 6-week physiotherapy sessions. You will also be required to attend the Tygerberg Physiotherapy Clinic to receive treatment for your anterior knee pain once per week for 6 weeks. You will also be expected to perform the home exercise program as instructed.

Will you benefit from taking part in this research?

You will receive treatment for your anterior knee pain at no cost.

Are there in risks involved in taking part in this research?

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There is a small risk that you may develop a skin reaction due to the electrodes. This skin reaction will settle within a day or two and will usually not require treatment.

If you do not agree to take part, what alternatives do you have?
You can receive treatment, at your own cost, at the FNB-3D Movement Analysis Clinic or, at any other therapist of your choice.

Who will have access to your medical records?
All information obtained from you will be treated as strictly confidential. Only the researchers involved in the study will have access to data collected.
We will publish the findings of the study in the scientific journals and will also present it at scientific meetings/ conferences. Anonymity of your identity will be maintained.

What will happen in the unlikely event of some form injury occurring as a direct result of you taking part in this research study?
The university's indemnity insurance will cover the cost of any unfortunate incidents incurred during the testing procedures.

Will you be paid to take part in this study and are there any costs involved?
No, you will not be paid to take part in the study but there will be no costs involved for you, if you do take part. You will also receive 6 weeks of physiotherapy treatment and a motion analysis report free of charge. You will be reimbursed for petrol costs.

Is there anything else that you should know or do?
You can contact Prof Q. Louw at tel 021 9389667 if you have any further queries or encounter any problems.
You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your study doctor.
You will receive a copy of this information and consent form for your own records.

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Declaration by participant

By signing below, I …………………………………….………… agree to take part in a research study entitled *(insert title of study)*.

I declare that:

I read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.

I had a chance to ask questions and all my questions have been adequately answered.

I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.

I may choose to leave the study at any time and will not be penalised or prejudiced in any way.

I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ....…........……………. on (*date*) …………....……… 2017.

Signature of participant Signature of witness

Declaration by investigator

I *(name)* ……………………………………………..……… declare that:

I explained the information in this document to……………………………

I encouraged him/her to ask questions and took adequate time to answer them.

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I am satisfied that he/she adequately understands all aspects of the research, as discussed above

I did/did not use an interpreter. (*If an interpreter is used then the interpreter must sign the declaration below.*

Signed at (*place*) ....…........……………. on (*date*) …………...……… 2017.

Signature of investigator Signature of witness

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STELLENBOSCH UNIVERSITY
FACULTY OF HEALTH SCIENCES

PARTICIPANT INFORMATION LEAFLET AND ASSENT FORM

TITLE OF THE RESEARCH PROJECT:
The Effect of Physiotherapy on Anterior Knee Pain and Underlying Mechanisms

RESEARCHERS NAME(S): Miss DC Leibbrandt, Prof QA Louw, DR JH Muller

ADDRESS: Faculty of Medicine & Health Sciences, Division of Physiotherapy, Stellenbosch University, 4th floor, Teaching Building, Tygerberg, 7505

CONTACT NUMBER: 0219389667/ 0822558753

What is RESEARCH?
Research is something we do to find new knowledge about the way things (and people) work. We use research projects or studies to help us find out more about disease or illness. Research also helps us to find better ways of helping, or treating children who are sick.

What is this research project all about?
Anterior knee pain commonly affects teenagers and young adults causing them to be less physically active. The aim of this study is to better understand the causes of anterior knee pain and to assess the effect of physiotherapy on the knee joint and muscle function.

This study will take place at the at the FNB-3D Movement Analysis Clinic, Stellenbosch University, Tygerberg Campus. This project will include 45 individuals, aged between 14 and 40 years who experience anterior knee pain.

Participants will be assessed and treated for anterior knee pain by the senior physiotherapist at the FNB-3D Movement Analysis Clinic. You will also undergo tests to measure your knee movement. All these procedures will involve the placement of electrodes or reflective markers on your muscles or bony landmarks on your body. We will also measure your height, weight, leg length and other

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body measurements. The biomechanical testing will be done at the FNB-3D Movement Analysis Clinic, Stellenbosch University, Tygerberg Campus. The duration will be about 90 minutes and you will be requested to walk down a walkway in the laboratory and do a few squats. We will also ask you to answer some questions about your knee pain.

Why have I been invited to take part in this research project?
You have been invited to participate in this the study because you experience pain at the front of your knee and responded to our invitations or advertisements.

Who is doing the research?
The main researcher, Dominique Leibbrandt, is doing the research as part of her PhD.

What will happen to me in this study?
You will be required to visit the FNB-3D Movement Analysis Clinic and Physiotherapy Clinic for the treatment and biomechanical testing. These tests will be done before the physiotherapy treatment and again immediately after the 6-week physiotherapy sessions. You will also be required to receive treatment for your knee pain once a week for the 6 weeks treatment program. You will also be expected to do home exercises.

Can anything bad happen to me?
There is a small risk that you may develop a skin reaction due to the electrodes. This skin reaction will settle within a day or two and will usually not require treatment. Your muscles might be a bit stiff the day or two after the treatment. This will go away.

Can anything good happen to me?
You will receive treatment for your anterior knee pain at no cost.

Will anyone know I am in the study?
No, you will be given a code and all your information will be stored anonymously. Only the researchers involved in the study will have access to data collected and your photographs.

Who can I talk to about the study?
You can contact Prof Q. Louw or Ms D. Leibbrandt at tel 021 9389667 if you have any further queries or encounter any problems.

You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your study doctor.

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What if I do not want to do this?
You may choose to leave the study at any time and will not be used against you in any way.Do you understand this research study and are you willing to take part in it?

YES	NO

Has the researcher answered all your questions?

YES	NO

Do you understand that you can pull out of the study at any time?

YES	NO

____________________________ _______________________
Signature of Child Date

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Appendix D: Definitions and synonyms for AKP.

Crossley, Bennell, Green, & McConnell, 2001	PFPS AKP	An umbrella term used to encompass all anterior or retropatellar pain in the absence of other specific pathology. All pathologies that may manifest as anterior or retropatellar pain.
Harvie, O'Leary, & Kumar, 2011	PFPS	Diffuse retro/peripatellar pain, aggravated with activities which load the patellofemoral joint, such as climbing stairs, squatting, running, and prolonged sitting.
Aminaka & Gribble, 2005	PFPS	A condition presenting with anterior knee pain or pain behind the patella (retropatella). It is commonly experienced during running, squatting, stair climbing, prolonged sitting and long-sitting.
Cook, Mabry, Reiman, & Hegedus, 2011	Chondromalacia patella PFPS AKP	Old term used for PFPS. Anterior knee pain including the patella, but not including tibiofemoral or peripatellar structures. Anterior knee pain of more than 3 months duration, aggravated by sitting, squatting, stairs. All pain at the front of the knee.
Nunes, Stapait, Kirsten, de Noronha, & Santos, 2013	PFPS	In the absence of other intra-articular disorders, there is currently consensus that anterior knee pain, which limits activities of daily living that demand knee flexion such as climbing and descending stairs, squatting or remaining seated. Synonyms include chondromalacia patellae, patella arthralgia, patella pain
Lake & Wofford, 2011	Runner's knee PFPS	Synonym for PFPS as it is common in runners and other endurance athletes. AKP characterised by diffuse anterior knee pain, aggravated with specific activities that heighten the compressive loading forces across the patellofemoral joint including ascending and descending stairs, squatting, and prolonged sitting.
Collins, Bisset, Crossley, & Vicenzino, 2012	AKP	Synonym for PFPS. Chronic musculoskeletal overuse condition of the knee that affects an individual's ability to perform routine daily activities such as stair ambulation, walking and running, and thus impacts on work-related activities and participation in physical activity.
Barton, Hons, Hons, Menz, & Hons, 2008	PFPS	AKP of insidious onset defined as the presence of pain in the retropatellar or peripatellar region during tasks that increase patellofemoral joint loading, such as walking, running, negotiating stairs, squatting, prolonged sitting and kneeling. Anterior knee pain or

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		retro-patellar pain in the absence of other specific pathology
Heintjies et al., 2009	PFPS	Retropatellar pain (behind the kneecap) or peripatellar pain (around the kneecap) when ascending or descending stairs, squatting or sitting with flexed knees.
Prins & van der Wurff, 2009	PFPS	The remainder of knee pain cases after intra-articular pathologies, patella tendinopathies, peripatellar bursitis, plica syndrome, Sinding-Larsen Johnson and Osgood-Schlatter have been excluded.
Callaghan & Selfe, 2012	PFPS AKP	The clinical presentation of knee pain related to changes in the patellofemoral joint. Pain at the front of the knee, separate from arthritis. Gradual onset of knee pain with none of the features associated with other knee injuries or diseases. Pain at the front of the knee, used synonymously with PFPS.
Waryasz & McDermott, 2008	PFPS AKP	A variety of pathologies or anatomical abnormalities leading to a certain type of AKP. Broader term for all pathologies causing pain at the front of the knee, including referred pain from the lumbar spine or hip.
Heintjies et al., 2008	PFPS Retropatellar pain	A common complaint in adolescents and young adults, most frequently characterised by diffuse peripatellar and retropatellar localised pain, typically provoked by ascending or descending stairs, squatting and sitting with flexed knees for prolonged periods of time. Retropatellar pain in which no cartilage damage is evident. A self-limiting condition of the knee, that includes cartilage damage.
Lankhorst, Bierma-Zeinstra, & van Middelkoop, 2012	PFPS AKP	A condition of anterior knee pain. Pain in or around the patella. This pain increases after prolonged sitting, squatting, kneeling, and stair climbing. Covers all problems related to the anterior part of the knee.

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Appendix E: Clinical appraisal tool (CAT) for assessing systematic reviews

General systematic review (SR) quality criteria			
	Yes	No	Can't tell
Does the SR explicitly report and perform a comprehensive and reproducible literature search?			
Does the SR formulate a clearly focused question?			
Does the SR's methods section explicitly state the basis for inclusion or exclusion of primary RCTs?			
Does the SR report data from primary RCTs (e.g., size, interventions used, results from individual RCTs)			
Does the SR assess the methodological quality of primary studies, and take these into account where necessary?			
Meta-analysis: does the SR combine primary studies appropriately?			
Meta-analysis: does the SR state how results are combined statistically?			
Meta-analysis: does the SR report absolute numbers as well as appropriate summary statistics?			
Does the SR discuss the reasons for any variations/heterogeneity between individual RCTs/overall results?			
Does the SR report on the clinical relevance/importance of the results?			

RCT: Randomised controlled trail; SR: Systematic review

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Appendix F: Search Strategy for PubMed

Limits applied to the database:

Type of search: Advanced search

Publication dates: Inception to November 2016

Publication type: Clinical trial; Controlled clinical trial; Randomised controlled trial (RCT)

Language: English

Search terms:
1. Anterior knee pain [MESH]
2. Kinematics OR biomechanics
3. #1 AND #2
4. Gait OR walking OR locomotion
5. #1 AND #2 AND #4
6. Stairs
7. #1 AND #2 AND #6
8. Squatting
9. #1 AND #2 AND #8

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Appendix G: Functional questionnaires (AKPS and LEFS)

KUJALA SCORING QUESTIONNAIRE

Name: ________ ________ Date: ________
First Last

Physician: ________

1. Limp:
- a) None
- b) Slight or periodic
- c) Constant

2. Support:
- a) Full support without pain
- b) Painful
- c) Weightbearing impossible

3. Walking:
- a) Unlimited
- b) More than 2 km
- c) 1-2 km
- d) Unable

4. Stairs:
- a) No difficulty
- b) Slight pain when descending
- c) Pain both when ascending and descending
- d) Unable

5. Squatting:
- a) No difficulty
- b) Repeated squatting painful
- c) Painful each time
- d) Possible with partial weightbearing
- e) Unable

6. Running:
- a) No difficulty
- b) Pain after more than 2 km
- c) Slight pain from the start
- d) Severe pain
- e) Unable

7. Jumping:
- a) No difficulty
- b) Slight difficulty
- c) Constant pain
- d) Unable

8. Prolonged sitting with knee flexed:
- a) No difficulty
- b) Pain after exercise
- c) Constant pain
- d) Severe pain
- e) Unable

9. Pain:
- a) None
- b) Slight and occasional
- c) Interferes with sleep
- d) Occasionally severe
- e) Constant and severe

10. Swelling:
- a) None
- b) After severe exertion
- c) After daily activities
- d) Every morning
- e) Constant

11. Abnormal painful kneecap movements:
(patellar subluxations)
- a) None
- b) Occasionally in sports activities
- c) Occasionally in daily activities
- d) At least one dislocation after surgery
- e) More than two dislocations

12. Atrophy of thigh:
- a) None
- b) Slight
- c) Severe

13. Flexion deficiency:
- a) None
- b) Slight
- c) Severe

Score ____ Print Form Submit

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The Lower Extremity Functional Scale

We are interested in knowing whether you are having any difficulty at all with the activities listed below **because of your lower limb problem** for which you are currently seeking attention. Please provide an answer for **each** activity.

Today, *do you* or *would you* have any difficulty at all with:

	Activities	Extreme Difficulty or Unable to Perform Activity	Quite a Bit of Difficulty	Moderate Difficulty	A Little Bit of Difficulty	No Difficulty
1	Any of your usual work, housework, or school activities.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
2	Your usual hobbies, re creational or sporting activities.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
3	Getting into or out of the bath.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
4	Walking between rooms.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
5	Putting on your shoes or socks.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
6	Squatting.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
7	Lifting an object, like a bag of groceries from the floor.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
8	Performing light activities around your home.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
9	Performing heavy activities around your home.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
10	Getting into or out of a car.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
11	Walking 2 blocks.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
12	Walking a mile.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
13	Going up or down 10 stairs (about 1 flight of stairs).	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
14	Standing for 1 hour.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
15	Sitting for 1 hour.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
16	Running on even ground.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
17	Running on uneven ground.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
18	Making sharp turns while running fast.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
19	Hopping.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
20	Rolling over in bed.	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐
	Column Totals:					

Minimum Level of Detectable Change (90% Confidence): 9 points **SCORE: _____/ 80 (fill in the blank with the sum of your responses)**

Source: Binkley et al (1999): The Lower Extremity Functional Scale (LEFS): Scale development, measurement properties, and clinical application. Physical Therapy. 79:371-383.

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Appendix H: Reporting guideline checklists used for different studies

GRRAS checklist for reporting of studies of reliability and agreement (Chapter 4)

Version based on Table I in: Kottner J, Audigé L, Brorson S, Donner A, Gajeweski BJ, Hróbjartsson A, Robersts C, Shoukri M, Streiner DL. Guidelines for reporting reliability and agreement studies (GRRAS) were proposed. J Clin Epidemiol. 2011;64(1):96-106

Section	Item #	Checklist item	Reported on page #
Title/Abstract	1	Identify in title or abstract that interrater/intrarater reliability or agreement was investigated.	Pg. 59
Introduction	2	Name and describe the diagnostic or measurement device of interest explicitly.	Pg. 60, 4.1
	3	Specify the subject population of interest.	Pg. 60, 4.1
	4	Specify the rater population of interest (if applicable).	N/A
	5	Describe what is already known about reliability and agreement and provide a rationale for the study (if applicable).	Pg. 61, 4.1
Methods	6	Explain how the sample size was chosen. State the determined number of raters, subjects/objects, and replicate observations.	Pg. 62, 4.2.2
	7	Describe the sampling method.	Pg. 62, 4.2.2
	8	Describe the measurement/rating process (e.g. time interval between repeated measurements, availability of clinical information, blinding).	Pg. 63, 4.2.3
	9	State whether measurements/ratings were conducted independently.	Pg. 63, 4.2.3
	10	Describe the statistical analysis.	Pg. 64, 4.2.5

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Results	11	State the actual number of raters and subjects/objects which were included and the number of replicate observations which were conducted.	Pg. 65, 4.3
	12	Describe the sample characteristics of raters and subjects (e.g. training, experience).	Pg. 65, 4.3
	13	Report estimates of reliability and agreement including measures of statistical uncertainty.	Pg. 66-68, 4.3.1-4.3.3
Discussion	14	Discuss the practical relevance of results.	Pg. 69-71, 4.4
Auxiliary material	15	Provide detailed results if possible (e.g. online).	Available on request

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TIDieR
Template for Intervention Description and Replication

The TIDieR (Template for Intervention Description and Replication) Checklist*:
(Chapter 5)
Information to include when describing an intervention and the location of the information

Item number	Item	Where located ** Primary paper (page or appendix number)	Other † (details)
	BRIEF NAME		
1.	Provide the name or a phrase that describes the intervention.	Pg. 73______	____________
	WHY		
2.	Describe any rationale, theory, or goal of the elements essential to the intervention.	Pg.75-76, 5.1	____________
	WHAT		
3.	Materials: Describe any physical or informational materials used in the intervention, including those provided to participants or used in intervention delivery or in training of intervention providers. Provide information on where the materials can be accessed (e.g. online appendix, URL).	Pg.79-80, 5.2.4	Appendix J
4.	Procedures: Describe each of the procedures, activities, and/or processes used in the intervention, including any enabling or support activities.	Pg.79-80, 5.2.4	____________
	WHO PROVIDED		

5.	For each category of intervention provider (e.g. psychologist, nursing assistant), describe their expertise, background and any specific training given.	Pg. 79, 5.2.4___	______________
	HOW		
6.	Describe the modes of delivery (e.g. face-to-face or by some other mechanism, such as internet or telephone) of the intervention and whether it was provided individually or in a group.	Pg. 79, 5.2.4___	______________
	WHERE		
7.	Describe the type(s) of location(s) where the intervention occurred, including any necessary infrastructure or relevant features.	Pg. 76, 5.2.1___	______________
	WHEN and HOW MUCH		
8.	Describe the number of times the intervention was delivered and over what period of time including the number of sessions, their schedule, and their duration, intensity or dose.	Pg.79-80, 5.2.4	Appendix I____
	TAILORING		
9.	If the intervention was planned to be personalised, titrated or adapted, then describe what, why, when, and how.	Pg.79-80, 5.2.4	Table 16______
	MODIFICATIONS		
10.[‡]	If the intervention was modified during the course of the study, describe the changes (what, why, when, and how).	N/A for case series	Chapter 6_____
	HOW WELL		

11.	Planned: If intervention adherence or fidelity was assessed, describe how and by whom, and if any strategies were used to maintain or improve fidelity, describe them.	Not assessed- limitation	______________
12.ǂ	Actual: If intervention adherence or fidelity was assessed, describe the extent to which the intervention was delivered as planned.	N/A__________	______________

** **Authors -** use N/A if an item is not applicable for the intervention being described. **Reviewers** – use '?' if information about the element is not reported/not sufficiently reported.

† If the information is not provided in the primary paper, give details of where this information is available. This may include locations such as a published protocol or other published papers (provide citation details) or a website (provide the URL).

ǂ If completing the TIDieR checklist for a protocol, these items are not relevant to the protocol and cannot be described until the study is complete.

* We strongly recommend using this checklist in conjunction with the TIDieR guide (see *BMJ* 2014;348:g1687) which contains an explanation and elaboration for each item.

* The focus of TIDieR is on reporting details of the intervention elements (and where relevant, comparison elements) of a study. Other elements and methodological features of studies are covered by other reporting statements and checklists and have not been duplicated as part of the TIDieR checklist. When a **randomised trial** is being reported, the TIDieR checklist should be used in conjunction with the CONSORT statement (see www.consort-statement.org) as an extension of **Item 5 of the CONSORT 2010 Statement.** When a **clinical trial protocol** is being reported, the TIDieR checklist should be used in conjunction with the SPIRIT statement as an extension of **Item 11 of the SPIRIT 2013 Statement** (see www.spirit-statement.org). For alternate study designs, TIDieR can be used in conjunction with the appropriate checklist for that study design (see www.equator-network.org).

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TIDieR
Template for Intervention Description and Replication

The TIDieR (Template for Intervention Description and Replication) Checklist*:
(Chapter 7)
Information to include when describing an intervention and the location of the information

Item number	Item	Where located ** Primary paper (page or appendix number)	Other † (details)
	BRIEF NAME		
1.	Provide the name or a phrase that describes the intervention.	Pg. 108, 7.1	
	WHY		
2.	Describe any rationale, theory, or goal of the elements essential to the intervention.	Pg.108, 112, 7.1, 7.2.6	
	WHAT		
3.	Materials: Describe any physical or informational materials used in the intervention, including those provided to participants or used in intervention delivery or in training of intervention providers. Provide information on where the materials can be accessed (e.g. online appendix, URL).	Pg.111-113, 7.2.6	Appendices J and L
4.	Procedures: Describe each of the procedures, activities, and/or processes used in the intervention, including any enabling or support activities.	Pg.110, 7.2.5	Figure 19

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	WHO PROVIDED		
5.	For each category of intervention provider (e.g. psychologist, nursing assistant), describe their expertise, background and any specific training given.	Pg. 113, 7.2.6	
	HOW		
6.	Describe the modes of delivery (e.g. face-to-face or by some other mechanism, such as internet or telephone) of the intervention and whether it was provided individually or in a group.	Pg. 112, 7.2.6	
	WHERE		
7.	Describe the type(s) of location(s) where the intervention occurred, including any necessary infrastructure or relevant features.	Pg. 112, 7.2.6	
	WHEN and HOW MUCH		
8.	Describe the number of times the intervention was delivered and over what period of time including the number of sessions, their schedule, and their duration, intensity or dose.	Pg. 112-113, 7.2.6	Appendix K, Figure 19
	TAILORING		
9.	If the intervention was planned to be personalised, titrated or adapted, then describe what, why, when, and how.	Pg.112, 7.2.6	Appendix K
	MODIFICATIONS		
10.[‡]	If the intervention was modified during the course of the study, describe the changes (what, why, when, and how).	Pg.112, 7.2.6	Appendix K

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	HOW WELL		
11.	Planned: If intervention adherence or fidelity was assessed, describe how and by whom, and if any strategies were used to maintain or improve fidelity, describe them.	Pg. 120, 7.3.4	Appendix L____
12.[ǂ]	Actual: If intervention adherence or fidelity was assessed, describe the extent to which the intervention was delivered as planned.	Pg. 120, 7.3.4__	Table 23______

** **Authors -** use N/A if an item is not applicable for the intervention being described. **Reviewers** – use '?' if information about the element is not reported/not sufficiently reported.

† If the information is not provided in the primary paper, give details of where this information is available. This may include locations such as a published protocol or other published papers (provide citation details) or a website (provide the URL).
ǂ If completing the TIDieR checklist for a protocol, these items are not relevant to the protocol and cannot be described until the study is complete.

* We strongly recommend using this checklist in conjunction with the TIDieR guide (see *BMJ* 2014;348:g1687) which contains an explanation and elaboration for each item.
* The focus of TIDieR is on reporting details of the intervention elements (and where relevant, comparison elements) of a study. Other elements and methodological features of studies are covered by other reporting statements and checklists and have not been duplicated as part of the TIDieR checklist. When a **randomised trial** is being reported, the TIDieR checklist should be used in conjunction with the CONSORT statement (see www.consort-statement.org) as an extension of **Item 5 of the CONSORT 2010 Statement.** When a **clinical trial protocol** is being reported, the TIDieR checklist should be used in conjunction with the SPIRIT statement as an extension of **Item 11 of the SPIRIT 2013 Statement** (see www.spirit-statement.org). For alternate study designs, TIDieR can be used in conjunction with the appropriate checklist for that study design (see www.equator-network.org).

