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# Proximal muscle rehabilitation is effective for patellofemoral pain: a systematic review with meta-analysis

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## ABSTRACT

**Background** Proximal muscle rehabilitation is commonly prescribed to address muscle strength and function deficits in individuals with patellofemoral pain (PFP). This review (1) evaluates the efficacy of proximal musculature rehabilitation for patients with PFP; (2) compares the efficacy of various rehabilitation protocols; and (3) identifies potential biomechanical mechanisms of effect in order to optimise outcomes from proximal rehabilitation in this problematic patient group.

**Methods** Web of Knowledge, CINAHL, EMBASE and Medline databases were searched in December 2014 for randomised clinical trials and cohort studies evaluating proximal rehabilitation for PFP. Quality assessment was performed by two independent reviewers. Effect size calculations using standard mean differences and 95% CIs were calculated for each comparison.

**Results** 14 studies were identified, seven of high quality. Strong evidence indicated proximal combined with quadriceps rehabilitation decreased pain and improved function in the short term, with moderate evidence for medium-term outcomes. Moderate evidence indicated that proximal when compared with quadriceps rehabilitation decreased pain in the short-term and medium-term, and improved function in the medium term. Limited evidence indicated proximal combined with quadriceps rehabilitation decreased pain more than quadriceps rehabilitation in the long term. Very limited short-term mechanistic evidence indicated proximal rehabilitation compared with no intervention decreased pain, improved function, increased isometric hip strength and decreased knee valgum variability while running.

**Conclusions** A robust body of work shows proximal rehabilitation for PFP should be included in conservative management. Importantly, greater pain reduction and improved function at 1 year highlight the long-term value of proximal combined with quadriceps rehabilitation for PFP.

## INTRODUCTION

Patellofemoral pain (PFP) is one of the most common presentations at both primary care and sports injury clinics.<sup>1–2</sup> Prevalence rates in groups of active individuals, including military recruits and novice runners, are reported to be between 3% and 20%.<sup>3–5</sup> PFP has been linked to reduced contact area and increased stress in the lateral patellofemoral joint (PFJ)<sup>6–7</sup> as a result of patellar maltracking, including greater lateral patellar translation,<sup>8–10</sup> tilt<sup>8</sup> and spin.<sup>9</sup> The cause of maltracking in PFP is thought to be multifactorial with local,<sup>11</sup> distal<sup>12</sup>

and proximal<sup>13</sup> factors proposed to contribute to it, with good evidence that long axis femoral rotation in relation to the patella is a key contributor to maltracking and a valid rehabilitation target.<sup>14</sup>

Consistent with the multifactorial nature of PFP, management of PFP has traditionally focused on a variety of interventions, including rest, analgesia, general quadriceps and vastus medialis oblique rehabilitation exercises, proximal rehabilitation exercises, patellar taping, foot orthoses and gait retraining.<sup>15</sup> Each of these interventions has a varying level of efficacy, with multimodal interventions appearing to be the most effective.<sup>16–17</sup> Growing evidence for impaired proximal muscle strength<sup>18–20</sup> and function,<sup>21</sup> combined with links between hip mechanics and increased risk of PFP,<sup>5–22</sup> has resulted in promotion of rehabilitation aimed at addressing impairments in proximal musculature.<sup>14</sup> Our recent mixed methods study of international experts' clinical reasoning when managing PFP supported this recommendation, but a lack of supporting level-one evidence was also identified.<sup>17</sup> The effectiveness of proximal rehabilitation protocols have been evaluated in high quality recent research,<sup>23–26</sup> and commonly consist of open and closed kinetic chain exercises which reflect clinical practice.<sup>27</sup>

A recent low quality (LQ) systematic review concerning proximal rehabilitation for PFP<sup>28</sup> concluded that hip interventions were effective in improving pain and function in individuals with PFP. However, the search for available evidence was limited to a 2-year period (January 2011–January 2013), with no attempt at data pooling nor mechanistic exploration and there is, therefore, a need for a more detailed and inclusive review in order to optimally guide practice.

Our systematic review and meta-analysis aims to (1) evaluate the effects of proximal muscle rehabilitation for patients with PFP, (2) compare the effects of various rehabilitation protocols, and (3) evaluate potential mechanism of action in order to optimally guide clinical practice in rehabilitating patients. Further, we aimed to promote clarity in rehabilitation programme design and reporting, with particular respect to the term 'strengthening'.

