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A systematic review of the effect of open and closed kinetic chain exercises on the vastus medialis oblique and vastus lateralis muscles of patients with patellofemoral pain syndrome

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Abstract

Objectives: The purpose of the present study is to review the existing literature regarding the response of the vastus medialis oblique (VMO) and vastus lateralis (VL) muscles of patients with patellofemoral pain syndrome (PFPS) to open and closed kinetic chain exercises.

Search methods: A search was conducted for randomised and non-randomised controlled trials published by July 2016 and involving comparative analysis of exercise treatment with control groups or various exercise treatment types. The following resources were searched: the Cochrane Bone, Joint and Muscle Trauma Group and Cochrane Rehabilitation and Related Therapies Field specialised registers, the Cochrane Controlled Trials Register, The Physiotherapy Evidence Database (PEDro), MEDLINE, EMBASE, and CINAHL.

Data collection and analysis: Trials were excluded if they were not concerned with exercise therapy in individuals with PFPS. Thus, only nine out of 91 trials found were included and they all employed statistical techniques to assess the response of VMO and VL muscles to open and closed kinetic chain exercises.

Main results: The trials under review are too few in number and are inconsistent with regard to rehabilitation strategies and outcome assessment. They underline the necessity for reviewing RCT trials on a wider scale as the evidence they supply in support of use of open and closed kinetic chain exercises is insufficient. Trials have to be comparable in terms of participant traits, intervention and outcome assessment to improve the validity of the conclusions drawn. It was not possible to definitely say whether one intervention was better than another, because different interventions were implemented in the reviewed trials. Furthermore, future research should also include placebo-controlled trials to ascertain the efficiency of various interventions.

Keywords: Kinetic chain exercises, vastus medialis oblique, vastus lateralis muscles, patellofemoral pain syndrome

1. Introduction

The patellofemoral pain syndrome (PFPS) is a retropatellar or peripatellar pain caused by patellofemoral joint modifications of a physical and biomechanical nature. Individuals with painful knees often receive a diagnosis of PFPS (Lankhors, Bierma-Zeinstra and van Middelkoop, 2012) [29], which is worsened by performance of activities like stair climbing/descending, squatting, or prolonged sitting with knees in a flexed position (Lankhors *et al.* 2012) [29]. This condition has a prevalence of 22/1000 person years and women, particularly those between 18 and 35 years of age (Roush and Bay, 2012), are twice as likely to be affected compared to men (Boling *et al.*, 2010) [2]. Moreover, PFPS accompanies a quarter of knee injuries sustained during sports (Fredericson and Yoon, 2006) [15], yet no comprehensive understanding has been achieved regarding how this condition develops and how it is classified, diagnosed and treated. However, many researchers have concurred that PFPS is not the outcome of just one, but several causative factors (Nunes *et al.*, 2013) [32], including excessive use, trauma, anatomical aspects, inadequate muscle functioning,

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and abnormal lower limb alignment (Lankhorns *et al.*, 2012)^[29]. Additionally, quadriceps deficiency or atrophy, especially imbalanced movement of quadriceps components, is considered the main biochemical factor underpinning PFPS development, although conclusive evidence has not been produced so far (Nunes *et al.*, 2013; Giles *et al.*, 2013)^[32].

The vastus lateralis (VL) muscle supports the lateral movement of the patella while the vastus medialis muscle, especially the vastus medialis oblique (VMO), supports the medial patellar movement. The fibres of the VMO are angled almost horizontally (50-55°) with regard to the shaft of the femur, serving more to stabilise the patella medially rather than contributing significantly to knee extension (Miao *et al.*, 2015)^[31]. Despite the fact that their efficiency is unclear, exercises meant to strengthen the VMO are frequently prescribed to PFPS sufferers (Powers, 2000)^[35]. Double-leg semi-squat with hip adduction and squats with concomitant squeezing of a ball between knees are two of the exercises commonly prescribed to rehabilitate PFPS. Nonetheless, as observed by Bolgla and Malone (2005)^[3], there is not enough objective evidence to confirm that such exercises are indeed efficient.

The exercises typically prescribed to strengthen the VMO can be classified into two categories, namely, open and closed kinetic chain exercises. One study reported that exercises meant to extend the knee at varying angles between 0° and 60° resulted in VMO activation (Dannelly *et al.*, 2011)^[12]. As explained by Fagan and Delahunt (2008)^[13], exercises for knee extension pull the patella within the trochlear groove of the femur by the quadriceps and cranial slides, and therefore are deemed to correct the imbalance between the VMO and VL that characterises PFPS, and in this way, they make patellar tracking more stable. Meanwhile, according to Lam and Ng (2001)^[27], both open and closed kinetic chain exercises contributed to alleviation or prevention of PFPS.

