THE OUTCOME OF HIP EXERCISE IN PATELLOFEMORAL PAIN: A SYSTEMATIC REVIEW

Abstract

Patellofemoral pain (PFP) is one of the most common lower extremity conditions seen in clinical practice. Current evidence shows that there are hip strength deficits, delayed onset and shorter activation of gluteus medius in people with PFP. The aim of this review was to systematically review the literature to investigate the outcome of hip exercise in people with PFP.

Method

AMED, CINAHL, Cochrane, EMBASE, PEDro, Pubmed, Science direct and SPORTDiscus databases were searched from inception to November 2014 for RCTs, non-randomised studies and case studies. Two independent reviewers assessed each paper for inclusion and quality.

Results

Twenty one papers were identified;eighteen investigating strengthening exercise, two investigating the effect of neuromuscular exercise and one study investigated the effect of hip exercise for the prevention of PFP.

Hip and knee strengthening programmes were shown to be equally effective. Limited evidence indicates that the addition of hip exercise to an exercise programme is beneficial. Limited evidence demonstrates that motor skill retraining in a participant group who displayed abnormal hip alignment in running improves pain.

Conclusion

The evidence consistently demonstrated that both hip strengthening and neuromuscular exercise has a beneficial effect on pain and function in people with PFP. Strengthening exercise predominantly addressed abductor and external rotator muscle groups.

A consensus from PFP researchers for standardisation of methodology is recommended to enable meaningful comparison between trials.

Keywords: patellofemoral, hip, neuromuscular, exercise, review

INTRODUCTION

Patellofemoral pain (PFP) is characterised by retropatellar or peripatellar pain associated with activities involving lower limb loading such as running, jumping, sustained sitting, kneeling, ascending or descending stairs, and squatting (Davis and Powers, 2010; Nijs et al., 2006). It is a common musculoskeletal disorder (Witvrouw etal., 2000) and was the most common overuse running injury in a prospective study of 2002 runners, accounting for 37.4% of knee injuries (Taunton et al., 2002). PFP has a reported incidence ranging from 3-40% of the population (Callaghan and Selfe, 2007) and females are 2.23 times more likely to develop the condition (Boling et al., 2010). It is not uncommon for patients to have long term symptoms. It was shown that 80% people with PFP who had completed a rehabilitation programme reported pain at a five year follow up, and 74% had reduced their physical activity level (Blond and Hansen, 1998). This may be due to underlying factors that contribute to the development of PFP not being addressed.

It is widely accepted that PFP is a multi-factorial condition (Powers,2012). There is increasing evidence that proximal factors may be associated with the pathogenesis of PFP.Biomechanical studies have shown that excessive femoral internal rotation in weight bearing leads to increased lateral patellar tracking, reduction in patellofemoral contact area (Besier et al., 2008; Huberti and Hayes, 1984; Lee et al., 2003; Li et al., 2004; Salsich and Perman, 2007) and increased lateral patellofemoral joint stress (Souza et al., 2010). This is proposed to lead to change in the patellofemoral joint articular cartilage, overloading the subchondral bone, causing pain (Powers, 2012).

It has been proposed that that there are hip strength deficits in adults with PFP(Rathleff et al., 2014). However, evidence demonstrating that reduced muscle strength is accompanied by altered hip kinematics in PFP is conflicting, with some studies showing an association between a reduction in muscle strength with altered kinematics (Boling and Padua, 2013; Souza and Powers, 2009; Nakagawa et al., 2012) and others that there is not (Willson et al., 2008). There is delayed onset and shorter activation of gluteus medius in adults with PFP(Barton et al., 2013) and some evidence to show that altered gluteal muscle activation patterns accompanies altered hip kinematics in PFP (Souza and Powers 2009; Nakagawa et al., 2012). It follows that both strength and neuromuscular exercises of the gluteal muscles may be important factors to include in the management of PFP.

A recent Cochrane review demonstrated consistent support for exercise in PFP (van der Heijden et al., 2015), but did not include neuromuscular exercise. This review included RCTs and quasi-randomised studies. However, clinical decision making based on evidence based medicine should not be confined to RCTs; all available evidence should be considered and synthesised (Doherty, 2005; Koes and Hoving 1998). Observational studies with lower rigour but with higher generalisability may be of more clinical value (Milanese, 2011; Berbano and Baxi 2012) and when properly conducted with rigorous methods can be valuable in clinical research (Grossman and Mackenzie, 2005; Baker, 2011; Sharp, 1998). A more inclusive review of all proximal exercise will aid in the clinical management of PFP.

The aim of this review was to evaluate the effect of hip strengthening and neuromuscular exercise in people with PFP, providing clinicians with information to help plan effective management.

METHODOLOGY

Search strategy

A systematic literature search was conducted of the electronic databases AMED, CINAHL, the Cochrane database, EMBASE, PEDro, Pubmed, Science direct and SPORTDiscus from their inception to November 2014. A search strategy from the Cochrane review on exercise therapy on PFP (Heintjes et al., 2003) was used for diagnosis terms and combined with key terms glute or proximal or hip or trunk; and exercise or rehabilitation and strength or endurance or motor control. A secondary search of relevant journals identified from related published research articles was also undertaken. These included Journal of Orthopaedic and Sports Physical Therapy, American Journal of Sports Medicine, British Journal of Sports Medicine and Journal of Sports Rehabilitation.

A search of the grey literature was undertaken using the databases WHO International Clinical Trials registry platform, OpenSIGLE, Zetoc and UK clinical research network study portfolio. Post-graduate theses were searched on the Index to theses database.

Relevant researchers in the field were contacted for information on unpublished research.

The reference list of each article was hand searched to identify additional papers.

Study eligibility

Full text, English language articles were eligible.Randomised controlled trials (RCTs), non-randomised studies (NRS), cohort studies, case control studies and case studies investigating the effect of strengthening, endurance or neuromuscular exercise at the hip in subjects with patellofemoral pain were included,with at least one measure of pain, function or biomechanical outcome.

Study Types

No restrictions were applied to the types of studies included. All available evidence was considered and synthesised to ensure a comprehensive review.

A patellofemoral pain checklist was used (Table 1), with key inclusion and exclusion criteria for patellofemoral pain diagnosis (Barton et al.,2010). Studies investigating patellofemoral instability or patellofemoral osteoarthritis were excluded. There was no restriction on gender or age limits.

Review process

Identified studies were downloaded into the bibliographic software programme Endnote Version X5 reference manager (Thomson Reuters). All identified titles and abstracts and subsequent full text articles were screened for eligibility. The final decision about inclusion was made by two independent researchers. A third researcher was consulted if a consensus was not reached. The researchers were not blinded to either source or author.

Data extraction

Data on the study design; participant characteristics; specific exercise; position; repetitions; frequency; intensity and outcome measures was extracted by two investigators.

Methodological Quality assessment

The PEDro scale (www.pedro.org.au) was used to assess the RCTs and NRS. The observational studies were assessed by appraisal tools from the Critical Appraisal Skills Programme (CASP) (www.casp-uk.net). The Oxford Centre of Evidence Medicine (CEBM) (www.cebm.net) appraisal tool for a case study was used for single case studies. Following the quality assessment a level of evidence was awarded for each of the studies, whichwas downgraded if there were serious limitations ("The Oxford 2011 Levels of Evidence").

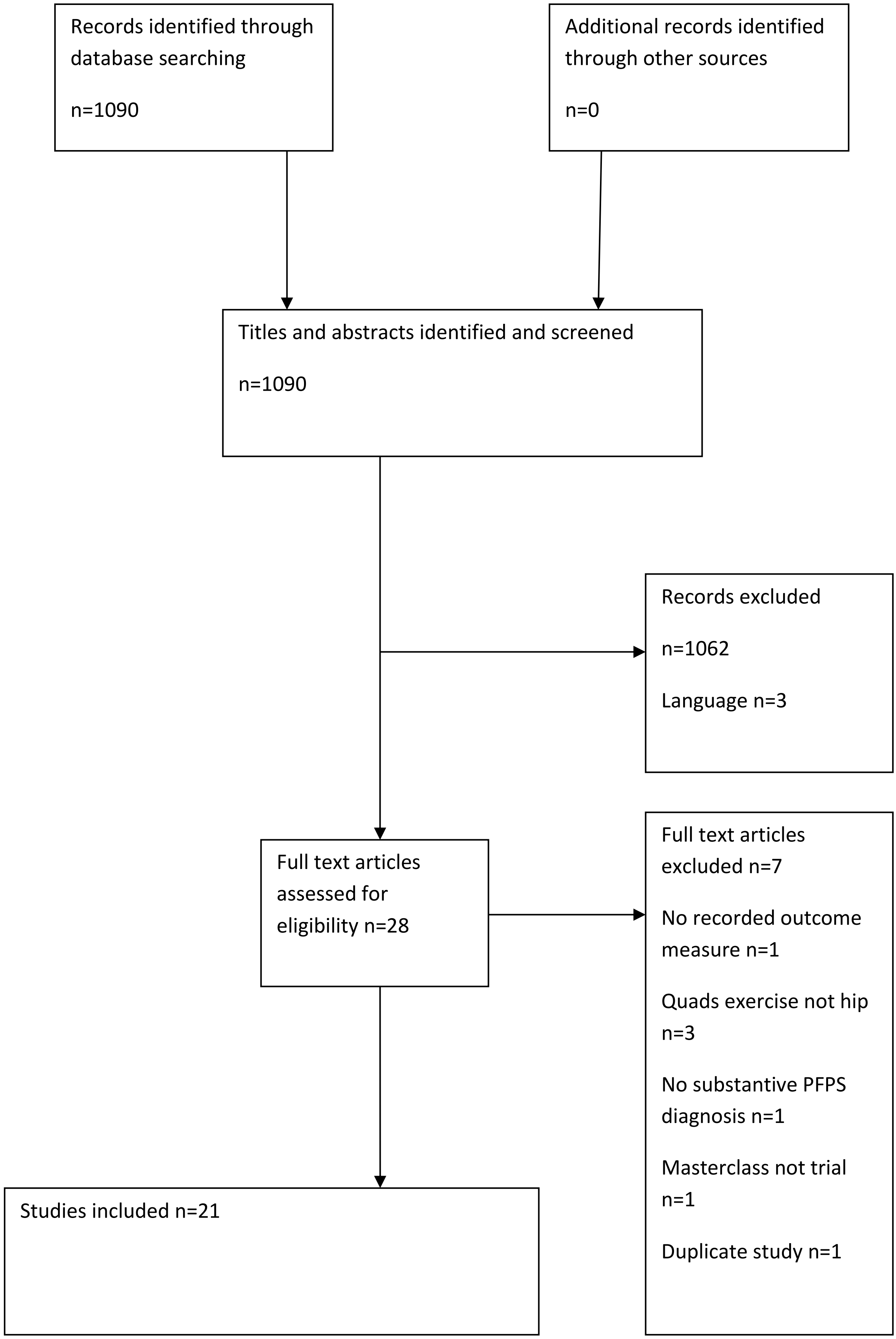
RESULTS

The initial search identified 1090 potentially relevant articles, of which 1062 were excluded based on title and abstract (figure 1). Full texts of28 articles were obtained; of these seven were excluded.

One study provided detailed data from participants in a previous study; the data from these two papers were combined (Willy et al., 2012; Willy and Davis, 2013). This left 21 papers fulfilling the eligibility criteria.

Figure 1.

Flow diagram to illustrate the search results



Quality Assessment

The methodological assessment of the reviewed papers is summarised in tables 2-4. The scores on the PEDro scale for RCTs ranged between three and nine out of a possible eleven. The main limitation was a lack of blinding of participants and therapists. One study did not meet the PEDro criteria for randomisation as participants were sequentially allocated (Khayambashi et al., 2012). A further study (Baldon et al., 2014) used block randomisation with groups of four, with no stratification.

The three case control studies scored seven and eight on the CASP Case control score out of a possible eleven. All subjects were recruited by convenience sampling. Two studies used an asymptomatic control group (Boling et al., 2006; Ferber et al., 2011). Confounding factors were poorly addressed. Case series studies scored between four and nine out of ten. The main limitation was that one researcher was responsible for data analysis in all studies.

Table 1 Patellofemoral Pain Diagnosis Checklist

	Inclusion Clear definition of location	Insidious onset unrelated to trauma	Symptoms consistent with diagnosis	Exclusion Previous knee surgery	Internal derangement	Ligamentous instability	Other sources of anterior knee pain	Total score
Avraham et al., 2007	Y	Y	Y	N	Y	N	Y	5
Baldon et al., 2014	Y	Y	Y	Y	Y	Y	Y	7
Boling et al., 2006	Y	Y	Y	Y	N	N	Y	5
Coppack et al., 2011	Y	Y	Y	Y	Y	Y	Y	7
Dolak et al., 2011	Y	Y	Y	Y	Y	Y	Y	7
Earl et al., 2011	Y	Y	Y	Y**	Y	Y	Y	7
Ferberet al., 2011	Y	Y	Y	Y	N	N	Y	5
Ferber et al., 2014	Y	Y	Y	Y	Y	Y	Y	7
Fukuda et al., 2010	Y	N	Y	Y	Y	Y	Y	6
Fukuda et al., 2012	Y	N	Y	Y	Y	Y	Y	6
Ismail et al., 2013	Y	Y	Y	Y	Y	Y	Y	7
Khayambashi et al., 2012	Y	N	Y	Y	Y	Y	Y	6
Khayambashi et al., 2014	Y	N	Y	Y	Y	Y	Y	6
Lowry et al., 2008	N	N	N	Y	Y	Y	N	3
Mascal et al., 2003	Y	Y	Y	N	Y	Y	Y	6
Nakagawa et al., 2008	Y	Y	Y	Y	Y	Y	Y	7
Noehren et al., 2011	Y	Y	N	N	N	N	N	2
Razeghi et al., 2010	Y	Y	Y	Y*	Y	Y	Y	7
Song et al., 2009	Y	Y	Y	Y	N	N	Y	5
Tyler et al., 2006	Y	Y	Y	Y**	Y	Y	Y	7
Willy et al., 2012	Y	Y	Y	Y	N	N	Y	5