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Appendix I: Exercise prescription logbook for case series participants over 6-week period

Participant one exercise logbook

WEEK	EXERCISES	SETS
1	• Mini-lunge on step • Single-leg stand and reach on pillow • Standing to sitting (1/4 ROM)	2-3 (3 if pain allows)
2	• Mini-lunge on step (60 degrees) • Single-leg stand and reach on pillow • Standing to sitting (1/2 ROM) • Stork stand	2-3 (3 if pain allows)
3	• Mini-lunge on step (80 degrees) • Single-leg stand and reach on pillow • Standing to sitting (1/2 ROM) • Stork stand	2-3 (3 if pain allows)
4	• Lunge on step (90 degrees) • Single-leg stand and reach on pillow • Standing to sitting all the way down • Stork stand	2-3 (3 if pain allows)
5	• Lunge on step with step up (90 degrees) • Single-leg stand and reach on pillow • Standing to sitting (lower chair to 90-degree knee bend) • Stork stand	3 sets on each leg
6	• Step up with a dip • Stand to sit to 90 degrees • Single leg stand and reach • Stork 30 seconds eyes closed	• 3 sets on each leg • Except for stork (1 set of 30s)

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Participant two exercise logbook

WEEK	EXERCISES	SETS
1	1) Chair lunge and quad stretch, holding on to table 2) Step up and dip 3) Standing to sitting (45-degree knee bend)	2-3 for all (3 if pain allows)
2	1) Walking lunges (to 45 degrees) 2) Chair lunge and quad stretch, holding on to table 3) Step up and dip 4) Standing to sitting (60-degree knee bend)	2-3 for all (3 if pain allows)
3	1) Walking lunges (to 45 degrees) 2) Chair lunge and quad stretch, holding on to table 3) Step up and dip 4) Standing to sitting (60-degree knee bend with pillow between knees)	1 for walking lunges; 3 for rest
4	1) Walking lunges (to 45 degrees) 2) Chair lunge and quad stretch, **NO** holding on to table 3) Step up and dip with 1 kg weight 4) Standing to sitting (60-degree knee bend with 1 kg ball between knees)	1 for walking lunges; 3 for rest
5	1) Walking lunges (to 45 degrees) 2) Chair lunge and quad stretch, **NO** holding on to table 3) Step up and dip with 1 kg weight 4) Standing to sitting (60-degree knee bend, holding 1 kg ball and theraband around knees)	1 for walking lunges; 3 for rest
6	1) Walking lunges (to 45 degrees) 2) Chair lunge and quad stretch, **NO** holding on to table **AND** with 1 kg weight 3) Step up and dip with 1 kg weight 4) Standing to sitting (**90**-degree knee bend, holding 1 kg ball and theraband around knees)	1 for walking lunges; 3 for rest

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Participant three exercise logbook

WEEK	EXERCISES	SETS	REPS
1	1) Wall squat with stability ball (to 45 degrees knee flexion) 2) Hip hike on step 3) Single leg stand and reach on pillow	1) 3 2) 3 3) 3	1) 10 2) 5 each side 3) 5 each side
2	1) Wall squat without stability ball (to 45 degrees knee flexion) 2) Hip hike on step 3) Single leg stand and reach on pillow	1) 3 2) 3 3) 3	1) 10 2)8 each side 3) 8 each side
3	1) Standing to sitting (to 45 degrees of knee flexion) 2) Hip hike on step 3) Single leg stand and reach on pillow	1) 3 2) 3 3) 3	1) 10 2)10 each side 3) 10 each side
4	1) Standing to sitting (to 60 degrees of knee flexion) 2) Hip hike on step (all the way to ground and slowly back up) 3) Single leg stand and reach on pillow	1) 3 2) 3 3) 3	1) 10 2)10 each side 3) 10 each side
5	1) Standing to sitting (**all the way down to chair OR 80 degrees of knee flexion**) 2) **Forward step down** (all the way to ground and slowly back up) 3) Single leg stand, reach **and twist** on pillow 4) **Single leg stand eyes closed (aim for 15 seconds on each side)**	1) 3 2) 3 3) 3 4) 1	1) 10 2) 8 each side 3) 10 each side 4) 1 rep for 15s hold
6	1) Standing to sitting (all the way down to chair **with theraband around knees**) 2) Forward step down (all the way to ground and slowly back up) 3) Single leg stand, reach and twist on pillow 4) Single leg stand eyes closed (aim for **30 seconds** on each side)	1) 3 2) 3 3) 3 4) 1	1) 10 2) 10 each side 3) 10 each side 4) 1 rep for 30s hold

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Participant four exercise logbook

WEEK	EXERCISES	SETS	REPS
1	1) Squat using chair as guide 2) ¼ lunge on pillow 3) Single leg stand on pillow	1)8 reps 2)5 reps 3)10 seconds	2-3 sets on each side 3 if pain allows
2	1) Squat using chair as guide 2) Wall squat (1/4 ROM) 3) 1/2 lunge on pillow 4) Single leg stand and reach on pillow	1) 8 reps 2) 8 reps 3) 5 reps 4) 5 reps	1) 2 sets 2) 1 set 3) 3 sets 4) 3 sets
3	1) Wall squat (1/2 ROM) 2) 1/2 lunge on pillow 3) Balance progressions Set 1 single leg stand and reach Set 2 single leg stand and twist Set 3 single leg stand closed	1) 10 reps, 3 sets 2) 10 reps, 3 set 3) 5 reps of sets 1 and 2, 30s hold set 3	1) 3 sets 2) 3 sets 3) 3 sets
4	1) Wall squat (1/2 ROM) 2) Single leg lunge (Foot supported on plinth holding on to table) 3) Balance progressions Set 1 single leg stand and reach Set 2 single leg stand and twist Set 3 single leg stand closed	1) 10 reps, 3 sets 2) 10 reps, 3 set 3) 5 reps of sets 1 and 2, 30s hold set 3	1) 3 sets 2) 3 sets 3) 3 sets
5	1) Wall squat (1/2 ROM) with theraband 2) Single leg lunge (Foot supported on plinth, no holding on to table) 3) Balance progressions Set 1 single leg stand and reach Set 2 single leg stand and twist Set 3 single leg stand closed	1) 8 reps 2) 8 reps 3) 5 reps of sets 1 and 2, 30s hold set 3	1) 3 sets 2) 3 sets 3) 3 sets
6	1) Wall squat (1/2 ROM) with theraband 2) Single leg lunge (Foot supported on plinth, no holding on to table) 3) Balance progressions Set 1 single leg stand and reach Set 2 single leg stand and twist Set 3 single leg stand closed	1) 10 reps, 3 sets 2) 10 reps, 3 set 3) 5 reps of sets 1 and 2, 30s hold set 3	1) 3 sets 2) 3 sets 3) 3 sets

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Participant five exercise logbook

WEEK	EXERCISES	SETS	REPS
1	1) Running man 2) Step up and twist 3) Stork standing	1) 3 2) 3 3) 1	1) 5 on each side 2) 5 on each side 3) 10 seconds
2	1) Running man 2) Step up and twist 3) Stork standing 4) Multi-directional lunge	1) 3 2) 3 3) 1 4)1	1) 8 on each side 2) 10 on each side 3) 20 second hold 4) 3 on each side
3	1) Running man 2) Step up and twist, with 2 kg weight 3) Stork standing 4) Multi-directional leg reaches (lunge clock)	1) 3 2) 3 3) 1 4)1	1) 10 on each side 2) 10 on each side 3) 30 second hold 4) 3 on each side
4	1) Running man **on pillow** 2) Step up and twist, with **3 kg weight** 3) Stork standing 4) Multi-directional leg reaches (lunge clock)	1) 3 2) 3 3) 1 4)1	1) 10 on each side 2) 10 on each side 3) 30 second hold 4) 5 on each side
5	1) Running man **on pillow** 2) Step up, **dip** and twist, with 3 kg weight 3) Stork standing (eyes closed) 4) Multi-directional leg reaches (lunge clock)	1) 3 2) 3 3) 1 4) 1	1) 10 on each side 2) 10 on each side 3) 30 second hold 4) 5 on each side
6	1) Single leg deadlift 2) Step up, **knee up** and twist, with 3 kg weight 3) Stork standing (eyes closed) 4) Multi-directional leg reaches (lunge clock)	1) 3 2) 3 3) 1 4) 1	1) 10 on each side 2) 10 on each side 3) 60 second hold on each side 4) 5 on each side

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Participant six exercise logbook

WEEK	EXERCISES	SETS	REPS
1	1) Lateral wall reaching 2) Single leg stand on pillow 3) Mini-lunge on step (45-degree knee bend, front and back leg)	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 1	1) 5 2)30 second hold on each leg 3) 5 on each leg
2	1) Lateral wall reaching with lower body shifting 2) Single leg stand and reach on pillow 3) Small knee bend onto step (45-degree knee bend, back leg extended) 4) Mini-lunge on step (60-degree knee bend, front and back leg)	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 2-3 (3 if pain allows) 4) 2-3 (3 if pain allows)	1) 10 2)10 3) 5 on each leg 4) 5 on each leg
3	1) Lateral wall reaching with lower body shifting 2) Single leg stand and reach on pillow 3) Lunge onto step (80-degree knee bend)	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 2-3 (3 if pain allows)	1) 10 2)10 3) 10 on each leg
4	1) Lateral wall reaching with lower body shifting 2) Single leg stand and reach on pillow 3) Lunge onto step (80-degree knee bend)	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 2-3 (3 if pain allows)	1) 10 2)10 3) 10 on each leg
5	1) Lateral wall reaching with lower body shifting 2) Single leg stand and reach on pillow 3) Reverse lunge onto step (80-degree knee bend) 4) Tandem stance and walk	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 2-3 (3 if pain allows) 4) 2-3 (3 if pain allows)	1)10 2)10 3) 10 on each leg 4) 10 steps on each leg
6	As week 5		

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Participant seven exercise logbook

WEEK	EXERCISES	SETS	REPS
1	1) Standing to sitting onto high table (50-degree knee bend) 2) Lunge onto step (45-degree knee bend) 3) Single leg stand on pillow	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 1	1) 8 2) 5 on each leg 3) 30 second hold on each leg
2	1) Standing to sitting onto high table (50-degree knee bend) 2) Lunge onto step (45-degree knee bend) 3) Single leg stand and reach on pillow	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 3	1) 10 2) 8 on each leg 3) 5 on each leg
3	1) Standing to sitting onto high table with theraband around knees (50-degree knee bend) 2) Lunge onto step (60-degree knee bend) 3) Single leg stand and reach on pillow (reaching further to each side)	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 3	1) 10 2) 10 on each leg 3) 8 on each leg
4	1) Standing to sitting onto lower table with theraband around knees (65-degree knee bend) 2) Lunge onto step (60-degree knee bend) step up??? 3) Single leg stand and reach on pillow, reaching opposite arm and leg	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 3	1) 10 2) 10 on each leg 3) 10 on each leg
5	1) Standing to sitting onto lower table with theraband around knees (65-degree knee bend) 2) Lunge onto step (60-degree knee bend) step up??? 3) Single leg stand and reach on pillow, reaching opposite arm and leg	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 3	1) 10 2) 10 on each leg 3) 10 on each leg
6	As week 5		

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Participant eight exercise logbook

WEEK	EXERCISES	SETS	REPS
1	1) Step up with rotations (holding 3 kg ball) 2) Step down lunge (60-degree knee bend, alternating legs) 3) Running man	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 2-3 (3 if pain allows)	1)8 each side 2) 8 each side (3 if pain allows) 3) 10 each side (3 if pain allows)
2	1) Step up with rotations (holding 3 kg ball) 2) Step down lunge (higher step) 3) Running man	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 2-3 (3 if pain allows)	1)10 each side 2) 10 each side (3 if pain allows) 3) 10 each side (3 if pain allows)
3	1) Step up, **knee up,** with rotations (holding 3 kg ball) 2) Step down lunge **(80-90-degree knee bend)** 3) Running man with **1kg weight in each hand**	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 2-3 (3 if pain allows)	1)10 each side 2) 10 each side (3 if pain allows) 3) 10 each side (3 if pain allows)
4	1) Step down, **knee up,** with rotations (holding 3 kg ball) 2) Step down lunge **(80-90-degree knee bend)** 3) Running man with **on pillow**	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 2-3 (3 if pain allows)	1)10 each side 2) 10 each side (3 if pain allows) 3) 10 each side (3 if pain allows)
5	1) Step down, **knee up,** with rotations (holding 4 kg ball) 2) Step down lunge **(80-90-degree knee bend)** 3) Running man **on pillow**	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 2-3 (3 if pain allows)	1)10 each side 2) 10 each side (3 if pain allows) 3) 10 each side (3 if pain allows)
6	1) Step down, **knee up,** with rotations **on pillow** (holding 4 kg ball) 2) Step down lunge **(80-90-degree knee bend) with 2 kg dumbbell** 3) Running man **on pillow with 2 kg dumbbell**	1) 2-3 (3 if pain allows) 2) 2-3 (3 if pain allows) 3) 2-3 (3 if pain allows)	1)10 each side 2) 10 each side (3 if pain allows) 3) 10 each side (3 if pain allows)

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Appendix J: Functional exercise examples

FUNCTIONAL EXERCISE EXAMPLES WEEK1-3

Protocol:

- Choose three exercises at appropriate level for patient (level 1, 2 or 3 according to database)
- Progress from partial ROM to FROM if applicable
- Increase reps until 3 sets of 10-12 with good control
- If bilateral progress to unilateral
- If holding on for support decrease support
- Add a weight (dumbell or theraband)
- OR unstable surface (trampoline/ wobble board)
- Change exercises from walking database to sqautting database at week 3
- Change exercises if more than 3/10 pain

Gait retraining walking drills (warm up)

Walking drills- knee flexion

- Step forward lifting your knee up until it is in line with your hip. Your knee should be bent at 90 degrees. March across the room repeating this movement while alternating legs.

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Gait retraining walking drills (warm up)

Walking drill hip-lunge walks

- Step forward into a mini lunge, keeping knee facing forward and not passing over front of toes. Maintain upright posture with shoulders over hips. Push off of front leg and step forward into opposite leg lunge. Walk across the room alternating this movement.

Gait retraining walking drills (warm up)

Walking drill side shuffle

- Position yourself standing with your feet shoulder width apart. Practice walking sideways by placing one leg directly out to the side and moving the other leg sideways towards the leading leg. Keep both hips and knees in line. Walk sideways across the room.

LEVEL 1- proximal focus

Single leg mini-lunge with foot support and front support

- Place one leg on top of a chair and bring the other leg in front of you. Ensure that your pelvis is level. Hold onto a table or chair in front of you for support. Bend the front knee to 30-45 degrees by dropping downward with your weight down on your heel. Push back upwards with control by slowly straightening the knee.

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LEVEL 1- proximal focus

Mini-lunge

- Stand with feet shoulder width apart and your hands either on your hips or crossed across your chest. Take a step forward allowing the front knee to bend to approximately 45 degrees. Your back knee may bend as well. Keep your pelvis level and knees and feet facing straight forwards. Your front knee should be in line with your second toe and should not pass over the front of the toes. Return to the original position stepping back with control.

LEVEL 1- local focus

Swing phase knee flexion

- Stand on one leg and swing the other leg fully back and forth, allowing your arms to move normally. Your trunk should stay vertical and your leg should swing in a straight line. Your pelvis and spine should stay as still as possible throughout the movement. If unstable hold onto a chair or table for support.

LEVEL 1- local focus

Forward lunge on step

- Stand with a step in front of you. Place your front foot on the step and allow just the front knee to bend to 45-60 degrees. Do not allow your front knee to pass over the front of your toes. Repeat on the other side.

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LEVEL 1- local focus

Cone step over

- Place a cone or other object approximately 30cm high on the floor. Leading with the affected leg, step over the cone with a high knee step as shown. Once you get to the end, return to the original position by stepping backward over the cones leading with the affected leg.

LEVEL 2- proximal focus

Lunge with twist

- Step into a lunge position keeping your feet in line and facing forwards. With your hands out in front of you, twist your trunk towards your front leg and then away. Step back into starting position and repeat on other side. Maintain balance and make sure your hips and pelvis stay level throughout.

LEVEL 2- proximal focus

Static lunge on step without support

- Start in a ½ kneeling position with your back shin touching the step. Keeping your legs straight and thighs parallel with each other, raise up until your legs are straight then lower back in a controlled manner. Hold on a chair of table for support if unstable.

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LEVEL 2- local focus

Reverse lunges

- Stand with feet shoulder width apart and hands on hips. Pick up one foot and take a large step backwards. Lunge into the step while keeping your front knee directly over the ankle. Come back to standing. Repeat on the other foot.

LEVEL 2- local focus

Step up knee up

- Stand with feet shoulder width apart in front of a higher step (5cm). Step up onto the step with one leg and then lift the other leg and drive it forward to 90 degrees of hip flexion. Place the foot of the lifted leg back onto the floor and then step down with the leading leg.

LEVEL 3- proximal focus

Running man

- Start in a single leg balancing position. Lift the unsupported leg up to 90 degrees of hip flexion and then straight back into a lunge position touching the toe to the ground and not putting the foot down. Keep the supporting leg knee slightly bent throughout. Progress to add dumbbells or weights.

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LEVEL 3- proximal focus

Single leg lunge with foot on chair holding weight

- Place one leg on top of a chair and bring the other leg in front of you. Holding a 2kg weight (medicine ball, dumbbell) in both hands. Hold weight just in front of your chest with your elbows bent. Ensure that your pelvis is level. Bend the front knee to 30-45 degrees by dropping downward with your weight down on your heel. Push back upwards with control by slowly straightening the knee and squeezing the glute on the same side.
  Don't let the knees go over the front of the toes and keep the knee cap of the squatting leg facing forwards.

LEVEL 3- proximal focus

Weighted lunge with rotation

- Hold a 1-2 kg weight (medicine ball, dumbbell or 2 litre bottle of water) in both hands. Hold the weight just in front of your chest at with your elbows bent. Step into a lunge position keeping your feet in line and facing forwards. With your hands out in front of you, twist your trunk towards your front leg and then away. Step back into starting position and repeat on other side. Maintain balance and make sure your hips and pelvis stay level throughout.

LEVEL 3- local focus

Step down lunge

- Stand with both feet on a step (3cm height) shoulder width apart. Step down with one leg in front of the step and go into a forward lunge. Keep both feet and knees facing forwards. Then push back up from the front leg and lift the leg back up onto the step. Progress to add weight.

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LEVEL 3- local focus

Resistance band multi-directional lunge

- With a resistance band attached to ankle, lunge forward 10 times, lunge to the side 10 times and lunge with a ¼ turn 10 times. Repeat on other leg. Progress to increase the resistance of the band.

FUNCTIONAL EXERCISE EXAMPLES WEEK 4-6

LEVEL 1- proximal focus

Wall squats

- Start by standing up and leaning your low back against a wall or door. If there is too much friction to slide smoothly, put a towel between your back and the wall. Your feet should be should width apart. Next slowly bend your knees and lower your buttocks towards the floor. Knees should bend in line with your second toe and should not pass over the front of the toes. Knees should bend to about 45 degrees. Hold for 5 seconds. Return slowly with control.

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LEVEL 1- proximal focus

Wall squats with ball

- Start by standing up and leaning your low back against an exercise ball on the wall. Your feet should be shoulder width apart. Next slowly bend knees and lower your buttocks towards the floor. Knees should bend in line with your second toe and should not pass over the front of the toes. Knees should bend to about 45 degrees. Hold for 5 seconds. Return slowly with control.

LEVEL 1- proximal focus

Standing knee press

- Stand next to a wall with feet together. Lift one knee and place it on the wall. First you need to focus on your stance leg. Make sure your hip is directly over the knee and stays in this position throughout the exercise.
- Press out with your lifted knee into the wall, keeping your pelvis facing forward. Count to 10.

LEVEL 1- local focus

Squat using chair as guide

- Stand with feet shoulder width apart in front of a chair that is facing you, bend your knees and lower your body towards the floor. The chair seat is a guide so that your knees do not pass over your toes. Your body weight should mostly be directed through the heels. Return to a standing position.

LEVEL 1- local focus

Standing to sitting (higher chair or table)

- Sit on a high chair or table with hip bent to approximately 45 degrees. Feet should be shoulder width apart. Putting equal weight through both feet, stand up slowly keeping knees behind the front of your toes. Keep knees facing forwards throughout. Lower slowly with control. Sit down and repeat.

LEVEL 2- proximal focus

Standing hip rotation

- Stand upright with arms out to side and lift one knee until it is level with your hip. Move your knee across your body, keeping the chest facing forward. Your knee should move past your supporting leg. Progress to add weights in hands.

LEVEL 2- proximal focus

Hip hikes

- While standing on a low step, lower one leg downward towards the floor by tilting your pelvis to the side. Continue to lower the leg until the toe touches the ground. Without putting the foot down, return the pelvis/ leg back up to a levelled position. The movement should come from the pelvis and hips not the knees. The supporting leg knee should only bend slightly.

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LEVEL 2- proximal focus

Squat rotations

- Begin in a squat position with knees bent to approximately 60 degrees. With your pelvis in neutral and kneecaps pointing forwards, turn your shoulders and move the weight or medicine ball around the body. Return to the start position and repeat to the other side.

LEVEL 2- proximal focus

Squat with hip abduction (resistance band)

- Perform a squat with a resistance band tied just above the knees. Sit back into a squat of about 60 degrees of knee bend. Push the knees out to the side and back against the band as fast as possible repeatedly whilst maintaining good form. Keep the shoulders over the knees and knees over toes. Knees and feet should face forwards throughout. Bend as deep as you can with control. Aim for at least 30 repetitions whilst maintaining the knee bend.

LEVEL 2- proximal focus

Low squat chop with weight

- Start by holding a weight (dumbbell, medicine ball or any other weight of approximately 2kg) down by your ankle while on a squat position. Next return to a standing position as you raise the ball up and over the opposite shoulder. Maintain neutral position of knees and ankles.

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LEVEL 2- local

Supported single leg squats

- Stand on one leg and hold onto a stable support such a table and maintain your balance. Bend your knee and lower your body towards the floor until your knee bends to 45-60 degrees. Slowly return to and standing position. Knee should bend in line with the second toe and should not pass the front of the foot.

LEVEL 2- local

Wall sits:

- Stand with your back against the wall, feet shoulder width apart and slightly in front of you and knees facing forwards. Drop quickly to approximately 90 degrees of knee bend. Hold for 30 seconds and slowly push back up to starting position. Repeat three times. Progress by increasing the time that the position is held.

LEVEL 2- local

Jump squats

- Start in a squatting position. Move hips down and back, lift chest up, keep core tight, and feel the weight in your heels. Use your arms to get momentum and jump as high as you can. When coming down to a landing position make sure you land nice and softly with your knees bent back in that squatting position.

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LEVEL 3- proximal focus

Single leg standing to sitting

- Stand in front on a chair or table of appropriate height. Lift one leg off the floor. Using the supporting leg, sit hips back slowly as if sitting until sitting back on chair. Next using the same leg raise up to standing without using your hands for support. Keep knees facing forwards throughout.

LEVEL 3- proximal focus

Single leg squat with rotation

- Stand on one foot with the other knee lifted behind you. Hold a weight (dumbbell, medicine ball or any other weight of approximately 2kg) between both hands. Reach down and to the outside of the opposite foot with the keeping the back straight. Return slowly. Repeat on the other side.

LEVEL 3- proximal focus

Single leg lateral jumps

- Start balanced on one leg and jump sideways and land softly on other foot. Pause 1 second (stick landing) and repeat to other side. Repeat at least 10 times on each leg before switching sides. Do 3 sets on each leg. Be aware of the position of your hips knees and ankles on landing and correct if necessary before continuing to jump back to the other side.

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LEVEL 3- local focus

Split squat with weights

- Begin in a stride standing position with weight on the front foot and the toe of the back leg. The back leg should be in line with the hip, ie pelvis facing forwards and not rotated backwards. Go down into a split squat with the weight going through the heel of the front leg. The back leg is just touching the ground for balance. Return to starting position. Progress to holding a 1-2 kg weight in each hand. Repeat on other side.

LEVEL 3- local focus

Single leg wall sit

- In a mini wall squat position (knees bent to 45 degrees), flatten your back against the wall and lift one leg off the floor by straightening the knee. Keeping the lifted leg straight, bend the supporting leg a bit further, hold for a few seconds and return to the starting position, alternate legs.

LEVEL 3- local focus

Eccentric single leg squat

- Do a single leg squat (45-60 degrees) standing on a slant board, lowering slowly and with control. At the end of the squat put both legs on the board and return to the starting position.