Despite the fact that their efficiency remains a matter of debate, open chain leg extension exercises are often recommended in clinical practice to engage the VMO (Laprade, Culham and Brouwer, 1998)^[28]. Open kinetic chain exercises involve moving just one joint with no weight bearing and a free distal extremity. By contrast, closed kinetic chain exercises involve movement of more than one joint with weight bearing and a fixed distal extremity (Stensdotter *et al.*, 2003)^[43].

1.1 Literature search

Earlier reviews were searched in order to assess the comprehensiveness with which the subject under consideration has been investigated. Results suggested that the response of the VMO and VL muscles of PFPS patients to open or closed kinetic chain exercises was not addressed by any of the studies reviewed.

1.2 Current reviews

The focus of the review conducted by Smith *et al.* (2009a)^[39] was on considerations such as the attachment of the vastus medialis (VM) muscle to the patella and the extent of this attachment, how long the distal VM tendon was, and whether these aspects underpinned the aetiology of patellofemoral conditions. A number of eight studies were obtained from electronic and manual search of works published in English and concerned with examination of how the distal VM attached to the patella based on cadaver dissection or radiography. According to the results, in most cases, the attachment of the distal VM was proximal or at the midpoint

of the patella. Furthermore, it was found that the distal VM attached to the patella in a proportion of 10% of its length, and the distal VM tendon was between 1.4 and 3.5 cm long. However, the insufficiency of comprehensive studies on this topic hindered formulation of conclusions as to whether these aspects contributed to patellofemoral condition aetiology.

The review conducted by Smith *et al.* (2009b)^[40] focused on determining whether preferential strengthening could be achieved through greater activation of the VMO compared to the VL by modifying how the joints of the lower limbs are oriented or how different muscles contract together. The review encompassed a number of twenty studies with an overall sample size of 387 participants. The results of most of these studies indicated that VMO was not preferentially activated over VL based on modification of lower limb joint orientation or muscle co-contraction. Furthermore, several notable shortcomings of methodology were distinguished. Therefore, to address these shortcomings and accomplish a comprehensive exploration of the subject, the authors suggested that future research must have a better design and include larger numbers of participants with patellofemoral joint problems.

To the current researcher's knowledge, this topic has not been approached by any other previous study, which means that the results of this study will be significant for both PFPS patients and for professionals in charge of exercise therapy.

1.3 The review question

The researchers do not know of any randomised controlled trials concerned with VMO and VL response to open and closed kinetic chain exercises among PFPS patients that have been systematically reviewed. Therefore, the present study, is the first to review randomised clinical trials in a thorough and systematic manner.

2. Objectives

- To systematically evaluate how efficient open and closed kinetic chain exercises are in activating the VMO and VL muscles of PFPS patients;
- To compare how different open and closed kinetic chain exercises influence VMO and VL activity and therapeutic interventions;
- To identify what are the most efficient open and closed kinetic chain exercises.

2.1 Methods

A systematic review can be understood as a methodological tool with which the literature associated with a specific subject can be searched and examined to achieve a certain aim (Collins and Fraser, 2005)^[8]. Similarly, Cronin Ryan and Coughlan, (2008)^[11] explained that the systematic review employs specific factors of identification, evaluation and compilation to scrutinise all published and unpublished works related to a topic.

The systematic review is considered the ideal strategy for investigating randomised control trials (RCTs) because it helps to avoid bias in interpretation that direct selection of studies by the researcher may engender.

2.2 Search strategy

The study was undertaken an electronic search of relevant journals, books, conference proceedings and reference lists, as well as a manual search with inclusion of all published and unpublished works written in English and related to the subject in question. Both abstracts and full texts were examined.

2.3 Criteria for inclusion in the study

The study will employ specific inclusion and exclusion criteria in order to ensure that the systematic review will yield interpretations and conclusions that are pertinent and objective. This is in keeping with Rochon *et al.* (2005) [36], who suggested that, to obtain unbiased findings, a review should only encompass works that demonstrate certain aspects or features. Thus, the search in this study will be guided by the following criteria:

2.4 Study type

To accomplish the research goal, the study design of randomised controlled trial (RCT) has been chosen so that the efficiency of therapeutic interventions can be assessed impartially (Britton and Cousins, 1998) [5]. Because it selects and organises participants randomly, the RCT is deemed the 'gold standard' in clinical research (Greenhalgh, 2001; Concato, Shah and Horwitz, 2000) [9] and is underpinned by quantitative methodology since it is geared towards measuring outcomes with regard to intervention groups.