## METHODS

The PRISMA statement was consulted prior to the start of this review and the checklist completed.<sup>29</sup>

## Inclusion and exclusion criteria

Randomised clinical trials (RCTs) and cohort studies evaluating proximal muscle rehabilitation programmes were considered for inclusion. A



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proximal muscle rehabilitation protocol was defined as progressive exercise directed at the hip or lumbopelvic musculature or both. Studies of multimodal interventions were included where the effects of adding proximal rehabilitation could be clearly determined. Case reports and non-English studies were excluded. The inclusion criteria required participants to be described as having PFP, anterior knee pain or chondromalacia patella in the absence of other knee pathologies, including patellar tendinopathy, Osgood-Schlatters disease and Sinding-Larsen-Johanssons syndrome. Studies evaluating all age ranges were considered for inclusion, as well as studies involving both single sex and mixed sex sample groups.

### Search strategy

Web of Knowledge, CINAHL, EMBASE and Medline (via OVID) databases were searched from inception to December 2014, using the search strategy outlined in [box 1](#). Reference lists of included publications were screened and citation tracking was completed in Google Scholar.

### Review process

Titles and abstracts identified using the search strategy were downloaded into EndNote X7.1 (Thomson Reuters, California, USA). Duplicates were deleted before all abstracts were screened for inclusion by two independent reviewers (SL and OS). A third reviewer (CB) was available to settle any disputes if necessary. Full texts were obtained where necessary.

### Quality assessment

Study methodological quality was assessed with the PEDro scale<sup>30</sup> and a PFP inclusion/exclusion criteria checklist<sup>31</sup> by two independent reviewers (OS and SL). Discrepancies were resolved by consensus, with a third reviewer (CB) available, if needed. Based on the PEDro scores,<sup>30</sup> and guidance by Moher *et al*,<sup>32</sup> studies scoring >6 were considered high quality (HQ) and ≤6 as LQ. The PFP diagnosis checklist<sup>31</sup> is a seven-item scale that identifies key inclusion and exclusion criteria for the diagnosis of PFP. Higher scores indicate a greater number of key criteria having been reported.

### Study analysis

Sample sizes, participant demographics, interventions, variables evaluated and follow-up times were extracted from each study. Further analysis of intervention programme design was completed to determine the type of ‘rehabilitation’ that was prescribed ([table 2](#)) allowing for direct comparison between

reported training methodology and accepted principles of ‘neuromuscular activation’ (exercise performed at <30% 1 repetition maximum, for >20 repetitions), ‘strength’ (exercise performed ≥70% 1 repetition maximum), ‘strength-endurance’ (exercise performed at 30–70% 1 repetition maximum) and ‘power’ (exercise performed at either 85–100% 1 repetition maximum or 0–60% 1 repetition maximum at an explosive velocity).<sup>33</sup> This was in response to concerns raised at the recent PFP research retreat in Vancouver<sup>15</sup> that the word strengthening or strength training is used synonymously for all types of rehabilitation exercise consequently limiting the identification of exercise prescription specificity. It was considered that evaluating methods of exercise prescription (eg, focus on strength, endurance, etc.) and summarising the range of specific exercise descriptors (% repetition maximum, repetitions, time-under-tension) could maximise the clinical utility of this review and facilitate translation to clinical practice.

Means and SDs for all baseline and follow-up data were extracted and entered into Cochrane Review Manager (V5.2) to allow calculation of standard mean differences (SMDs). Meta-analysis was completed where studies evaluated similar interventions using comparable outcome measures (eg, VAS, Visual Analogue Scale and NPRS, Numeric Pain Rating Scale). Where multiple measures were used, a consistent measure between studies was used for pooling (eg, stair ascent). Pooling of data across time points was performed for studies that evaluated outcomes in the ‘short term’ (<3 months), ‘medium term’ (3–12 months), and ‘longer term’ (≥12 months). All outcome measure scores were converted so that favourable outcomes (reduced pain, improved function, improved strength, etc) were entered as positive values into Cochrane Review Manager Software, to facilitate consistent visual representation of SMDs and pooled findings along with 95% CIs. For studies without comparative groups, the results were extracted and reported in the results section, but no meta-analysis performed. Following methodology proposed by Hume *et al*,<sup>34</sup> individual and pooled SMDs were categorised as small (≤0.59), medium (0.60–1.19), or large (≥1.20). These criteria were chosen to increase stringency compared to traditional criteria.<sup>35</sup> Statistical heterogeneity of pooled data was established using the X<sup>2</sup> and I<sup>2</sup> statistics (with heterogeneity being defined as p<0.05). Levels of evidence were guided by recommendations proposed by Van Tulder *et al*:<sup>36</sup> *Strong evidence*=based on results derived from multiple studies, including a minimum of two HQ studies, which are statistically homogenous (I<sup>2</sup><50%).