*past 2 years**previous patellar surgery

Table 2 Quality assessment RCTs PEDro scale

	Eligibility specified	Randomis-ation	Allocation concealed	Groups similar at baseline	Subjects blinded	Therapists blinded	Assessors blinded	Key outcome obtained from 85%	Intention to treat	Between group statistical outcome	Point measure	Total Score
Avraham et al., 2007	N	Y	N	N	N	N	Y	N	N	Y	N	3
Baldon et al., 2014	Y	N	Y	Y	Y	N	N	Y	Y	Y	Y	8
Coppack et al., 2011	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	9
Dolak et al., 2011	Y	Y	N	Y	N	N	Y	N	Y	Y	Y	7
Ferber et al., 2014	Y	Y	Y	Y	N	N	Y	N	Y	Y	Y	8
Fukuda et al., 2010	Y	Y	Y	Y	N	N	Y	Y	N	Y	Y	8
Fukuda et al., 2012	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	9
Ismail et al., 2013	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	9
Khayambashi et al., 2012	Y	N	N	Y	N	N	N	Y	Y	Y	Y	6
Khayambashi et al., 2014	Y	N	N	Y	N	N	N	Y	Y	Y	Y	6
Nakagawa et al., 2008	N	Y	Y	Y	Y	N	Y	N	Y	Y	Y	8
Razeghi et al., 2010	Y	Y	N	N	N	N	N	Y	N	Y	Y	5
Song et al., 2009	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	9

www.pedro.org.au

Table 3 Quality assessment CASP Case control

	Clearly focused issue?	Appropriate method?	Cohort recruited in an acceptable way?	Exposure accurately measured?	Outcome accurately measured?	Confounding issues identified and accounted for?	Follow-up complete enough and long enough?	Results- bottom line and precise?	Results believable?	Can the results be applied to local population?	Do the results fit with other available evidence?	Total score
Boling et al., 2006	Y	Y	Y	Y	Y	N	Y	N	Y	N	Y	8
Ferber et al., 2011	Y	Y	Y	Y	Y	N	Y	Y	Y	N	Y	9

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Table 4 Critical Appraisal Exercise CEBM Case study quality

	Clearly focused question?	Study design appropriate?	Setting and subjects representative?	Researcher's perspective taken into account?	Methods for collecting data described?	Methods analysing data valid and reliable?	Analysis repeated by more than one researcher?	Results credible and relevant to practice?	Conclusions drawn justified by results?	Findings transferable to other settings?	Total score
Earl et al., 2011	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	9
Lowry et al., 2008	N	Y	Y	Y	Y	Y	N	N	N	N	5
Mascal et al., 2003	Y	Y	Y	Y	Y	N	N	Y	Y	Y	8
Noehren et al., 2011	Y	Y	N	Y	Y	Y	N	Y	Y	N	7
Tyler et al., 2006	Y	Y	Y	Y	Y	N	N	N	Y	Y	7
Willy et al., 2012	Y	Y	N	Y	Y	Y	N	Y	Y	Y	8
Willy et al., 2013	Y	Y	N	Y	Y	Y	N	Y	Y	Y	8

Consistent support for the benefit of hip exercise in PFP was evident. Seven level two studies, two level three and eleven level four studies demonstrated a beneficial effect. Conversely, one level two paper demonstrated no benefit for hip exercise in PFP (see table 5).

Table 5 Levels of evidence.

CEBM level of evidence	Level 2	Level 3	Level 4
Beneficial effect of hip exercise in PFP	Baldon et al., 2014 Coppack et al., 2011 Ferber et al., 2014 Fukuda et al., 2010 Fukuda et al., 2012 Ismail et al.,2013 Nakagawa et al., 2008	Dolak et al., 2011 Khayambashi et al., 2012	Avraham et al., 2007 Boling et al., 2006 Earl & Hoch 2011 Ferber et al., 2011 Khayambashi et al., 2014 Lowry et al., 2008 Mascal et al.,2003 Noehren et al .,2011 Razheghi et al., 2010 Tyler et al.,2006 Willy et al., 2012
No benefit of hip exercise in PFP	Song et al., 2009		

www.cebm.net/ocebm-levels-of-evidence

Strengthening exercise

Eighteen studies investigated strengthening exercise (table 6) including one prospective study investigating the prevention of anterior knee pain (Coppack et al., 2011).

753 PFP participants (578 females, 133 males, 42 genders unknown) with an age range between 14 and 50 years were included. Eight studies included females only; one study did not state gender. The number of participants in the exercise groups were generally small, ranging from 15-35 although there were two large RCTs with 111 and 759 proximal exercise participants. Studies were commonly underpowered; only six had sample size calculations that were adhered to.

Nine studies included participants with both bilateral and unilateral symptoms, five studies only included participants with unilateral symptoms, one study included participants with bilateral symptoms and two studies did not include this data. Five studies evaluated the most symptomatic knee, two studies the most painful knee on initial testing, and three studies evaluated both knees.

Six studies investigated participants who did not regularly participate in exercise, four investigated participants who participated in sports; there was no available data on activity levels from the remaining studies.

Table 6 Study characteristics: Strengthening exercise

Study	Study design	Population	Sample size	Sample size calculation	Age	Gender	Additional inclusion criteria PFP	Unilateral/bilateral PFP
Avraham et al 2007	RCT Comparison of three groups: Hip orientated, knee orientated and hip and knee orientated exercise	No data on activity levels	42	No	Mean age 35 years No other data recorded	Unknown	Not specified	Unknown
Baldon et al 2014	RCT Comparison of two groups: Functional stabilisation training (FST) = Hip, lower limb and trunk exercise and Standard Training (ST) = quadriceps exercise	Recreational athletes	31 16 hip group 15 quadriceps group	Yes; numbers at 3 month follow-up did not equate to sample size	18-30 years	female	Duration >8 weeks VAS >3/10	Unknown
Coppack et al 2011	RCT Prospective study for the prevention of anterior knee pain. Intervention group of gluteal and quadriceps exercise and control group of running and upper body exercise.	Military recruits	1502 759 intervention group 743 control group	Numbers in study did not equate to numbers needed from sample size calculation	17-25 years	male (1092) female (410)	N/A	N/A
Dolak et al 2011	RCT	No data on activity levels.	33	No	16-35 years	female	Duration >1 month	Unilateral (17)

	Comparison of two groups: initial hip exercise group or initial knee exercise group prior to same functional exercises		17 hip group 16 knee group					bilateral (16) - most painful limb during initial testing used for analysis
Ferber et al., 2014	RCT Comparison of two groups: Hip & core exercise group or knee exercise group	Recreationally active	199 111 hip group 88 knee group	Yes	29+/-7years	male (66) female (133)	Duration >4 weeks VAS >3/10	Unilateral / bilateral No data re numbers Bilateral- both limbs exercised, most affected limb included in data
Fukuda et al 2010	RCT Comparison of three groups: Hip & knee exercise group, knee exercise group Control group- no exercise	Sedentary	70 22 hip group 23 knee group 25 control group	Yes	20-40 years	female	Duration >3 months	Unilateral
Fukuda et al 2012	RCT Comparison of two groups: knee exercise group and knee and hip exercise group	Sedentary	54 knee group 26 hip group 28	Yes	20-40 years	female	Duration >3 months	Unilateral
Ismail et al 2013	RCT	No data on activity levels	32	No	18-30 years	male(9) female(23)	Duration >6 weeks	Unilateral

	Comparison of two groups: CKC exercise and same CKC exercise with addition of OKC hip exercise		16 per group					
Khayambashi et al 2012	RCT Comparison of two groups: a hip exercise group to a no-exercise control group who took 1000mg Omega-3 and 400mg calcium daily	Sedentary. No previous physiotherapy.	28 14 per group	No	Hip group 28.9 +/-5.8 years Control group 30.5+/-4.8 years	female	Duration >6 months	Bilateral- both knees exercised & tested
Nakagawa et al 2008	RCT Comparison of two groups: a quadriceps strengthening group, a group with the addition of hip exercise	No data re activity levels.	14 7 per group	No	17-40 years	male(4) female(10)	Duration >4 weeks	Unilateral/bilateral. No data re numbers. Bilateral - most affected limb included.
Razeghi et al 2010	RCT Comparison of two groups: hip and knee exercise group and knee exercise group	No data	33 17 hip and knee 16 knee	No	18-30 years	female	Not specified	Unilateral/bilateral (52 knees)
Song et al 2009	RCT Comparison of three groups: leg press exercise group, leg press with addition of hip	No regular sports.	89 leg press 30 leg press with hip	Yes	<50 years	male(20) female(69)	Duration >1 month Excluded VAS >8/10	Unilateral/bilateral PFP. No data re numbers. Bilateral- most symptomatic knee included. Stratified allocation re

	adduction and no-exercise control group		adduction 29 control group 30					unilateral/bilateral symptoms
Boling et al 2006	Case control Rehabilitation programme of weight bearing exercise. Matched no-exercise control group of asymptomatics	No data re activity levels	28 14 exercise group 14 no exercise group	No	18-42 years	male (5) female(9)	Excluded if duration <2 months	Unilateral/bilateral No data re numbers Bilateral- most affected limb analysed. Controls- R limb analysed.
Earl and Hoch 2011	Case series Rehabilitation "proximal stability programme"	Participated in exercise/sports	28	Yes	22.68+/-7.19 years	female	Not specified	Unilateral/bilateral PFP. No data re numbers. Bilateral- most painful limb tested
Ferber et al 2011	Case control Hip abductor strengthening group compared to a no-exercise control group of asymptomatics	Recreational runners	25 15 PFP 10 control group	Yes	PFP 35.2+/-12.2 years Controls 29.9+/-8.3 years	male (5) female(10)	Excluded duration >2 months VAS >3/10	Unilateral
Khayambashi et al 2014	Case control study. Comparison of hip exercise group to a quadriceps exercise group	Sedentary	36 18 per group	No	Hip group 28.2+/-7.9 years Knee group 27.3+/-6.7 years	male(18) female(18)	Excluded duration <6 months	Unilateral(14) or bilateral (22) Limb reported to be most painful during initial testing evaluated

Lowry et al., 2008	Case study x5 Multi-modal treatment (combination of thrust and non-thrust manipulation directed at the joints of the lower quarter, trunk and hip stabilization exercises, patellar taping, and foot orthotics)	No data re activity levels	5	N/A	14,15,15,25, 50 years	male (3) female (2)	Not specified	Bilateral (3) Unilateral (2)
Mascal 2003	Case study x 2 subjects (excluded one as patellar instability,previous dislocation/positive apprehension test)	Sedentary	1	N/A	37 years	female		Unilateral
Tyler 2006	Case series Hip flexibility and strengthening programme	No data re activity levels.	35	No	33+/-16 years	female(29) male(6)	Duration >4 weeks	Unilateral / bilateral PFP. Bilateral (8) both knees included- 43 knees in study.

PFP- Patellofemoral pain

RCT-randomised controlled trial

CKC- closed kinetic chain

OKC- open kinetic chain

VAS - Visual analogue scale

Strengthening Exercise Protocols

Widespread variation in the exercise protocols was evident (see table 7). Thirteen out of the eighteen studies compared exercise groups. Four investigated the addition of hip exercises to an exercise regime; three were additional open kinetic chain (OKC) hip exercises. Three studies compared hip and knee exercises.

Most hip protocols targeted the hip abductors and external rotators. In contrast, one study investigated isometric adduction (Song et al., 2009).Ten studies included both OKC and closed chain (CKC) exercises. Four used OKC only. Twelve studies included OKC abduction, and seven OKC external rotation. Thirteen hip protocols included CKC exercises; seven unilateral CKC exercise.

All control group exercises included CKC exercise except one (Coppack et al., 2011), with three including unilateral CKC exercise and four, squats.

All studies progressed exercise except one (Razeghi et al., 2010). The criteria for progression in eleven studies was time, with six studies taking ability into account and two pain. Progression was achieved with increasing repetitions of exercise in five studies, increasing load in thirteen studies and increasing demand of the exercise in five studies.

Exercise was carried out three times a week in ten of the studies, with four prescribing more frequent and three less frequent exercise. One did not state frequency of exercise. Exercise programmes were carried out from three weeks to fourteen weeks; thirteen were at least six weeks duration. The majority of studies analysed the results at the end of the programme. Two studies evaluated the long term effects at six months and one additionally at one year (Fukuda et al., 2012).