2.5 Types of participants

To be included in the review, studies had to examine both male and female participants in the age range 18-40 years old, suffering from PFPS in at least one lower limb (Syme *et al.*, 2009) [44].

2.6 Forms of interventions

Every study that employed conventional open and closed kinetic chain exercises for lower extremities and proprioceptive rehabilitation programs for the VMO and VL muscles was included in the review.

2.7 Outcome measures

As highlighted by Megens and Harris (1998) [30], the research outcome measures are highly important, determining how reliable the findings are as well as how robust and valid the entire research is. For research to be considered valid, it must be based on outcomes grounded in reliable data. The primary outcome measures employed in this systematic review are static postural control (SPC) and dynamic postural control (DPC) for PFPS patients. In addition, two flexible electrogoniometers are used to measure the flexion and extension angles of the knee in relation to time (Rower *et al.*, 2001) [37], whilst heel and toe foot-switches for each foot enable the determination of gait stance and swing phases.

2.8 Exclusion criteria

Comments, letters, editorials, protocols, guidelines, abstracts, conference proceedings, review papers, unpublished papers, such as university theses and dissertations, studies relying on animal models, and studies written in languages other than English were all excluded from the review so as to make sure that every original work was critically evaluated.

3. Data collection and analysis

3.1 The study selection process

The subjectivity of the individual performing the selection process may skew the choice of studies included in the review. This issue can be avoided if a minimum of two reviewers undertake the process of selection once the relevant studies have been determined, so as to prevent bias and ensure the impartiality of the selection (Higgins and Green, 2006) [21].

3.2 Study selection

As mentioned earlier, the researcher was the only reviewer of the studies obtained from the search of the literature, owing to restrictions of time and resources. All studies that met the selection criteria were thoroughly read by the researchers to ensure their relevance with regard to the subject under investigation.

3.3 Data collection

According to Van de Voorde and Leonard (2007) [46], representation of acquired data in a visual manner can facilitate the assessment of the selected studies. The standardised collection of data was undertaken in keeping with a number of criteria, including information related to publication, research question, research design, experiment techniques, randomisation, binding, information related to participants, such as inclusion and exclusion criteria and recruitment, as well as findings related to intervention outcomes.

3.4 Data analysis and synthesis

As suggested by Higgins and Green (2006), meta-analysis can enable the measurement of the impact of open and closed kinetic chain exercises on the VMO and VL muscles. This is a statistical technique designed to synthesise data from several identical studies. The narrative method of systematic representation is employed to analyse and compare the research results in the event that identical studies are not available. Furthermore, adverse effects and withdrawal rates can be recorded as well, provided that the data allow it. If trials are non-uniform, then additional outcomes may be evaluated.

3.5 The process of search

The electronic databases AMED, CINAHL, the Cochrane database, EMBASE, ovid Medline, Physiotherapy Evidence Database (PEDro), and Pubmed were searched from their first issue to August 2016. The keywords used to structure the search were chosen based on their sensitivity rather than their specificity (White and Schmidt, 2005) [49] and encompassed "vastus medialis", "vastus medialis obliquus", "VMO", "anatomy", "vastus lateralis", "VL", "open kinetic chain exercise", "closed kinetic chain exercise", "exercise therapy", and "patellofemoral pain syndrome". The keywords were deliberately non-specific so that the search would yield all the works of potential relevance. Furthermore, the search of electronic databases was supplemented with a manual search.