Appendix K: Exercise prescription details for 6-week intervention period (6 case examples)

Week	AKP code	Exercises	Sets and reps	Progressions	Notes
1	AKP05	1) Mini-lunge 2) Single leg mini-lunge lunge with foot support and front support 3) Static lunge with support	1) 3 sets of 10 reps 2) 2 sets of 8 reps 3) 2 sets of 8 reps	N/A	
2	AKP05	1) Full lunge 2) Single leg mini-lunge lunge with foot support and front support 3) Static lunge with support	1) 3 sets of 8 reps 2) 3 sets of 8 reps 3) 3 sets of 8 reps	1) Increased knee bend 2) Added a set 3) Added a set	
3	AKP05	1) Full lunge on step 2) Single leg mini-lunge lunge with foot support and front support 3) Static lunge with support	1) 3 sets of 10 reps 2) 3 sets of 10 reps 3) 3 sets of 10 reps	1) on step 2) Increased reps, back leg lifted higher 3)Increased reps	
4	AKP05	1) Wall squats 2) Squat with hip abduction (resistance band) 3) Lunge with twist	1) 2 sets of 10 reps 2) 2 sets of 10 reps 3) 2 sets of 10 reps	N/A	New exercises

5	AKP05	1) Wall squats 2) Squat with hip abduction (resistance band) 3) Lunge with twist	1) 3 sets of 10 reps 2) 3 sets of 10 reps 3) 3 sets of 10 reps	Increased reps	
6	AKP05	1) Wall squats 2) Squat with hip abduction (resistance band) 3) Lunge with twist	1) 3 sets of 10 reps 2) 3 sets of 10 reps 3) 3 sets of 10 reps	1) Increased knee bend 1) Increased resistance 2) Add a 1kg weight	
Week	**AKP code**	**Exercises**	**Sets and reps**	**Progressions**	**Notes**
1	AKP10	1) Swing phase knee flexion 2) Forward lunge on step 3) Cone step over	1) 3 sets of 5 reps 2) 3 sets of 5 reps 3) 3 sets of 5 reps	N/A	
2	AKP10	1) Swing phase knee flexion 2) Forward lunge on step 3) Cone step over	1) 3 sets of 8 reps 2) 3 sets of 8 reps 3) 3 sets of 8 reps	Increased reps	Experienced 7/10 pain after exercise today
3	AKP10	1) Swing phase knee flexion 2) Forward lunge on step 3) Cone step over	1) 3 sets of 8 reps 2) 3 sets of 8 reps 3) 3 sets of 8 reps	1) Decreased support 2) Holding 2 kg weight 3) Holding 2 kg weight	
4	AKP10	1) Standing to sitting 2) Standing knee press 3) Wall squats	1) 3 sets of 5 reps 2) 3 sets of 5 reps 3) 3 sets of 5 reps	N/A	New exercises

5	AKP10	1) Standing to sitting 2) Standing knee press 3) Wall squats	1) 3 sets of 5 reps 2) 3 sets of 8 reps 3) 3 sets of 8 reps	1) Same 1) Increased reps 2) Increased reps	
6	AKP10	1) Standing to sitting 2) Standing knee press 3) Wall squats	1) 3 sets of 5 reps 2) 3 sets of 8 reps 3) 3 sets of 10 reps	1) Lower chair 2) Hold for 10 seconds 3) Increased reps	
Week	**AKP code**	**Exercises**	**Sets and reps**	**Progressions**	**Notes**
1	AKP15	1) Step up knee up 2) Step down lunge 3) Single leg mini lunge with foot supported but no front support	1) 3 sets of 5 reps 2) 3 sets of 5 reps 3) 3 sets of 5 reps	N/A	
2	AKP15	1) Step up knee up 2) Step down lunge 3) Single leg mini lunge with foot supported but no front support	1) 3 sets of 8 reps 2) 3 sets of 8 reps 3) 3 sets of 8 reps	Increased reps 2) Add 2 kg weight	
3	AKP15	1) Step up knee up 2) Step down lunge 3) Single leg mini lunge with foot supported but no front support	1) 3 sets of 8 reps 2) 3 sets of 8 reps 3) 3 sets of 8 reps	Same as week 2	Flu symptoms therefore no progressions

4	AKP15	1) Standing knee press 2) Squat with hip abduction 3) Standing to sitting (high chair)	1) 3 sets of 5 reps 2) 3 sets of 10 reps 3) 3 sets of 5 reps	N/A	New exercises 1) Struggles with this one on left 2) Needed to correct technique a few times
5	AKP15	1) Standing knee press 2) Squat with hip abduction 3) Standing to sitting (high chair)	1) 3 sets of 8 reps 2) 3 sets of 8 reps 3) 3 sets of 8 reps	Increased reps for all	
6	AKP15	1) Standing knee press 2) Squat with hip abduction 3) Standing to sitting	1) 3 sets of 10 reps 2) 3 sets of 10 reps 3) 3 sets of 10 reps	1) Increased reps 2) Increased resistance 3) Lower chair	
Week	**AKP code**	**Exercises**	**Sets and reps**	**Progressions**	**Notes**
1	AKP20	1) Single leg mini lunge with front and foot support 2) Split squat 3) Lunge with twist	1) 3 sets of 8 2) 3 sets of 8 3) 3 sets of 8		
2	AKP20	1) Single leg mini lunge and foot support 2) Split squat 3) Lunge with twist	1) 3 sets of 8 2) 3 sets of 8 3) 3 sets of 8	1) No front support 2) 2kg weight in each hand 3) 2kg weight in each hand	

3	AKP20	1) Single leg mini lunge with front and foot support 2) Split squat 3) Lunge with twist	3 sets of 10 for all	Increased reps for all	
4	AKP20	1) Standing to sitting 2) Squat using chair as guide 3) supported single leg squat	1) 3 sets of 5 2) 3 sets of 5 3) 3 sets of 5	1) Higher chair or table 2) No added weight 3) 45-degree knee bend	2) Don't lean forward with trunk. Struggles with balance 3) Struggles to keep hips level
5	AKP20	1) Standing to sitting 2) Squat using chair as guide 3) Supported single leg squat	1) 3 sets of 8 2) 3 sets of 8 3) 3 sets of 8	1) lower chair 2) Add 2kg weight 3) Increased reps	
6	AKP20	1) Standing to sitting 2) Squat using chair as guide 3) Supported single leg squat	3 sets of 10 for all	1) Lower chair 2) Wall squats (no chair for support) 3) Decreased supported (foot on wall)	
Week	**AKP code**	**Exercises**	**Sets and reps**	**Progressions**	**Notes**
1	AKP25	1) Single leg squat foot supported 2) Step up knee up	1) 3 sets of 10 2)3 sets of 5 3)3 sets of 5	1) added 2kg weight	

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		3) Step down lunge			
2	AKP25	1) Single leg squat foot supported 2) Step up knee up 3) Step down lunge	1) 3 sets of 10 2)3 sets of 5 3)3 sets of 8	1) 5kg weight 2) step up dip (not putting supporting foot down on the ground) 3) Increased reps	
3	AKP25	1) Single leg squat foot supported 2) Step up knee up 3) Step down lunge	3 sets of 10 for all	Increased reps for exercises 2 and 3	
4	AKP25	1)Split squat with weights 2) Jump squats 3)Single leg standing to sitting	1) 3 sets of 8 2) 3 sets of 8 3) 3 sets of 8 on each leg	1) 1-2 kg weight 3) High chair or table	New exercises 2) Focus on landing softly and not through heels
5	AKP25	1)Split squat with weights 2) Jump squats 3)Single leg standing to sitting	1) 3 sets of 8 2) 3 sets of 8 3) 3 sets of 5 on each leg	1) Back foot on wall 2) Same 3) Lower chair	
6	AKP25	1)Split squat with weights 2) Jump squats 3)Single leg standing to sitting	3 sets of 10 for all	2) Single leg hops	
Week	**AKP code**	**Exercises**	**Sets and reps**	**Progressions**	**Notes**

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1	AKP30	1) Sls with foot supported on chair 2) Lunge rotation 3) Running man	1) 3 sets of 10 2) 3 sets of 10 3) 3 sets of 5	1) No weight 2) With 2 kg weight 3) Hip does have to fully extend	
2	AKP30	1) Sls with foot supported on chair 2) Lunge rotation 3) Running man	1) 3 sets of 10 2) 3 sets of 10 3) 3 sets of 10	1) 2 kg weight 2) 4 kg weight 3) Increased reps, fully extend hips	
3	AKP30	1) Sls with foot supported on chair 2) Lunge rotation 3) Running man	1) 3 sets of 12 2) 3 sets of 12 3) 3 sets of 12	1) Decreased support 2) 5 kg weight 3) 1 kg weight in each hand	1) Foot on wall
4	AKP30	1) Jump squats 2) Standing to sitting 3) Squat rotations	1) 3 sets of 10 2) 3 sets of 10 3) 3 sets of 10	1) Bilateral 2) Bilateral 3) 2 kg weight in each hand	New exercises 1) Focus on soft landing 2) Low chair
5	AKP30	1) Single leg jumps 2) Standing to sitting 3) Weighted chop squats	1) 3 sets of 5 2) 3 sets of 10 3) 3 sets of 10	1) Single leg jumps 2) Faster return from sitting 3) 2 kg weight	1) and 3) new exercises (more challenging)

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6	AKP30	1) Single leg jumps 2) Standing to sitting 3) Weighted chop squats	1) 3 sets of 10 2) 3 sets of 10 3) 3 sets of 10	1) Same 2) Single leg on higher chair 3) 4 kg weight	

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Appendix L: Weekly pain and exercise compliance diary

PAIN DIARY: RECORDED AT SAME TIME AND DAY ONCE A WEEK

Date	Time	Description of pain	0-10	What aggravated pain	What eased pain	Other comments (pain, mood, activities, medication, etc)

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EXERCISE COMPLIANCE DIARY: RECORDED AT SAME TIME AND DAY ONCE A WEEK

Date	Time	How many times this week did you do your exercises (1-7 days)	On those days were all sets or repetitions performed?	Other comments

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Appendix M: Patient case example (AKP27) weekly exercises

EXERCISES WEEK 1 **11/10/2016**

WARM UP:

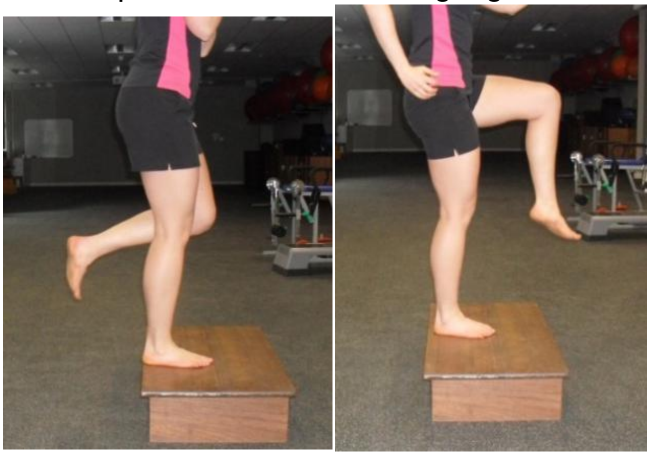
Walking drill hip-lunge walks

Step forward into a lunge, keeping knee directly over toes. Maintain upright posture, shoulders over hips. Push off of front leg and step forward into opposite leg lunge.

EXERCISES

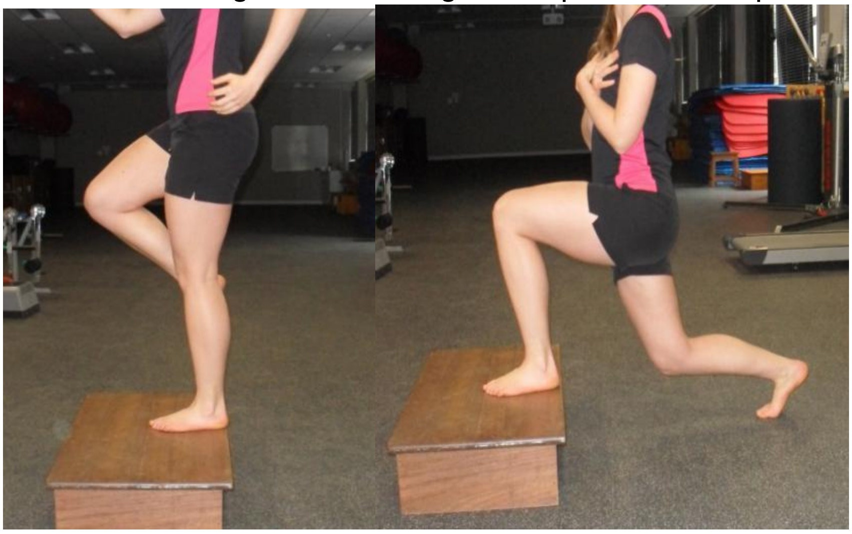
1) Step up knee up

Stand with feet shoulder width apart in front of a higher step (5cm). Step up onto the step with one leg and then lift the other leg and drive it forward to 90 degrees of hip flexion. Place the foot of the lifted leg back onto the floor and then step down with the leading leg.



2) <u>Reverse lunge off a step</u>

Stand with both feet on a step (3 cm height) shoulder width apart. Step backwards off the step with one leg and go into a reverse lunge. Focus on controlling the placement on the back foot. Keep both feet and knees facing forwards and do not allow your arch to collapse inwards. Then push back up from the back leg and lift the leg back up onto the step.



3) <u>Single leg lunge with foot on chair holding weight</u>

Place one leg on top of a chair and bring the other leg in front of you. Holding a 1-2 kg weight (medicine ball, dumbbell or 2 litre bottle of water) in both hands. Hold weight just in front of your chest with your elbows bent. Ensure that your pelvis is level. Hold onto a table or chair in front of you for support. Bend the front knee to 30-45 degrees by dropping downward with your weight down on your heel. Push back upwards with control by slowly straightening the knee.

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EXERCISES WEEK 5 **1/11/2016**

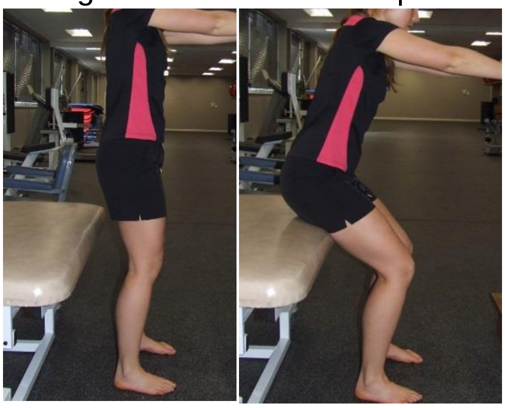
WARM UP:

Walking drill hip-lunge walks

Step forward into a lunge, keeping knee directly over toes. Maintain upright posture, shoulders over hips. Push off of front leg and step forward into opposite leg lunge.

1. Sitting to standing (lower chair or table)

Sit on a chair o with hip bent to approximately 60 degrees. Feet should be should width apart. Putting equal weight through both feet, stand up slowly keeping knees behind the front of your toes. Keep knees facing forwards throughout. Sit down and repeat.



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<u>2. Wall sits</u>
Stand with your back against the wall, feet shoulder width apart and slightly in front of you and knees facing forwards. Drop quickly to approximately 90 degrees of knee bend. Hold for 30 seconds and slowly push back up to starting position.

<u>3. Supported single leg squats</u>
Stand on one leg and hold onto a stable support such a table and maintain your balance. Bend your knee and lower your body towards the floor until your knee bends to 45-60 degrees. Slowly return to and standing position. Knee should bend in line with the second toe and should not pass the front of the foot.

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Weekly pain diary:

PAIN DIARY: RECORDED AT SAME TIME AND DAY ONCE A WEEK

Date	Time	Description of pain	0-10	What aggravated pain	What eased pain	Other comments (pain, mood, activities, medication, etc)
11/10/2016	11:00am	Vague swollen pain	3/10	Standing with straight knees	Bending knees slightly, sitting	No activity just lots of standing
18/10/2016	11:00am	Stiffness	2/10	Standing with straight knees	Bending knees slightly, sitting	Not a lot of pain but knee feels stiffer
25/10/2016	9:30am	Stiffness	3/10	Sharp turns, twisting at the knee	Keep knee in a neutral position (not twisting)	Not a lot of activity but did try a short run
1/11/2016	11:00am	Stiffness, with occasional sharp pain	2/10	Sharp turns, twisting at the knee	Keep knee in a neutral position (not twisting)	Wind surfing
8/11/2016	11:00am	None	0/10	Felt like twisting would have aggravated it so avoided this	Keep knee in a neutral position (not twisting)	One run and wind surfing
15/11/2016	11:00am	None	0/10	Awareness (although not pain) of knee after walking all day	Keep knee in a neutral position (not twisting)	A lot of walking 7-8 hours a day

EXERCISE COMPLIANCE DIARY: RECORDED AT SAME TIME AND DAY ONCE A WEEK

Date	Time	How many times this week did you do your exercises (1-7 days)	On those days were all sets or repetitions performed?	Other comments
18/10/2016	11:00am	6	Yes	Was in Johannesburg for a few days but was able to continue
25/10/2016	9:30am	6	Yes	No problems
1/11/2016	11:00am	3	Yes, Increased reps by 5 per set	Finding them easy (boring) now
8/11/2016	11:00am	3	Yes	Enjoying new exercises, more challenging
15/11/2016	11:00am	4	Yes	No problems
22/11/2016	11:00am	4	Yes	No problems

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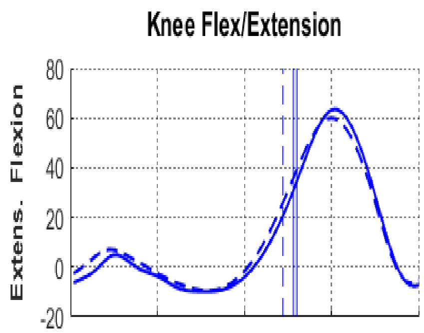
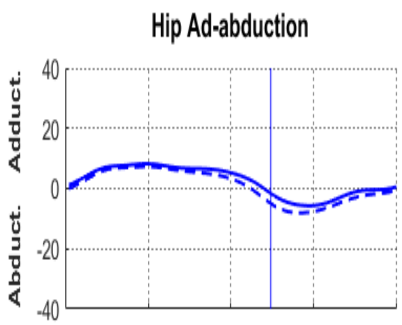
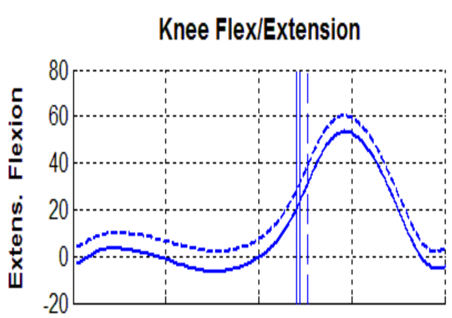
Appendix N: Details of the included sample and individual patient gait arrays

Key: —— Pre- intervention (degrees)
- - - - Post- intervention (degrees)

<table>
<tr><th>Subject number</th><th>Patient description</th><th>Main feature</th><th>Clinically meaningful change</th></tr>
<tr><td>AKP01</td><td>A 38-year-old female, with a 6-month history of L sided AKP. Her pain was aggravated by running, squatting, lunging, prolonged sitting, kneeling and jumping. She had previously tried wearing a knee guard, massage and some exercises with no success. She wanted to go back to running park runs.</td><td>
</td><td>No</td></tr>
<tr><td>AKP02</td><td>An 18-year-old female, with a 6-month history of R sided AKP. Her pain was aggravated by squatting, stair ascent and descent, lunging and jumping. She had previous tried massage and exercises. She wanted advice on how to strengthen her knee without aggravating the pain.</td><td>
</td><td>No</td></tr>
<tr><td>AKP03</td><td>A 39-year-old female with a 3-month history of L sided AKP. Her pain was aggravated by running, squatting and walking up the stairs. She had previously tried taping with no success. Her goal was to be able to continue to increase her running training as she wanted to run her first marathon.</td><td>
</td><td>Yes+</td></tr>
</table>

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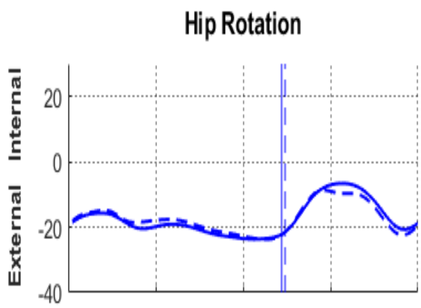
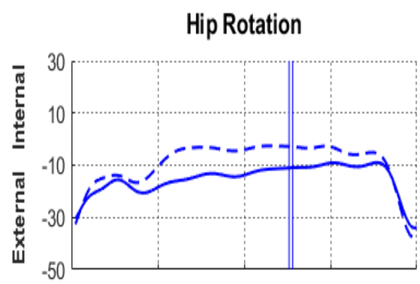
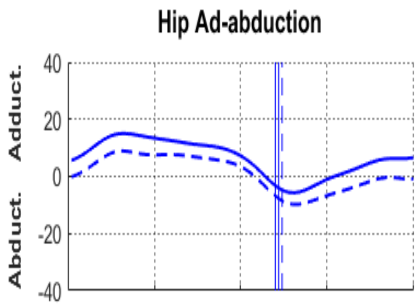
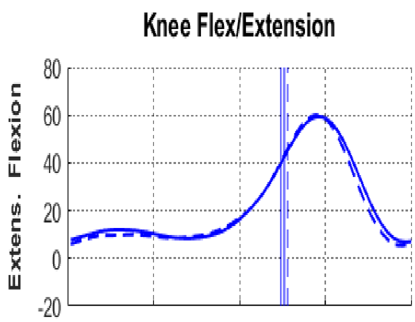
AKP04	A 29-year-old male with a 3-month history of R sided AKP. His pain was aggravated by changing directions while running, lunging and squatting. He had tried no previous physiotherapy or other treatment for his knee pain. He wanted to run half marathons and to continue to play soccer without knee pain.		No
AKP05	31-year-old male with a one-year history of L sided AKP. His pain was aggravated by stair ascent and descent, squatting and running. He had tried no previous physiotherapy or other treatment for his knee pain. He wanted to go back to running 10km.		Yes +
AKP06	37-year-old male with a 2-year history of R sided AKP. His pain was aggravated by running on unstable surfaces, squatting, walking uphill and lunging. He had tried no previous physiotherapy or other treatment for his knee pain. His goal was for his pain to be completely gone.		Yes+
AKP07	15-year-old female with a 4-year history of R sided AKP. Her pain was a hockey player and her pain was aggravated by squatting, running fast, ascending and descending stairs, lunging and kneeling. She had tried pain killers to treat her knee pain previously, but this only provided temporary relief. She wanted to be able to participate fully in hockey without her knee pain limiting her.		No

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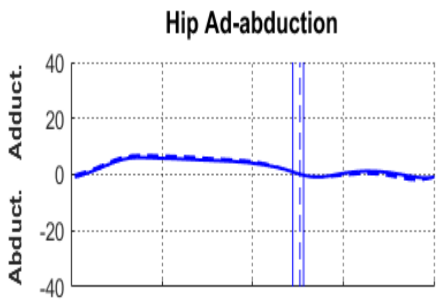
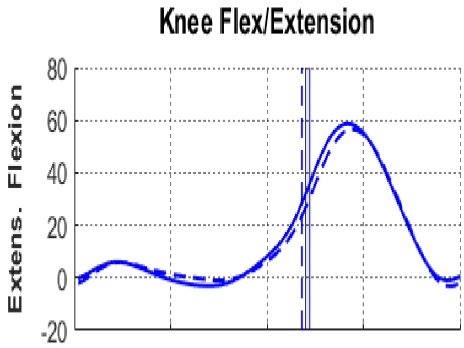
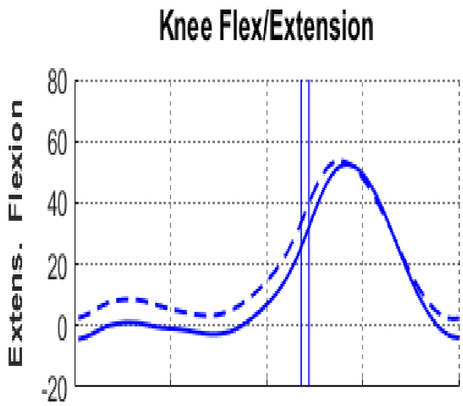
AKP08	40-year-old male with a 1.5-year history of L AKP. His pain was aggravated by running, cycling, walking up the stairs, squatting, prolonging sitting and lunging. He had tried no previous physiotherapy or other treatment for his knee pain. His goal was for his pain to no longer limit his participation in running and cycling.		No
AKP09	18-year-old male with a 2-year history of L sided AKP. His pain was aggravated by squatting, stair ascent and descent, lunging and jumping. He had only tried transact patches for his knee pain with no success. His main concern was to understand what was causing his knee symptoms to put his mind at ease.		Yes+
AKP10	14-year-old female with an 18-month history of R sided AKP. Her pain was aggravated by prolonged sitting, stair ascent and descent, running and blocking when playing hockey. She had previously tried massage, taping, medication and rest for her knee pain and these only provided temporary relief. Her aim was to be able to participate in school hockey and athletics without knee pain.		Yes+