Table 7 Strengthening Exercise Protocols

Study	Exercise	Progression	Additional exercise	Time frame for exercise	Reps, intensity, frequency	f/u period
Avraham et al 2007	Knee group 1. SLR 10 secs Hold 10secs rest. 7.5 minutes 2. Single leg squats 7.5minutes 3. TENS 15 minutes Hip group 1. Therapist assisted ITB stretch 10 secs hold, 10 secs rest, 3 minutes 2. Therapist assisted Hamstring stretch (SLR) 10 secs hold, 10 secs rest, 3 minutes 3. Hip external rotation. Ipsilateral side-lying, knee & hip flexion 90 degrees, limb over edge of bed. From full internal rotation to 30 degrees external rotation. 9 minutes. 4. TENS 15 minutes Hip and knee group 1. SLR 10 secs Hold 10 secs rest. 3 minutes 2. Single leg squats 3 minutes 3. Therapist assisted ITB stretch 10 secs hold, 10 secs rest, 3 minutes 4. Therapist assisted Hamstring stretch (SLR) 10 secs hold, 10 secs rest, 3 minutes 5. Hip external rotation. Ipsilateral side-lying, knee & hip flexion 90 degrees, limb over edge of bed. From full internal rotation to 30 degrees external rotation. 3 minutes.	Patients instructed to increase load, time and reps as able	See individual group data	3 weeks	2 x week in clinic, exercises only at home 4 x week	3 weeks

	6. TENS 15 minutes					
Baldon et al 2014	<u>Standard training</u>: <u>Weeks 1-8</u> 1. Therapist assisted quadriceps (prone) and lateral retinaculum stretches 3 x 30 secs 2. Stretches hamstrings, gastrocnemius, soleus, ITB 3 x 30 secs <u>Weeks 1-2</u> 1. SLR with ankle weights, 2 x 20 reps, initial load 50% 1RM, progression increasing 0.5kg 2. Seated knee extension 90-45 degrees knee flexion, 2 x 20 reps, initial load 50% 1RM, progression increasing 2-5kg 3. Leg press 0-45 degrees knee flexion, 2 x 20 reps initial load 50% 1RM, progression increasing 5-10kg 4. Wall squat 0-60 degrees knee flexion, 2 x 20 reps with 5 secs isometric hold, progression increasing 2 secs hold <u>weeks 3-5</u> 1. SLR with ankle weights, 3 x 12 reps, initial load 75% 1RM, progression increasing 0.5kg 2. Seated knee extension 3 x 12 reps, initial load 75% 1RM, progression increasing 2-5kg 3. Leg press 3 x 12 reps, initial load 75% 1RM, progression increasing 5-10kg 4. Wall squats with weights with 10 secs isometric hold, 3 x 12 reps, initial load 10% body mass, progression increasing 5% body mass 5. Step-up and step-down from 20cm step holding weights, 3 x 12 reps, initial load	Time. See individual exercises for reps, load progression		8 weeks	3 x week	8 weeks and 3 months

	10% body mass, progression increasing 5% body mass weeks 5-8 1. Week 3-5 exercises 2. Single leg stand on unstable platform 3 x 30 secs, progression eyes open to eyes closed Functional Stabilisation training Weeks 1-2 1. Transversus and multifidus in quadruped and prone 2 x 15 reps with 10 secs isometric co-contraction 2. Sitting on swiss ball with 20 secs isometric co-contraction, progression increasing 5 secs hold 3. Isometric hip abduction/lateral rotation in standing, 2 x 20 reps, 5 secs isometric contraction, progression increasing 2 secs hold, hip flexion and forward trunk lean emphasised 4. Hip abduction/lateral rotation/extension in side-lying with ankle weight, 2 x 20 reps, 5 secs isometric hold, initial load 20% 1RM, progression increasing 0.5kg 5. Hip extension/lateral rotation in prone, 5 secs isometric hold, ankle weights, 2 x 20 reps, initial load 20% 1RM, progression increasing 0.5kg 6. Hip abduction/lateral rotation in side-lying, slight hip and knee flexion. 2 x 20 reps 5 secs isometric hold, elastic band resistance, initial load 2 bands less than 1RM, progression increasing 1 level of band					

	7. Prone knee flexion 2 x 20 reps, 50% 1RM, progression increasing 1-2 kg 8. Seated knee extension, 90-45 degrees knee flexion, 2 x 20 reps, 50% 1RM, progression increasing 2-5 kg 9. Single leg stand on unstable platform 3 x 30 secs, transversus and multifidus co-contraction, hip flexion and forward trunk lean emphasised <u>weeks 3-5</u> 1. Lateral and ventral bridges 5 x 30 secs progression increasing 5 secs holds, exercises with knee support 2. Trunk extension on swiss ball, 3 x 12, progression increasing 2 reps, performed with arms crossing thorax 3. Hip abduction/lateral rotation/extension in side-lying with ankle weight, 3 x 12 reps, 5 secs isometric hold, initial load 75% 1RM, progression increasing 0.5kg 4. Hip extension/lateral rotation in prone, 5 secs isometric hold, ankle weights, 3 x 12 reps, initial load 75% 1RM, progression increasing 0.5kg 5. Hip abduction/lateral rotation in side-lying, slight hip and knee flexion. 3 x 12reps 5 secs isometric hold, elastic band resistance, initial load 1 band less than 1RM, progression increasing 1 level of band 6. Pelvic drop in standing 3 x 12 with ankle weight, initial load 75% 1RM,progression increasing 1-2kg 7. Hip lateral rotation in CKC, with elastic band resistance, initial load 1 band level					

	lower than 1RM, progression increasing 1 elastic resistance level 8. Single leg deadlift 3 x 12 reps, elastic band resistance initial load 1 band level lower than 1RM, progression increasing 1 elastic resistance level 9. Prone knee flexion 3 x 12 reps, initial load 75% 1 RM, progression increasing 1-2kg 10. Seated knee extension 3 x 12reps, 75% 1RM, progression increasing 2-5kg 11. Single leg stand on unstable platform 3 x 30 secs, transversus and multifidus co-contraction, hip flexion and forward trunk lean emphasised, with external perturbation with medicine ball emphasising hip eccentric abductor and lateral rotator muscle contraction <u>weeks 5-8</u> 1. Lateral and ventral bridges 5 x 45-60 secs, progression increasing 5 secs holds, exercises with feet support 2. Trunk extension on swiss ball 3 x 12, progression inc 2 reps, performed with hands behind back 3. Hip abduction/lateral rotation/extension in side-lying with ankle weight, 3 x 12 reps, 5 secs isometric hold, initial load 75% 1RM, progression increasing 0.5kg 4. Hip extension/lateral rotation in prone, 5 secs isometric hold, ankle weights, 3 x 12 reps, initial load 75% 1RM, progression increasing 0.5kg 5. Hip abduction/lateral rotation in side-lying, slight hip and knee flexion. 3 x 12 reps 5 secs isometric hold, elastic band resistance, initial load 1 band less than					

	1RM, progression increasing 1 level of band 6. Pelvic drop in standing 3 x 12 with ankle weight, initial load 75% 1RM,progression increasing 1-2kg 7. Hip lateral rotation in CKC, with elastic band resistance, initial load 1 band level lower than 1RM, progression increasing 1 elastic resistance level 8. Single leg deadlift 3 x 12 reps, elastic band resistance initial load 1 band level lower than 1RM, progression increasing 1 elastic resistance level. Exercise performed with elastic resistance around knee of support limb to encourage hip abduction and lateral rotation 9. Single leg squat 3x 12 no load. Exercise performed in front of mirror with elastic resistance around the knee of support limb to encourage hip abduction and lateral rotation. Hip flexion and forward trunk lean were emphasised 10. Forward lunge. 3 x 12 no load. Exercise performed in front of mirror with elastic resistance around the knee of anterior limb to encourage hip abduction and lateral rotation. Hip flexion and forward trunk lean were emphasised 11. Prone knee flexion 3 x 12 reps, initial load 75% 1 RM, progression increasing 1-2kg 12. Seated knee extension 3 x 12reps, 75% 1RM, progression increasing 2-5kg 13. Single leg stand on unstable platform 3 x 30 secs, transversus and multifidus co-contraction, hip flexion and forward trunk lean emphasised, with external					

	perturbation with medicine ball emphasising hip eccentric abductor and lateral rotator muscle contraction					
Coppack et al 2011	<u>Prevention group</u> 1. Isometric hip abduction against wall in standing 2. Forward lunges 3. Single leg step-downs from 20cm step 4. Single leg squats to 45 degrees knee flexion with isometric gluteal contraction <u>Control group</u> 1. Slow running 2. General upper and lower body stretching 3. Abdominal curls 4. Push-up drills	<u>Criteria</u>- time at week 7 and 13 increase in reps	Quadriceps, ITB, hamstring, calf stretches	14 weeks	7 x week 1. <u>Hip abduction.</u> weeks 1-6 x10 reps weeks 7-12 x15 reps weeks 13-14 x15 reps 2.<u>lunges</u> weeks 1-6 x10 reps weeks 7-12 x12 reps weeks 13-14 x14 reps 3.<u>step-downs</u> weeks 1-6 x10 reps weeks 7-12 x12 reps weeks 13-14 x14 reps 4.<u>single leg squats</u> weeks 1-6 x10 reps weeks 7-12 x12 reps weeks 13-14	14 weeks

					x14 reps	
Dolak et al 2011	Hip group OKC hip exercise Week 1-4 1. Side lying Hip abduction/external rotation 2. Standing hip abduction 3. Seated hip external rotation week 2 Added "quadruped hydrant" exercise =hip abduction/external rotation knee group OKC quadriceps exercises week 1-4 1. Quadriceps sets 2. Short arc quadriceps 3. Straight leg raises Week 2 Replaced quadriceps sets with terminal knee extensions All subjects week 5-8 functional weight bearing exercises- week 5 1. Single leg balance with front pull 2. Wall slides with resistance 3. Lateral step down off a 10cm step 4. 2 leg calf raises Week 6 1. Single leg balance with diagonal pull 2. Single leg mini-squats 3. Lateral step-downs off a 15.25 step 4. Single leg calf raises week 7 1. Single leg balance on airex pad 2. Lunges to a 20.3cm step	Criteria- time Weeks 1-4 increasing % body weight from week 2-4 (3%/5%/7%) Weeks 5-8 increasing demand of exercise	Hamstring (in sitting), Quadriceps (standing), TA (against wall)stretches	8 weeks	3 x 10 reps 3 x week (1 supervised, 2 home)	8 weeks

	3. Lateral step-downs off a 15.25cm step with resistance 4. Single leg calf raises off a step <u>week 8</u> 1. Single leg standing on airex pad with diagonal pull 2. Lunges to 10cm step 3. Lateral step-down off a 20.3cm step 4. Single leg calf raises on airex pad					
Ferber et al 2014	<u>Knee group</u> <u>Week 1</u> 1. Isometric quads setting 2. knee extensions-standing 3. Double- legged one quarter squats <u>Week 2</u> 1. Isometric quads setting 2. Double- legged one half squats 3. Terminal knee extension with theraband 4. Double-legged one quarter squats <u>Week3</u> 1. Double- legged one half squats 2. Single- legged one quarter squats 3. Double- legged one quarter wall squats 5. Terminal knee extension with theraband <u>Week 4</u> 1. Single- legged one half squats 2. Forward one quarter lunge 3. Lateral step-down (4" step) 4. Forward step-down (4" step) 5. Double- legged one half wall squats <u>Week 5-6</u> 1. Double- legged wall squats to maximum 90 degrees knee flexion 2. Lateral step-down (6-10" step)	Progression- increase/decrease in sets/reps, duration, changes in theraband at discretion of Athletic trainer delivering exercises, based on patient feedback, PFP, swelling and symptoms during exercise.		6 weeks, with additional 2 weeks if no initial benefit	Exercises minimum of 6 x week, with supervised exercise maximum of 3 x week <u>Knee group</u> <u>Week 1</u> 3 x 10 reps <u>Week 2</u> 3 x 15 reps Double legged one quarter squats 3 x 30 secs <u>Week 3-4</u> 3 x 10 reps Double legged one half wall squat 3 x 30 secs <u>Week 5-6</u>	6 weeks

	3. Forward step-down (6-10" step) 4. Forward one half full lunge to maximum 90 degrees knee flexion 5. Single- legged one half full squatsto maximum 90 degrees knee flexion <u>Hip group</u> With emphasis on stabilising core musculature before initiating movement <u>Week 1</u> 1. Hip abduction standing 2. Hip external rotator standing 3. Hip external rotator seated <u>Week 2</u> 1. Hip abduction standing 2. Hip internal rotator standing 3. Hip external rotator standing <u>Week 3</u> 1. Hip abduction standing 2. Hip internal rotator standing 3. Hip external rotator standing 4. Balancing 2 feet airex pad <u>Weeks 4-6</u> 1. Hip extension at 45 degrees -standing 2. Hip internal rotator standing 3. Hip external rotator standing 4. Balancing 1 foot airex pad				3 x 15 reps Double legged wall squats 3 x 30-45 secs <u>Hip group</u> <u>Weeks 1-3</u> 3 sets of 10 reps Balance 3 x 30-45 secs <u>Week 3</u> stronger theraband <u>Weeks 4-6</u> 3 sets of 10-15 reps Balance 3x 45-60 secs	
Fukuda et al 2010	<u>Both knee and hip groups</u>- 1. Iliopsoas strengthening non-weight bearing 2. Seated knee extension 90-45 degrees 3. Leg press 0-45 degrees 4. Squatting 0-45 degrees	1RM and 10RM reviewed weekly	Hamstring, calf, quadriceps, ITB therapist assisted stretches	4 weeks	3 x 10 reps, Load 70% 1RM or 10 RM with theraband 3 x week	4 weeks

	Hip group- in addition 1. Hip abduction in standing with theraband 2. Hip abduction side-lying plus weight 3. Hip external rotation in sitting with theraband 4. Side step with theraband in standing 3 x 1minute					
Fukuda et al 2012	Knee and hip groups 1. Seated knee extension 90-45 degrees 2. Leg press 0-45 degrees 3. Squats 0-45 degrees 4. Single leg calf raises 5. Prone knee flexion Hip group Addition of 1. Side-lying hip abduction +weight 2. Standing hip abduction + theraband 3. Sitting hip external rotation +theraband 4. Hip extension machine resistance	1RM and 10RM reviewed weekly	Hamstrings, plantarflexors, quadriceps, ITB stretches both groups	4 weeks	3 x10 reps, Load 70% 1RM or 10 RM with theraband 3 x week	3 weeks, 6 months, 12 months post treatment
Ismail et al 2013	Both groups CKC exercise 1. Mini wall squat 2. Forward step-up 3. Lateral step-up 4. Knee extension in standing with theraband resistance Group 2 additional hip OKC 1. Side-lying hip abduction 2. Seated external rotation	New 10RM calculated weekly	LL stretches both groups	6 weeks	2x10 reps 60% 10RM 3 x week	6 weeks
Khayambashi et al 2012	Control group no exercise Exercise group	Theraband(reps) both legs Week 1-2 red(20) green(20) blue (20)		8 weeks	3 x 20 reps 3 x week (supervised)	8 weeks 6 months (exercise group)

	1. Hip abduction +theraband in standing 0-30 degrees 2. Hip external rotation in sitting + theraband 0-30 degrees	Week 3-4 red (25) green (25) blue (25) Week 5-6 green (20) blue(20) black (20) Week 7-8 green (25) blue(25) black (25)				
Nakagawa et al 2008	Control group- 1. Stretches (all exercise sessions) • Sitting hamstring stretch 3 repetitions/30 secs hold • Sitting patellar mobilization • Standing quadriceps stretch • Standing calf stretch • Standing iliotibial band stretch Weeks 1 and 2 exercises 2. Isometric quadriceps contractions while sitting with 90 degrees of knee flexion 2 sets of 10 reps 10 secs hold 3. Straight-leg raise in supine position 3 sets of 10 reps 4. Mini squats to 40degrees of knee flexion 4 sets of 10 reps Weeks 3 and 4 exercises 5. Wall slides (0–60degrees of knee flexion) 3 sets of 10 reps 6. Steps-up and steps-down from a 20-cm step 3 sets of 5 reps	Criteria- time, every 2 weeks. Increasing demand of exercise, addition of theraband		6 weeks	2 x 15 reps 5 x week	6 weeks