Table 1: Data extraction table

publication details	the research question and purpose	participant characteristics	Physiotherapy exercise modality	Outcome measurements function, pain, and QoL	Findings
1) Fehr <i>et al.</i> (2006)	To analyse the therapeutic effects of the open kinetic chain (OKC) and closed kinetic chain (CKC) exercises to treat the patellofemoral syndrome (PFSD).	24 volunteers, bearers of the PFSD were randomly divided in two groups: group I (n = 12) performed the OKC exercises; group II (n = 12) performed the CKC exercises.	Open & closed Chain exercises	the electromyographic signals (EMG) were collected using bipolar surface electrodes quantified by the root mean square (RMS) to measure the pain intensity upon the rest and while performing functional activities, the VAS and the Kujala scale were respectively applied	The results found in this study suggest that according to the conditions of the trial, the OKC and CKC exercises provoke no changes in the patterns of the EMG activation in the VMO and VL muscles.
2) Laprade <i>et al.</i> , 1998	Comparison of Five Isometric Exercises in the Recruitment of the Vastus Medialis Oblique in Persons With and Without Patellofemoral Pain Syndrome	19 female control subjects were 24 years, 165.8 cm, and 58.9 kg, respectively. 8 female subjects with PFPS were recruited into the study. Were 24 years, 165.6 cm, and 60.9 kg, respectively.	Subjects performed two submaximal isometric contractions and one maximal isometric contraction	The raw EMG signals were recorded in all subjects using bipolar gold-plated	No significant differences in the EMG VMO:VL proportion were found between control subjects and those with patellofemoral syndrome.
3) Coqueiro <i>et al.</i> , 2005	to investigate the effect of hip adduction on the activity of the Vastus Medialis Obliquus (VMO) and Vastus Lateralis Longus (VLL) muscles during semisquat exercises.	Ten healthy subjects (age: 21.8 ± 2.52 years old) Ten sedentary PFPS subjects (age: 23.2 ± 2.65 years)	Double-leg semisquat exercise associated with hip adduction (DLSS-HA) isometric contraction & double-leg semisquat (DLSS) exercise	electromyographic muscle The electrical activity of the VMO and VLL muscles was detected by active differential surface EMG electrodes, supplied by Lynx Electronics Technologies (Brazil).	there was no preferential VMO muscle activation,
4) Santos <i>et al.</i> (2008)	The purpose of this study was to evaluate the amplitude and onset of electrical activation of the vastus medialis obliquus (VMO), vastus lateralis longus (VLL) and vastus lateralis obliquus (VLO) during functional activities in individuals with patellofemoral pain syndrome (PFPS).	Twenty women participated in the study: ten in a control group and ten in the group with PFPS.	The electromyographic signal of the quadriceps muscle was detected using simple active differential surface electrodes and a four-channel electromyography system, during open kinetic chain activities (using an isokinetic dynamometer) and closed kinetic chain activities (step and squat maneuvers).	To measure VMO activity, a standard MyoTrac biofeedback device was used (Premier Medical, Kent, WA).	: Under the experimental conditions used, this study suggests that there is an imbalance in the electric activity and abnormal recruitment patterns among the VMO, VLL and VLO muscles in individuals with PFPS, with greater delay and lower amplitude of activation of the VMO in this group.
5) syme <i>et al.</i> , 2006	to compare the effects of rehabilitation with emphasis on retraining the VMO component of the quadriceps femoris muscle and rehabilitation.	Patients with PFPS (n = 69)	physiotherapy exercises emphasising selective activation and retraining of the VMO muscle relative to the VL muscle was undertaken by using a dual channel surface electromyographic biofeedback unit	Two flexible electrogoniometers were used to measure knee flexion/extension angles with respect to time. the Modified Functional Index Questionnaire (MFIQ) and the Short Form-36 Health Evaluation questionnaire (SF-36)	This study did not demonstrate that rehabilitation with selective VMO exercise significantly improves outcome above that provided by general open and closed chain strengthening exercises
6) Boling <i>et al.</i> , 2006	To determine the effects of a weight-	Twenty-eight subjects (14 controls, 14	The rehabilitation program	Electromyographic onsets of the	Subjects diagnosed with PFPS