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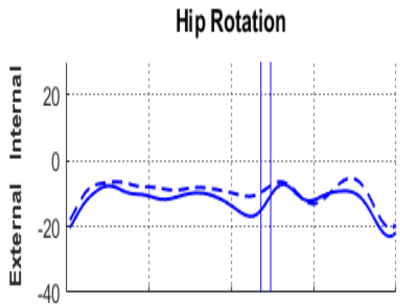
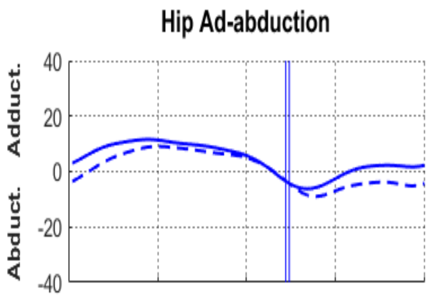
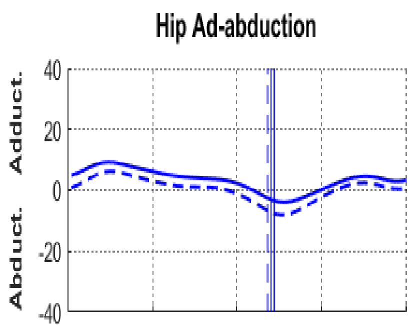
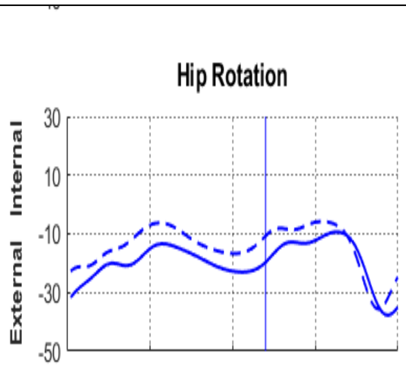
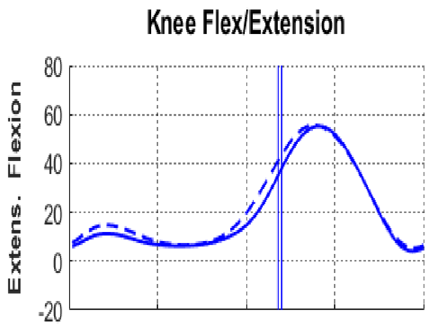
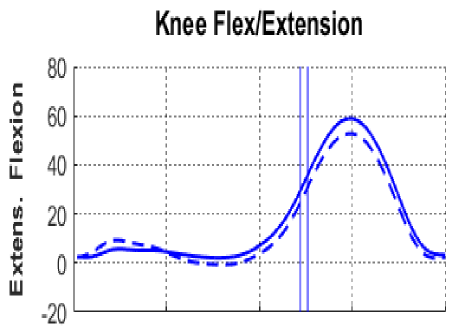
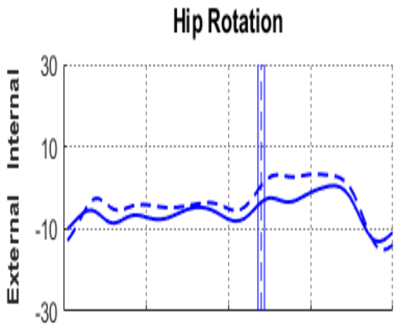
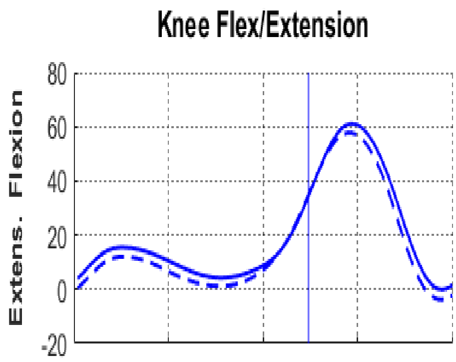
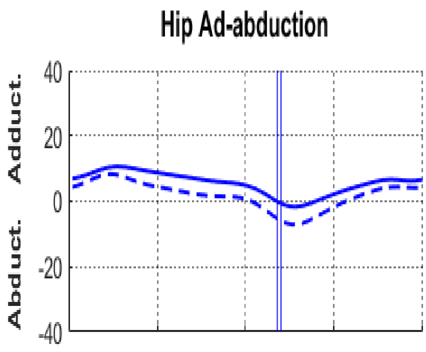
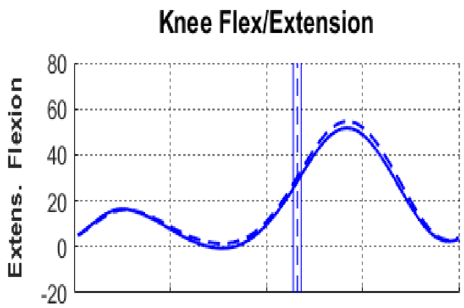
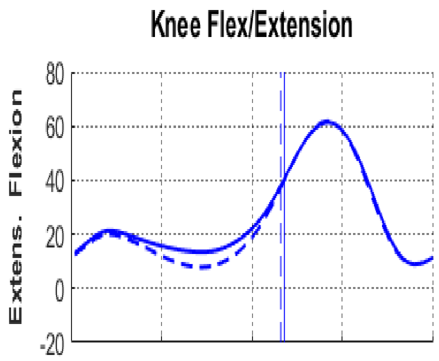
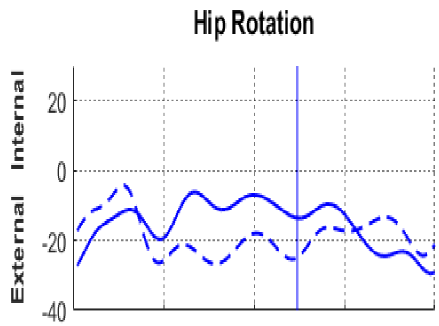
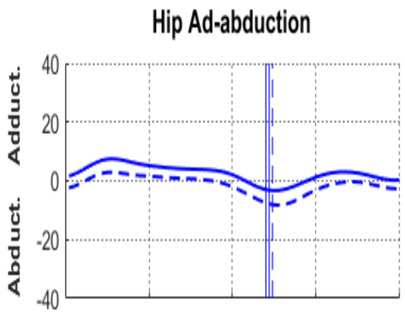
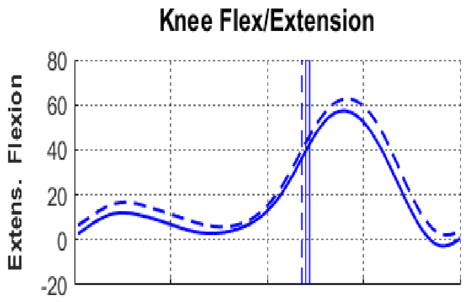
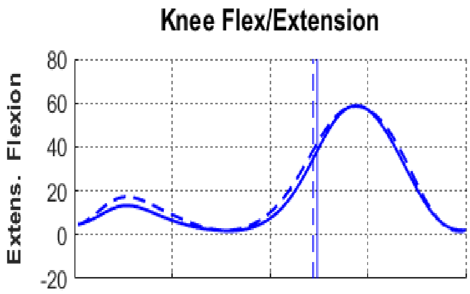
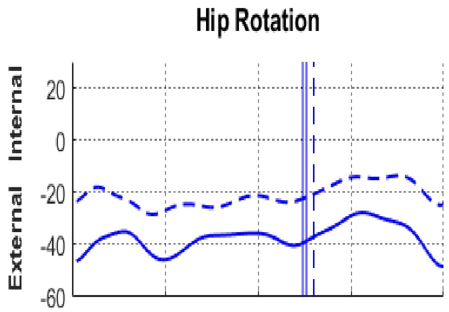
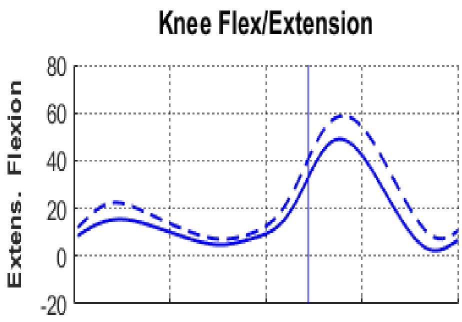
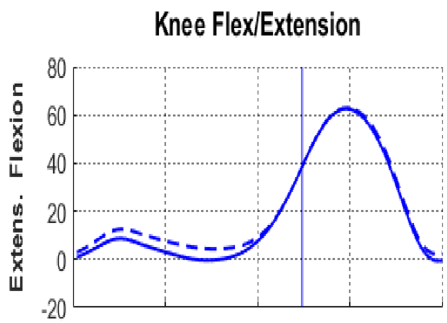
AKP11	37-year-old female with a 6-month history of L sided AKP. Her pain was aggravated by squatting, stair ascent and descent, lunging and burpees during gym class. She had tried no previous treatment strategies for her knee pain. Her aim for treatment was to strength her knee and to be able to push herself in her gym aerobics classes without pain.		Yes+
AKP12	17-year-old female who says she has experienced R sided AKP for as long as she can remember. Her pain was aggravated by squatting, prolonged sitting, walking on an incline or decline, kneeling, lunging and jumping. She had previously tried massage, taping and pain medication to treat her knee pain with no success. Her main concern was to understand why her knee hurt and to be able to continue with horse riding and show jumping.		Yes+
AKP13	14-year-old female with a 5-year history of R sided AKP. Her pain was aggravated by stair ascent and descent, kneeling, running, lunging and jumping. She had previously tried manual physiotherapy, taping and medication to treat her knee symptoms with no success. She wanted to be able to continue with school hockey, netball and athletics without her knee pain interfering.		Yes+

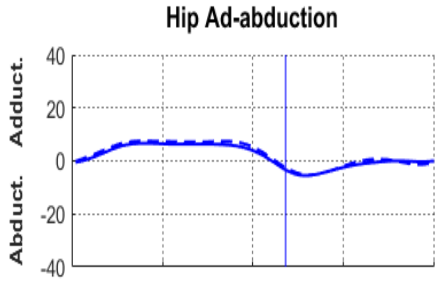
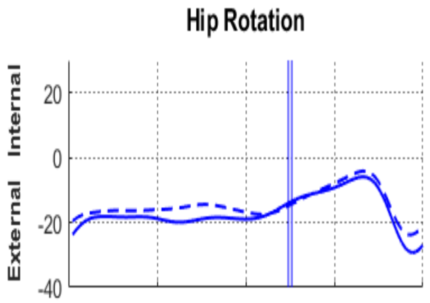
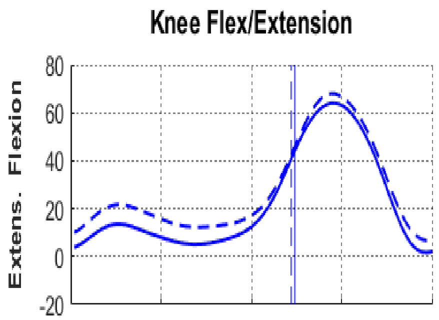
AKP14	39-year-old female with a 2-year history of L sided AKP. Her pain was aggravated by running, squatting, stair ascent, kneeling, lunging and jumping. She had previously tried dry needling and shockwave therapy to treat her knee pain. Both provided temporary relief only. Her main aim was to be able to run half marathons again.		Yes+
AKP15	31-year-old male with a 2-year history of L sided AKP. His pain was aggravated by road running (trail running pain free), squatting, stair ascent and descent, kneeling and lunging. No had tried no previous treatment strategies to address his knee pain. His main concern was that his knee would get progressively worse with age, so he wanted to understand the causes and re-assurance that he could continue running.		Yes+
AKP16	40-year-old female with a 3-month history of R sided AKP. Her pain was aggravated by squatting, prolonged sitting, running, stair ascent and descent, kneeling and lunging. She had previously tried physiotherapy (manual) and biokinetics to treat her knee pain with no success. Her main concern was to get rid of the knee pain and prevent it from reoccurring so that she could start running again.		No

AKP17	40-year-old male with a two-year history of L sided AKP. His pain was aggravated by squatting, lunging and stair descent. He had previously tried lower body resistance training to treat his knee pain but this had worsened his symptoms. His main aim was to understand the causes of his knee pain and to strengthen his knees to prevent future damage.		Yes+
AKP18	25-year-old male with a 3-month history of L sided AKP. His pain was aggravated by running downhill, especially off-road, and walking down the stairs. He has previously tried cataflam painkillers to treat his knee pain, however these provided temporary relief only. His main goal was to be able to go back to trail running without the knee pain slowing his down on the downhills.		Yes -
AKP19	24-year-old female with a 1-year history of R sided AKP. Her pain was aggravated by squatting, prolonged sitting, running on unstable surfaces, lunging and jumping. She has tried no previous treatment or physiotherapy. Her main goal was to get rid of her knee pain so that she could compete for her university team at cross country events.		Yes +

AKP20	29-year-old female with a 12-month history of L sided AKP. Her pain was aggravated by squatting, stair descent, running downhill, kneeling, lunging and jumping. Her main goal was to be able to run the Two Oceans half marathon without knee pain the following year.		Yes+
AKP21	34-year-old female with a 6-month history of R sided AKP. Her pain was aggravated by running long distances, squatting, prolonged sitting, stair descent, kneeling and lunging. She had tried no previous treatment or physiotherapy for her knee pain. Her main concern was having to stop running marathons and dancing competitively.		No
AKP22	33-year-old female with a 3-year history of L sided AKP. Her pain was aggravated by squatting, ascending stairs, kneeling and lunging. She had previously tried taping for her knee pain which provided temporary relief. Her main concern was pain relief during the day and to decrease stiffness.		No
AKP23	31-year-old male with a 6-month history of L sided AKP. His pain was aggravated by running long distances, squatting, prolonged sitting, stair ascent and descent, kneeling, lunging and jumping. He had previously tried seeing a knee specialist who told him that it would come right with time. He		Yes+

	had also tried seeing a physiotherapist, a chiropractor and gym training to strength his quadriceps. His main concern was that he was unable to run as he wanted to run the Comrades Ultramarathon the following year.		
AKP24	40-year-old female with a 6-month history of L sided AKP. Her pain was aggravated by running, squatting, prolonged sitting, stair descent, lunging and jumping. She had previously tried biokinetics, physiotherapy (massage and taping) and taking a glucosamine supplement, which seemed to ease the pain slightly. Her main concern was to go back to running half marathons.		Yes+
AKP25	27-year-old male with a 4-month history of L sided AKP. His pain was aggravated by running far or hilly routes as well as stair ascent and descent. He had tried no previous treatment for his knee pain. His main concern was for his knee pain to decrease to the point where he could run marathons again.		Yes+

AKP26	31-year-old female with a 12-month history of L sided AKP. Her pain was aggravated by squatting, prolonged sitting and walking. She had tried pain medication, taping, massage and strengthening exercises to relieve her pain and nothing had provided relief. Her main concern was to decrease the pain so that she could go back to mountain biking and ballroom dancing.		Yes+
AKP27	33-year-old male with 7-year history of L sided AKP. His pain was aggravated by squatting, stair descent, downhill hiking and running and kneeling. He had previously tried stretching, taping and massage for his knee pain, but his pain did not subside. His main concern was understanding the cause of his pain and to not be limited by his knee pain when hiking and running.		Yes+
AKP28	27-year-old female with a 4-year history of L sided AKP. She has had no previous treatment for her knee pain. Her pain was aggravated by squatting, running, stair ascent and descent, and running. Her main concern was to be able to run without pain.		Yes+

AKP29	37-year-old female with a 3-month history of L sided AKP. Her pain was aggravated by squatting, prolonged sitting, kneeling and lunging. She had previously tried medication and taping which provided some relief. Her main concern was pain relief.		No
AKP30	36-year-old male with a 1.5-year history of L sided AKP. His pain was aggravated by squatting and running. He had previously tried stretching, strengthening, massage and seeing a chiropractor. None of these strategies had improved his symptoms. His main concern was to be able to run far again without his knee pain limiting him.		No
AKP31	32-year-old male with a 2-year history of L sided AKP. His pain was aggravated by stair ascent and running. He had previously tried wearing a knee strap which gave him more confident but did not remove the pain. His main concern was to be able to go back to running, trail running and soccer for health, fitness and weight loss.		Yes+

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Appendix O: Exit interview

- How long had you suffered from knee pain before you enrolled in the study?
- Which treatment strategies did you try before the study (e.g. massage, taping, medication)?
- What did you want to achieve when you volunteered for the study? What was your main concern?
- Did you achieve this? Explain.
- Have there been any changes in your symptoms (good or bad) since the end of the study?
- If so which activities are easier or more difficult?
- What is your current level of knee pain at rest (0-10)?
- What is your current level of knee pain during activity (0-10)?
- Please rate how well “recovered” you think you are from your original knee pain on a scale of 1-7 as shown below.

  1. Completely recovered
  2. Strongly recovered
  3. Significant improvement
  4. Moderate improvement
  5. Little improvement
  6. Slightly recovered
  7. Worse than ever

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Appendix P: Publication PDFs for included studies

South African Journal of Physiotherapy
ISSN: (Online) 2410-8219, (Print) 0379-6175

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The development of an evidence-based clinical checklist for the diagnosis of anterior knee pain

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Dates:
Received: 22 Mar. 2016
Accepted: 03 Dec. 2016
Published: 31 Mar. 2017

How to cite this article:
Leibbrandt, D.C. & Louw, Q., 2017, 'The development of an evidence-based clinical checklist for the diagnosis of anterior knee pain', *South African Journal of Physiotherapy* 73(1), a353. https://doi.org/10.4102/sajp.v73i1.353

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Background: Anterior knee pain (AKP) or patellofemoral pain syndrome is common and may limit an individual's ability to perform common activities of daily living such as stair climbing and prolonged sitting. The diagnosis is difficult as there are multiple definitions for this disorder and there are no accepted criteria for diagnosis. It is therefore most commonly a diagnosis that is made once other pathologies have been excluded.

Objectives: The aim of this study was to create an evidence-based checklist for researchers and clinicians to use for the diagnosis of AKP.

Methods: A systematic review was conducted in July 2016, and an evidence-based checklist was created based on the subjective and objective findings most commonly used to diagnose AKP. For the subjective factors, two or more of the systematic reviews needed to identify the factor as being important in the diagnosis of AKP.

Results: Two systematic reviews, consisting of nine different diagnostic studies, were identified by our search methods. Diagnosis of AKP is based on the area of pain, age, duration of symptoms, common aggravating factors, manual palpation and exclusion of other pathologies. Of the functional tests, squatting demonstrated the highest sensitivity. Other useful tests include pain during stair climbing and prolonged sitting. The cluster of two out of three positive tests for squatting, isometric quadriceps contraction and palpation of the patella borders and the patella tilt test were also recommended as useful tests to include in the clinical assessment.

Conclusion: A diagnostic checklist is useful as it provides a structured method for diagnosing AKP in a clinical setting. Research is needed to establish the causes of AKP as it is difficult to diagnose a condition with unknown aetiology.

Introduction

Knee pain affects about 70% of clients visiting the community health centres in the Western Cape (Parker & Jelsma 2010). This alarming occurrence of knee problems is associated with moderate to high levels of disability.

Anterior knee pain (AKP) or patellofemoral pain syndrome (PFPS) frequently affects the knee joint and impairs functional ability (Parker & Jelsma 2010).

The international incidence has been reported to be 25%–43% in sports injury clinics (Callaghan & Selfe 2007; Witvrouw et al. 2000). AKP has a tendency to become chronic, and it has been estimated that 91% of patients diagnosed with AKP still experience symptoms four years after its onset. AKP is particularly common in adolescents, between the ages of 12 and 17 years (Rathleff et al. 2013), and may limit an individual's ability to perform common activities of daily living such as stair climbing and prolonged sitting (Nunes et al. 2013).

AKP is thought to be multifactorial in origin (Aminaka & Gribble 2008). It also has the tendency to become chronic, especially in active individuals, adding an additional aspect of complexity to the treatment (Collins et al. 2012). There is agreement among recent reviews that conservative approaches are the preferred choice of treatment for AKP (Collins et al. 2012; McCarthy & Strickland 2013). Surgical options such as distal realignment of the extensor mechanism, lateral retinacular release or debridement are generally only considered when conservative methods have failed or in the case of severe instability (McCarthy & Strickland 2013).

The aetiology of AKP is not well understood. In addition, the aetiology may differ depending on whether symptoms are acute or chronic. There are a variety of pathways that could result in

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ongoing pain (psychological, pathophysiological, mechanical). However, the onset of the condition is hypothesised to involve excessive joint stress during activities that load the flexed knee joint. This patellofemoral joint stress is then transmitted through the cartilage, thereby exciting nociceptors in subchondral bone resulting in pain (Fulkerson 2002). Over time, this joint stress may result in articular cartilage pathology (Powers et al. 2014).

There are many definitions and synonyms for AKP. It is often used as an umbrella term for pathologies that cannot be classified as anything else, and therefore can include a variety of different pathologies. The term has been used interchangeably with PFPS, chondromalacia patellae, runner's knee, patellofemoral joint dysfunction and patella arthralgia (Collins et al. 2012; Cook et al. 2010; Lake & Wofford 2011; Nunes et al. 2013). For the purpose of this article, we will be using the term 'anterior knee pain'.

Appendix 1 illustrates the range of definitions reported in systematic reviews.

The multiple definitions of AKP make accurate and standardised clinical diagnosis a challenging task for clinicians.

AKP is frequently defined as retropatellar or peripatellar pain, of more than three months duration, in the absence of intra-articular pathology, that is aggravated by activities that load a flexed knee joint (Crossley et al. 2001; Harvie, O'Leary & Kumar 2011; Nunes et al. 2013; Prins & van der Wurff 2009). The diagnosis of AKP is most commonly made based on the definition as well as the exclusion of other pathologies. However, this diagnostic procedure is vague and difficult to reproduce in a clinical setting.

The aim of this study was to create an evidence-based checklist for researchers and clinicians to use for the diagnosis of AKP.

Methods

Study selection criteria

English-only studies reporting on the clinical diagnostic tests for AKP were considered for inclusion. Due to the abundance of literature on AKP, only systematic reviews were eligible for inclusion.

Studies describing the subjective information used for the diagnosis of AKP, such as the age of the patient, the duration of the symptoms, aggravating activities and previous history of trauma or other known knee injuries, were considered for inclusion.

Studies describing objective clinical tests used for the diagnosis of AKP were included. Radiographic procedures such as MRIs were excluded as these procedures cannot form part of a physiotherapy clinical assessment. For the same reason, arthroscopic procedures were also excluded.

The subjects of the studies included both genders. Exclusions were for studies that may have incorporated diagnoses of Osgood-Schlatter and osteoarthritis in participants younger than 18 years or older than 40 years. In addition, studies portraying knee abnormalities such as patella subluxation or intra-articular pathology were also omitted.

Search strategy

Publications from inception to July 2016, located in PubMed, Ebscohost (MEDLINE, CINAHL, SportDiscuss), Scopus and Science Direct, were accessed in library databases at the Medical Library at Stellenbosch University during July 2016.

The keywords used by the researcher (D.L.) in all the searches were: 'anterior knee pain', 'patellofemoral pain syndrome', 'diagnosis', 'clinical tests' and 'systematic reviews'. Searches were database-specific with MeSH terms for 'patellofemoral pain syndrome' used in search engines such as PubMed.

PRISMA Guidelines were followed with the reviewer (D.L.) screening the titles and abstracts of the first hits and consulting with the second reviewer (Q.L.) as needed. Both reviewers retrieved all potential complete texts independently and used the same criteria to decide which ones were relevant for inclusion in the review after having considered possible discrepancies in the texts. The individual diagnostic studies within the included reviews were then analysed.

Methodological quality appraisal

A clinical appraisal tool (CAT) for systematic reviews was used for the appraisal of included studies. This CAT comprises 10 questions assessing the methodological quality of the study and validity of the findings.

This CAT, as well as a detailed explanation of the criteria, can be found on the BMJ website (http://clinicalevidence.bmj.com/x/set/static/ebm/toolbox/665052.html) and is present in Appendix 2.

Development of a diagnostic checklist

An evidence-based checklist was created based on the subjective and objective findings. For the subjective factors, two or more of the systematic reviews were needed to identify the factor as being important in the diagnosis of AKP. For the objective factors, two or more of the reviews were needed to recommend the test based on either a sensitivity (more than 70%) or a positive likelihood ratio (more than 5). A positive likelihood ratio of between 0 and 5 is considered to generate small but clinically important changes in probability (Nijs, Van Geel & Van de Velde 2006). Clusters of tests found to improve diagnosis in any of the included reviews were also considered for the checklist.

Results

Two systematic reviews (Cook et al. 2012; Nunes et al. 2013), consisting of nine different diagnostic studies, were identified

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by our search methods. Of the nine diagnostic studies, four full texts were excluded as they used arthroscopic surgery for diagnosis and not clinical tests. A PRISMA flow chart is given in Figure 1.

The final checklist is presented in Appendix 3. Based on these studies, initial information that should be included in the subjective assessment includes age, area of pain, duration of symptoms, previous history of lower limb trauma or surgery and common aggravating factors. A flow chart of the diagnostic procedure is given in Figure 2.

As AKP is still largely a diagnosis of exclusion, patients should not be diagnosed with AKP if they are known to have any of the following pathologies: osteoarthritis, rheumatoid arthritis, patella fractures, patella subluxation and dislocation, fat pad impingement or bursitis, growth disorders such as Osgood-Schlatter, intra-articular pathology, patellar tendinitis, or referred pain from the lumbar spine or hip (Cook et al. 2010; Haim et al. 2006; Nijs et al. 2006; Sweitzer et al. 2010).

Objective tests can be divided into functional clinical tests, manual tests and exclusion of intra-articular pathologies.

Table 1 summarises the accuracy of commonly used diagnostic tests for AKP. Clinical functional tests that most commonly reproduce symptoms in patients with AKP are squatting, kneeling, stair climbing and prolonged sitting. Squatting is the most accurate functional test with a sensitivity of 91%. Kneeling, stair ascent or descent and prolonged sitting follow with sensitivities of 84%, 75% and 72%, respectively (Cook et al. 2010; Haim et al. 2006; Näslund et al. 2006; Nijs et al. 2006; Sweitzer et al. 2010).

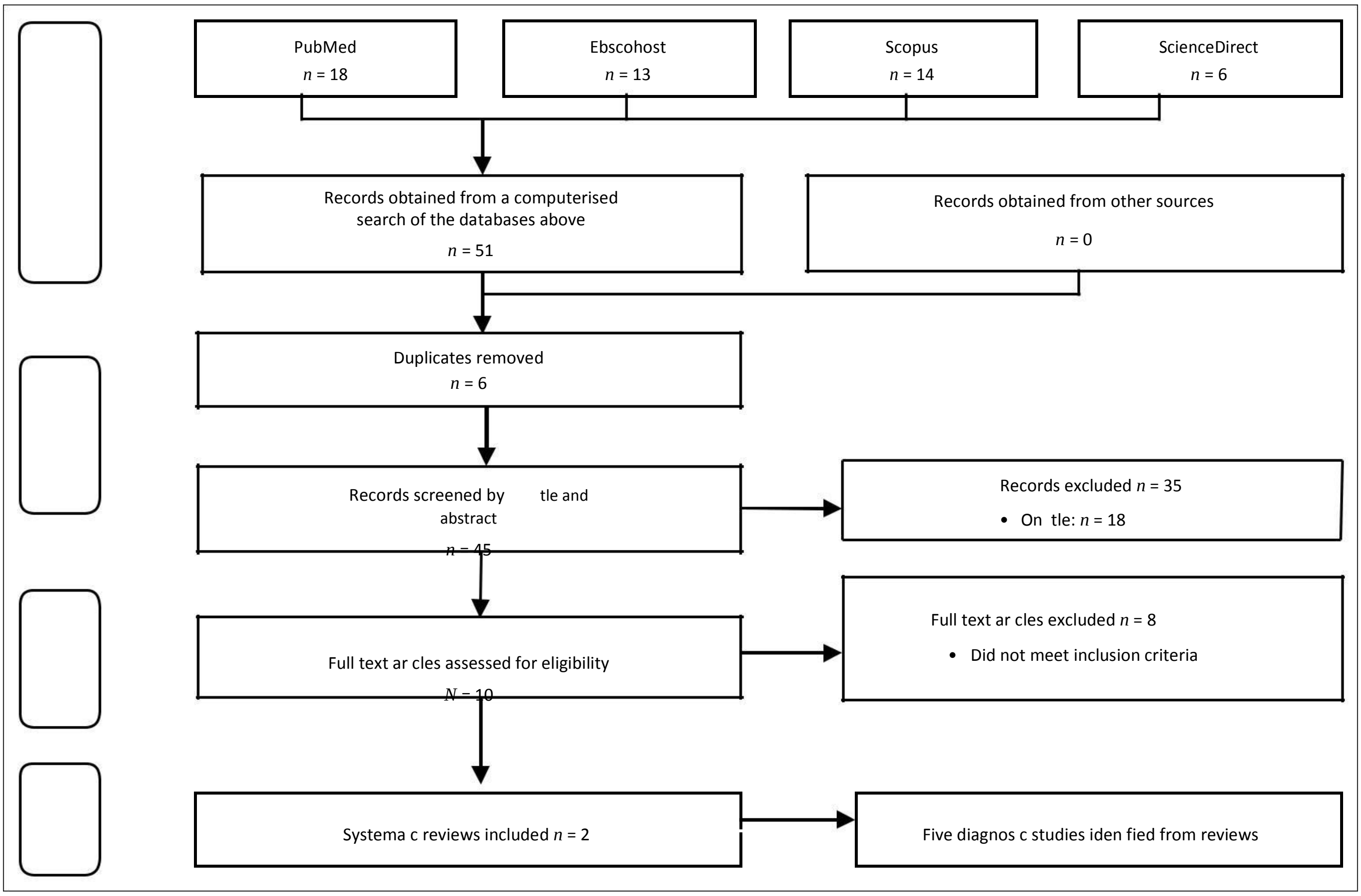
It has been suggested that patients should present with pain in two or more of these activities in order to be diagnosed with AKP (Cook et al. 2012).