	7. Forward lunges (0–45degrees of knee flexion) 3 sets of 10 reps Weeks 5 and 6 exercises, as for weeks 3 and 4 plus: 8. Balance exercises: unilateral stance on the floor and on an air-filled disc, with opened and closed eyes 3 sets of 30s hold 9. Progressive walking or running programme Intervention group: Control group exercise with the addition of Weeks 1 and 2 exercises 1. Transversus abdominis muscle contraction in the quadruped position 2 sets of 15 reps 10 secs hold 2. Isometric combined hip abduction–lateral rotation in side-lying with the hips and knees slightly flexed, elastic resistance 2 sets of 15 reps 10 secs hold 3. Side-lying isometric hip abduction with extended knee 2 sets of 15 reps/10 secs hold 4. Isometric combined hip abduction–lateral rotation in the quadruped position2 sets of 15 reps/10 secs hold Weeks 3 and 4 exercises 5. Pelvic drop exercise on a 20-cm step 2 sets of 15 reps/10 secs hold					

	6. Upper extremity extension of the contralateral arm with elastic resistance performed in single-leg stance 3 sets of 10 reps 7. Rotation of the body in the direction of the contralateral side, holding an elastic resistance with the ipsilateral arm while maintaining the lower extremity static 2 sets of 15 reps 10 secs hold Weeks 5 and 6 exercises, as for weeks 3 and 4 Additional elastic resistance around the affected leg in the forward lunges to encourage lateral rotation and abduction of the hip					
Razeghi et al 2010	Knee group 1. Mini squats 2. 90-50 degrees resisted knee extension 3. Terminal knee extension Hip and knee group Bilateral symptoms 1. All hip muscles and knee extensor muscles. Details not provided. Unilateral symptoms 1. Hip muscle group if strength deficit detected compared to unaffected limb and knee extensor muscles. Details not provided.	No data		4 weeks	No data	4 weeks
Song et al 2009	Group 1. Unilateral leg press 45-0 degrees knee extension Group 2.	Exercise at 60% 1RM. Re-measured and adjusted every 2 weeks	Exercise groups Quadriceps, hamstring, ITB, calf stretches	8 weeks	5 x 10 reps 60% 1RM 3 x week	8 weeks

	Unilateral leg press 45-0 degrees knee extension plus theraband abduction force of 50N Control group No exercise					
Boling et al 2006	week 1 1. Wall slides (0-40 degrees knee flexion) 2. Lateral step-down off 4" step 3. Single leg heel raises 4. Theraband front pull (standing on injured limb and perform standing resisted hip flexion with the contralateral limb) week 2 1. Wall slides (0-40 degrees knee flexion with theraband resistance around knees) 2. Lateral step-down off 6" step 3. Single leg heel raises on airex balance pad 4. Theraband diagonal pull (single leg stance on injured limb and perform standing resisted hip flexion in a diagonal pattern) week 3 1. Wall slides (0-40 degrees knee flexion standing on airex balance pad with theraband resistance around knees) 2. Lateral step-down off 4" step with theraband resistance pulling knee anteriorly 3. Single leg stance on airex balance pad bouncing ball off wall 4. Mini-squat (0-30 degrees knee flexion) week 4 1. Mini squat (0-30 degrees knee flexion) on airex balance pad	Progressed when exercise pain-free. Increasing demand of exercise	Hamstring(sitting), quadriceps (standing), TA stretches	6 weeks	3 x 10 reps 3 x week (1 supervised, 2 xhome)	6 weeks

	2. Lateral step-down off 6" step with theraband resistance behind knee pulling anteriorly 3. Backward walk with theraband resistance around ankles (subjects stand with slight knee flexion and take steps backwards with resistance between ankles) 4. Forward lunges onto 8" step without push-off (subjects lunge onto 8" step to 40 degrees knee flexion) week 5 1. Single leg mini squat (0-30 degrees knee flexion) 2. Lateral step-down off 4" step standing on airex balance pad with theraband resistance behind knee pulling anteriorly 3. Side-stepping with theraband resistance around ankles (subjects stand in slight knee flexion and take steps laterally with resistance between ankles) 4. Forward lunges onto 8" step with push-off (subjects lunge onto step to 40 degrees flexion and push-off to starting position) week 6 1. Single leg mini squat (0-30 degrees knee flexion) standing on airex balance pad 2. Lateral step-down off 6" step standing on airex balance pad with theraband resistance pulling anteriorly 3. Monster walks with theraband resistance around ankles (subjects stand with 30 degrees knee flexion and walk forward with resistance between ankles)					

	4. forward lunges to ground level (subjects lunge on level surface to 40 degrees knee flexion)					
Earl and Hoch 2011	<u>Phase 1 (weeks 1-2)</u> Abdominal exercise and OKC abduction GOAL- improve volitional control of hip and core muscles 1. Abdominal draw in exercises 2. Side-lying clamshells 3. Side-lying SLR 4. Supine arm/leg extensions 5. Quadruped arm/leg extensions 6. Isometric single leg stance 7. Hamstring stretch 8. Quadriceps stretch 9. Calf stretch <u>Phase 2 (weeks 3-5)</u> OKC abduction with load, CKC functional exercise, increasing demand of abdominal exercise GOAL- restore reflex contractions to perturbations 1. Isometric single leg stand with hip abduction 2. Single leg cable column exercise • Facing towards weights • Facing away from weights • Beside weights 3. Single leg stand quick kicks 4. Prone plank exercises 5. Side plank exercises 6. Bilateral mini squat 7. Hamstring stretch 8. Quadriceps stretch 9. Calf stretch	Progression based on ability to perform exercise. <u>Dynamic exercise</u> 3 x 10 reps 3 x 15 reps 3 x 20 reps <u>Isometric exercise</u> 2 x 15 reps 10sec hold-progress by adding weight (2.5-5lb) or resistance(up one level/colour theraband)	LL stretches	8 weeks	3 x week plus 8-15 supervised rehabilitation sessions over 8 week period	8 weeks

	10. ITB "pretzel" stretch Phase 3 (weeks 6-8) CKC functional exercise with load or increasing demand GOAL- restore pattern generated movements 1. Monster walks 2. Single leg stand with sports specific upper body movement 3. Mini-squat progression (mini-lunge – single leg stand- step-down) 4. Hamstring stretch 5. Quadriceps stretch 6. Calf stretch 7. ITB "pretzel" stretch					
Ferber et al 2011	Exercise group 1. Hip abduction +theraband in standing 2. Hip abduction/extension + theraband in standing 45 degree angle extension/abduction Control group- no exercise	Reviewed after 7-10 days Increased theraband resistance if too easy		3 weeks	3 x 10 reps both legs daily	3 weeks
Khayambashi et al 2014	Hip exercise group 1. OKC hip abduction 0-30 degrees against theraband resistance in side-lying 2. OKC hip external rotation 0-30 degrees against theraband resistance in sitting, knee flexion 90 degrees Quadriceps exercise group	Progressed every 2 weeks Theraband colour/resistance (reps) Week 1-2 red (20) green (20) blue (20) Week 3-4 red (25)		8 weeks	3 x 20/25 reps 3x week (supervised) Exercises bilaterally in bilateral PFP, unilaterally in unilateral PFP	8 weeks

	1. OKC knee extension from 30 degrees flexion to full extension, in sitting, against theraband resistance 2. Partial squatting 30 degrees flexion to full extension against theraband resistance, while squeezing ball between knees	green (25) blue (25) Week 5-6 green (20) blue(20) black (20) Week 7-8 green (25) blue(25) black (25)				
Lowry 2008	Non-weight bearing exercise 1. Isometric abdominal bracing in hook-lying with heel slide, bent knee lifts and SLR 2. Bridging 3. Side-lying clamshells 4. Quadruped hip extension with opposite shoulder flexion 5. Quadruped hip abduction/extension Weight bearing exercise 1. Double leg press on gym machine 2. Single leg press on gym machine 3. Eccentric step-downs from step 4. Eccentric side step-downs from step 5. Hip abduction on side-stepping with theraband resistance 6. Squats 7. Lunges 8. "clock balance and reach" (single leg stand, reach with opposite heel to 12:00, and to the side (1:00) and so forth in a circle	Non weight bearing exercises for 2 weeks until achieved 2x10 reps	Stretches Piriformis Gluteals Hamstrings Quadriceps ITB Gastrocnemius/soleus Manual therapy to lumbar spine, hip, patellofemoral and tibiofemoral joints Taping if relieved pain on step-down test Orthotics if excessive pronation (defined >3mm drop in functional activity)	6-14 weeks	Exercises individualised per patient, 1-2 x daily, no further detail	At D/C and 6 months
Mascal 2003	1. Non-weight-bearing OKC hip abduction, gluteus medius and gluteus maximus exercises	Criteria - ability to achieve 2 x15 reps or 10 secs		14 weeks	2-3 x 10-15 reps 2 x daily	14 weeks

	2. Weight-bearing in single leg stance 3. Functional exercise	isometric hold. Progressed to increasing demand of exercise.				
Tyler 2006	<u>Phase 1</u> 1. Hip progressive resisted exercise(PREs) seated hip flexion, adduction, extension, abduction 2. Modalities prescribed as needed 3. Stretching manual and self (hip flexors, Quads , ITB,) 4. Hip PREs self stretching 5. Manual therapy: medial and lateralretinaculum 6. Mini squats 7. Balance exercises- unilateral stance, balance board, etc 8. Step-ups varying height of step, reps and speed 9. Upper extremity reaches <u>Clinical milestones</u> • Ability to mini-squat to 45 degrees without pain • Improved stability with unilateral stance • Step-ups from 4"platform with no pain and good concentric control • Minimal to no pain on therapeutic exercises <u>Phase 2</u> 1. Continue with hip PREs 2. Patient resumes self stretching, continue manual stretching	Specific criteria for progression based on ability to perform exercises	Manual therapy to PFJ Manual and self LL stretches	6 weeks	Daily, no further information	6 weeks

	3. Lower extremity reaches focus on weakest plane of motion 4. Step-downs varying height of step, reps and speed 5. Increase difficulty of balance exercises <u>Clinical milestones</u> • Step-downs from 4" platform with no pain and good eccentric control • Progress reaches by moving further from target and increasing speed <u>Phase 3</u> 1. Home stretching discontinue manual stretching if necessary 2. Discontinue reaches perform other activities that focus on same deficit 3. Plyometrics/agility exercises 4. Lunges 5. Return to sport activities <u>Return to activity clinical milestones</u> • Vertical jump test (<20% normative height data adjusted for body size) • Functional hop test for distance(pain free) • Pain free sports specific test (comparable sign)					

<u>Key:</u>

OKC- open kinetic chain

CKC- closed kinetic chain

SLR- straight leg raise

RM- repetition maximum

PRE – progressive resisted exercise

Reps- repetitions

Secs - seconds

LL- lower limb

PFJ-patellofemoral joint

<u>Table 8 Exercises known to recruit Gluteal muscles</u>(Reiman et al., 2011).

	Very high activation Gluteus maximus		High activation Gluteus maximus		Moderate activation Gluteus maximus		Very high activation Gluteus medius		High activation Gluteus medius		Moderate activation Gluteus medius	
	Proximal exercise	Control Group	Proximal exercise	Control Group	Proximal exercise	Control Group	Proximal exercise	Control Group	Proximal exercise	Control Group	Proximal exercise	Control Group
Avraham et al., 2007			SLSq	SLSq			SLSq	SLSq				
Baldon et al., 2014		Step-up	Single leg deadlift	Wall-squat Step-down	Forward lunge		Lateral bridge		Pelvic drop Single leg deadlift	Step-up Wall-squat	Forward lunge	
Boling et al., 2006		N/C	Wall slides Lateral step-down SLSq		Forward lunge		SLSq		Wall slide Lateral step-down		Forward lunge	
Coppack et al., 2011			SLSq step-down				SLSq				Forward lunge step-down	
Dolak et al., 2011			Wall slide Lateral step-down, SLSq		Addition side-ly OKC abd	Forward lunge	SLSq		Wall slide Lateral step-down Addition side-ly OKC abd		Forward lunge	
Earl et al., 2011		N/C	SLSq Quad		Clam Side-ly OKC abd		SLSq		Side-ly OKC abd, Quad		Prone-plank, clam	
Ferber et al., 2011		N/C										

Ferber et al., 2014				SLSq, Lateral step-down Wall squat		Forward lunge		SLSq		Lateral step-down Wall squat		Forward lunge
Fukuda et al., 2010					Addition side-ly OKC abd				Addition side-ly OKC abd			
Fukuda et al., 2012					Addition side-ly OKC abd				Addition side-ly OKC abd			
Ismail et al., 2013	Forward step-up		Lateral step-up		Addition side-ly OKC abd				Forward step-up Lateral step-up	Addition side-ly OKC abd		
Khayambashi et al., 2012		N/C										
Khayambashi et al., 2014					Side-ly OKC abd					Side-ly OKC abd		
Lowry et al., 2008		N/C	Quad		Clam, forward lunge				Quad		Forward lunge, clam	
Mascal et al., 2003		N/C	SLSq		Side-ly OKC abd		SLSq		Side-ly OKC abd			
Nakagawa et al., 2008		Step-up		Wall slide	Additionside-ly OKC abd	Forward lunge			Addition side-ly OKC abd, pelvic drop	Step-up Wall slide		Forward lunge
Razeghi et al., 2010												
Song et al., 2009		N/C										
Tyler et al., 2006	Step-up	N/C			Forward lunge				Step-down		Forward lunge	

OKC- open kinetic chain

Quad- Quadruped, contralateral arm/leg lift

SLSq- Single leg squat

Abd- abduction

Side-ly- side lying

N/C – no control exercise group

Effect of hip strengthening exercise on pain

All studies demonstrated that hip exercises in PFP resulted in a reduction in pain from baseline values (table 9). Six studies used the visual analogue scale (VAS) for usual or worst pain and achieved the minimally clinically important difference (MCID) in patellofemoral pain of 2cm (Crossley et al., 2004).

All control exercise programmes demonstrated a significant improvement in pain. There was superior improvement in the hip group in seven studies, although this did not consistently reach clinical significance.