	bearing rehabilitation program on quadriceps and gluteus medius electromyographic activity, pain, and function in subjects diagnosed with patellofemoral pain syndrome (PFPS).	experimental) between the ages of 18 and 42 years were recruited. For the experimental group, we recruited 5 men and 9 women (age, 24.6y)	consisted of weight-bearing exercises that focused on strengthening the quadriceps and hip abductor musculature	vastus medialis oblique (VMO) A visual analog scale (VAS) and Functional Index Questionnaire (FIQ)	responded favorably and quickly to a therapeutic exercise program that incorporated quadriceps and hip musculature strengthening
7) Song <i>et al.</i> , 2009	The objective of this study was to determine the surplus effect of hip adduction on the VMO.	Eighty-nine patients with PFPS participate (69 females) mean age 40.2 (9.9)	Participants were randomly assigned to 1 of 3 groups: hip adduction combined with leg-press exercise (LPHA group), leg-press exercise only (LP group), or no exercise (control group). Training consisted of 3 weekly sessions for 8 weeks.	Ratings of worst pain as measured with a 100-mm visual analog scale (VAS-W), Lysholm scale scores, and measurements of VMO morphology (including cross-sectional area [CSA] and volume) were obtained before and after the intervention.	Similar changes in pain reduction, functional improvement, and VMO hypertrophy were observed in both exercise groups
8) Kang <i>et al.</i> (2014)	This study aimed to examine the effects of closed kinetic chain exercise using electromyography (EMG) biofeedback for selective strengthening of the vastus medialis oblique (VMO) on patellofemoral joint pain and functional characteristics of patellofemoral joint muscles.	The subjects of this study were 30 patellofemoral pain syndrome (PFPS) patients and they were equally and randomly assigned to a control group (I), a closed kinetic chain exercise group (II), and an EMG biofeedback closed kinetic chain exercise (III).	<i>a closed kinetic chain exercise group</i>	Surface EMG (MyoTrace™ 400, Noraxon Inc., USA) and electrode patches (Medi-Trace 200, Kendall, USA)	PFPS patients' muscle functions improved by enhancing muscle control and response ability using EMG biofeedback with which real-time bioinformation on the muscles is provided during closed kinetic chain exercise in order to raise treatment efficiency.
9) Hwangbo, (2015)	The purpose of this study was to identify the effects of performing squat exercises with visual feedback on the activation of the vastus medialis oblique (VMO) and vastus lateralis (VL) muscles in young adults with an increased quadriceps angle (Q-angle).	20 young adults with an increased Q-angle, who were then divided into a squat group that received visual feedback (VSG, n=10) and a squat group that received no visual feedback (SG, n=10).	squat exercises with a maximum of 90° of knee flexion within a route marked on a mirror	The activation of VL and VMO was recorded with surface electromyography (EMG) during	This study confirmed that squat exercises with visual feedback are effective in activation of the VMO and VL muscles. The findings are meaningful in terms of preventing the occurrence of patellofemoral pain.

Table 2: Studies excluded from the review

No.	The study	Reason for exclusion
1	Harrison <i>et al.</i> (1999)	No specification of muscles
2	Witvroue <i>et al.</i> (2003)	Focus on VMO and VL reflex response
3	IRISH <i>et al.</i> (2010)	Inclusion of healthy individuals
4	Hashmiy <i>et al.</i> (2011)	Rules of conduct
5	Pattyn <i>et al.</i> (2011)	Case-control study Use of MRI for assessment of VMO size in individuals with PFPS
6	Ismail <i>et al.</i> (2013)	No specification of muscles
7	Chang <i>et al.</i> (2014)	Inclusion of healthy females
8	Lam, 2001	Not RCT
9	Miao, 2015	cross-sectional study
10	O'Sullivan & Popelas 2005	lack of a control group
11	Tang, 2001	Case-control study

4. Results

4.1 Study selection

A number of 91 possible studies were obtained from the search of the electronic databases and the manual search of the references listed in every relevant article. Of these, 39 studies were eliminated after the titles and abstracts were screened because they failed to satisfy the inclusion and exclusion

criteria. Regarding the rest of 52 studies, their full texts were downloaded and scrutinised, and after the elimination of duplicates from different databases, a number of nine full-text studies were obtained. These were again subjected to appraisal with respect to the inclusion and exclusion criteria, as shown in Figure 1.