Of the manual tests considered, only the patella compression test (sensitivity of 83%) and the patella tilt test (likelihood ratio = 5.4) can be recommended as diagnostic tests for AKP (Haim et al. 2006; Näslund et al. 2006; Sweitzer et al. 2010).

On clinical appraisal of the two included systematic reviews (Cook et al. 2012; Nunes et al. 2013), both studies achieved scores of 8/10, or 80%. Therefore, these reviews can be considered to be of high methodological quality. Table 2 shows the scoring according to the CAT.

Discussion

In this article, we created a standardised method for the diagnosis of AKP based on a systematic review of the evidence.



Source: www.**prisma**-statement.org/**PRISMA**Statement/**FlowDiagram**.aspx
N, total number.

FIGURE 1: PRISMA flow diagram of literature search.

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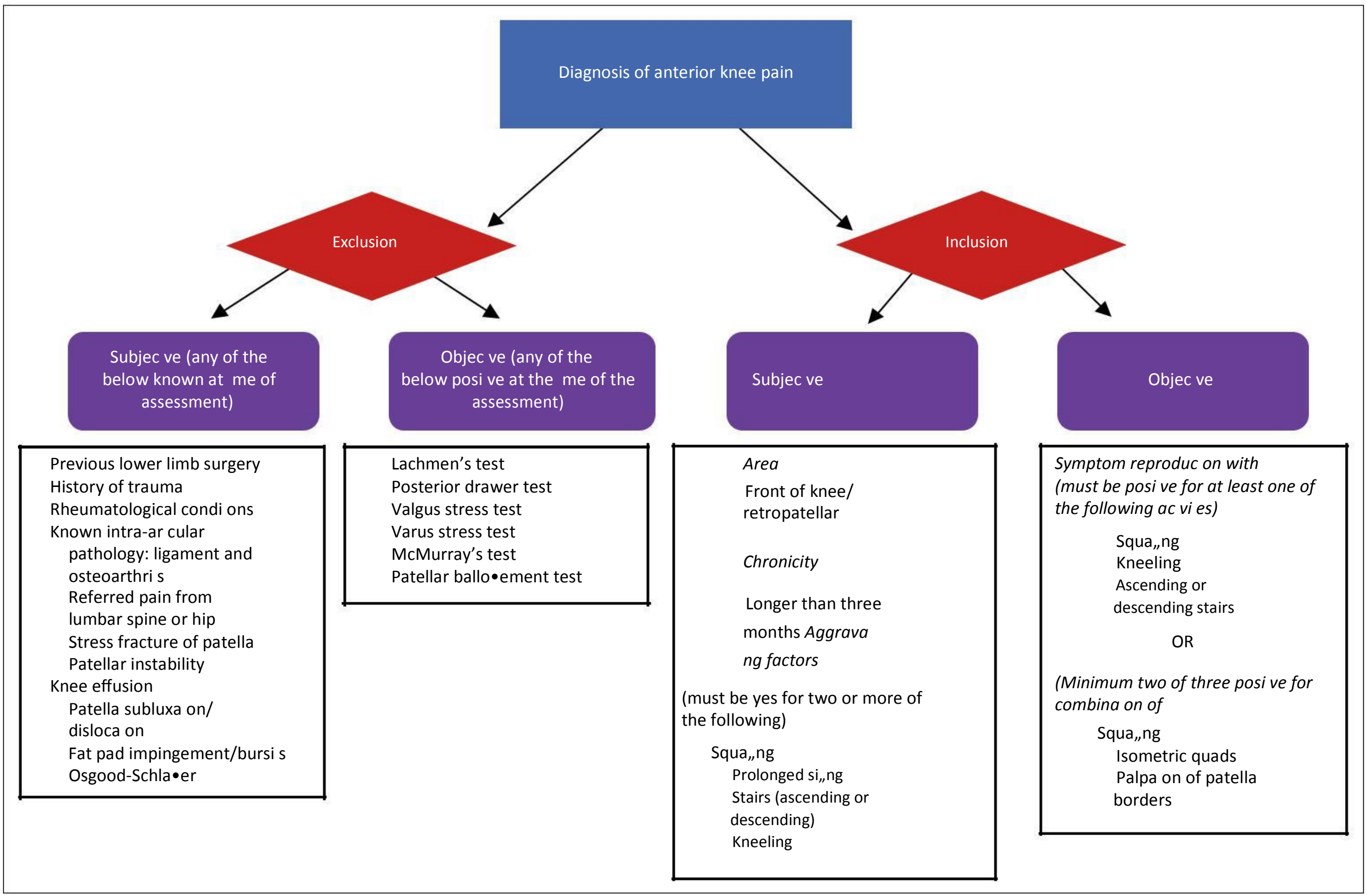

Source: Cook et al. 2012; Nunes et al. 2013

FIGURE 2: Flowchart demonstrating the process of diagnosis for anterior knee pain.

TABLE 1: Accuracy of diagnostic tests.

Test	Sensitivity	Specificity	LR+	LR–	PV+	PV–
Squatting	91	50	1.8	0.2	79	74
Kneeling	84	50	1.7	0.3	79	61
Stairs – ascending and descending	75	43	1.3	0.6	73	46
Prolonged sitting	72	57	1.7	0.5	77	50
Patella tilt test	43	92	5.4	0.6	93	40
Patella compression test	83	18	1.0	1.0	63	38

Source: Cook et al. 2010; Haim et al. 2006; Näslund et al. 2006; Nijs et al. 2006; Sweitzer et al. 2010
LR, likelihood ratio; PV, predictive value.

TABLE 2: Quality of evidence.

Study	Cook et al. 2011			Nunes et al. 2013		
SR quality criteria	Yes	No	Can't tell	Yes	No	Can't tell
1	×	-	-	×	-	-
2	-	×	-	-	×	-
3	×	-	-	×	-	-
4	×	-	-	×	-	-
5	×	-	-	×	-	-
6	×	-	-	×	-	-
7	×	-	-	×	-	-
8	×	-	-	×	-	-
9	×	-	-	×	-	-
10	-	×	-	-	×	-
Total	**8/10**	-	-	**8/10**	-	-

Source: http://clinicalevidence.bmj.com/x/set/static/ebm/toolbox/665052.html SR, systematic review.

Diagnosis of AKP is based on the area of pain, age, duration of symptoms, common aggravating factors, manual palpation, and exclusion of other pathologies.

AKP can be defined as pain in the infrapatellar or retropatellar regions, in the absence of intra-articular pathology, that restricts activities of daily living that require knee flexion such as ascending or descending stairs, squatting and prolonged sitting (Cook et al. 2010; Haim et al. 2006; Näslund et al. 2006; Nijs et al. 2006; Sweitzer et al. 2010).

The subjective examination is important in the diagnosis of AKP. The interview should localise the pain, define the timing of onset and determine acute versus chronic versus overuse (Pećina & Bojanić 1993). This information is important as it helps the clinician to rule out competing diagnoses. Extensor mechanism dysfunction is most commonly as a result of chronic repetitive trauma. AKP can also be patella subluxation or dislocation, ruptured patella or quad tendons. AKP during rest is often indicative of chondral lesions or dysfunctions (Post 1999; Smith et al. 2010).

A systematic review by Nunes et al. (2013) looked at five studies, that in total analysed 25 tests commonly used to diagnose AKP. The review concluded that there is no

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consistent evidence regarding the accuracy of commonly used diagnostic tests for AKP. However, the patellar tilt test (Haim et al. 2006) and the pain during squatting test (Cook et al. 2010) showed a strong tendency towards the PFPS diagnosis. The pain during squatting test demonstrated the highest sensitivity.

The other systematic review that was acquired through our search procedures (Cook et al. 2011) included nine studies; however, four were excluded as they made use of arthroscopy. The review included a variety of tests used to reproduce AKP including functional tests, patella mobility tests, special tests and the Q angle test. Of these the functional tests, in particular squatting, stair climbing and prolonged sitting, demonstrated the highest accuracy.

Five diagnostic studies were identified from these two reviews (Cook et al. 2010; Haim et al. 2006; Näslund et al. 2006; Nijs et al. 2006; Sweitzer et al. 2010).

Nijs et al. (2006) investigated the validity of five clinical tests for AKP, including the vastus medialis coordination test, the patellar apprehension test, Waldron's test, Clarke's test and the eccentric step test.

In this study, the vastus medialis and patellar apprehension tests had a ratio of 2.26 and the eccentric step test scored 2.34. Waldron's test and Clarkes's test both scored below 2, thus questioning their validity. Limitations of the study included inability to standardise the amount of force used, the tests were performed in isolation and in reality these tests would be combined with other tests as part of a full subjective and objective clinical evaluation. The order of the tests also should have been standardised. Based on our criteria for inclusion, none of these tests is accurate enough to be considered for diagnosis.

Cook et al. (2010) explored the diagnostic accuracy of physical tests and functional activities commonly used to diagnose AKP. Clusters of functional findings and physical examination tests were also tabulated to determine combinations that improved diagnostic accuracy. Patients with intra-articular pathology were excluded. Measures used were manual compression of kneecap against femur
(1) during rest and (2) during an isometric knee contraction, palpation of the posterio-medial and posterio-lateral borders of the patella, resisted isometric quadriceps femoris muscle contraction, squatting, stair climbing, kneeling and prolonged sitting. These measure were investigated as they are routinely used to measure AKP even though very few of these measures have been investigated for accuracy. The authors found that clusters may marginally improve accuracy. The cluster of two out of three positive tests for squatting, isometric quadriceps contraction and palpation of the patella borders scored the highest with a positive likelihood ratio of 4. The authors recommended the use of this cluster of tests to diagnose AKP in a clinical assessment.

Individually, squatting, palpation, stepping down and the patella tilt test were recommended as useful tests to include in the clinical assessment.

Sweitzer et al. (2010) investigated the accuracy of patella mobility tests including superior-inferior patellar mobility, medial-lateral patellar mobility, patellar tendon mobility and patellar inferior pole tilt. However, all of these tests demonstrated poor sensitivity (19%–63%) as well as positive likelihood ratios (1.4–1.9) and have therefore not been included in our checklist.

In a study by Näslund et al. in 2006, a physiotherapist and an orthopaedic surgeon examined 80 patients clinically diagnosed with AKP and referred for physiotherapy. The examination included a case history and a clinical examination. The four tests used in the clinical examination were the patella compression test, medial and lateral tenderness on extension, passive gliding of the patella and the Q angle test. The results indicated that the compression test demonstrated the highest sensitivity (83%), but none of the tests could predict findings seen in radiographic examinations. The authors suggested that the Q angle test can no longer be considered a reliable test in diagnosing AKP, as it shows great inter- and intra-observer variability. This is in agreement with a recent systematic review of prospective studies that demonstrated that the Q angle is not a risk factor for AKP, thus questioning its relevance (Smith, Hunt & Donell 2008). The authors (Näslund et al. 2006) suggested the AKP is still ultimately a diagnosis of exclusion as it is a term used for knee pain that can be attributed to multiple causes. Therefore, more research on pathophysiology needs to be done.

A very important aspect of diagnosis for AKP is the exclusion of intra-articular pathologies. These include ligaments such as ACL, PCL, MCL and LCL and the meniscii (medial and lateral). The most accurate tests to achieve this have been given in Table 3 (Benjaminse, Gokeler & van der Schans 2006; Day, Fox & Paul-Taylor 2009; Malanga et al. 2003; Nijs et al. 2006). Based on this, we have chosen to include the anterior drawer test, the posterior drawer test, the valgus stress test, the varus stress test, McMurray's test and the patellar ballottement test in our checklist for the purpose of exclusion.

TABLE 3: Most accurate tests for exclusion of intra-articular pathology.

Test	Structure	Sensitivity (%)	Specificity (%)
Lachmen's	ACL	85	94
Anterior drawer	ACL	92	91
Posterior drawer	PCL	51–100	99
Valgus stress	MCL	86–96	Not reported
Varus stress	LCL	25	Not reported
Pivot shift	Meniscus	24	98
McMurray's	Meniscus	16–58	77–98
Apley's grind	Meniscus	13–16	80–90
Patella ballottement	Effusion	32	100

Source: Benjaminse et al. 2006; Day et al. 2009; Malanga et al. 2003; Nijs et al. 2006

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The two reviews used for the creation of our evidence-based checklist were both of high quality. The reviews evaluated the quality of the included studies and took this into consideration when making the recommendations. Consequently, we can be confident that the checklist is based on high-quality evidence.

Nevertheless, in order to improve on this evidence, it is necessary to establish possible causes of AKP. Causes are believed to be multifactorial, and diagnosis is still largely a diagnosis of exclusion in a specific population of younger active people. Subgroups of individuals with AKP and aetiology may vary.

Conclusion

AKP can be defined as retro- or peri-patellar pain, of more than three months duration, in the absence of intra-articular pathology, that is aggravated by activities that load a flexed knee joint (Crossley et al. 2001; Harvie et al. 2011; Nunes et al. 2013; Prins & van der Wurff 2009). The diagnosis of AKP is made based on the definition as well as the exclusion of other pathologies. There are many clinical tests used to diagnose AKP; however, there is no standard method to diagnose AKP and many of the tests are not accurate. A diagnostic checklist is useful as it provides a structured method for diagnosing AKP in a clinical setting. Research is needed to establish the causes of AKP as it is difficult to diagnose a condition with unknown aetiology.

Acknowledgements

The authors wish to acknowledge that this work is based on the research supported in part by the National Research Foundation (NRF) of South Africa (Grant number CSUR1309 0332637). They would also like to express gratitude towards Stellenbosch University for the use of their facilities. The study would not have been possible without the input of these institutions.

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

D.C.L. and Q.L. screened the articles for inclusion, planned the article and critically appraised the included reviews. D.C.L. performed the searches, extracted data, compiled the checklist and drafted the original article. Q.L. edited the article and approved the final draft.

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Appendix 1

TABLE 1-A1: Definitions and synonyms for AKP.

Crossley et al. 2001	PFPS AKP	An umbrella term used to encompass all anterior or retropatellar pain in the absence of other specific pathology. All pathologies that may manifest as anterior or retropatellar pain.
Harvie et al. 2011	PFPS	Diffuse retro/peripatellar pain, aggravated with activities which load the patellofemoral joint, such as climbing stairs, squatting, running and prolonged sitting.
Aminaka & Gribble 2005	PFPS	A condition presenting with anterior knee pain or pain behind the patella (retropatella). It is commonly experienced during running, squatting, stair climbing, prolonged sitting and long sitting.
Cook et al. 2011	Chondromalacia patellae PFPS AKP	Old term used for PFPS. Anterior knee pain including the patella, but not including tibiofemoral or peripatellar structures. Anterior knee pain of more than three months duration, aggravated by prolonged sitting, squatting, and ascending and descending stairs. All pain at the front of the knee.
Nunes et al. 2013	PFPS	In the absence of other intra-articular disorders, there is currently consensus that anterior knee pain, which limits activities of daily living that demand knee flexion such as climbing and descending stairs, squatting or remaining seated. Synonyms include chondromalacia patellae, patella arthralgia and patella pain.
Lake & Wofford 2011	Runner's knee PFPS	Synonym for PFPS as it is common in runners and other endurance athletes. AKP characterised by diffuse anterior knee pain, aggravated with specific activities that heighten the compressive loading forces across the patellofemoral joint including ascending and descending stairs, squatting and prolonged sitting.
Collins et al. 2012	AKP	Synonym for PFPS. Chronic musculoskeletal overuse condition of the knee that affects an individual's ability to perform routine daily activities such as stair ambulation, walking and running, and thus impacts on work-related activities and participation in physical activity.
Barton, Webster & Menz 2008	PFPS	AKP of insidious onset defined as the presence of pain in the retropatellar or peripatellar region during tasks that increase patellofemoral joint loading, such as walking, running, negotiating stairs, squatting, prolonged sitting and kneeling. Anterior knee pain or retropatellar pain in the absence of other specific pathology.
Heintjes et al. 2003	PFPS	Retropatellar pain (behind the kneecap) or peripatellar pain (around the kneecap) when ascending or descending stairs, squatting or sitting with flexed knees.
Prins & Van der Wurff 2009	PFPS	The remainder of knee pain cases after intra-articular pathologies, patella tendonopathies, peripatellar bursitis, plica syndrome, Sinding-Larsen Johnson and Osgood-Schlatter have been excluded.
Callaghan & Selfe 2012	PFPS AKP	The clinical presentation of knee pain related to changes in the patellofemoral joint. Pain at the front of the knee, separate from arthritis. Gradual onset of knee pain with none of the features associated with other knee injuries or diseases. Pain at the front of the knee, used synonymously with PFPS.
Waryasz & McDermott 2008	PFPS AKP	A variety of pathologies or anatomical abnormalities leading to a certain type of AKP. Broader term for all pathologies causing pain at the front of the knee, including referred pain from the lumbar spine or hip.
Heintjes et al. 2004	PFPS Retropatellar pain	A common complaint in adolescents and young adults, most frequently characterised by diffuse peripatellar and retropatellar localised pain, typically provoked by ascending or descending stairs, squatting and sitting with flexed knees for prolonged periods of time. Retropatellar pain in which no cartilage damage is evident. A self-limiting condition of the knee, which includes cartilage damage.
Lankhorst, Bierma-Zeinstra & Van Middelkoop 2012	PFPS AKP	A condition of anterior knee pain. Pain in or around the patella. This pain increases after prolonged sitting, squatting, kneeling and stair climbing. Covers all problems related to the anterior part of the knee.

AKP, anterior knee pain; PFPS, patellofemoral pain syndrome.

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Appendix 2

TABLE 1-A2: Framework for assessing systematic reviews.

General systematic review quality criteria	Yes	No	Can't tell
Does the SR explicitly report and perform a comprehensive and reproducible literature search?			
Does the SR formulate a clearly focused question?			
Does the SR's methods section explicitly state the basis for inclusion or exclusion of primary RCTs?			
Does the SR report data from primary RCTs (e.g. size, interventions used, results from individual RCTs)			
Does the SR assess the methodological quality of primary studies, and take these into account where necessary?			
Meta-analysis: does the SR combine primary studies appropriately?			
Meta-analysis: does the SR state how results are combined statistically?			
Meta-analysis: does the SR report absolute numbers as well as appropriate summary statistics?			
Does the SR discuss the reasons for any variations or heterogeneity between individual RCTs and overall results?			
Does the SR report on the clinical relevance or importance of the results?			

RCT, randomised controlled trial; SR, systematic review.

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Appendix 3

Checklist for diagnosis of anterior knee pain.

SUBJECTIVE INFORMATION:

Age (must be yes)	YES	NO
14–50[1,2,3,4,5]		

Area (must be yes)		
Front of knee or retropatella[1,2,3,4,5]		

Chronicity		
Longer than three months[1,3,5]		

Aggravated by (must be yes for two or more of the following)		
Squatting[1,2,3,4,5]		
Prolonged sitting[1,2,3,4,5]		
Stairs (ascending or descending)[1,2,3,4,5]		
Kneeling[1,2,3,4,5]		

Excluded if any of the below is known		
Previous lower limb surgery[1,3,5]		
History of trauma[1,3,5]		
Rheumatological conditions[1,3,5]		
Known intra-articular pathology: ligament and osteoarthritis[1,2,3,4,5]		
Patellar instability[1,4]		
Knee effusion[1,5]		
Patella subluxation/dislocation[1,5]		
Fat pad impingement/bursitis[3,5]		
Osgood–Sclatter[1,3]		

OBJECTIVE TESTS:

Symptom reproduction with (must be positive for at least one of the following activities)		
Squatting[1,2,3,4,5]		
Kneeling[1,2,3,4,5]		
Ascending or descending stairs[1,2,3,4,5]		

Positive for at least one of the following		
Patella compression test[1,4]		
Patella tilt test[1,4]		

OR

(Minimum two out of three) positive for combination of		
Squatting[3]		
Isometric quads[3]		
Palpation of patella borders[3]		

Excluded if positive for			
Lachmen's test[6,7,8]	ACL		
Posterior drawer test[6,8]	PCL		
Valgus stress test[6,8]	MCL		
Varus stress test[6,8]	LCL		
McMurray's test[6,8]	MENISCUS		
Patellar ballottement test[5]	Effusion		

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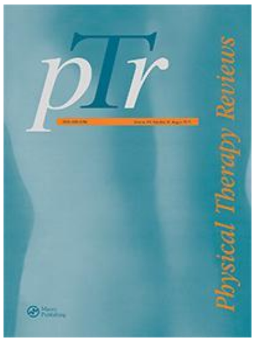

Physical Therapy Reviews

ISSN: 1083-3196 (Print) 1743-288X (Online) Journal homepage: http://www.tandfonline.com/loi/yptr20

Kinematic factors associated with anterior knee pain during common aggravating activities: a systematic review

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To cite this article: Dominique Leibbrandt & Quinette Louw (2017): Kinematic factors associated with anterior knee pain during common aggravating activities: a systematic review, Physical Therapy Reviews, DOI: 10.1080/10833196.2017.1283832

To link to this article: http://dx.doi.org/10.1080/10833196.2017.1283832

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Kinematic factors associated with anterior knee pain during common aggravating activities: a systematic review

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Background: AKP is a common condition with unknown etiology. There are many proposed biomechanical factors associated with AKP; however, it is unclear which factors are the most important and clinically relevant.
Objectives: To systematically review and summarise the literature on kinematic factors associated with AKP. The secondary objective was to create an evidence-based algorithm to be used by clinicians for screening purposes.
Method: A comprehensive search was conducted in November 2016 of all accessible electronic databases of published research available at Stellenbosch University library. The review was done according to Prisma guidelines. Two reviewers screened the full-text articles for inclusion based on our criteria.
Results: Nineteen studies were included in this review, with a total sample of 734 subjects, 415 of which had been diagnosed with AKP. Subjects with AKP had significantly reduced peak hip internal rotation during gait (MD = −5.54; CI −7.54, −3.5); and significantly increased peak trunk ipsilateral lean (MD = 2.76; CI: 0.96, 4.56), hip adduction (MD = 4.51; CI: 1.98, 7.04) and knee valgus (MD = 4.93; CI 2.06, 7.80) during single leg squatting compared to controls. No meta-analyses were possible for stair climbing outcomes due to study heterogeneity.
Conclusions: Clinicians should target the factors supported by the most evidence first in treatment. Gait and single leg squatting are currently the best activities to use for screening of abnormal biomechanics in subjects with AKP. Future research should focus on high-quality prospective studies to determine causality.

Keywords: Patellofemoral pain, Gait analysis, Movement retraining, Kinematics, Targeted intervention

Introduction

Anterior Knee Pain (AKP) is prevalent in young, athletic populations.[1] The incidence of AKP is estimated to be as high as 25–43% in sports injury clinics.[2] The symptoms associated with AKP are also persistent, with an estimated 91% of patients diagnosed with AKP still experiencing symptoms four years after its onset.[1,3] The duration of pain (pain for more than a 3 months) is a consistent predictor of poor long-term prognosis, including poor outcome at 12 months (Visual Analogue Scale, Anterior Knee Pain Scale, and Functional Index Questionnaire). An Anterior Knee Pain Scale score of less than 70/100 is also a consist-ent poor prognostic factor. Therefore, early management may be important in enhancing prognosis.[3]

The long-term impact of AKP may be significant as there is a proposed link between AKP and Patellofemoral joint (PFJ) osteoarthritis later in life.[4] Persistent AKP may also have long-term implications for participation in daily work tasks as well as sporting activities. It frequently hinders an individual's ability to perform common activities of daily living (ADLs) such as stair climbing and prolonged sitting, as well as sporting activities such as running and jumping.[5]

AKP is a poorly defined condition that is often used interchangeably with the term 'patellofemoral pain syndrome'.[6] The definition is commonly based on the area of pain, the duration of symptoms, exclusion of intra-articular pathologies and the aggravating activities.[5, 7] Definitions have included AKP that is intensified by stairs, prolonged sitting and squatting[8]; pain in and around the patella[9]; the insidious onset of retropatella or anterior knee pain of greater than 6 weeks, provoked by selected activities[10] and AKP related to dysfunction of the Patellofemoral joint after other pathologies, have been excluded.[6] For the purpose of this review, AKP can be defined as retropatella or peripatellar pain, that is aggravated by activities that load a flexed knee joint.[5, 7]

The onset of AKP is thought to involve excessive joint stress during activities that load the flexed knee joint. This patellofemoral joint stress is then transmitted through the cartilage thereby exciting nocioceptors in subchondral bone resulting in pain.[11] Over time, this joint stress may result in articular cartilage pathology.[12, 13] However, the etiological pathways are unknown.[13] Their causes are thought to be multifactorial in origin, involving a variable

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DOI 10.1080/10833196.2017.1283832

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combination of malalignment of the lower extremity, muscle imbalance around the hip and knee and overactivity.[14, 15] Abnormalities in kinematics and alignment that may contribute towards increased joint stress include an increased dynamic Q angle, increased genu valgum, increased tibia varum, lateral displacement of the patella within the femoral trochlear and muscle imbalances.[15, 16] As AKP is most prevalent in a young active population, over-activity (in particular a sudden increase in training) should be considered a potential cause of the onset of pain.[1, 17]

Distal, proximal and local factors may contribute towards the development of AKP and therefore an understanding of the various contributing factors for AKP is essential to improve our understanding of the condition. Despite prolific information on factors associated with AKP, the findings remain inconclusive. An evidence synthesis from three systematic reviews[15, 18, 19] found that the only evidence-based factor that is strongly linked to AKP is decreased knee extensor strength. However, none of these reviews included primary studies into kinematic factors during functional activity. One systematic review has specifically investigated gait-related biomechanical contributing factors for AKP. Barton et al. [20] evaluated gait-related kinematics in subjects with AKP during a vari-ety of functional activities such as walking, running and stair and ramp ascent and descent.