Pain was significantly reduced in all four studies that investigated the addition of hip exercises to an exercise protocol. Three added OKC hip exercises; all demonstrated a significant reduction in pain in the hip group compared to the control group, with two demonstrating change above the MCID in patellofemoral pain of 1.2 on the numerical pain rating scale (Piva et al., 2009) in the hip group only.

All three studies that compared hip and knee exercise demonstrated a significant reduction in pain in both groups which was above VAS MCID levels in two studies, with superior results in the hip group in one which was maintained at six month follow-up. One compared initial OKC hip or knee exercises prior to functional exercises; only the hip group had a significant reduction in pain after the initial exercise. There was no between group difference at the end of the exercise programme.

Effect of hip strengthening exercise on function

All fourteen studies that evaluated function demonstrated a significant improvement (table 9). Although the majority of exercise programmes demonstrated functional improvement there were superior results for proximal exercise across all protocols. Seven studies used the anterior knee pain scale achieving a change in ten points which signifies a clinical difference in PFP (Crossley et al., 2004) and five the lower extremity functional scale achieving a MCID of nine points.

Three of the four studies that investigated the addition of hip exercise to a standard programme used a functional outcome and demonstrated improvement in both groups. All demonstrated a clinically relevant change with proximal exercise which only occurred in one measure in one study for the control exercise.

Studies that compared hip and knee exercise demonstrated a significant improvement in both groups, with superior results in the hip groups, reaching significance in one which was maintained at six month follow-up.

There were greater functional gains with proximal strengthening exercise including instruction on lower limb alignment although both groups reached clinical significance (Baldon et al., 2014).

Effect of hip strengthening exercise on kinematics

Evidence for improvement in kinematics was conflicting (table 9). One study demonstrated no change; two showed an improvement, but both included instruction on lower limb alignment with the strengthening exercise.

Effect of hip strengthening exercises for the prevention of PFP

The incidence of PFP after hip strengthening exercise was reduced (table 9).

Table 9 Outcome measures with strengthening exercise

Study	Pain outcome	Functional outcome	Other
Avraham et al 2007	VAS (no detail specified) No numerical data recorded Bar graphs with p values comparing groups demonstrated reduction in pain in all groups; greater reduction in hip and hip & knee exercise groups	Patellofemoral evaluation scale No numerical data recorded Bar graphs with p values comparing groups demonstrated improvement in function in all groups; greater reduction in hip and hip & knee exercise groups	
Baldon et al 2014	VAS (cm)(worst pain previous week) Both groups less pain at 8 weeks and 3 months p<0.001 FST group less pain than ST group at 8 weeks p=0.06 and 3 months p=0.04 Standard training (ST):6.1+/-1.8 to 3.1+/-3.2 (8 weeks) to 2.5+/-2.7 (3 months) Functional standard training (FST): 6.6+/-1.1 to 1.4+/-1.4 (8 weeks) to 0.9+/-1.5 (3 months)	LEFS Both groups improved score p<0.001, not significant between groups p=0.07 ST: 57.6+/-7.2 to 70.6+/-8.0 (8 weeks) to 70.4+/-8.4 (3 months) FST: 55.4+/-12.8 to 74.3+/-4.6(8 weeks) to 74.9 +/-3.9 (3 months) Single leg triple hop (cm): only hip group improved from baseline p<0.001 greater distance than quadriceps group at 8 weeks p=0.04 ST: 325.1+/-82.4 to 330.1+/-72.5 (8 weeks) FST: 336.4 to 375.3 +/-48.3 (8 weeks)	GRC (scale -7-+7) Subjects at least +4 in GRC scale ST: 75% 12/16 subjects(8 weeks) 69% 11/16 subjects (3 months) FST: 100% 14/14 subjects (8 weeks) 92% 12/13 subjects (3 months) Kinematics **Sagittal plane:** Trunk extension(+) flexion(-) ST -3.0+/-6.7 to -3.7+/-5.5 FST -0.9+/-7.8 to -4.1+/-9.4 Between group difference in change score FST-ST groups -2.5 (-6.1, 1.0) Pelvic anteversion(+) retroversion(-) ST 13.1+/-6.5 to 11.2+/-8.3 FST 16.4+/-8.9 to 24.7+/-9.3 Between group difference in change score FST-ST groups 10.3 (4.2, 16.3)

			FST statistically different from baseline p<0.05 and between groups p<0.05 Hip flexion(+) extension (-) ST 46.9+/-9.3 to 45.4+/-12.3 FST 52.5+/-14.6 to 67.5+/-14.0 Between group difference in change score FST-ST groups 16.4 (6.3, 26.6) FST statistically different from baseline p<0.05 and between groups p<0.05 **Frontal plane** Trunk ipsilateral(+) contralateral(-) inclination ST 7.3+/-3.4 to 7.5+/-4.2 FST 9.7+/-4.1 to 6.8+/-2.6 Between group difference in change score FST-ST groups -3.1 (-0.6, -5.6) FST statistically different from baseline p<0.05 Pelvis elevation(+) depression(-) ST -7.3+/-3.3 to -7.2+/-3.0 FST -11.1+/-4.4 to -7.3+/-4.4 Between group difference in change score FST-ST groups 3.7 (0.9, 6.4) FST statistically different from baseline p<0.05 Hip adduction(+) abduction(-) ST 17.1+/-4.3 to 15.4+/-4.6 FST 23.5+/-6.2 to 12.3+/-6.9 Between group difference in change score FST-ST groups -9.6 (-12.7, -6.4)

			FST statistically different from baseline $p<0.05$ Knee adduction(+) abduction(-) ST -11.0+/-7.2 to -10.9+/-7.4 FST -12.3+/-5.2 to -9.0+/-6.3 Between group difference in change score FST-ST groups 3.3 (0.3, 6.2) FST statistically different from baseline $p<0.05$
Coppack et al 2011	N/A	N/A	36 new cases of anterior knee pain in control group = 4.8% incidence. 10 medically discharged, 16 completed training,10 other. 10 new cases anterior knee pain in intervention group = 1.3% incidence. 1 discharged ("unfit for army service", not medically discharged) 9 completed training.
Dolak et al 2011	VAS (cm) 0-10(worst pain in the last week) At 4 weeks Hip group VAS less than knee group p= 0.035 (hip 2.4 +/- 2, knee 4.1 +/- 2.5) Hip group baseline 4.6+/-2.5 significantly less at 4 weeks (2.4+/-2) p= 0.001, and at 8 weeks (2.4+/-2.8) p= 0.003, 2.1+/-2.5 at 3 months Knee group baseline 4.2+/-2.3, not significantly diff to baseline at 4 weeks(4.1+/-2.5) , significantly less at 8 weeks (2.6+/-2.0) than baseline p=0.028, 2.4+/-2.3 at 3 months	LEFS-0-80 improved regardless of protocol p=0.006 Hip group baseline 59+/-12, 4 weeks 67+/-11, 8 weeks 70+/-10, 3 months 70+/-10 Knee group baseline 54+/-12, 4 weeks 59+/-14, 8 weeks 65+/-13, 3 months 67+/-11 Step down test (no reps in 30 secs) Improved regardless of protocol $p<0.001$ Hip group baseline 15+/-5, 4 weeks 17+/-5, 8 weeks 19+/-5	Isometric strength Hip Abductor strength Hip group increase from baseline to 8 weeks p=0.001 Hip group baseline 5.2+/-1.5, 4 weeks 6.2+/-1.1, 8 weeks 6.6+/-0.9 Knee group baseline 5.7+/-2.2, 4 weeks 5.5+/-1.9, 8 weeks 6.2+/-1.8 Hip External Rotator strength Increased over 8 weeks both groups p=0.004

		knee group baseline 14+/-8, 4 weeks 17+/-7, 8 weeks 20+/-6	Hip group baseline 2.1+/-0.7, 4 weeks 2.5+/-0.7, 8 weeks 2.7+/-0.7 Knee group baseline 2.1+/-1.0, 4 weeks 2.5+/-0.7, 8 weeks 2.7+/-0.7 Knee Extensor strength No effect Hip group baseline 6.1+/-2.6, 4 weeks 6.8+/-1.9, 8 weeks 7.0+/-1.4 Knee group baseline 6.3+/-2.1, 4 weeks 6.1+/- 1.9, 8 weeks 6.6 +/-1.9
Ferber et al 2014	VAS (cm)(worst pain in the last week) Knee group Baseline 4.96+/-1.66 At 6 weeks 1.99+/-2.05 p<0.05 Difference 2.98+/-2.08 Hip group Baseline 5.12+/-1.66 At 6 weeks 1.96+/-1.92 p<0.0 Difference 3.11+/-2.22	AKPS Knee group Baseline 75.62+/-9.81 At 6 weeks 87.67+/-10.53 p<0.05 Difference 12.90+/-13.55 Hip group Baseline 75.00+/-9.74 At 6 weeks 87.95+/-11.26 p<0.05 Difference 12.58+/-11.93	MVIC All results p<0.05 compared to baseline Hip abductor Knee group Baseline 3.15+/-1.19 At 6 weeks 3.41+/-1.28 % change 8.21 Hip group Baseline 3.21+/-1.14 At 6 weeks 3.58+/-1.08 % difference 11.46 Hip group improved greater than knee group p<0.05 Hip extensor Knee group Baseline 2.44+/-1.09 At 6 weeks 2.61+/-1.18 % change 7.13 Hip group

			Baseline 2.39+/-1.01 At 6 weeks 2.66+/-1.15 % difference 11.34 Hip group improved greater than knee group p<0.05 Hip external rotator Knee group Baseline 11.18+/-0.45 At 6 weeks 1.25+/-0.44 % change 5.87 Hip group Baseline 1.19+/-0.42 At 6 weeks 1.29+/-0.41 % difference 8.33 Hip internal rotator Knee group Baseline 1.42+/-0.64 At 6 weeks 1.49+/-0.62 % change 5.43 Hip group Baseline 1.48+/-0.55 At 6 weeks 1.56+/-0.59 % difference 5.42 Knee extensor Knee group Baseline 3.93+/-0.47 At 6 weeks 4.18+/-1.60 % change 6.37 Hip group Baseline3.88+/-1.59 At 6 weeks 4.19+/-1.50 % difference8.04

Fukuda et al 2010	NPRS- 0-10 Ascending stairs Controls 4.9+/-2.5 to 5.0+/-2.5 Knee -4.9+/-2.9 to 3.4+/-2.3 Hip – 5.2+/-1.6 to 3.0+/-1.8 Descending stairs Controls- 4.4+/-2.4 to 4.1+/-2.3 Knee group- 4.5+/-2.8 to 3.5+/-2.5 Hip group- 4.9+/-1.6 to 2.3+/-1.5 At 4 weeks only hip group significantly reduction in pain p<0.01compared to baseline At 4 weeks knee and hip group significantly lower than controls, not between groups p<0.01 Lack of significant difference between knee and hip groups, both groups improved more than controls p<0.05 But hip group showed greater difference for all scales than knee group	AKPS 0-100 Controls- 63.8+/-15.5 to 64.5+/-11.1 Knee group- 70.4+/-12.5 to 80.6+/-13.9 p<0.05 Hip group -63.9+/-11.7 to 78.9+/-16.0 p<0.01 Single limb hop (cm) Controls 81.0+/-25.5 to 80.3+/-16.0 Knee group- 76.1+/-37.7 to 86.5+/-32 p<0.05 Hip group- 76.1+/-33.8 to 91.8+/-34.4 p<0.05 LEFS 0-80 Controls 48.8+/-17.0 to 51.2+/-15.1 Knee group- 55.6+/-15.9 to 65.6+/-14.5 p<0.05 Hip group 49.1+/-11.9 to 65.7+/-13.5 p<0.05	
Fukuda et al 2012	NRPS 0-10 Ascending stairs Knee group 6.6+/-1.2 to 5.3+/-1.3 (3 months) 5.5+/-1.2 (6 months) 6.5+/-1.0 (12 months) Hip group 6.2+/-1.1 to 1.2+/-1.1 (3 months) 1.7+/-1.0 (6 months) 2.9+/-0.8 (12 months) Descending stairs Knee group 6.4+/-1.4 to 5.0+/-1.2 (3 months) 5.6+/-1.4 (6 months) 6.4+/-1.1 (12 months)	LEFS 0-80 Knee group 49.0+/-13.0 to 49.4+/-11.2 (3 months) 47.7+/-10.5 (6 months) 46.1+/-10.9(12 months) Hip group 51.7+/-10.4 to 74.1+/-5.6 (3 months) 72.4+/-6.1 (6 months) 69.6+/-5.2 (12 months) AKPS 0-100 Knee group 61.8+/-9.0 to 64.6+/-10.2 (3 months) 62.0+/-9.3 (6 months) 60.0+/-8.3 (12 months) Hip group 65.9+/-8.5 to 85.7+/- 9.0 (3 months) 81.7+/-7.6 (6 months) 79.0+/- 7.7 (12 months)	

	Hip group 5.8+/-1.2 to 1.6+/-1.1 (3 months) 2.0+/-0.8 (6 months) 2.5+/-0.9 (12 months)	Single hop test (cm) Knee group 61.7+/-22.6 to 69.9+/-21.8 (3 months) 67.3+/-21.5 (6 months) 65.6+/-21.2 (12 months) Hip group 69.9+/-10.4 to 85.7+/-10.2 (3 months) 84.0+/-10.9 (6 months) 82.3+/-10.2 (12 months)	
Ismail et al 2013	VAS (cm) (average pain in last week) CKC Group 4.5+/-1.8 to 2.3+/- 1.1 Difference 2.26+/-1.3 CKC+OKC Group 5.3+/-1.6 to 2.0+/-1.1 Difference 3.2+/-0.9	AKPS 0-100 CKC Group 76.4+/- 10.4 to 85.0+/- 6.7 Difference 8.6+/-7.3 CKC+OKC Group 71.5+/-7.8 to 85.1+/-6.2 Difference 13.7+/-5.5	Isokinetic strength Both groups improved from baseline p<0.05 Hip abductor concentric CKC group 2.1+/-0.6 to 2.5+/-0.7 (6 weeks) CKC+OKC group 1.7+/-0.6 to 2.4+/-0.8 (6 weeks) Hip abductor eccentric CKC group 2.2+/-0.5 to 2.4+/-0.5 CKC+OKC group 2.0+/-0.6 to 2.4+/-0.8 (6 weeks) Hip external rotator concentric CKC group 1.0+/-0.4 to 1.2+/-0.4 CKC+OKC group 0.9+/-0.6 to 1.3+/- 0.6 Hip external rotator eccentric CKC group 1.4+/-0.4 to 1.6+/-0.3 (6 weeks) CKC+OKC group 1.4+/- 0.4 to 1.8+/-0.8
Khayambashi et al 2012	VAS (cm)(average pain of both knees while performing activities that aggravated symptoms during the previous week) Exercise group 7.9+/-1.7 to 1.4+/-1.9 at 8 weeks p<0.001 remained reduced at 6 months(1.7+/-2.7) control group 6.6+/-2.0 to 6.7+/-2.4	WOMAC 0-96, larger numbers indicating worse health status Exercise group 54.0+/-18.1 to 10.7+/-16.1 p<0.001 Control group 55.9+/-15.7 to 59.9+/-12.6	Isometric strength Hip Abductor strength Hip group Right side 11.6+/-2.3 to 15.3+/-2.5 (8 weeks)p<0.001 Left side- 11.2+/-2.7 to 15.9+/-3.1(8 weeks)p<0.001 Control group Right side 12.3+/-2.9 to 11.2+/-2.5