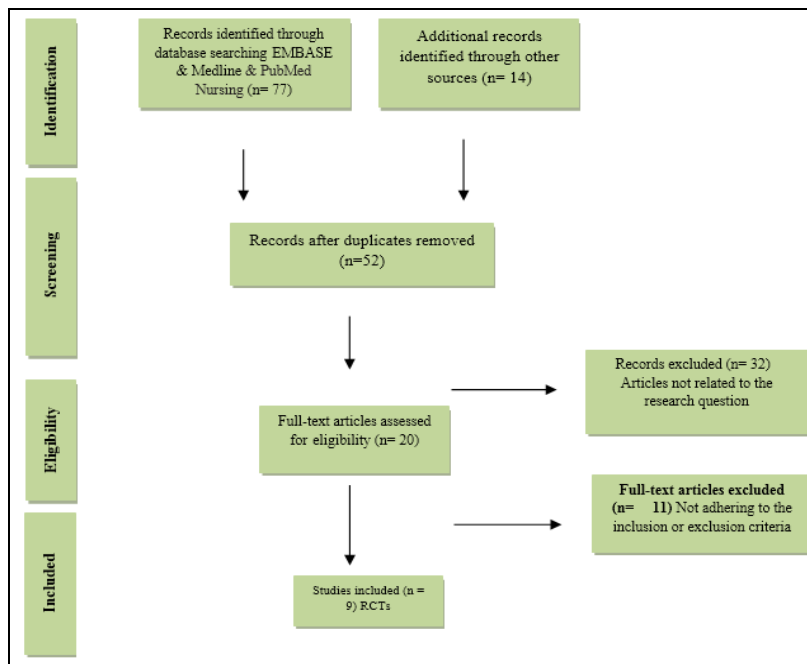


Fig 1: The outcome of the application of the search strategy PRISMA flow diagram

The nine RCTs obtained from the electronic and manual search for inclusion in the review were Fehr *et al.* (2006) [14], Coqueiro *et al.* (2005) [10] and Santos *et al.* (2008) [38], all from Brazil, Laprade *et al.* (1998) [28] (Canada), Syme *et al.* (2009) [44] (UK), Boling *et al.* (2006) [4] (US), Song *et al.* (2009) [41] (Taiwan), and Kang, Kim and Kim, (2014) [26] and Hwangbo (2015) [23], both from the Republic of Korea.

4.2 Assessment of the quality of methodology

In accordance with Hill and Spittlehouse (2001) [22], the

methodological quality was evaluated in order to make sure that there was good understanding of the research evidence and that there was satisfactory agreement between theoretical and practical aspects.

The critical assessment instrument PEDro, consisting of eleven items, is useful for the measurement of internal validity and recording of statistical measures, and therefore it was applied to assess the quality of the research methodology of each selected study (PEDro, 1999).

Table 2: PEDro criteria

PEDro criteria	1) Fehr <i>et al.</i> , 2006	2) Laprade <i>et al.</i> , 1998	3) Coqueiro <i>et al.</i> , 2005	4) Santos <i>et al.</i> , 2008	5) syme <i>et al.</i> , 2009	6) Boling <i>et al.</i> , 2006	7) Song <i>et al.</i> , 2009	8) Kang <i>et al.</i> , 2014	9) Hwangbo, 2015
1. Eligibility criteria	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. Random allocation	No	No	No	N/M	Yes	No	Yes	Yes	No
3. Concealed allocation	No	No	No	NO	Yes	No	Yes	N/M	No
4. Comparable baseline	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5. Subjects blinded	No	No	No	No	No	No	No	No	No
6. Therapists blinded	No	No	No	No	No	No	Yes	No	No
7. Assessors blinded	No	No	No	No	Yes	No	Yes	No	No
8. Outcomes for 85% of initial participants	N/M	N/M	N/M	Yes	Yes	Yes	Yes	Yes	Yes
9. Intention-to- treat analysis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10. Between group stat comparison	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11. Point & variability measures	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Total score	3	3	5	6	9	6	10	7	6

4.3 Quality of evidence

The studies conducted by Syme *et al.* (2009) and Song *et al.* (2009) [41], Kang *et al.* (2014) were demonstrated good quality (≥ 7), according to the cut-off points established earlier. Meanwhile, the studies undertaken by Coqueiro *et al.* (2005) [10], Santos *et al.* (2008) [38], Boling *et al.* (2006) [4] and Hwangbo (2015) [23] deemed to be of moderate quality (< 7), whereas the studies by Fehr *et al.* (2006) [14] and Laprade *et al.* (1998) [28] were of poor quality (< 4).

4.4 Summary and evaluation of the evidence

Laprade *et al.* (1998) [28] compared individuals with and without PFPS in terms of VMO activation based on five isometric exercises. The participants were all female and 24 years old, and of the total of 27 participants, 19 did not have PFPS whereas 8 had the condition. The participants were asked to perform two submaximal isometric contractions and four maximal isometric knee extension contractions, whilst they were attached bipolar gold-plated electrodes to document the raw EMG signals. According to the results, there was no notable difference between the participants with and without PFPS with regard to EMG VMO or VL proportions. Nonetheless, the study was graded only a 3 on the PEDro scale of methodological quality because it did not apply randomisation.