Twenty-four studies were included in this review. Twenty-three of these had case-control designs and one study was prospective.[21] Due to significant study heterogeneity, no effect size calculations or meta-analyses were possible. However, there were some potential trends that emerged. The review showed a trend towards reduced gait velocity during all activities tested in subjects with PFPS. In terms of kinematics, those results showed that individuals with AKP might have increased peak rear foot eversion at heel-strike, delayed peak rear foot eversion during walking and running and reduced hip internal rotation during walking. There was limited evidence for reduced peak hip internal rotation, reduced peak knee flexion in the stance phase during walking and greater knee external rotation at peak knee extensor moment during running. Findings of hip internal rotation parameters were inconsistent for walking and running. The findings of the review showed insufficient evidence for kinematic differences in any outcomes during stair and ramp climbing.

The authors concluded that due to the limited evidence for gait-related kinematics, more evidence is required to establish common biomechanical contributing factors for AKP. They recommended that prospective research should be conducted in future investigations to establish which factors may be predictive of pain. Due to the limited evidence found in 2009, an updated review is warranted.

An additional challenge is that the clinical implications of biomechanical factors are not always clear. Distinct recommendations for clinicians based on the best available evidence are needed so that they know which features to address.

Therefore, the aims of this review are to systematically review and summarise the body of evidence for kinematic risk factors in an AKP population and to create an evidence-based checklist for clinicians that highlights the most likely contributing factors for screening, in order to facilitate rehabilitation.

Methodology

The study protocol was approved by the Health Research Ethics Committee of Stellenbosch University in Cape Town, South Africa under ethics number N13/05/078. The authors certify that they have no affiliations with or financial involvement in any organisation or entity with a direct financial interest in the subject matter or materials discussed in the article.

Study selection criteria

Studies written in English reporting on the 3D kinematic factors associated with AKP were considered for inclusion. Studies were included if they were conducted to determine whether lower limb kinematic differences exist between subjects with or without AKP. Case-control, cross-sectional studies and prospective studies were eligible for inclusion. Qualitative research was excluded.

The review included studies on any individuals diagnosed with AKP which could include any of the many synonyms associated with this condition (Patellofemoral pain syndrome, patellofemoral joint dysfunction, retropatellar pain, patella malalignment syndrome, chondromalacia patella).

Males and females were included. Studies that included participants under the age of 18 or over the age of 40 were excluded in order to rule out osgood–schlatter and osteoarthritis as differential diagnoses. Studies that did not describe the diagnostic criteria used for the inclusion of participants were excluded. Studies that described other disorders of the knee such as osteoarthritis, patella subluxation or intra-articular pathology were excluded.

Studies were included if they assessed kinematics dur-ing one of the following functional activities: walking, stair ascent or descent or single leg squatting.

The primary outcomes of interest for this review were the kinematic parameters of the lower extremity and trunk associated with AKP. Therefore, studies that used 3D motion analysis to acquire trunk, pelvic, hip, knee, ankle and foot joint kinematics were included. For the purpose of this study, we only included tibiofemoral joint biomechanics for the knee joint, as advanced modelling is required to determine patellofemoral outcomes. Magnetic Resonance Imaging (MRI), Computed Tomography (CT) scan and X-ray studies were excluded as functional movement is not possible during these investigations.

Search strategy

A comprehensive search was conducted in November 2016 in all accessible library databases of published research reports available at the Stellenbosch University Medical

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Library. The following databases were searched from the inception of research to November 2016: PubMed, Ebscohost (MEDLINE, CINAHL, SportDiscuss), SCOPUS and Science Direct. A number of key words were applied to each database's search tool to narrow the search and to develop the most precise strategy for that database. Only English articles were included. The same key search terms were used for all databases with the appropriate trun-cation and Boolean operators (such as 'AND' and 'OR').

The following key words were used for the searches: 'anterior knee pain', 'patellofemoral pain syndrome', 'bio-mechanics', 'kinematics', 'gait', 'walking', 'locomotion' OR 'stairs' OR 'squatting'. The same approach was used for all searches and adapted as necessary according to specifics for that database. MeSH terms were used for 'patellofemoral pain syndrome' in search engines, such as PubMed, that made use of that function. The searches were conducted by the researcher (DL) with experience in systematic review searches.

This review was done in accordance with the Prisma Guidelines. One reviewer (DL) screened the titles and abstracts of all initial hits. All potential full texts were downloaded and duplicates removed. A second reviewer (QL) was consulted when necessary. Both reviewers (DL and QL) retrieved the full texts of all potentially relevant articles and then screened them independently using the same criteria to determine the eligibility of the papers for inclusion in the review. The reviewers compared the full texts that had been accepted for inclusion and any discrep-ancies were discussed. A full search strategy for Pubmed can be found attached as Appendix A. This strategy was adapted as necessary for each database.

Methodological quality appraisal

A Clinical Appraisal Tool (CAT) which used to assess quantitative studies was used to appraise the quality of the included papers.[22] The CAT consisted of 16 questions addressing three main issues: the results of the studies, the validity and whether the results are helpful (clinical significant). An answer of 'yes' or 'no' was required to answer the questions. Two randomly selected papers were screened by the second reviewer (QL) and discrepancies in the results were discussed. The following descriptive categories were used for interpretation of the methodo-logical quality: a CAT score above 75% was considered good methodological quality; a score between 50 and 75% was considered moderate quality and a score lower than 50% was deemed to be of poor methodological quality.[22]

Evidence grading

Grading of evidence and subsequent recommendations for clinicians to isolate factors associated with AKP were obtained using the FORM framework, which was devised and scrutinised for an updated edition of the Australian NHMRC (National Health and Medical Research Council) standards.[23] In this study, three components, namely level

Table 1 NHMRC grading of evidence for aetiology

Evidence level	Study design
I	Systematic review of prospective cohort studies
II	One prospective cohort study
III	One retrospective cohort study
IV	A case control study
V	A cross-sectional study or case series

of evidence, consistency of evidence and the clinical impact are considered. The former pertains to the quality of evidence displayed by each biomechanical risk factor,[23] graded according to the NHMRC hierarchy for etiology as reflected in Table 1.[24]

The latter, clinical impact or effect size, refers to a subjective measure of the benefits that any research out-come would exert on a specific population.[23] Where there were noticeable differences between subjects with AKP and controls, effect size was determined using the mean difference in angles.

Data extraction

Two customised excel spreadsheets, based on Cochrane forms, were used for data extraction. These spreadsheets extracted information regarding the sample demographics as well as the setting, study aims, study design, biome-chanical outcomes of interest, functional activity assessed and results (*p*-values, means and standard deviations).

Data analysis or synthesis

Data were described narratively using tables or narrative summaries where appropriate. A random effects model in Revman version 5.3 was used to calculate mean differ-ences and 95% confidence intervals (CI), provided that means and standard deviations (SD) were reported. Forest plots illustrating the mean difference and 95% CI were generated for graphic illustration. A meta-analysis was conducted for parameters which were reported in at least two studies, provided that homogeneity in the outcomes and samples were present.

Development of a clinical algorithm

The risk factors were classified according to their level of evidence. Grading the evidence allowed for a clinical algorithm to be developed for the screening/prevention and management AKP. The algorithm was originally developed by Aderem and Louw[25] for identification of biomechanical factors associated with Illiotibial Band Syndrome (ITBS). Three algorithms were created for the three activities considered in this review, namely walking (Figure 1), single leg squatting (Figure 2) and stair climbing (Figure 3). These algorithms act as a guide for clinicians to screen for kinematic factors which may contribute towards the development or chronicity of a patients's AKP. The gender for each risk factor was speci-fied. Findings were then classified into whether they were statistically significant or insignificant. Effect size was

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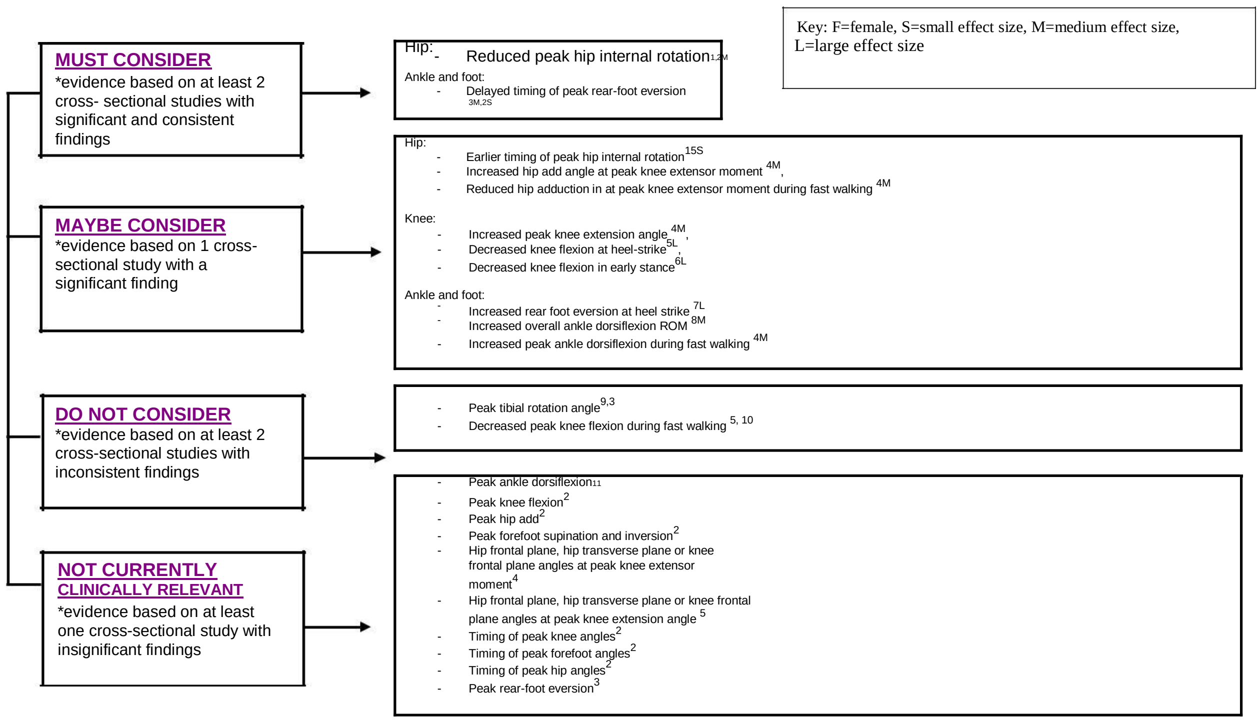

Figure 1 **Walking: Evidence from cross-sectional studies.**

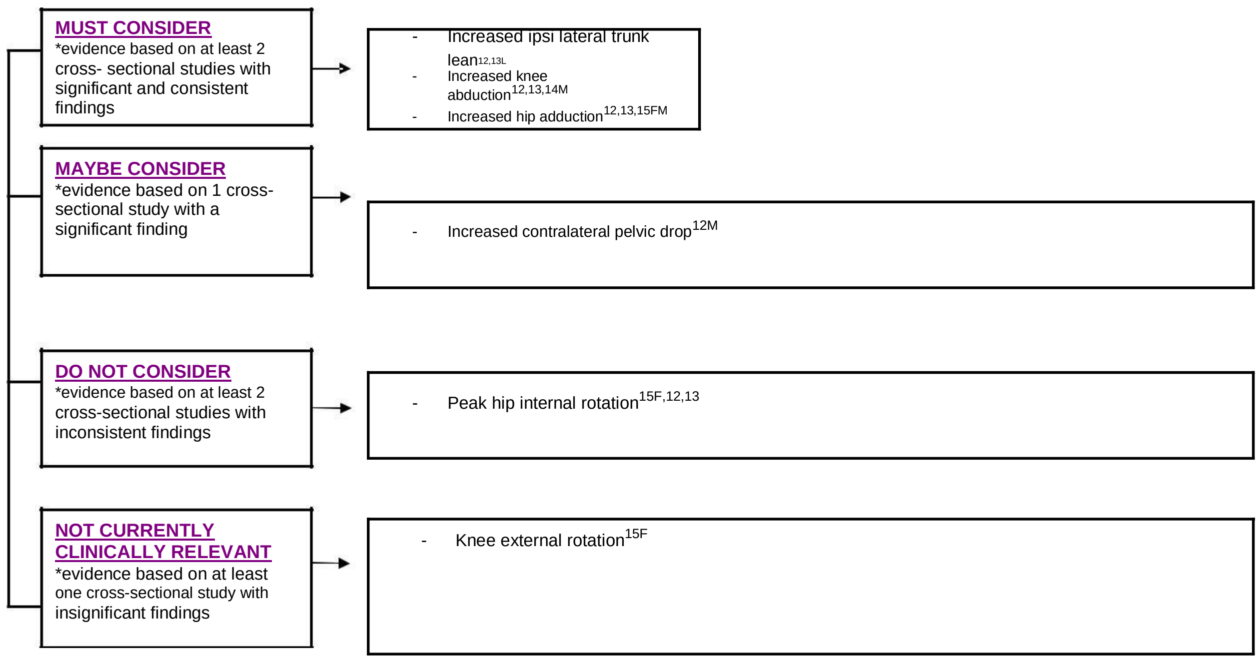

Figure 2 **Single leg squatting: Evidence from cross-sectional studies.**

determined for statistically significant findings. Cross-sectional findings were classified within four categories which were based on whether the findings were 'significant', 'insignificant', 'consistent' or 'inconsistent'. Effect sizes for the 'must consider' and 'maybe consider' categories were determined. An outcome was classified as 'must consider' when there was supporting evidence based on at least two cross-sectional studies with significant and consistent findings. These are the priority contributing factors that clinicians should address first with treatment if a patient presents with them. An outcome was classified as 'maybe consider' if there was supporting evidence based on a single study with significant findings. These factors should be considered if there are no 'must consider' con-tributing factors present. Outcomes were classified as 'do not consider' if there was conflicting evidence based on two or more studies and 'not currently clinically relevant' if a single study yielded statistically insignificant findings. Factors in these two categories should not be addressed in treatment.

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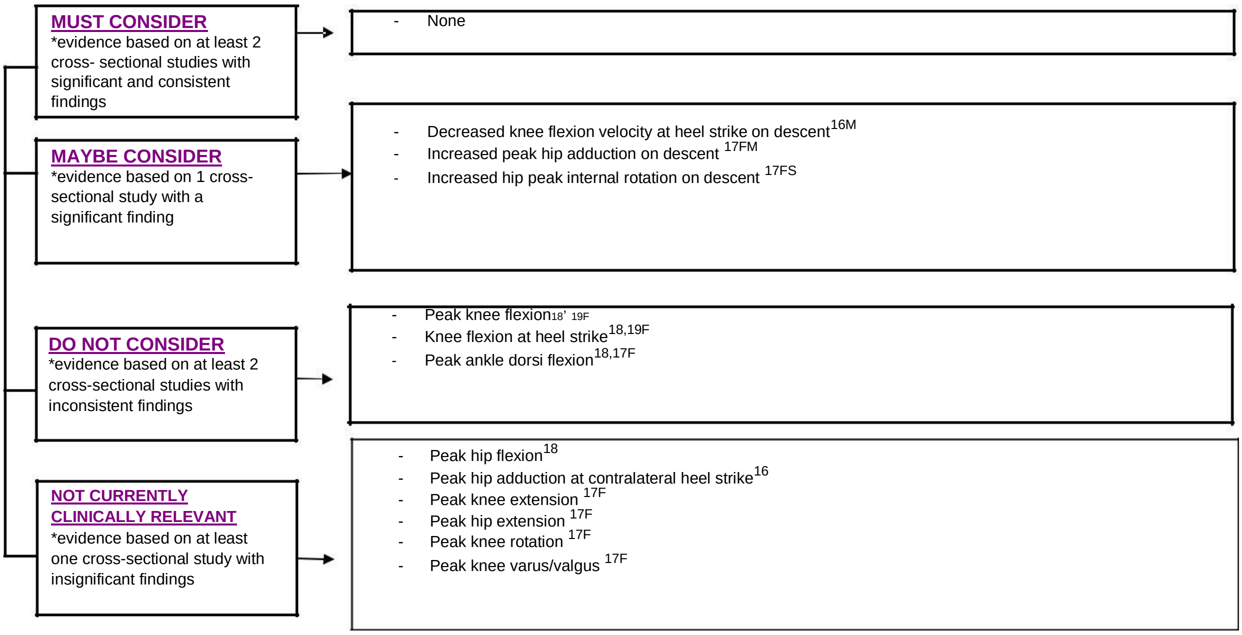

Figure 3 **Stair climbing: Evidence from cross sectional studies.**

Results

The initial search based on the keywords described above yielded a total of 309 hits. Duplicates were removed reducing the total number of potential studies for inclusion to 267. Following the application of the inclusion and exclusion criteria to the titles, 183 studies were excluded. The main reason for exclusion by title was that the studies were looking at conditions other than AKP. After abstracts were read, 57 studies were excluded. The primary reason for excluding these studies was that the risk factors investigated were not biomechanical (strength, flexibility, etc.). After reading the 27 full texts that were still eligible, the number of studies to be included in this systematic review was reduced to 19. The reason for excluding three of the full texts was that the activity used for the assessment was not walking, stairs or squatting as outlined in the inclu-sion criteria. Results of the search strategy can be seen in Figure 4.

Sample description

The number of participants in each study varied from 10 to 80. The total sample was *n* = 734. In the eligible studies, 415 subjects had AKP and the mean sample size was *n* = 38.6. Twelve of the studies included females only.[26–37] A sample description of the 19 eligible studies can be seen in Table 2. The ages of participants, anthropometrics and study settings appear similar.

Study design, aims and outcomes

The study design, aims and outcomes are summarised in Table 3. A common aim among all studies was to determine whether kinematic differences existed between groups with and without AKP. All the studies had cross-sectional designs and compared kinematics in an AKP population to pain-free controls. There was significant heterogeneity in terms of the functional activities that were used for assessment. Four studies investigated single leg squatting, three assessed gait biomechanics and two looked at stair climbing.

Methodological quality

All studies were cross-sectional with level V evidence. The methodological quality scores of the eligible studies can be seen in Table 4. The mean methodological score was 79.6% which, based on our criteria, can be considered moderate to good quality (80% considered good). All the included studies achieved moderate to good quality scores.

Biomechanical results

Walking

A summary of the evidence for kinematics during gait can be seen in Figure 1. Evidence from the previous review[20] was included to create a comprehensive algorithm.

Two kinematic outcomes showed significant and consistent results from two or more studies: the peak hip rotation and timing of peak rear foot eversion. Pooling of data was possible for one outcome. Figure 5 illustrates the peak hip internal rotation angle during gait in subjects with AKP compared to controls. Data from two studies[35,38] were pooled showing consistent findings of a statistically significant reduction in hip internal rotation in subjects with AKP. There was no significant statistical heterogeneity amongst the studies ($p = 0.67$), indicating that there was no significant clinical or methodological diversity among the studies. The overall effect was a statistically signifi-cant reduction in peak hip internal rotation during gait in subjects with AKP compared to controls (MD = −5.54; CI −7.54, −3.5).

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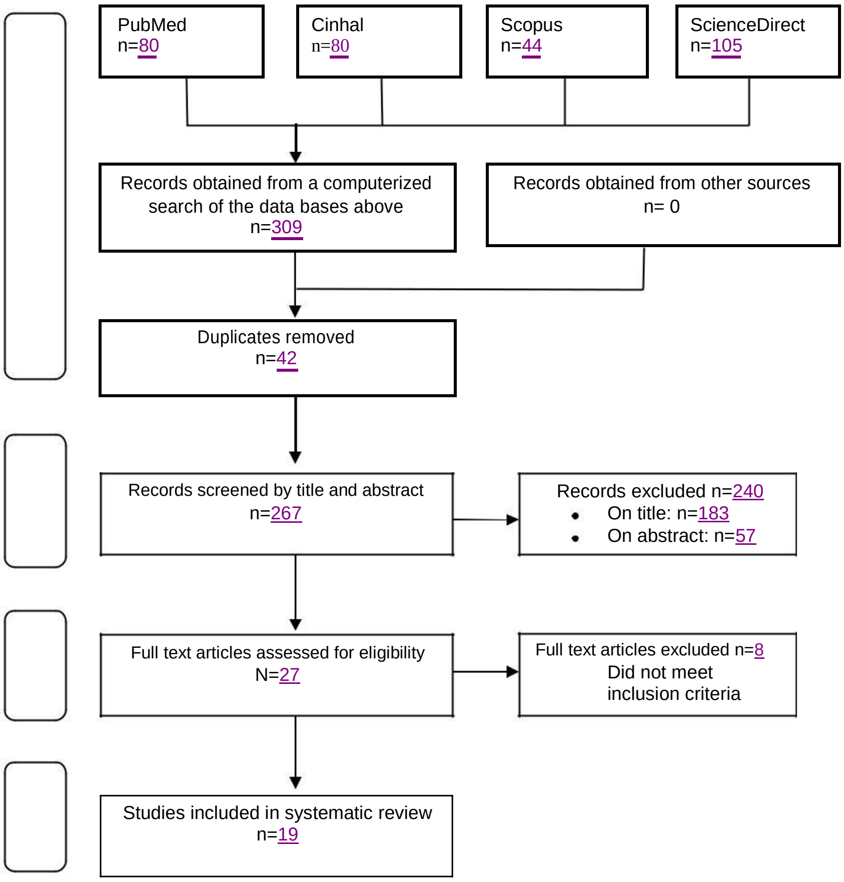

Abbreviations: n= total number

Figure 4 PRISMA flow diagram of literature search.

Two studies found that subjects with AKP had delayed timing of peak rear foot eversion that was statistically significant.[33,38] However, pooling of data was not possible due to differences in measuring timing. Levinger and Gilleard[33], measured the percentage of time spent in stance phase (7% later in stance phase), whereas Barton et al.[38] measured timing as the percentage of the gait cycle (5% later over the gait cycle).

Significant findings from single studies looking at hip kinematics indicated earlier timing of peak hip internal rotation,[38] increased peak hip adduction at peak knee extensor moment during walking at a self-selected speed[26] and decreased peak hip adduction at peak knee extensor moment during fast walking[26] in subjects with AKP com-pared to controls.

Significant findings from single studies looking at knee kinematics indicated: increased peak knee extension,[26] decreased knee flexion at heel strike[36] and decreased knee flexion in early stance[39] in subjects with AKP compared to controls.

Significant findings from single studies looking at ankle and foot kinematics indicated increased rear foot eversion at heel strike,[32] increased overall ankle range of movement,[40] and increased peak ankle dorsiflexion during fast walking[26] in subjects with AKP compared to controls.

The findings for all other kinematic outcomes were either conflicting or insignificant.

Single leg squatting

A summary of the evidence for kinematics during sin-gle leg squatting can be seen in Figure 2. The previous review[20] did not include single leg squatting as an activity of interest. Pooling of data was possible for three out-comes. Figure 6 illustrates the peak knee valgus angle during single leg squatting in subjects with AKP compared to controls. Data from three studies[29, 41, 42] were pooled showing consistent findings of a statistically significant increase in knee valgus in subjects with AKP. There was no significant heterogeneity between the studies ($p = 0.07$). The overall effect was a statistically significant increase in peak knee valgus in subjects with AKP compared to controls (MD = 4.93; CI 2.06, 7.80).