			Left side - 12.5+/-3.7 to 11.4+/-3.1 (8 weeks) Hip External Rotator strength Hip group Right side 8.6+/-2.3 to 11.8+/-2.2 (8 weeks)p<0.001 Left side - 7.0+/-1.8 to 10.9+/-2.6 (8 weeks)p<0.001 Control group R side 8.9+/-2.1 to 8.3+/-2.3 (8weeks) Left side 7.5+/-1.6 to 7.3+/-1.9 (8weeks)
Nakagawa et al 2008	VAS (cm) Controls Usual pain 4.7+/-2.6 to 4.0+/-2.6 p=0.31 Worst pain 5.5+/-1.5 to 3.4+/-1.9 p=0.2 Stair climbing 5.0+/-3.4 to 2.6+/-2.8 p=0.13 Descending stairs 4.7+/-3.3 to 2.0+/-2.4 p=0.43 Squatting 4.8+/-3.0 to 3.0+/-3.1 p=0.12 Prolonged sitting 5.2+/-2.8 to 2.9+/-3.1 p=0.09 Intervention group- Usual pain 3.8+/-2.1 to 1.1+/- 1.2 p=0.03 Worst pain 5.0+/-2.1 to 1.4+/-1.3 p=0.03 Stair climbing 3.5+/-3.7 to 0.4+/-0.6 p=0.04 Descending stairs 4.5+/-3.1 to 0.3+/-0.4 p=0.03 Squatting 5.7+/-3.2 to 0.4+/-0.6 p=0.02 Prolonged sitting 2.0+/-3.2 to 1.1+/-1.6 p=0.14		Gluteus medius EMG during MVIC Controls- 72.3+/-42.7 to 57.0+/-36.6 p=0.31 Intervention group- 51.7+/-29.5 to 127.8+/-145.6 p=0.03 Gluteus medius EMG during eccentric contraction Controls – 72.3+/-50.2 to 74.6+/-74.0 p=0.31 Intervention group- 57.6+/-46.6 to 96.4+/-122.9 p=0.24 Isokinetic eccentric peak torque(Nm/kg) Knee extensor Controls 283.6+/-45.0 to 301.9+/-63.4 p=0.02 Intervention group 264.9+/-84.8 to 318.9+/-96.8 p=0.04 Hip abductor

			Controls 114.6+/-32.1 to 120.4+/-30.4 Intervention group 89.1+/-29.5 to 102.2+/-19.8 Hip lateral rotator Controls 60.4+/-16.5 to 62.9+/-24.9 Intervention group 55.5+/-14.6 to 59.4+/-18.9
Razeghi et al 2010	VAS(no detail recorded) Hip and knee group 6.68+/-1.62 to 3.37+/-1.5 p=0.001 Knee group 6.31+/-1.25 to 4.81+/-1.79 p=0.005		Isometric muscle strength of hip flexors, abductors, external rotators, internal rotators, adductors and extensors measured. No numerical data recorded for specific exercise groups. Pooled data recorded for successful versus unsuccessful treatment (defined as 1.5cm reduction in VAS) irrespective of group.
Song et al 2009	VAS (cm)(worst pain previous week) Leg press group- 4.85+/-2.49 to 2.26+/-2.2 p<0.005 Leg press plus hip adduction group 4.8+/-2.26 to 2.62+/-2.51 p<0.005 Controls 4.99+/-2.18 to 4.81+/- 2.55 p=0.715	Lysholm scale Leg press group 75.7+/-12.8 to 86.5+/-10.4 p<0.005 Leg press plus hip adduction group 74.8+/-12.1 to 85.7+/-8.5 p<0.005 Controls 75.1+/-9.3 to 75.7+/-10.9 p=0.714	VMO cross-sectional area (cm^2) Leg press group 3.75+/-1.59 to 4.46+/-1.90 p<0.005 Leg press plus hip adduction group 3.67+/-1.45 to 4.24+/-1.43 p=0.004 Controls 3.39+/-1.47 to 3.38+/-1.52 p=0.962 VMO volume (cm^3) Leg press group 3.38+/-2.37 to 4.45+/-2.52 p<0.005 Leg press plus hip adduction 3.04+/-2.18 to 4.12+/-1.83 p<0.005 Controls 2.76+/-2.01 to 2.82+/-1.91 p=0.838

Boling et al 2006	VAS(no detail recorded) no values recorded PFP group reduced pain p=0.001, control group no change, significant by group interaction p=0.001	FIQ No values recorded Increased for PFP group from baseline, control group ISQ, group interaction effect p=0.001	Gluteus medius onset ascending stairs PFP group -81.64+/-153.33 to -49.56+/-136.7 Controls -19.54+/-52.21 to -32.38+/-41.34 Gluteus medius onset descending stairs PFP group -158.93+/-69.30 to -133.76+/-96.17 Controls -154.26+/-58.70 to -131.95+/-59.94 Gluteus medius duration ascending stairs PFP group 631.67+/-74.03 to 578.48+/-148.17 Controls 621.77+/-152.34 to 606.64+/-154.35 Gluteus medius duration descending stairs PFP group 329.64+/-85.85 to 303.24+/-125.31 Controls 363.43+/-145.72 to 357.46+/-165.35 Onset- significantly earlier during descent compared with ascent, duration in concentric phase longer than eccentric Pre and post test values onset/duration no significant

			difference and no significant difference between groups
Earl and Hoch 2011	VAS (mm)(usual pain in a day) 40 +/-18 to 5+/-7p<0.0005, 15 improved >20mm	AKPS 70.4+/-11.2 to 83.7+/-11.2 p=0.001, 2 unsuccessful	
Ferber et al 2011	VAS (cm)(average amount of pain during past week when running) 5.8+/-2.10 to 3.30 +/-1.90 43.1% reduction in score p=0.01		Peak genu valgum angle no different to baseline p=0.55 or to control group p=0.65 Stride-stride variability PFP increased from baseline p=0.01, no differences to control group p=0.36 Controls- no significant diff from baseline
Khayambashi et al 2014	VAS(cm) ("based on activities that aggravate pain in the last week") Hip group 7.63+/-1.79 to 2.11+/-1.6 (8 weeks) to 2.00+/-1.97 (6 months) Knee group 6.91+/-1.94 to 3.27 +/- 2.19 (8 weeks) to 4.00+/-2.44 (6 months)	WOMAC (0-96) Hip group 46.83+/-21.86 to 6.22+/-3.87 (8 weeks) to 6.94+/-5.70 (6 months) Knee group 44.11+/-22.05 to 21.89+/-16.55 (8 weeks) to 23.16+/-14.15 (6 months)	
Lowry 2008	VAS(no definition) Pt 2- 7/10-to 3/10 at D/C 2/10 (6 months) Pt 3- 6/10-to 1/10 at D/C to 0/10 (6 months) Pt 4- 2/10-to 0/10 at D/C to 2/10 (6 months) Pt 5- 8/10-to 3/10 at D/C to 0/10 (6 months)	AKPS Pt 2- 85 to 93 at D/C 93 (6 months) Pt 3 69 to 100 at D/C to 100 (6 months) Pt 4- 69 to 84 at D/C to 87 (6 months) Pt 5- 31 to 78 at D/C to 89 (6 months) LEFS	

		Pt 2- 71 to 75 (D/C) to 72 (6 months) Pt 3- 59 to 77(D/C) to 80 (6 months) Pt 4 - 58 to 68 (D/C) to 76 (6 months) Pt 5 28 to 61(D/C) to 69 (6 months) GRC Pt 2- 0 (4th visit) to 0 (6 months) Pt 3- 6 (4th visit) to 7 (6 months) Pt 4 4 (4th visit) to 3 (6 months) Pt 5 6 (4th visit) to 7 (6 months)	
Mascal 2003	VAS (greatest amount of pain during most pain provoking activity) improved from 10/10 to 2/10	AKPS improved from 70 to 84	No kinematic data
Tyler 2006	VAS (cm)(with ADL) With exercise 5.8+/-0.4 to 3.0+/-0.4 p<0.001 Treatment success defined minimum 1.5cm reduction- 26 knees (21pts) successful, 17 knees (14pts) unsuccessful		

VAS-visual analogue scale

WOMAC- Western Ontario and McMaster Universities questionnaire

AKPS- anterior knee pain scale

ADL- activities of daily living

FST- functional stabilisation training

LEFS- lower extremity functional scale

pt- patient

ST- standard training

NRPS- numerical rating pain scale

OKC- open kinetic chain

CKC- closed kinetic chain

GRC -Global rating of change

PFP- patellofemoral pain

Neuromuscular exercise

Two case series including 20 female runners with both unilateral and bilateral PFP, aged 18-45 years investigated neuromuscular exercise (Tables 10-11). One paper analysed the dominant leg in subjects with bilateral symptoms, the other the limb with more marked hip adduction when running.

Table 10 Study characteristics of neuromuscular control exercise

Study	Study design	Population	Sample size	Sample size calculation	Age	Gender	Inclusion	Unilateral/bilateral PFP
Noehren et al 2011	Case series	Runners	10	Yes	23.3 years (5.8) Range not recorded	female	Duration >2/12 VAS >4/10	Unilateral/bilateral If bilateral PFP leg with greater hip adduction used for analysis
Willy & Davis 2012	Case series	Runners	10	Yes	18-40 years	female	VAS >3/10 when running	Unilateral/bilateral If bilateral most dominant limb used for analysis
Willy & Davis 2013	Case study of 2 runners from paper above, additional data	Runners	2	N/A	18-40years	female		One unilateral, one bilateral- most painful knee assessed

PFP- patellofemoral pain

VAS- visual analogue scale

Table 11 Exercise protocols: Neuromuscular exercise

Study	Exercise	Progression	Time frame for exercise	Frequency of exercise	Follow up period
Noehren et al 2011	Real time kinematic visual feedback of hip adduction during stance phase in 30 minute run	Increase in running time from 15 to 30 minutes. Reduction in visual feedback from continual over last 4 sessions	2 weeks	4 x week	1 month
Willy, Scholz & Davis 2012	Real time mirror visual feedback of hip adduction and internal rotation during stance phase in 30 minute run	Increase in running time, from 15 to 24 minutes session 1-4, 30 minutes run final session. Reduction in visual feedback over last 4 sessions from full running time to 3 minutes	2 weeks	4xweek	3 months
Willy & Davis 2013	Real time mirror visual feedback of hip adduction and internal rotation during stance phase in 30 minute run	Increase in running time, 15 minutes to 24 minutes in sessions 1-4, 30 minutes run final session. Reduction in visual feedback over last 4 sessions, last visit 3 minutes feedback.	2 weeks	4 x week	3 months

Hip neuromuscular training was effective for reducing pain, improving function and improving hip kinematics (Table 12). Pain reduced considerably, being in the region of 90% reduction in both studies, which was maintained at follow-up despite a trend for the hip mechanics to revert toward baseline.

A significant reduction in hip adduction and contra-lateral pelvic drop was evident in both studies and reduction of 23% in hip internal rotation in one (Noehren et al., 2011); this did not reach significance. There were kinematic improvements in untrained activities, in single leg squat and step-descent, demonstrating transfer of motor skill learning.

Table 12 Outcomes with neuromuscular exercise

Study	Pain	Functional outcome	Kinematics
Noehren et al 2011	VAS- pre 5.0(2.0) post 0.5(1.3) p=0.001	LEFS- pre 64.0(11) post 75.0(3.5) p=0.008	Reduction in HADD 22.0(1.5) post 16.5(2.2) Reduction in HIR 11.0(4.1) post 8.3(6.0) By 23% but not significant Pelvic drop -9.4(2.5) post -7.1(1.6) p=0.002 SLS peak HADD reduced by 3 degrees p=0.005
Willy, Scholz & Davis 2013	Reduction in pain (no data on figures) p>0.05 effect size 3.81–7.61	LEFS increase in score (no data on figures)	Running: Reduction in peak HADD 20.7(1.0) to 14.8(3.1) p=0.02, increased to 15.9 (2.7) at 1 month16.4(2.5) at 3 months Reduction in peak CPD -9(2.5) to -7.5(2.2) post to -7.5(2.3) 1 month to -7.0(2.2) at 3 months Peak Thigh ADD 9.8(1.2) to 7.2(2.7) post to 7.3(1.8) 1 month to 8.1(1.4) at 3 months HABDM -1.180(0.185) to -1.054(0.184) post to -1.074(0.173) 1 month to -1.153(0.145) 3 months HIR 8.6(5.4) to 7.1(8.7) to 6.2(7.9) to 5.7(6.3) 3 months Squat Peak HADD 11.6(3.4) to 7.6(2.6)post to 7.7(2.6) 1 month to 9.2(2.1) 3 months Peak CPD 0.6(2.0) to 2.3(2.5) to 2.6(2.6) 1 month to 2.2(2.4) 3 months Peak thigh ADD 11.5(2.0) to 10.1(2.2) to 9.8(2.2) to 10.1(1.9) HABDM -0.470(0.064) to -0.412(0.070) to -0.431(0.071) to -0.477(0.039) HIR 3.0(6.4) to 5.9(8.5) to 3.9(7.6) to 4.0(6.4) Step descent

			Peak HADD 15.1(6.8) to 11.6(3.2) to 11.1(4.2) to 11.8(4.2) Peak CPD -5.0(3.5) to -5.2(2.7) to -4.0(3.0) to -1.8(2.6) Thigh ADD7.8(2.7) to 6.8(2.2) to 6.2(2.2) to 6.4(2.0) HABDM -0.556(0.122) to -0.520(0.085) to -0.498(0.0813) to -0.506(0.083) HIR 7.0(5.7) to 7.3(8.9) to 6.0(8.8) to 8.0(5.1)
Willy & Davis 2013	Runner 1 VAS running pre 4/10 to post 0.5/10 1/12 2.5/10 3/12 0/10 step ascent pre 2/10 to post 0/10 1/12 0/10 3/12 0/10 Runner 2 pre 3.5/10 to post 0/10, 0/10 1/12, 0/10	Runner 1 LEFS post 75/80, 1 month 79/80 Runner 2 LEFS 80/80 at post, 1 months, 3 months	Running Runner 1 HADD 20.8 to 15.6 CPD -6.4 to -3.8 HIR -1.1 to 1.5 Runner 2 HADD 22.5 to 16.3 CPD -8.9 to -7.2 HIR 7.7 to 6.2 Step ascent Runner 1 HADD 16.9 to 13.9 CPD -10.5 to -6.9 HIR -9.9 to -5.4 Runner 2 HADD 14.1 to 14.6 CPD -12.6 to -14.1 HIR -1.8 to 1.4

HADD- hip adduction SLS- single leg stand HABDM-Internal hip abduction moment VAS- visual analogue scale

HIR- hip internal rotation ADD- adduction CPD- contralateral pelvic drop LEFS- lower extremity functional scale

DISCUSSION

This review aimed to investigate the outcome of hip exercise in PFP. There was strong evidence for the benefit of hip strengthening exercise and limited evidence for the benefit of neuromuscular exercise. A strength of this review was consistent support across all types of studies.