Coqueiro *et al.* (2005) [10] investigated the effect of semi-squat exercises with hip adduction on the VMO and VL muscle activity. The research sample consisted of 20 participants, of which ten had PFPS (21.8 ± 2.52 years old) and ten did not have PFPS (23.2 ± 2.65 years old). They were asked to carry out double-leg semi-squats (DLSS) with and without hip adduction. The electrical signals from the VMO and VL muscles were documented with active differential surface EMG electrodes (Lynx Electronics Technologies, Brazil). No preferential activation was exhibited by the VMO muscle. A score of 5 on the PEDro scale was awarded to this study, indicating moderate methodological quality.

Syme *et al.* (2009) conducted an RCT on 69 participants with PFPS to investigate rehabilitation outcomes of interventions that involved retraining the quadriceps femoris element of the VMO and strengthening of the entire quadriceps femoris. To ensure that only the VMO muscle was activated and retrained and not the VL muscle, physiotherapy exercises were administered with a dual channel surface electromyographic biofeedback unit. Two flexible electrogoniometers permitted the measurement of knee extension and flexion angles. However, as stressed by Rowe *et al.* (2001) [37], this approach was found to be valid and reliable only for people who did not suffer from PFPS. The findings did not confirm that selective VMO activation led to better outcomes compared to open and closed chain strengthening exercises.

The pragmatic nature of the applied interventions hindered an evaluation of the extent to which the different elements of the rehabilitation program were significant. In spite of this, studies employing just one intervention contradict clinical practice, as physiotherapists typically employ more than one intervention strategy (Bithell, 2000; Grimmer *et al.*, 2004) [1, 18]. Hence, it can be said that the nature of the employed interventions can contribute to make the results of a study more valid and more amenable to generalisation. Meanwhile, a series of relevant issues were highlighted in the study as well.

Clinicians should not attribute greater importance to selective activation before the rehabilitation program is commenced, especially in the case of individuals with chronic conditions whose participation is significantly restricted. This conclusion

is derived from the fact that the study did not confirm that selective VMO activation was more effective compared to open and closed kinetic chain strengthening exercises in enhancing rehabilitation outcomes (Witvrouw *et al.*, 2004; Bolgla and Boling, 2011) [48, 2]. Nevertheless, the study scored 9 on the PEDro scale with regard to methodological quality.

A total of 28 participants in the age range 18-42 years old, of which 14 were assigned to the control group and 14 to the experimental group, were recruited by Boling *et al.* (2006) [4] to examine how weight-bearing rehabilitation affected VMO and VL electromyographic activity, pain and function. The rehabilitation strategy applied to the experimental group comprising five males and nine females with an average age of 24 years old consisted of weight-bearing exercises intended to alter muscle pain, function and activation patterns by balancing, stretching and strengthening the quadriceps and hip abductor muscles. Participants with PFPS responded favourably and immediately to this intervention.

The low reliability of the electromyographic measures and the absence of a control group with PFPS diminished the validity of the results obtained. The lack of a research design framework also constituted a limitation.

Song *et al.* (2009) [41] recruited 89 participants with PFPS for their RCT and randomly assigned them to one of three groups, namely, hip adduction combined with leg-press exercise (LPHA group), leg-press exercise only (LP group), and no exercise (control group). The duration of the rehabilitation program was two months with three sessions weekly. The maximum levels of pain were measured before and following training on the basis of a 100-mm visual analog scale (VAS) and Lysholm scale scores. The characteristics of low pain, improved function and VMO hypertrophy were exhibited by the groups subjected to exercise activities. The study adopted a blind or non-discriminatory approach, with a single physical therapist unaware of the research goals carrying out the randomisation and interventions. Furthermore, two sessions of evaluation were undertaken by another physical therapist who had no knowledge of the manner in which the participants were divided into groups.

According to the results obtained, a rehabilitation program implemented over a period of two months and comprising simple LP training (45° flexion to full knee flexion) and stretching significantly improved VMO hypertrophy and knee function whilst also reducing pain. Nonetheless, the study scored only 10 on the PEDro scale in terms of methodological quality.

There are several limitations to this study. The fact that the healthy participants did not have any pain or symptoms associated with the patella and neither did their muscle activity show similarity with that of participants with PFPS is a significant limitation. Moreover, the sample size was not large enough to permit the results to be generalised. Hence, the study scored 6 on the PEDro scale with regard to methodological quality.