Figure 7 illustrates the peak hip adduction angle during single leg squatting in subjects with AKP compared to controls. Data from two studies[41, 42] were pooled showing consistent findings of a statistically significant increase in hip adduction in subjects with AKP. These two studies were conducted by the same authors but included differ-ent participants. There was no significant heterogeneity between the studies ($p = 0.77$). The overall effect was a

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Table 2 Sample size and demographic information

	Sample size (*n*)			Gender (F/M)		Mean Age (yr) (SD)		Mass (kg) (SD)		Height (m) (SD)		
	Total	PFPS	CON	PFPS	CON	PFPS	CON	PFPS	CON	PFPS	CON	Study setting
Salsich and Long-Rossi (2010)	40	20	20	0M 20F	0M 20F	25.6 (6.8)	24.0 (4.3)	62.3 (10.2)	66.1 (13.2)	1.63 (0.04)	1.67 (0.07)	Motion Analysis Laboratory Saint Louis University, USA
Barton et al. (2011)	46	26	20	5M 21F	4M 16F	25. (4.6)	23.4 (2.3)	66.7 (12.8)	66.0 (15.4)	1.68 (0.08)	1.71 (0.08)	Motion Analysis Laboratory La Trobe University, Australia
Barton et al. (2012)	46	26	20	5M 21F	4M 16F	25.1 (4.6)	23.4 (2.3)	66.7 (12.8)	66.0 (15.4)	1.68 (0.08)	1.71 (0.08)	Motion Analysis Laboratory La Trobe University, Australia
McKenzie et al. (2010)	20	10	10	10F	10F	23.5 (3.4)	22.3 (2.4)	65.7 (13.8)	60.8 (9.4)	1.32 (0.085)	1.31 (0.066)	Motion Analysis Laboratory McMaster university, Canada
Nakagawa et al. (2015)	60	30	30	20F 10M	20F 10M	22.7 (3.4)	22.3 (3.0)	65.3 (10.3)	63.3 (9.8)	1.71 (0.092)	63.3 (9.8)	Motion Analysis Laboratory University of São Carlos, Brazil
Nakagawa et al. (2012)	80	40	40	20M 20F	20M 20F	23.5 (3.75)	22.6 (3.2)	71.5 (8.5)	67 (8.2)	1.7 (0.55)	1.7 (0.67)	Motion Analysis Laboratory University of São Carlos, Brazil
Herrington (2013)	42	12	30	12F	30F	24 (3.2)	20 (1.4)	66.9 (9.9)	63.9 (6.0)	1.64 (0.09)	1.66 (0.1)	Motion Analysis Laboratory University of Salford, Manchester, UK
Willson and Davis (2008)	40	20	20	20F	20F	23.3 (3.1)	23.7 (3.6)	61.7 (10.6)	61.1 (5.4)	1.66 (0.08)	1.66 (0.06)	Motion Analysis Laboratory At the University of Delaware.
De Oliveira Silva et al. (2015)	54	29	25	29F	25 F	21.5 (2.98)	22.01 (3.05)	63.25 (10.76)	62.12 (7.31)	1.65 (0.02)	1.64 (0.06)	Motion Analysis Laboratory At the University of Sao Paulo, Brazil
Brechter and Powers (2002)	20	10	10	5M 5F	5M 5F	38.2	32.0	70.8	67.9	1.67	1.67	Motion Analysis Laboratory At University of Southern California
Crossley et al. (2004)	66	48	18	17M 31F	9M 9F	28	35	69.5	66.3	1.7	1.72	Motion Analysis Laboratory At University of Melbourne
Grenholm et al. (2009)	34	17	17	17F	17F	27.7	26	63	61	1.67	1.67	Motion Analysis Laboratory At Univeristy of Sweden
Levinger and Gilleard (2007)	37	13	14	13F	14F	38.4	25.1	70.6	61.3	1.66	1.66	Motion Analysis Laboratory At Southern Cross University, Australia
Levinger and Gilleard (2005)	35	11	14	11F	14F	36.3	25.1	64.9	61.3	1.66	1.66	Motion Analysis Laboratory At Southern Cross University, Australia
Nadeau et al. (1997)	10	5	5	2M 3F	2M 3F	28.4	25.5	67.6	67.0	1.72	1.7	Motion Analysis Laboratory At University of Montreal, Canada
Powers et al. (1997)	38	19	19	19F	19F	24.4	27.5	62.4	59.2	1.65	1.65	Motion Analysis Laboratory At University of Southern California
Powers et al. (1999)	25	15	10	15F	10F	26.6	31.5	65.3	63.7	1.64	1.7	Motion Analysis Laboratory At University of Southern California
Powers et al. (2002)	42	24	18	24F	18F	25.4	27.6	63.6	59.6	1.65	1.66	Motion Analysis Laboratory At University of Southern California
Powers et al. (1996)	35	26	19	26F	19F	25.6	27.5	63.9	59.2	1.65	2.65	Motion Analysis Laboratory At University of Southern California

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Table 3 Study information

Study	Study aim	Design	Biomechanical outcome of interest	Functional activity
Salsich, and Long-Rossi (2010)	To determine if females with patellofemoral pain (PFP) have increased hip adduction, hip medial rotation, and knee valgus during the stance phase of gait.	Cross-sectional	Hip frontal and transverse plane angle and knee frontal plane angle at peak knee extensor moment and peak knee extension angle	Free speed and fast speed walking
Barton et al. (2011)	To compare kinematics at the knee, hip and foot/ankle in a group of individuals with PFPS to a group of asymptomatic controls.	Cross-sectional	Variables of interest included magnitude and timing of peak angles and ranges of motion during stance for: Forefoot dorsiflexion, abduction and supination; Rearfoot dorsiflexion, internal rotation, and eversion; Knee flexion, abduction/valgus and internal rotation; Hip adduction and internal rotation.	Walking- self-selected speed
Barton et al. (2012)	To establish the relationship of rearfoot eversion with tibial internal rotation and hip adduction during walking in individuals with and without patellofemoral pain syndrome.	Cross-sectional	Variables of interest included peak angles and ranges of motion during stance for: Rearfoot eversion; Tibia transverse plane internal rotation; Hip frontal plane adduction.	Walking- self-selected speed
McKenzie et al. (2010)	To compare the knee and hip motions (and their coordination) during stair stepping in female athletes with and without PFPS.	Cross-sectional	3D hip and knee joint angles at foot contact	Stair ascent and descent
Nakagawa et al. (2012)	To determine whether there are any differences between the sexes in trunk, pelvis, hip, and knee kinematics, hip strength, and gluteal muscle activation during the performance of a single-leg squat in individuals with patellofemoral pain syndrome (PFPS) and control participants.	Cross-sectional	Peak 3D trunk, pelvis, hip, and knee kinematics	Single leg squatting
Nakagawa et al. (2015)	To compare trunk kinematics, strength and muscle activation between people with PFP and healthy participants during single leg squatting.	Cross-sectional	Peak ipsilateral trunk lean, hip adduction, and knee abduction were angles	Single leg squatting
Herrington (2013)	To investigate the degree of knee valgus, assessed as 2D frontal plane projection angle (FPPA) during single leg squatting (SLS) in patients with PFP and compare their performance to controls and the uninjured limb.	Cross-sectional	The average FPPA angle value for from the three trials was used for analysis.	Single leg squatting
Willson and Davis (2008)	To compare lower extremity kinematics in females with and without PFPS during the progressively demanding activities of single leg squats, running, and repetitive single leg jumps.	Cross-sectional	Peak knee external rotation, hip internal rotation, and hip adduction angles and excursions	Single leg squatting
De Oliveira Silva et al. (2015)	To investigate whether there is a decrease in knee flexion in adults with AKP compared to controls during stair ascent	Cross-sectional	Peak knee flexion angle	Stair ascent
Brechter and Powers (2002)	To determine whether individuals with patellofemoral pain (PFP) demonstrate elevated patellofemoral joint (PFJ) stress compared with pain-free controls during free and fast walking.	Cross-sectional	Peak knee flexion	Free speed and fast speed walking
Crossley et al. (2004)	To investigate the amount of stance-phase knee flexion in individuals with and without PFP during stair climbing	Cross-sectional	Peak stance phase knee flexion	Stair ascent and descent
Grenholm et al. (2009)	To address whether lower extremity kinematics are altered in young women with PFP during stair descent.	Cross-sectional	3D mean hip adduction, knee flexion and ankle dorsiflexion	Stair descent
Levinger and Gilleard (2007)	To measure rearfoot and tibia motion, and the ground reaction force (GRF) during the stance phase of walking in subjects with PFPS and compare them to healthy subjects.	Cross-sectional	Timing of peak rearfoot eversion and peak ankle dorsiflexion	Walking- self-selected speed
Levinger and Gilleard (2005)	To compare the peak and timing of the heel strike transient force between subjects with PFPS and healthy controls.	Cross-sectional	Mean rearfoot eversion/inversion pattern of motion relative to the tibia during the stance phase	Walking- self-selected speed
Nadeau et al. (1997)	To examine the gait pattern of PFPS patients walking at a preferred speed in order to determine if they presented kinematic and kinetic alterations during gait.	Cross-sectional	Overall saggital plane ROM hip, knee and ankle	Walking- self-selected speed
Powers et al. (1997)	To determine the influence of pain and muscle weakness on gait variables in subjects with patellofemoral pain (PFP)	Cross-sectional	Mean stance phase sagittal-plane motion of the ankle, knee, and hip joints was measured.	Free speed and fast speed walking
Powers et al. (1999)	To determine if subjects with patellofemoral pain demonstrate excessive lower limb loading during gait.	Cross-sectional	Knee flexion and heel strike Peak stance phase knee flexion	Free speed and fast speed walking
Powers et al. (2002)	To test the hypothesis that subjects with PFP would exhibit larger degrees of foot pronation, tibia internal rotation, and femoral internal rotation compared to individuals without PFP.	Cross-sectional	Three-dimensional kinematics of the foot, tibia, and femur segments Magnitude and timing of peak foot pronation and tibia rotation and femoral internal rotation	Walking- self-selected speed
Powers et al. (1996)	To ascertain whether there were differences in the activity of the vastus muscles that would be suggestive of patellar instability in subjects with PFP.	Cross-sectional	Sagittal plane knee Rom throughout the gait cycle	Walking- self-selected speed

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Table 4 Critical appraisal of included studies

		Salsich and Long-Rossi (2010)	Barton et al. (2011)	Barton et al. (2012)	McKenzie et al. (2010)	Nakagawa et al. (2012)	Nakagawa et al. (2015)	Herring-ton (2013)	Willson and Davis (2008)	De Oliveira Silva et al. (2015)
1	Was the purpose of the study clearly stated?	+	+	+	+	+	+	+	+	+
2	Was the study design appropriate?	+	+	+	+	+	+	+	+	+
3	Were the sample biases detected in the study?	+	–	–	+	–	–	+	+	+
4	Were the measurement biases detected in the study ?	–	–	–	–	–	–	–	–	+
5	Was the sample size stated?	+	+	+	+	+	+	+	+	–
6	Was the sample described in detail?	+	+	+	+	+	+	+	+	+
7	Was the sample size justified?	+	–	+	–	–	–	–	+	+
8	Were the outcomes clearly stated and relevant to the study?	+	+	+	+	+	+	+	+	+
9	Was the method of measurement described sufficiently?	+	+	+	–	+	+	+	+	+
10	Were the measures reliable?	+	–	–	–	+	+	–	–	+
11	Were the measures valid?	+	–	–	–	–	–	–	–	+
12	Were the results reported in terms of statistical significance	+	+	+	+	+	+	+	+	–
13	Were the analysis methods appropriate?	+	+	+	+	+	+	+	+	+
14	Was clinical importance reported?	–	–	+	+	+	–	–	–	+
15	Were missing data reported where appropriate?	+	+	+	+	+	+	+	+	+
16	Were the conclusions relevant and appropriate given the methods and results of the study?	+	+	+	+	+	+	+	+	+
	Total CAT score /16	14	12	14	11	14	14	11	12	14
	Total CAT %	87.5%	75%	87.5%	68.75%	87.5%	87.5%	68.75%	75%	87.5%

		Brechter and Powers (2002)	Crossley et al. (2004)	Grenholm et al. (2009)	Levinger and Gilleard (2007)	Levinger and Gilleard (2005)	Nadeau et al. (1997)	Powers et al. (1997)	Powers et al. (1999)	Powers et al. (2002)	Powers et al. (1996)
1	Was the purpose of the study clearly stated?	+	+	+	+	+	+	+	+	+	+
2	Was the study design appropriate?	+	+	+	+	+	+	+	+	+	+
3	Were the sample biases detected in the study?	+	+	–	–	–	+	–	–	–	–
4	Were the measurement biases detected in the study ?	–	–	–	–	–	–	–	–	–	–
5	Was the sample size stated?	+	+	+	+	+	+	+	+	+	+
6	Was the sample described in detail?	+	+	+	+	+	+	+	+	+	+
7	Was the sample size justified?	–	–	–	+	–	–	–	–	–	–
8	Were the outcomes clearly stated and relevant to the study?	+	+	+	+	+	+	+	+	+	+
9	Was the method of measurement described sufficiently?	+	+	+	+	+	+	+	+	+	+
10	Were the measures reliable?	–	–	–	+	+	–	–	–	+	–
11	Were the measures valid?	–	–	–	+	+	–	–	–	+	–
12	Were the results reported in terms of statistical significance	+	+	+	+	+	+	+	+	+	+
13	Were the analysis methods appropriate?	+	+	+	+	+	+	+	+	+	+
14	Was clinical importance reported?	+	+	+	–	–	–	+	–	–	–
15	Were missing data reported where appropriate?	+	+	–	+	+	+	+	+	+	+
16	Were the conclusions relevant and appropriate given the methods and results of the study?	+	+	+	+	+	+	+	+	+	+
	Total CAT score /16	12	12	12	15	13	11	13	12	14	12
	Total CAT %	75%	75%	75%	93.75%	81.25%	68.75%	82.25%	75%	87.5%	75%

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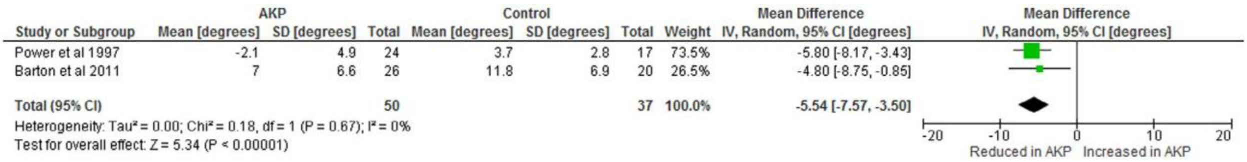

Figure 5 Forest plot of comparison: 1 Peak angles during walking, outcome: 1.1 Peak hip internal rotation [degrees].

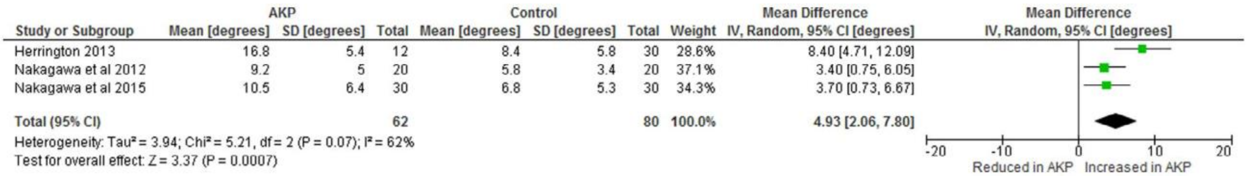

Figure 6 Forest plot of comparison: 2 Peak angles during single leg squatting, outcome: 2.1 Peak knee valgus [degrees].

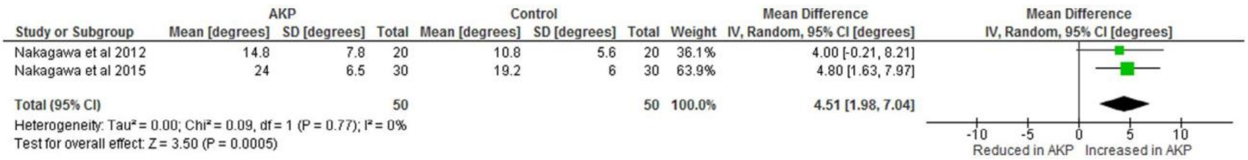

Figure 7 Forest plot of comparison: 2 Peak angles during single leg squatting, outcome: 2.2 Peak hip adduction [degrees].

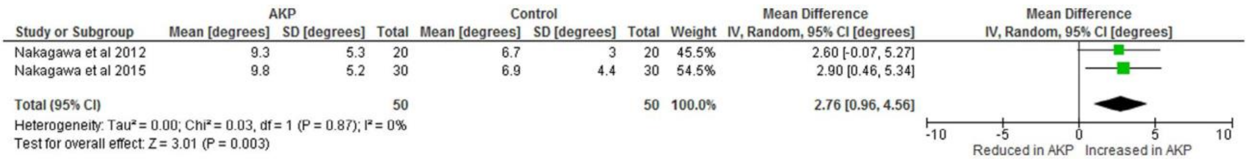

Figure 8 Forest plot of comparison: 2 Peak angles during single leg squatting, outcome: 2.3 Ipsilateral trunk lean [degrees].

statistically significant increase in peak hip adduction in subjects with AKP compared to controls (MD = 4.51; CI: 1.98, 7.04).

Figure 8 illustrates the peak ipsilateral trunk lean angle during single leg squatting in subjects with AKP compared to controls. Data from two studies[41, 42] were pooled showing consistent findings of a statistically significant increase in ipsilateral trunk lean in subjects with AKP. There was no significant heterogeneity between the studies ($p = 0.87$). The overall effect was a statistically significant increase in peak ipsilateral trunk lean in subjects with AKP compared to controls (MD = 2.76; CI: 0.96, 4.56).

A significant finding from one study[41] showed a statistically significant increase in contralateral pelvic drop during single leg squatting ($p = 0.003$).

The findings for all other biomechanical outcomes during single leg squatting were either inconsistent or insignificant.

Stair climbing

A summary of the evidence for stair ascent and descent can be seen in Figure 3. Pooling of data was not possible for any outcomes. Evidence from single studies found significant differences between subjects with AKP and controls for four outcomes; decreased knee flexion velocity at heel strike during stair descent,[43] Increased peak hip adduc-tion angle in females during stair descent,[28] increased peak hip internal rotation in females during stair descent[31] and decreased peak knee flexion during stair ascent in females.[27] There was inconsistent or insignificant evidence for all other outcomes.

Discussion

Our review is the first to create a screening tool based on the best available evidence that clinicians can use to identify kinematic contributing factors for AKP dur-ing common aggravating activities. Our review findings showed additional evidence that delayed timing of peak rear foot eversion (occurs 7% of the gait cycle later in stance phase and 5% later over the entire gait cycle) and peak hip internal rotation (5° less) during walking may be associated with AKP.

Our review is the first to synthesise the evidence for biomechanical factors during single leg squatting in subjects with AKP. Single leg squatting was not included in a similar previous review,[20] although it is commonly used in clinical practice. During single leg squatting, increased peak ipsilateral trunk lean, knee valgus/ abduction angle

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and peak hip adduction angle are the risk factors most strongly associated with AKP.[29, 30, 41, 42] Nakagawa et al.[42] proposed that these three factors may be linked and indicate an inability of the individual to stabilise the lower limb in the frontal plane. Both increased ipsilateral trunk lean and increased hip adduction may increase in the val-gus angle at the knee during single leg squatting as both features can increased the dynamic Q angle of the affected limb.[44] Increased valgus could then result in increased forces on the lateral patella facets and abnormal stresses on trochlear groove during loading and subsequently knee pain.[44, 45] Increased ipsilateral trunk lean and increased hip adduction may both be as a result of weak hip abductors.[46] Weakness and poor neuromuscular control of hip abduc-tor muscles have been hypothesised to play a role in the development of AKP. Bolgla et al.[47] found that women with AKP demonstrated 26% less hip abduction strength (P.001) than similar age-matched controls. The authors suggested that the weakness of these muscle groups may result in an inability to resist external valgus and internal rotation moments during demanding activities such as single leg squatting and running.

Increased trunk lean might be an attempt to decrease the demand on the hip abductor muscles; however, the compensatory effect might be an increase in the forces on the lateral patella due to the lateral weight shift of the body during loading on the affected side.[42] Another potential contributing factor could be decreased trunk lateral trunk strength, resulting in an increased knee abduction moment and consequently increased loading at the medial knee.[42]

Single leg squatting may be a useful activity to screen for kinematic factors associated with AKP in an athletic population with high functional demands. It may not be as relevant in less active subjects with AKP that do not per-form such demanding tasks on a regular basis. However, it should be interpreted with some caution as there is a lack of representative normative data-sets and there are variations in the position of the non-stance leg that may influence the lower extremity biomechanics of the per-formed task.[48]

Our review showed new evidence emerging from the current review links delayed timing of peak rearfoot eversion and AKP.[38] The potential link between rear-foot eversion and AKP has been proposed to involve an increase in genu-valgus resulting in malalignment between the patella and femur. This might result in increased contact stress between the articulating surfaces.[21] Our review also demonstrated addition evidence for decreased peak hip internal rotation during gait in subjects with AKP.[38] Powers et al.[37], suggested that this could be a compensa-tory attempt to decreased PFJ loading, as increased hip internal rotation increases the dynamic Q angle during loading thus increasing the stress on the medial knee. By limiting internal rotation subjects with AKP may limit this medial stress, but this compensation could shift stress to the lateral aspect of the knee. Levinger and Gilleard[33] suggested that delayed timing of peak rear foot eversion may be an indication of prolonged subtalar pronation. This prolonged pronation would then in turn disrupt the temporal kinematic sequencing of the lower limb joint motion.[37]

Our review demonstrates that proximal and distal kinematic factors are associated with AKP during gait. Barton et al.[40] described an association between rear foot eversion and hip adduction during gait. The authors concluded that subjects with AKP that demonstrated greater hip adduction during gait also presented with increased rear foot eversion. However, this study[40] was cross-sectional and therefore the direction of this association could not be established.

It has been suggested that treatment approaches that targeted either proximal or distal factors could equally benefit symptoms at the knee.[38] For example, prescribing orthot-ics would improve hip features and an approach aimed at the hip such as gluteal strengthening may decrease rear-foot eversion. It is unclear whether one approach is more effective than the other and therefore clinicians should address and treat the most prominent feature in the individual patient first.

Stair climbing was investigated in the previous review[20] and the authors concluded there was no consistent evidence for altered kinematics during stair ascent or descent. In our Review, no meta-analyses were possible for any outcomes. Results from single cross-sectional studies indicate that decreased knee flexion velocity at heel-strike on stair descent, increased peak hip flexion on stair ascent, increased peak hip internal rotation on descent and increased hip adduction on descent may be associated with AKP. Future research is needed to confirm these findings.

All the included studies ranked in the ‘moderate’ to ‘high’ categories based on critical appraisal of the methods. Although it is positive that the included studies are methodologically sound, the design of the included studies is a major limitation. Only cross-sectional studies were included as no prospective studies met our inclusion cri-teria. The implication of this is that no cause and effect relationship can be established between the parameters that we have highlighted and the development of AKP. We could establish associated factors, but causative or predictive risk factors for AKP need to be investigated in future prospective research.

A limitation of much of the literature in biomechanics and AKP is the inclusion of female participants only. In the current review, 12 of the included studies only investigated women. While literature suggests that the condition is twice as prevalent in women as in men,[2] it occurs frequently in both genders. Future research should investigate men and women to reduce gender bias and establish potential differences in the biomechanical risk factors between men and women as they might differ.[49]

A limitation of our Review is that only English studies were included and this could introduce language bias. Another limitation that became apparent when the

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algorithm was created is that the evidence base for biomechanical risk factors for AKP is still small and more risk factors need to be investigated. In addition, there needs to be consistency in the way that kinematic outcomes are measured so that studies can be synthesised and compared. Another limitation is that our procedures required motion analysis equipment which is not available in most clinics. Therefore, clinicians would need to refer patients for gait analysis in order to screen for the kinematic factors presented in our algorithm.

As demonstrated by our Review, gait analysis is currently the most appropriate activity to screen for biomechanical risk factors in individuals with AKP as it is a common ADL and there are well-established normative values for adults to which values can be compared to for screening purposes. Evidence for single leg squatting is limited but consistent. More evidence is need to establish normative values and to standardise procedures before it can be strongly recommended as a clinical screening tool for subjects with AKP stair climbing needs more primary evidence before it can be considered a clinically useful tool for biomechanical screening. This is important as pain during stair climbing (in especially stair descent) is a common complaint in patients presenting with AKP.[5] The presence of proximal, local and distal biomechan-ical factors for all three activities stresses the impor-tance of considering biomechanics of the entire kinetic chain and not just structures around the knee.

Conclusion

Our Review showed new evidence for kinematic fac-tors associated with AKP during single leg squatting and additional evidence for delayed timing of peak rear foot eversion and decreased peak hip internal rotation during walking. Our evidence synthesis suggests that the most important kinematic risk factors to address during rehabilitation are (1) reduced hip internal rotation and delayed timing of peak rear foot eversion during gait and (2) increased peak ipsilateral trunk lean, knee valgus/ abduction angle and peak hip adduction angle during single leg squatting may also be targeted with treatment. High-quality prospective studies are needed to determine risk factors that are predictive of AKP. Walking and single leg squatting are appropriate activities to use as biomechanical screening tools in a clinical setting as they have some factors that are supported by significant and consistent evidence. More research needs to be conducted investigating kinematic factors during stair climbing, particularly stair descent, as it is an activity that frequently aggravates AKP.

Geological information

This study was conducted at Tygerberg Medical Campus, in the Northern Surburbs of Cape Town located in the Western Cape Province of South Africa.

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Acknowledgements

We would also like to express gratitude towards Stellenbosch University for the use of their facilities. The study would not have been possible without the input of these institutions.

Disclosure statement

The authors declare that they have no financial or personal relationships or conflicts of interest that may have inappropriately influenced them in writing this article.

We also wish to declare that all authors have made substan-tial contributions to all the conception and design of the study, acquisition of data, analysing and interpretation of data, drafting the article and final approval of the version to be submitted.

Funding

This work was partially supported by the National Research Foundation (NRF) of South Africa [grant num-ber CSUR13090332637].

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Appendix A. Search strategy

Pubmed

Limits applied to the database:
Type of search: Advanced search
Publication dates: Inception to November 2016
Publication type: Clinical trial, Controlled clinical trial, Randomized controlled trial (RCT) Language: English

Search terms:

1. Anterior knee pain [MESH]
2. Kinematics OR biomechanics
3. #1 AND #2
4. Gait OR walking OR locomotion
5. #1 AND #2 AND #4
6. Stairs
7. #1 AND #2 AND #6
8. Squatting
9. #1 AND #2 AND #8

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Journal of Bodywork & Movement Therapies xxx (2017) 1e6

Contents lists available at ScienceDirect

Journal of Bodywork & Movement Therapies

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The test retest reliability of gait outcomes in subjects with anterior knee pain

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article info

Article history:
Received 28 February 2017
Received in revised form
4 May 2017
Accepted 16 May 2017

abstract

Introduction: Anterior knee pain (AKP) is a common condition frequently causing young, athletic patients to attend sports rehabilitation centres. Abnormal biomechanics are thought to contribute towards the development and chronicity of the condition. Gait analysis is commonly used to identify abnormal biomechanics in subjects with AKP, however the reliability of these measurements are unknown. Therefore, the aim of this study was to quantify the test retest reliability of hip, knee and ankle kine-matics during gait in an AKP population so the true effects of an intervention can be established.