Although RCTs are considered to be the gold standard of research they can be equally or more flawed than other study designs (Grossman and Mackenzie,2005). Paradoxically, as the features that ensure the robustness of internal validity are controlled there have been questions raised about the integration of the findings from RCTs into clinical practice (Koes and Hoving 1998; Milanese, 2011). The support from observational studies with lower rigour but with higher generalisability provides a sound rationale for the use of proximal exercise in clinical practice.

Hip strengthening exercise

Hip strengthening was found to be an effective form of exercise for people with PFP. However, improvements in comparative exercise protocols were also demonstrated. There was a tendency for superior results with the hip programmes, although this was not consistent. The lack of difference in the exercise regimes may relate to choice of exercise in both the trial and control groups, confounding factors being poorly addressed and inadequate rehabilitation protocols.

The majority of studies included weight bearing exercise with eleven including exercises with high or very high activation of gluteus medius (Table 8). There was less focus on gluteus maximus, with four studies including exercises that have demonstrated high level activation. However, it was common for control exercise groups to include exercises that activated gluteal muscles to a high level; this occurred in nine studies including all three studies that compared knee and hip protocols.

Only one study solely compared OKC hip and OKC knee exercise (Dolak et al., 2011). There was a 43% reduction in pain in the hip group compared to less than 3% for the knee group after a four week programme which was followed by functional exercises for both groups.The second phase was predominantly exercises in single leg stance. There was no between group difference at the end of the programme, but there were more pronounced differences in the hip group with all outcome measures. It could be argued that this was mainly targeted towards proximal strengthening, supported by the fact that both groups showed improvement in hip external rotator but not quadriceps strength.

The addition of OKC hip exercise to an exercise programme resulted in superior improvements in pain and function that were clinically relevant. However, all included OKC external rotation exercises at 90 degrees flexion. This may not have been the optimum position to strengthen this muscle group due to the reverse rotary action of some of the external rotators at 90 degrees flexion (Neumann, 2010). Outcomes may be further improved with OKC rotator exercise nearer to zero degrees or with exercises reflecting the muscles' main functional role, which is controlling pelvic and trunk rotation in single leg stance(Neumann, 2010); this was included in only three studies in this review .

Exercises targeting the abductors and external rotators predominated. Although there is evidence for hip abductor and external rotator weakness in PFP, hip strength deficits are not exclusive to these muscle groups (Rathleff et al., 2014). It is possible that the focus on hip abductor and external rotator exercise is too simplistic.

This review failed to demonstrate that hip adduction exercise was beneficial. However, this was based on one study investigating one isometric exercise. There may be an argument for incorporating adductor strengthening as there is evidence to show a deficit in isometric adduction strength in PFP (Rathleff et al., 2014). Additionally, the adductors contribute to the eccentric control of hip internal rotation, are considered to be important flexors and extensors of the hip, have a bidirectional sagittal plane torque which is useful for powering cyclic activities including sprinting and raising and descending a deep squat,and contribute to pelvis stability (Charnock et al., 2009; Gottschall et al., 2012; Leighton, 2006; Neumann, 2010).

Rehabilitation protocols were variable, with little adherence to recommended guidelines for exercise (ACSM's Guidelines for Exercise Testing and Prescription, 2010); future research protocols should take this into account.

Nine trials had mixed gender groups, including two out of the three studies investigating knee versus hip protocols, which may confound the outcome as a recent study demonstrated knee extensor deficits but no hip weakness in males with PFP (Bolgla et al., 2014). Additionally, it has been shown that there are gender specific differences in hip abduction strength (Brent et al.,2013; Ramskov et al., 2014), gluteal activation (Nakagawa et al., 2012) and trunk and lower limb kinematics (Nakagawa et al., 2012, Willy et al., 2012a) in both the normal and PFP population. There have been shown to be differences in hip strength deficits in males and females in PFP (Rathleff et al., 2014) suggesting that rehabilitation and future research trials should be gender specific.

Seven studies did not take activity levels into account. Strength gains in untrained participants improve faster than trained (Kraemer and Rataness, 2004) which may confound results.

Differences in the presentation of hip strength in individuals with unilateral and bilateral PFP have been demonstrated, although this is limited. (Cichanowski et al., 2007; Maghaeles et al., 2010). Further research is needed to establish whether this data is substantiated; if this is the case it may be preferable to sub-group accordingly in future research. A consensus from PFP researchers for standardisation of methodologywith subjects with bilateral symptoms is recommended to enable meaningful comparison between trials.

Evidence for alteration in lower limb kinematics with proximal strengthening was conflicting. Two out of three studies showed an improvement. However, both included verbal instruction on lower limb alignment, suggesting that the alteration may not relate to strength gains.

Neuromuscular exercise

Motor retraining was found to result in rapid and lasting reduction in PFP symptoms. A considerable reduction in pain occurred over a short time-frame in both neuromuscular studies given that participants had symptoms for an average of 75 and 51 months respectively. Although the effects were very positive the participantswere a pre-selected group who demonstrated abnormal hip alignment during running, which in one study was 10 out of 85 subjects analysed (Noehren et al., 2011). There may be a subset of people with PFP who would benefit from this type of rehabilitation. The subjects were all runners, and were altering kinematics in running. The results may be different in different PFP populations as motor skill acquisition is highly task specific and dependent on age, prior skill and activity levels (Dayan and Cohen, 2011).

The two main studies did not include strength measures or record EMG activity. Two subjects from the cohort of one study had EMG and strength assessments but did not show consistent results (Willy and Davis, 2013). It is therefore unknown whether the alteration in kinematics facilitated strength gain, improved activation patterns in the gluteal muscles, or whether the results relate to cortical neuroplastic changes.

The improvements in motor skills were transferred to the untrained tasks of step down (Willy et al., 2012b) and single leg squat (Noehren et al., 2011; Willy et al., 2012b) with significant improvement in hip adduction, which was the focus of the motor retraining task. This suggests that similar motor sequences may offer the greatest potential for positive transfer.

Longer term follow up demonstrated a trend for the hip mechanics to revert toward baseline values. The authors suggested this was due to subject’s initial over-correction of the abnormal mechanics (Willy et al., 2012b). However,it may be the case that the re-training had not been sufficient to consolidate the altered mechanics. New motor patterns are incorporated into existing neural circuits and this change may be impeded by old motor behaviours (Adkins et al., 1985). Long term retention of motor skill acquisition is strongly dependent on successful consolidation (Dayan and Cohen, 2011), which requires repetition (Luft and Buitrago, 2005), and is also dependent on the extent of conscious attention and skill (Hodges, 2011; Remple et al., 2001). Retraining running patterns in a group of runners may take more intense feedback over a longer timeframe.

Limitations

The results of this review should be interpreted with caution as it was commonly found that studies were under-powered due to low numbers. It was not possible to do a meta-analysis due to widespread methodological heterogeneity.

CONCLUSION

The evidence consistently demonstrated that both hip strengthening and neuromuscular exercise has a beneficial effect on pain and function in PFP subjects. Motor skill retraining was found to be effective in a participant group demonstrating abnormal kinematics. As PFP is multi-factorial in nature it may be preferential to assess hip strength deficits prior to instigating strengthening trials.

There is a bias towards exercises addressing abductor and external rotator strengthening; future research should consider identifying muscle group weakness prior to strengthening trials.

Hip and knee strengthening programmes were shown to be equally effective. However, results show promising results for the addition of hip exercise to a knee programme. Both OKC and CKC hip exercises were shown to be effective in the management of PFP.

A consensus from PFP researchers for standardisation of methodology is recommended to enable meaningful comparison between trials.

The relationships between muscle strength, endurance, neuromuscular control and kinematics need to be established with further research in order for a better understanding of proximal hip factors and PFP.

REFERENCES

ACSM's Guidelines for Exercise Testing and Prescription. (2010). (Eighth ed.). Philadelphia: Wolters Kluwer/ Lippincott Williams & WIlkins.

Adkins, D.L., Boychuk, J., Remple, M.S., Kleim, J.A. Motor training induces experience specific patterns across motor cortex and spinal cord. Journal of Applied Physiology 2005; 101(6): 1776-82

Avraham, F., Aviv, S., Ya'akobi, P., Faran, H., Fisher, Z., Goldman, Y., Neeman, G., Carmeli, E. The efficacy of treatment of different intervention programs for patellofemoral pain syndrome- A single blinded randomized clinical trial. The Scientific World Journal 2007; 7: 1256-1262

Baker, G. R. The contribution of case study research to knowledge of how to improve quality of care. BMJ Quality and Safety 2011; 20 Supplement 1: i30-35.

Baldon, R., Serrão, F.V., Silva, R.S., Piva, S.R. Effects of functional stabilization training on pain, function and lower extremity biomechanics in females with patellofemoral pain: A randomized clinical trial. Journal of Orthopaedic and Sports Physical Therapy 2014; 44(4): 240-A8

Barton, C.J., Lack, S., Malliaras, P., Morrissey, D. Gluteal muscle activity and patellofemoral pain: A systematic review. British Journal of Sports Medicine2013; 47(4): 207-214

Barton, C.J., Munteanu, S.E., Menz, H.B. The efficacy of foot orthoses in the treatment on individuals with patellofemoral pain syndrome: A systematic review. Sports Medicine 2010; 40: 377-395

Berbano, E. P., Baxi, N. Impact of patient selection in various study designs: identifying potential bias in clinical results. Southern Medical Journal 2012; 105(3): 149-155.

Besier, T. F., Gold, G. E., Delp, S. L., Fredericson, M., & Beaupre, G. S. The influence of femoral internal and external rotation on cartilage stresses within the patellofemoral joint. Journal of Orthopaedic Research 2008; 26(12): 1627-1635.

Blond, L., & Hansen, L. Patellofemoral pain syndrome in athletes: a 5.7-year retrospective follow-up study of 250 athletes. Acta Orthopaedica Belgica 1998; 64(4): 393-400.

Bolgla, L.A., Earl-Boehm, J., Emery, C., Hamstra-Wright, K., Ferber, R. Comparison of hip and knee strength in males with and without patellofemoral pain. Physical Therapy in Sport 2015; 16(3): 215-221

Boling, M., Bolgla, L. A., Mattacola, C. G., Uhl, T. L., Hosey, R. G. Outcomes of a weight-bearing rehabilitation program for patients diagnosed with patellofemoral pain syndrome. Archives of Physical Medicine and Rehabilitation 2006; 87(11): 1428-1435.

Boling, M., Padua, D., Marshall, S., Guskiewicz, K., Pyne, S., Beutler, A. Gender differences in the incidence and prevalence of patellofemoral pain syndrome. Scandinavian Journal of Medicine and Science in Sports 2010; 20(5): 725-730.

Boling, M., Padua, D. Relationship between hip strength and trunk, hip and knee kinematics during a jump landing task in individuals with patellofemoral pain. International Journal of Sports Physical Therapy 2013; 8(5): 661-669

Brent, J.L., Myer, G.D., Ford, K.R., Paterno, M.V., Hewett, T.E. The effect of age and gender on isokinetic hip abduction torques. Journal of Sport Rehabilitation 2013; 22: 41-46

Callaghan, M. J., Selfe, J. Has the incidence or prevalence of patellofemoral pain in the general population in the United Kingdom been properly evaluated? Physical Therapy in Sport 2007; 8: 37-43.

Charnock, B. L., Lewis, C. L., Garrett, W. E., Jr., Queen, R. M. Adductor longus mechanics during the maximal effort soccer kick. Sports Biomechanics 2009: 8(3): 223-234.

Cichanowski, H. R., Schmitt, J. S., Johnson, R. J., Niemuth, P. E. Hip strength in collegiate female athletes with patellofemoral pain. Medicine and Science in Sports and Exercise2007; 39(8): 1227-1232.

Collins, N.J., Bisset, L.M., Crossley, K.M., Vicenzino, B. (2012). Efficacy of nonsurgical interventions for anterior knee pain. Sports medicine 2012; 42(1) 31-49

Coppack, R. J., Etherington, J., Wills, A. K. The Effects of Exercise for the Prevention of Overuse Anterior Knee Pain: A Randomized Controlled Trial. American Journal of Sports Medicine 2011; 39(5): 940-948.

Crow, J., Pizzari, T., Buttifant, D. Muscle onset can be improved by therapeutic exercise: a systematic review. Physical Therapy in Sport 2011; 12(4): 199-209.