5. Discussion

5.1 Analysis of reviewed studies

Closed kinetic chain and weight-bearing exercises (e.g. double-leg squat, leg-press and lung exercises) were administered by Irish *et al.* (2010) [24] as well as Coqueiro *et al.* (2005) [10] with the purpose of strengthening the VMO muscle. The results they obtained provided evidence that these types of exercises are effective in activating the VMO and VL muscles. Furthermore, performance of squat exercises (i.e. mini-squat, semi-squat, wall-sit and wall-slide exercises)

together with hip adduction enhanced quadriceps activation not only in participants without PFPS, but also in those with PFPS.

An additional observation reported by Coqueiro *et al.* (2005)^[10] was that closed kinetic chain exercises augmented VMO activation more than VL activation. By contrast, performance of closed kinetic chain exercises alongside weight-bearing exercises led to an increase in pulling strength and intra-articular pressure, worsening PFPS symptoms.

On the other hand, Spairani *et al.* (2012)^[42] did not observe activation in the VMO that was significant enough to augment patellar tracking, therefore concluding that open kinetic chain exercises did not have a marked impact on PFPS rehabilitation. By contrast, Chang *et al.* (2015)^[7] stated that application of sling open chain knee extension (SOCKE) exercise in conjunction with sling exercise therapy (SET) intensified VMO activity compared to VL activity.

Most of the studies that were reviewed compared the responses of the VMO and VL muscles of participants with PFPS to open and closed kinetic chain exercises, but none of them compared experimental and placebo control groups. This may be explained in terms of the ethical issues associated with denial of therapy or the problems posed by the development of an effective physiotherapy placebo. In spite of this, however, the study findings lend credence to the efficiency of open and closed kinetic chain exercises in alleviating pain caused by PFPS.

The limited sample sizes meant that effects could be distinguished between the research groups only if they were sufficiently pronounced. Furthermore, intervention effects could not be monitored in the long-term in many experimental group participants who responded positively to the intervention, because a proportion of 48% of them withdrew from the research after twelve months. Hence, the credibility of the results is questionable. Even so, both open and closed kinetic chain exercises were found by many of the reviewed studies to be beneficial for improving pain and function in the long-term.

Even though physiotherapy was found to determine a reduction in pain, no definitive evidence was produced regarding the greater efficiency of one intervention type over another. Nevertheless, there can be no doubt that, of the various strengthening methods, muscle function benefitted the most from open and closed kinetic chain exercises.

The lack of agreement between the findings of the different reviewed studies may be due to discrepancies in methodology. Another potential cause is the fact that the open and closed kinetic exercises were not tailored to each participant according to individual problems (e.g. dysfunctional muscle motor control or excessive tightness of soft tissues surrounding the patellofemoral joint), but instead were applied in a standardised manner, with potential adverse implications for intervention outcome. This second cause ought to be inspected further with clinical trials.

Trials that are more scientifically sound should be undertaken to determine how efficient the applied interventions were. According to current evidence, an intervention approach integrating education, stretching and quadriceps strengthening, and application of soft corrective foot orthoses should be adopted to treat PFPS successfully.

5.2 Shortcomings

Two limitations of methodology are demonstrated by the present systematic review. The first limitation is that, owing to a desire to ensure quality, the review did not include data

sources that were not published (i.e. “grey literature”), but only studies that were peer-reviewed. Hence, this might have given rise to a publication bias that could have affected the results obtained. The other limitation is that, to save costs, the review did not include studies written in languages other than English.

5.3 Significance for practice

It is clear that pain associated with PFPS benefits from open and closed kinetic chain exercises, at least in the short-term; however, it is still unclear whether the efficiency of these exercises surpasses that of exercises that can be undertaken at home. Therefore, it is important to determine the factors related to PFPS development to devise efficient interventions that can be adapted to the requirements of each PFPS patient. Future research should then focus on the formulation of case-specific rehabilitation interventions and reliable measures of outcome evaluation.

6. Conclusion

The trials under review were too few in number and were inconsistent with regard to rehabilitation strategies and outcome assessment. They underline the necessity for reviewing RCT trials on a wider scale as the evidence they supplied in support of use of open and closed kinetic chain exercises was insufficient. Trials have to be comparable in terms of participant traits, intervention and outcome assessment to improve the validity of the conclusions drawn. Additionally, it was not possible to definitely say whether one intervention was better than another, because different interventions were implemented in the reviewed trials. Furthermore, future research should also include placebo-controlled trials to ascertain the efficiency of various interventions.

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