Methods: Thirty-one subjects with AKP attended the 3D Motion Analysis Laboratory at Tygerberg Medical Campus of Stellenbosch University in Cape Town, South Africa, for gait analysis. Participants returned seven days later at approximately the same time to repeat the gait analysis assessment from day one. The same assessor tested all subjects on both occasions. The intra-class correlation coefficients (ICC) and standard error of measurement (SEM) were calculated for hip, knee and ankle kinematic outcomes on the affected side and used for analysis.

Results: All outcomes obtained were acceptable to excellent test retest reliability scores for both mea-sures of relative reliability (ICC ¼ 0.78e0.9) and measures of absolute reliability (SEM ¼ 0.94e4.2). Hip frontal plane and ankle sagittal plane outcomes were the most reliable and had the lowest measurement error. Hip transverse plane outcomes were least reliable and demonstrated the highest measurement error.

Conclusion: Hip, knee and ankle kinematic factors that are commonly associated with AKP can be measured reliably using gait analysis. Daily and weekly variation in symptoms in an AKP population may influence the reliability of knee sagittal plane outcomes. Therefore, it is important to document factors that could influence the kinematics such as pain, activity levels and the use of pain medication.

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1. Introduction

Anterior knee pain (AKP) is a common condition characterised by pain perceived at the anterior aspect of the knee during activities that load a flexed knee joint. The term “anterior knee pain” is often used interchangeably with “patellofemoral pain syndrome” and the diagnosis is most commonly made based on the area; aggravating activities, as well as the exclusion of other pathologies (Nunes et al., 2013). AKP is thought to be multifactorial in nature and the etiology is not well understood (Aminaka and Gribble, 2008). Many studies have been done on the proposed mechanism of the condition yielding conflicting results and high intra-subject variability (Powers et al., 2014).

Accurate objective measures for anterior knee pain are of paramount importance as without them the accurate diagnosis and monitoring of treatment cannot take place. Reliable measurement of kinematics is also critical for data analysis because it ensures that changes in a specific measurement represent a true change in performance (Nakagawa et al., 2013). This is particularly important in epidemiological analyses where clinical decisions are made (Sinclair et al., 2012).

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http://dx.doi.org/10.1016/j.jbmt.2017.05.011
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Please cite this article in press as: Leibbrandt, D.C., Louw, Q.A., The test retest reliability of gait outcomes in subjects with anterior knee pain, Journal of Bodywork & Movement Therapies (2017), http://dx.doi.org/10.1016/j.jbmt.2017.05.011

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Three-dimensional (3D) gait analysis is a recommended and reliable method of examining lower limb function. Clinical gait analysis aims to distinguish between "abnormal" gait associated with injury and normal gait that one would expect to find in an asymptomatic individual (Baker, 2006).

Variability in pre-versus post-intervention measurements may be due to the effects of the intervention, measurement error or both. Therefore, quantifying measurement error allows researchers to establish whether or not a treatment effect is clinically mean-ingful and this limits the risk of over analysing small differences.

There are various factors that can result in measurement errors between sessions. These include marker placement errors, incon-sistent anthropometric measurements, variations in walking speed, data processing errors and measurement equipment errors (Monaghan et al., 2007).

McGinely et al., 2009, did a systematic review investigating the reliability of gait related kinematics and kinetics of normal adults tested using 3D motion analysis systems. They looked at reliability within and between subjects, within and between sessions and within and between assessors. Based on this review, the highest reliability was found in the sagittal hip and knee kinematics, the lowest errors were found in transverse and frontal plane pelvis and hip frontal plane kinematics and the lowest reliability and highest error was found in the transverse plane hip and knee outcomes (McGinely et al., 2009). However, these results were for asymp-tomatic populations only and therefore the authors recommended that for future reliability studies, the sample recruited should be symptomatic or clinically diagnosed with the condition being investigated (i.e. AKP) as one cannot assume that the reliability of gait outcomes will be the same in healthy and symptomatic pop-ulations. An error of 2 or less is considered to have good reliability, errors of 2e5 can be considered acceptable but small changes may require some caution in data interpretation and errors of more than 5 should raise concern as this could mislead clinical interpretation (McGinely et al., 2009).

The 3D gait analysis measurements are frequently used in clinical research on subjects with AKP for the objective measure of lower limb function. To date no studies have been done to establish the intra-session reliability of gait related kinematics for anterior knee pain. This means that the true result of gait analysis findings as well as treatment effects are unclear.

Therefore, the aim of this study is to use a repeated measures design to establish the test retest reliability of 3D hip, knee and ankle kinematics that have been shown to be associated with AKP during gait.

2. Methods

Ethics approval was obtained from the Health Research Council of the Stellenbosch University under ethics number N13/05/078. Informed consent was obtained from all participants over the age of 18 years and from parents/guardians for subjects under the age of 18 years.

2.1. Population and sample

Thirty-one subjects (meeting the eligibility criteria) with AKP were used to assess and the retest reliability of the measurement procedures. Our sample size was determined from a priori power analysis. We estimated the effect size using pilot data from a pre-vious case series on a sub-sample of 8 participants. A two-tailed Wilcoxon-signed rank test was used as we assumed that the data was abnormally distributed. Therefore, assuming that alpha ¼ 0.05, power ¼ 0.95 and effect size ¼ 0.75, we needed a sample size of n ¼ 27. We recruited 31 participants to allow for drop out.

2.2. Diagnostic criteria

Subjects were recruited by advertisements placed in commu-nity, university and school-based newspapers in order to attract a range of participants from a wide spectrum of activities, back-grounds, sports and ages. Advertisements/letters of invitation were also be sent to the clinics of all collaborators/sports groups. All potential participants were be screened using an evidence-based diagnostic checklist specifically developed for this study (Leibbrandt& Louw, 2017a) to ensure standardised diagnosis and exclusion of other pathologies. This checklist is based on an up-to-date evidence synthesis on systematic reviews and can be found attached as Appendix A.

At the first testing session, a clinical assessment was done by the physiotherapist (DL) to confirm that the participant had AKP. This assessment comprised specific functional tests, a palpation, and special tests to exclude other pathologies (seen in Appendix A). Once the subjects had met the criteria of the physical examination, they could proceed to the 3D motion analysis part of the assessment.

2.3. Setting

The study was conducted at the FNB 3D Motion Analysis Labo-ratory at Tygerberg Medical Campus of Stellenbosch University in Cape Town South Africa. The same assessor tested all subjects on both occasions.

2.4. Measurement procedure

2.4.1. Instrumentation

A VICON Motion Analysis (Ltd) (Oxford, UK) 3D system was used to obtain the 3D movement analysis data. The VICON has demon-strated high accuracy and reliability (Ehara et al., 1997). The T10 is a motion-capturing system with a unique combination of high-speed accuracy and resolution. The system has a resolution of 1-mega pixels and captures 10-bit grey scale images using 1120 896 pixels, with the ability to capture speeds of up to 250 frames per second. Retro-reflective markers with a diameter of 9.5 mm were used. The standard plug-in gait model was used, as the model provided the angle output sought in the current study. VICON-specific anthropometric measurements that were obtained included: height; weight; leg length, knee and ankle diameter. All marker placements were done by the researcher, who has received training in marker placement and has 2 years' experience in marker placement. This serves to reduce marker bias.

2.4.2. Trial capture procedure

Participants were required to perform six barefoot walking trials at a self-selected speed, in a straight line, across a flat walk way in the motion analysis laboratory. Participants returned seven days later at approximately the same time, to repeat the full testing procedure from day one. This interval was chosen because it is long enough to avoid memory bias from the first occasion (Meldrum et al., 2014) and short enough to avoid a change in gait due to variation in symptoms (Whatman et al., 2013).

Self-reported usual pain was also measured at both testing sessions using the numeric pain rating scale (NPRS).

2.4.3. Outcomes

The mean peak angles for hip transverse and frontal plane, Knee sagittal plane at foot contact, Peak knee sagittal plane, overall ankle sagittal plane ROM, ankle sagittal plane at foot contact and peak foot progression frontal plane obtained for the six trials were used for analysis. These outcomes were chosen as they are the factors

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most strongly associated with AKP based on a systematic review of the evidence (Leibbrandt and Louw, 2017b).

2.5. Data management and analysis

To determine test retest reliability, Inter-class correlation co-efficient (ICC) and Standard Error of Measurements (SEM) were calculated using Stata version 13. ICCs were used to analyse the reliability data as the rater remained the same. The 3D kinematic gait parameters in AKP patients were assessed using the means of the data obtained during the six trials of the first and of the second gait analysis sessions. The ICC provided a measure of relative reli-ability whereas the SEM provided an expression of the measure-ment error in the kinematic outcomes of interest in degrees (absolute reliability). The outcomes of this study ascertained the most reliable 3D kinematic outcomes. This will guide our choice of biomechanical outcomes to compare pre- and post-intervention. The SEM will assist us to determine whether the change in an outcome is a true effect attributable to the intervention.

The outcomes of this study will ascertain most reliable 3D ki-nematic outcomes. This will guide our choice of biomechanical outcomes to compare pre- and post-intervention. The SEM will assist us to determine whether the change in an outcome is a true effect attributable to the intervention.

An outcome with an ICC of greater of than 0.8 was considered to have good reliability and a value of over 0.9 was considered excellent. An outcome with an ICC of 0.7e0.8 was considered to have acceptable reliability, whereas less than 0.7 was considered questionable and less than 0.6 poor (Rankin and Stokes, 1998).

3. Results

Thirty-one subjects (13 males, 18 females) with unilateral AKP (20 left sided, 11 right sided) were included in this study. The average age was 30 (range 14e40; SD ¼ 8.4), height (mean ¼ 170.1 cm; SD ¼ 10.4 cm) and weight (mean ¼ 77.5 kg; SD ¼ 25.7 kg). Participant characteristics can be found below in Table 1.

3.1. Intra-class correlation co-efficient (ICC)

An analysis of kinematic data for all of the included participants using ICC values revealed acceptable to excellent test retest reli-ability (r ¼ 0.78e0.9) for all outcomes. The means of the six trials for both sessions were used for analysis. A summary of results can be found in Table 2.

3.2. Standard error of measurement (SEM)

The SEM values of the same kinematic variable taking the mean values of sessions 1 and 2 for all participants were between 0.94 and 4.2 for all included outcomes. All values were below 5 degrees of measurement error indicating that reliability was acceptable. However, one outcome (peak hip transverse plane) had a measurement error of above 2, indicating that although it is acceptable some caution should be taken when interpreting changes in this outcome due to an intervention. A summary of the SEM results can be found in Table 3.

3.3. Sub-group differences in ICC and SEM

A summary of the ICC and SEM reliability values for male par-ticipants, female participants, adolescent participants (14e19) and adult participants (20e40) can be seen in Table 4. Although most outcomes were similar between sub-groups some important dif-ferences should be noted. Most of the ICC values still demonstrated acceptable reliability co-efficient (>0.7) with the exception of knee sagittal plane outcomes in adolescents (r ¼ 0.68). Ankle sagittal plane outcomes were also less reliable in adolescents compared to adults. Gender differences include a larger error (SEM) in hip transverse plane outcomes for females compared to males.

3.4. Usual pain levels (NPRS)

The average (mean) pain levels measured using the NPRS as well as the standard deviation (SD) for each participant at the two ses-sions can be seen below in Fig. 1. The average NPRS for week 1 was 4.2/10 (SD ¼ 1.93) and week 2 was 3.97/10 (SD ¼ 1.82).

4. Discussion

This is the first study to quantify test retest reliability of 3D ki-nematic gait outcomes in an AKP population. The relative reliability (ICC) and absolute reliability (SEM) of all included outcomes were found to have acceptable to excellent reliability. The results showed that the hip frontal plane and ankle sagittal plane outcomes were the most reliable and had the lowest measurement error.

Hip transverse plane outcomes were least reliable and demon-strated the highest measurement error. This is in agreement with a previous systematic review on the reliability of gait outcomes in asymptomatic populations (McGinely et al., 2009). This may be related to the biomechanical model used to calculate the position of motion segments from markers placed on anatomical landmarks (Baker et al., 1999). Hip rotation angles are susceptible to errors related to misplaced thigh markers (Baker et al., 1999). It is there-fore important to establish that it was possible to obtain acceptable levels of reliability and error. However, small changes (less than 5) in this outcome as a result of an intervention should be interpreted with caution.

The findings of our study showed that females with AKP demonstrated higher measurement in error in peak hip transverse plane kinematics (SEM ¼ 5) than men (SEM ¼ 2.8). This might be explained by gender differences in hip strength and kinematics between males and females with AKP. Females with AKP demon-strate a larger static Q angle as well as increased dynamic hip in-ternal rotation and decreased hip strength compared to males with AKP (Nakagawa et al., 2012; Boling et al., 2010). These differences might result in less consistency in hip rotation control during gait in

Table 1
Participant characteristics for the included sample (affected side, age, gender, height and weight).

	Sample size (n)	Affected leg	Average age Mean (SD)	Average height Mean (SD)	Average weight Mean (SD)	Average BMI Mean (SD)
Males with AKP	13	8 Left 5 Right	31.54 (8.65)	176.9 (8.18)	85.62 (24.19)	27.4
Females with AKP	18	12 Left 6 Right	29 (7.97)	165.3 (11.6)	65.9 (23.98)	24.2
All subjects	31	20 Left 11 Right	30.19 (8.42)	170.16 (10.45)	77.5 (25.7)	26.8

Please cite this article in press as: Leibbrandt, D.C., Louw, Q.A., The test retest reliability of gait outcomes in subjects with anterior knee pain, Journal of Bodywork & Movement Therapies (2017), http://dx.doi.org/10.1016/j.jbmt.2017.05.011

Table 2
Between session reliability co-efficient (r) for all outcomes.

Outcome	Peak hip transverse plane		Peak hip frontal plane		Peak knee sagittal plane at FC		Peak knee sagittal plane		Average overall ROM ankle sagittal plane		Peak ankle sagittal plane		Peak foot progression	
Session	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Mean	0.17	1	7.29	7.77	6.01	6.8	59.15	60.22	32.83	32.73	14.38	14.39	3	2.84
SEM		4.21		1.08		2.13		2.17		1.96		0.94		1.84
ICC (r)		0.78		0.92		0.79		0.78		0.88		0.9		0.88

Table 3
Standard error of measurement (SEM) between sessions for all outcomes.

Outcome	Standard error of measurement (degrees)	Interpretation
Peak hip transverse plane	4.2	Acceptable but may require caution
Peak hip frontal plane	1.08	Good
Knee sagittal plane at foot contact	2.13	Good
Peak knee sagittal plane	2.17	Good
Average overall ankle sagittal plane ROM	1.9	Good
Ankle sagittal plane at foot contact	0.94	Good
Peak foot progression	1.84	Good

females with AKP.

The most reliable outcomes determined in the systematic review by McGinely et al. (2009) were those of the hip and knee sagittal plane. Sagittal plane errors were typically less than 4 . These find-ings on an asymptomatic population are consistent with the find-ings of the current study on an AKP population. However, the ICC value reported in McGinely et al. (2009) was 0.96, and the current study reported findings of 0.79 and 0.77. This suggests that knee sagittal plane outcomes are less reliable in an AKP population. One could argue that the reliability might be influenced by the unpre-dictable nature of the condition, causing variation in pain and symptoms. It has been suggested that some individuals may decrease knee flexion in stance phase and at foot contact during gait to try and avoid an increase in pain (Barton et al., 2009). Therefore, pain levels should be noted at the time of the assessment pre- and post-intervention as it could influence knee kinematics during gait.

Table 4 shows that the adolescent participants included in this study demonstrated less reliable measures of sagittal knee plane knee movement (r ¼ 0.68) than the adult participants (r ¼ 0.82). Previous research has suggested that adolescents with AKP between the ages of 12 and 16 may have a different aetiology of symptoms to adults and that abnormal movement patterns may play more of a role than

Table 4
Subgroup differences in ICC and SEM.

	Males (n ¼ 13)		Females (n ¼ 18)		Adolescents (n ¼ 6)		Adults (n ¼ 25)	
Outcome	r	SEM	r	SEM	r	SEM	r	SEM
Peak hip transverse plane	0.84	2.8	0.77	5	0.82	3.9	0.79	4.27
Peak hip frontal plane	0.94	0.9	0.9	1.19	0.92	0.83	0.92	1.13
Knee sagittal plane at foot contact	0.75	2.14	0.83	2.17	0.68	2.76	0.82	1.95
Peak knee sagittal plane	0.93	2.09	0.7	2.28	0.68	2.63	0.81	2.05
Average overall ankle sagittal plane ROM	0.89	1.78	0.84	2.08	0.72	2.4	0.9	1.84
Ankle sagittal plane at foot contact	0.92	0.9	0.91	0.95	0.78	1.07	0.9	0.9
Peak foot progression	0.86	1.85	0.86	4.97	0.89	4.5	0.78	4.55

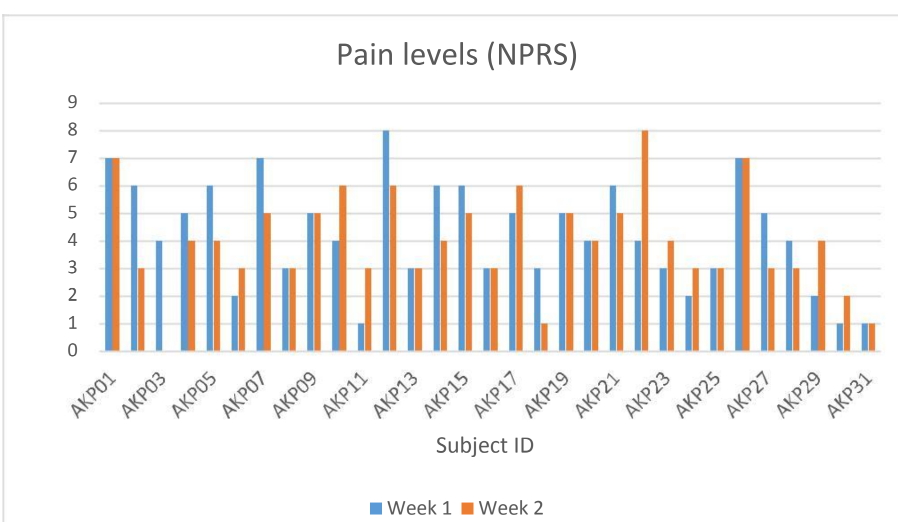

Fig. 1. Participant pain ratings at session 1 compared to session 2 (NPRS) AKP ¼ anterior knee pain (subject number).

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decreased strength in this population group (Rathleff et al., 2013). In the current study the average (mean) pain on a NPRS for week 1 was 4.2/10 and week 2 was 3.97/10 indicating that on average pain did not change between sessions. However, Fig. 1 and the SD indicates that there was intra-subject variability in pain levels. This demonstrates the intermittent and highly variable nature of the condition. Pain levels should be taken into consideration when performing gait analysis as the symptoms on the day could influ-ence the quality of movement.

Foot progression angle (foot frontal plane) is used to estimate peak rear foot eversion which is a key outcome associated with AKP. The results of this study showed good reliability (r ¼ 0.88) and low error (SEM ¼ 1.84) for these outcomes. Houck et al., 2008 found even higher ICC values of more than 0.9 and low SEM for rear foot eversion range of motion and static measurement in a standing position. However, the authors evaluated only asymptomatic in-dividuals. In addition, Houck et al., 2008 used a multi-segment foot model whereas the current study used a standard plug in gait model. Although the latter measurements are reliable, a multi-segment foot model would improve the validity of this outcome and would be recommended for a study focusing mainly on foot angles (Carson et al., 2001).

A limitation of this study is that it only quantifies test retest reliability and not inter-rater reliability. Wilken et al., 2012 found that the addition of a second rater did not appreciably affect the reliability of kinematic or kinetic data. However, marker placement error may increase if the raters are not adequately skilled and trained in marker placement. Therefore, the skill of the rater is an important consideration for the consistency and accuracy of the outcomes in both research and clinical applications using motion analysis to obtain kinematic outcomes.

The importance of providing clinical staff with adequate training in standardised protocols has been widely documented (Wilken et al., 2012; McGinely et al., 2009).

Table 1 demonstrates large standard deviations in anthropo-metrics in the included male and female participants. Male par-ticipants on average had a BMI of >25, which is classified as overweight. A recent study by Hart et al. (2016), showed that adults with AKP have a higher BMI than pain free controls as it is hypothesised that the increased loading can contribute towards symptoms. This is also important because anthropometrics can influence the reliability of gait data as there may be soft tissue artefact due to the movement of markers and wands in participants with increased soft tissue or muscle bulk (Baker et al., 2009).

A challenge that clinicians are faced with when trying to quantify measurement error is that it is difficult to tell whether errors that do occur are more as a result of marker placement, data processing errors or subject specific factors such as anthropomet-rics. However, if the errors are minimal and quantifiable this should not affect clinical outcomes.

Natural error should not be confused with measurement error (Schwartz et al., 2004). Therefore, clinicians should keep a careful record of potential subject specific confounding factors such as pain levels, activity levels and self-treatment strategies such as the use of pain medication when assessing changes in a participant's gait. These factors may vary for different pathological conditions and therefore researchers should consider doing repeated measures to calculate repeatability on a subsample of the study population in any study investigating the effect of a treatment strategy on a specific population.

5. Conclusion

Kinematic factors that commonly present in an AKP population can be measured accurately and reliably using 3D gait analysis. These outcomes all obtained acceptable to excellent reliability scores and acceptable to low measurement error between sessions. Therefore, these measurements may provide valuable information on the effects of an intervention. Compared to an asymptomatic population, knee sagittal plane outcomes in an AKP population may be slightly less reliable due to variation I pain and symptoms. In addition, hip transverse plane outcomes should be interpreted with caution if the changes are small as this outcome was the least reliable.

Conflicts of interest

The authors declare that they have no conflicts of interest that may have inappropriately influenced them in writing this article.

Acknowledgements

The authors wish to acknowledge that this work is based on the research supported in part by the National Research Foundation (NRF) of South Africa (Grant number CSUR13090332637). We would also like to express gratitude towards Stellenbosch Univer-sity for the use of their facilities. The study would not have been possible without the input of these institutions.

Appendix A. Checklist for diagnosis of anterior knee pain.

Subjective information:

	YES	NO
Age (must be yes)		
14-50 (Haim et al., 2006; Naslund€ et al., 2006; Cook et al., 2010; Sweitzer et al., 2010; Nijs et al., 2006)		
Area (must be yes)		
Front of knee or retropatella (Haim et al., 2006; Naslund€ et al., 2006; Cook et al., 2010; Sweitzer et al., 2010; Nijs et al., 2006)		
Chronicity		
Longer than 3 months (Haim et al., 2006; Cook et al., 2010; Nijs et al., 2006)		
Aggravated by (must be yes for 2 or more of the following)		
Squatting (Haim et al., 2006; Naslund€ et al., 2006; Cook et al., 2010; Sweitzer et al., 2010; Nijs et al., 2006)		
Prolonged sitting (Haim et al., 2006; Naslund€ et al., 2006; Cook et al., 2010; Sweitzer et al., 2010; Nijs et al., 2006)		
Stairs (ascending or descending) (Haim et al., 2006; Naslund€ et al., 2006; Cook et al., 2010; Sweitzer et al., 2010; Nijs et al., 2006)		
Kneeling (Haim et al., 2006; N€aslund et al., 2006; Cook et al., 2010; Sweitzer et al., 2010; Nijs et al., 2006)		
Excluded if any of the below known		
Previous lower limb surgery (Haim et al., 2006; Cook et al., 2010; Nijs et al., 2006)		
History of trauma (Haim et al., 2006; Cook et al., 2010; Nijs et al., 2006)		
Rheumatological conditions (Haim et al., 2006; Cook et al., 2010; Nijs et al., 2006)		
Known intra-articular pathology: ligament and osteoarthritis (Haim et al., 2006; Naslund€ et al., 2006; Cook et al., 2010; Sweitzer et al., 2010; Nijs et al., 2006)		
Patellar instability (Haim et al., 2006; Sweitzer et al., 2010)		
Knee effusion (Haim et al., 2006; Nijs et al., 2006)		
Patella subluxation/dislocation (Haim et al., 2006,Nijs et al., 2006)		
Fat pad impingement/bursitis (Cook et al., 2010; Nijs et al., 2006)		
Osgood Sclatter (Haim et al., 2006; Cook et al., 2010)		

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Objective tests:

		YES	NO
Symptom reproduction with (must be positive for at least 1 of the following activities)			
Squatting (Haim et al., 2006s; Naslund€ et al., 2006; Cook et al., 2010; Sweitzer et al., 2010; Nijs et al., 2006) Kneeling (Haim et al., 2006; N€aslund et al., 2006; Cook et al., 2010; Sweitzer et al., 2010; Nijs et al., 2006) Ascending or descending stairs (Haim et al., 2006; N€aslund et al., 2006; Cook et al., 2010; Sweitzer et al., 2010; Nijs et al., 2006)			
Positive for at least one of the following			
Patella compression test (Haim et al., 2006; Sweitzer et al., 2010)			
Patella tilt test (Haim et al., 2006; Sweitzer et al., 2010)			
OR			
(Minimum 2/3) positive for combination of			
Squatting (Cook et al., 2010)			
Isometric quads (Cook et al., 2010)			
Palpation of patella borders (Cook et al., 2010)			
Excluded if positive for			
Lachmen's Test (Benjaminse et al., 2006; Day et al., 2009; Malanga et al., 2003)	ACL		
Posterior Drawer Test (Benjaminse et al., 2006; Malanga et al., 2003)	PCL		
Valgus Stress Test (Benjaminse et al., 2006; Malanga et al., 2003)	MCL		
Varus Stress test (Benjaminse et al., 2006; Malanga et al., 2003)	LCL		
McMurray's Test (Benjaminse et al., 2006; Malanga et al., 2003)	MENISCUS		
Patellar Ballotment Test (Nijs et al., 2006)	Effusion		

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