Crossley, K.M., Bennell, K.L., Cowan, S.M., Green, S. Analysis of outcome measures for persons with patellofemoral pain: Which are reliable and valid? Archives of physical medicine and rehabilitation 2004; (85): 815-822

Davis, I. S., Powers, C. M. Patellofemoral pain syndrome: proximal, distal, and local factors, an international retreat, April 30-May 2, 2009, Fells Point, Baltimore, MD. Journal of Orthopaedics and Sports Physical Therapy 2010; 40(3): A1-16.

Dayan, E., Cohen, L.G. Neuroplasticity subserving motor skill learning. Neuron 2011; 72(3): 443-454

Doherty, S. Evidence based medicine: arguments for and against. Emergency medicine Australasia 2005; 17(4) 307-313

Dolak, K. L., Silkman, C., Medina McKeon, J., Hosey, R. G., Lattermann, C., Uhl, T. L. Hip strengthening prior to functional exercises reduces pain sooner than quadriceps strengthening in females with patellofemoral pain syndrome: a randomized clinical trial. Journal of Orthopaedic and Sports Physical Therapy 2011; 41(8): 560-570.

Earl, J. E., Hoch, A. Z. A proximal strengthening program improves pain, function, and biomechanics in women with patellofemoral pain syndrome. American Journal of Sports Medicine 2011; 39(1): 154-163.

Ferber, R., Kendall, K., Farr, L. Changes in Knee Biomechanics After a Hip-Abductor Strengthening Protocol for Runners With Patellofemoral Pain Syndrome. Journal of Athletic Training 2011; 46(2): 142-149.

Ferber, R., Bolgla, L., Earl-Boehm, J.E., Emery, C., Hamstra-Wright, K. Strengthening of the Hip and Core Versus Knee Muscles for the Treatment of Patellofemoral Pain: A Multicenter, Randomized Controlled Trial Journal of Athletic Training 2014; 49(3):doi: 10.4085/1062-6050-49.3.70

Fukuda, T. Y., Rossetto, F. M., MagalhÃes, E., Bryk, F. F., Lucareli, P. R. G., Carvalho, N. Short-term effects of hip abductors and lateral rotators strengthening in females with patellofemoral pain syndrome: a randomized controlled clinical trial. Journal of Orthopaedic and Sports Physical Therapy 2010; 40(11): 736-742.

Fukuda, T.Y., Melo, W.P., Zaffalon, B.M., Rossetto, F. M., MagalhÃes, E.,Bryk, F.F., Martin, R.L. Hip posterolateral musculature strengthening in sedentary women with patellofemoral pain syndrome: A randomized clinical trail with 1 year follow up. Journal of Orthopaedic & Sports Physical Therapy 2012; 42(10): 823-830.

Gottschall, J.S., Okita,N., Sheehan, R.C. Muscle activity of the tensor fascia lata and adductor longus for ramp and stair walking. Journal of Electromyography and Kinesiology 2012; 22(1): 67-73.

Groah, S.L., Libin, A., Lauderdale, M., Kroll, T., DeJong, G., Hsieh, J. Beyond the evidence-based practice paradigm to achieve best practice in rehabilitation medicine: a clinical review. Physical Medicine and Rehabilitation 2009; 1 (10):941-950

Grossman, J., Mackenzie, F.J. The randomised controlled trial. Gold standard orsimply standard. Perspectives in medicine 2005;48(4): 516-534

Heintjes E. M, B. M., Bierma-Zeinstra Sita MA, Bernsen Roos MD, Verhaar Jan AN, Koes Bart W. Exercise therapy for patellofemoral pain syndrome. Cochrane Database of Systematic Reviews 2003.

Higgins, J. P., Altman, D. G., Gotzsche, P. C., Juni, P., Moher, D., Oxman, A. D., Cochrane Statistical Methods, G. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ 2011; 343: d5928.

Hodges, P. Pain and motor control: from the laboratory to rehabilitation. Journal of Electromyography and kinesiology 2011; 21: 220-228.

Huberti, H. H., Hayes, W. C. (1984). Patellofemoral contact pressures. The influence of q-angle and tendofemoral contact. Journal of Bone and Joint Surgery Am 1984; 66(5): 715-724.

Ismail, M.M., Gamaleldein, M.H., Hassa, K.A. Closed kinetic chain exercises with or without additional hip strengthening exercises in management of patellofemoral pain syndrome: a randomized controlled trial. European Journal of Physical Rehabilitation Medicine 2013; 49(5): 687-698.

Khayambashi, K., Mohammadkhani, Z., Ghaznavi, K., Lyle, M. A., Powers, C. M. The effects of isolated hip abductor and external rotator muscle strengthening on pain, health status, and hip strength in females with patellofemoral pain: a randomized controlled trial. Journal of Orthopaedic and Sports Physical Therapy 2012; 42(1): 22-29.

Khayambashi, K., Fallah, A., Movahedi, A., Bagwell, J., Powers, C. Posterolateral hip muscle strengthening versus quadriceps strengthening for patellofemoral pain: A comparitive control trial. Archives of Physical Medicine and Rehabilitation 2014; 95(5): 900-907

Koes, B. W., Hoving, J. L. The value of the randomised clinical trial in the field of physiotherapy. Manual Therapy 1998; 3(4): 179-186.

Kraemer, W.J., Rataness, N.A. Fundamentals of resistance training: progression and exercise prescription. Medicine and Science in sports and exercise 2004; 674-688.

Lee, T. Q., Morris, G., Csintalan, R. P. The influence of tibial and femoral rotation on patellofemoral contact area and pressure. Journal of Orthopaedic and Sports Physical Therapy 2003; 33(11): 686-693.

Leighton, R. D. A functional model to describe the action of the adductor muscles at the hip in the transverse plane. Physiotherapy Theory and Practice 2006; 22(5); 251-262.

Li, G., DeFrate, L. E., Zayontz, S., Park, S. E., Gill, T. J. The effect of tibiofemoral joint kinematics on patellofemoral contact pressures under simulated muscle loads. Journal of Orthopaedic Research 2004; 22(4): 801-806.

Lowry, C.D., Cleland, J., Dyke, Management of Patients with Patelllofemoral Pain Syndrome using a multi-modal approach: A case series. Journal of Orthopaedic and Sports Physical Therapy 2008; 38(11):691-702

Luft A.R., Buitrago,M.M. Stages of motor skill learning. Molecular Neurobiology 2005; 32(3): 205-216.

MagalhÃes E., Fukuda, T. Y., Sacramento, S. N., Forgas, A., Cohen, M., & Abdalla, R. J. A comparison of hip strength between sedentary females with and without patellofemoral pain syndrome. Journal of Orthopaedic and Sports Physical Therapy 2010; 40(10): 641-647.

Mascal, C. L., Landel, R., Powers, C. Management of patellofemoral pain targeting hip, pelvis, and trunk muscle function: 2 case reports. Journal of Orthopaedic and Sports Physical Therapy 2003; 33(11): 647-660.

Milanese, S. The use of RCT's in manual therapy-are we trying to fit a round peg into a square hole? Manual Therapy 2011; 16(4): 403-405.

Nakagawa, T., Muniz, T., Baldon, R., Maciel, C., Reiff, R., Serrão, F. The effect of additional strengthening of hip abductor and lateral rotator muscles in patellofemoral pain syndrome: a randomized controlled pilot study. Clinical Rehabilitation 2008; 22(12): 1051-1060.

Nakagawa, T., Moriya, E. T., Maciel, C. D., Serrao, F. V. Trunk, pelvis, hip, and knee kinematics, hip strength, and gluteal muscle activation during a single-leg squat in males and females with and without patellofemoral pain syndrome. Journal of Orthopaedic and Sports Physical Therapy 2012; 42(6): 491-501.

Neumann, D. Kinesiology of the hip: A focus on muscular actions. Journal of Orthopaedic and Sports Physical Therapy 2010; 40(2):82-94.

Nijs, J., Van Geel, C., Van der auwera, C., Van de Velde, B. Diagnostic value of five clinical tests in patellofemoral pain syndrome. Manual Therapy 2006; 11(1): 69-77.

Noehren, B., Schoz, J., & Davis, I. The effect of real-time gait retraining on hip kinematics, pain and function in subjects with patellofemoral pain syndrome. British Journal of Sports Medicine 2011; 45(9): 691.

OCEBM Levels of Evidence Working Group. The Oxford 2011 Levels of Evidence.(2011) http://www.cebm.net/ocebm-levels-of-evidence/

Piva, S.R., Gil, A.B., Moore, C.G., Fitzgerald, G.K. Responsiveness of the activities of daily living scale of the knee outcome survey and numerical pain rating scale in patients with patellofemoral pain. Journal of Rehabilitation Medicine 2009; 41: 129-135

Powers, C. Patellofemoral pain: Proximal, Distal and Local factors 2nd International Research Retreat. Journal of Orthopaedic and Sports Physical Therapy 2012; 42(6): A1-A20.

Ramskov, D., Pedersen, M.B., Kastrup, K., Lonbro, S., Jacobsen, J.S., Thorborg, K., Nielsen, R.O., Rasmussen. S. Normative values of eccentric hip abduction strength in novice runners: An equation adjusting for age and gender. International Journal of Sports Physical Therapy 2014; 9(1): 68-75.

Rathleff, M.S., Rathleff, C.R., Crossley, K.M., Barton, C.J. Is hip strength a risk factor for patellofemoral pain? A systematic review and meta-analysis. British Journal of Sports Medicine 2014; 48(14): 1088-

Razeghi, M., Etamadi, Y., Taghizadeh, Sh., Ghaem, H. Could hip and knee strengthening alter the pain intensity in patellofemoral pain syndrome. Iranian Red Crescent Medical Journal 2010; 12(2):104-110

Remple, M.S., Bruneau, R.M., VandenBerg, P.M., Goertzen, C., Klein, J. Sensitivity of cortical representations to motor experience: evidence that skill learning but not strength training induces cortical reorganisation. Behavioural Brain Research 2001; 123: 133-141.

Reiman, M. P., Bolgla, L. A., Loudon, J. K. A literature review of studies evaluating gluteus maximus and gluteus medius activation during rehabilitation exercises. Physiotherapy Theory and Practice 2012; 28(4):257-268

Salsich, G. B., Perman, W. H. (2007). Patellofemoral joint contact area is influenced by tibiofemoral rotation alignment in individuals who have patellofemoral pain. Journal of Orthopaedic and Sports Physical Therapy 2007; 37(9): 521-528.

Sharp, K. The case for case studies in nursing research: the problem of generalization. Journal of Advanced Nursing 1998; 27(4): 785-789.

Song, C. Y., Lin, Y. F., Wei, T. C., Lin, D. H., Yen, T. Y., Jan, M. H. Surplus value of hip adduction in leg-press exercise in patients with patellofemoral pain syndrome: a randomized controlled trial. Physical Therapy 2009; 89(5): 409-418.

Souza, R. B., Draper, C. E., Fredericson, M., Powers, C. M. Femur rotation and patellofemoral joint kinematics: a weight-bearing magnetic resonance imaging analysis. Journal of Orthopaedic and Sports Physical Therapy 2010; 40(5): 277-285.

Souza, R. B., Powers, C. M. Differences in hip kinematics, muscle strength, and muscle activation between subjects with and without patellofemoral pain. Journal of Orthopaedic and Sports Physical Therapy 2009; 39(1): 12-19.

Taunton, J. E., Ryan, M. B., Clement, D. B., McKenzie, D. C., Lloyd-Smith, D. R., Zumbo, B. D. A retrospective case-control analysis of 2002 running injuries. British Journal of Sports Medicine 2002; 36(2): 95-101.

Tyler, T. F., Nicholas, S. J., Mullaney, M. J., McHugh, M. P. The role of hip muscle function in the treatment of patellofemoral pain syndrome. American Journal of Sports Medicine 2006; 34(4): 630-636.

van der Heijden, R.A., Lankhorst, N.E., van Linschoten, R., Bierma-Zienstra, S.M.A, van Middelkoop, M. Exercise for treating patellofemoral pain. The Cochrane Collaboration 2015

Willson, J. D., Binder-Macleod, S., Davis, I. S. Lower extremity jumping mechanics of female athletes with and without patellofemoral pain before and after exertion. American Journal of Sports Medicine 2008; 36(8): 1587-1596.

Willy, R.W., Manal, K.T., Witvrouw, E.E., Davis, I.S. Are mechanics different between male and female runners with patellofemoral pain? Medicine and Science in Sports and Exercise 2012a; 44(11): 2165-2171.

Willy, R.W., Scholz, J.P., Davis, I.S. Mirror gait retraining for the treatment of patellofemoral pain in female runners. Clinical Biomechanics 2012b; 27(10): 1045-1051.

Willy, R.W., Davis, I.S. Varied response to mirror gait retraining of gluteus medius control, hip kinematics, pain and function in two female runners with patellofemoral pain. Journal of Orthopaedic and Sports Physical Therapy 2013; 43(12): 864-874.

Witvrouw, E., Lysens, R., Bellemans, J., Cambier, D., Vanderstraeten, G. Intrinsic risk factors for the development of anterior knee pain in an athletic population. A two-year prospective study. American Journal of Sports Medicine 2000; 28(4): 480-489.

Appendix 1

Search results

	Pubmed	AMED	Cinahl	Sportdiscus	Embase
Arthralgia	11952	152	1981	56	4153
"Knee joint" or knee or patella	55163	9661	38088	35631	158499
#1 AND #2	1100	61	522	12	3658
"anterior knee pain"	1116	128	395	538	1397
Femoropatell* OR femoro-patell* OR retropatell* OR "patellofemoral pain syndrome" OR "patellofemoral pain"	1794	402	1147	1084	1926
"lateral compression syndrome" OR "lateral facet syndrome" OR "lateral pressure syndrome" OR "facet syndrome"	130	21	28	21	225
Chondromalac* OR chondropath*	1205	40	149	393	5756
#3 OR #4 OR #5 OR #6 OR #7	4721	40	149	3895	11981
Glute* OR proximal OR hip OR trunk	470444	8485	49990	25091	422058
Exercise OR rehabilitation OR strength OR endurance OR "motor control"	836171	83345	230029	271019	796429
#9 AND #10	37276	4144	9382	10280	33424
#8 AND #11	251	804	3	40	392