*Moderate evidence*=based on results derived from multiple studies, including at least one HQ study, which are statistically heterogeneous (I<sup>2</sup>>50%), or from multiple LQ studies which are statistically homogenous (I<sup>2</sup><50%).

*Limited evidence*=based on results derived from multiple LQ studies which are statistically heterogeneous (I<sup>2</sup>>50%), or from one HQ study.

*Very limited evidence*=based on results derived from one LQ study.

*Conflicting evidence*=based on insignificant pooled results derived from multiple studies regardless of quality, which are statistically heterogeneous (I<sup>2</sup>>50%).

### RESULTS

The results of the database search are shown in [figure 1](#). Fourteen studies were identified for the final review. Eleven of these studies were randomised or comparative control trials,<sup>23 24 26 37–44</sup> and three were cohort studies.<sup>25 45 46</sup> Study details, including sample sizes and participant demographics, are shown in online

#### Box 1 Search strategy

Patellofemoral Pain OR Anterior Knee Pain OR Patellofemoral Syndrome OR retropatellar pain OR peripatellar pain OR patellofemoral joint pain OR parapatellar pain OR PFP OR chondromalacia patellae

AND

Proximal OR gluteal

AND

Strength\*

AND

Training OR program OR exercise OR rehab\*

\* , a truncation indicator for searching.

**Table 1** PEDro scale

Author	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	Total score
Baldon <i>et al</i> <sup>44</sup>	1	1	1	1	1	0	1	1	1	1	1	10
Nakagawa <i>et al</i> <sup>40</sup>	0	1	1	1	1	0	1	1	1	1	1	9
Ismail <i>et al</i> <sup>39</sup>	1	1	1	1	0	0	0	1	1	1	1	8
Fukuda <i>et al</i> <sup>23</sup>	1	1	1	1	0	0	1	1	1	1	1	8
Fukuda <i>et al</i> <sup>38</sup>	1	1	1	1	0	0	1	1	1	1	1	8
Ferber <i>et al</i> <sup>42</sup>	1	1	1	0	0	0	1	0	1	1	1	7
Khayambashi <i>et al</i> <sup>43</sup>	1	1	0	1	0	0	0	1	1	1	1	7
Razeghi <i>et al</i> <sup>37</sup>	1	1	1	0	0	0	0	1	1	1	1	6
Dolak <i>et al</i> <sup>24</sup>	0	1	1	1	0	0	0	0	1	1	1	6
Ferber <i>et al</i> <sup>46</sup>	1	0	0	1	0	0	0	1	1	1	1	5
Khayambashi <i>et al</i> <sup>26</sup>	0	0	0	1	0	0	0	1	1	1	1	5
Avraham <i>et al</i> <sup>41</sup>	0	1	0	0	0	0	1	0	1	1	0	4
Tyler <i>et al</i> <sup>45</sup>	1	0	0	0	0	0	0	1	1	0	1	3
Earl and Hoch <sup>25</sup>	1	0	0	0	0	0	0	1	1	0	1	3

I=Eligibility criteria specified, II=Random allocation, III=Concealed allocation, IV=Similar at baseline, V=Subject blinding, VI=Therapist blinding, VII=Assessor blinding, VIII=Outcome measures obtained from >85%, IX=Treatment received as allocated, X=Between-group statistical comparison, XI=Point measures and measures of variability.

supplementary file 1. Intervention and control/comparison group protocols, outcome measures and follow-up duration findings are presented in online supplementary files 2–5.

### Quality assessment

Results from the PFP diagnostic checklist and the PEDro scale are shown in online supplementary file 6 and [table 1](#), respectively. All 12 studies scored five or greater out of seven on the PFP diagnostic checklist, demonstrating a good level of consistency between studies for diagnostic inclusion/exclusion criteria. Scores ranged between 3 and 10 for the PEDro scale. Of the 14 studies, 7 were classed as HQ,<sup>23 38–40 42–44</sup> and 7 were classed as LQ.<sup>24–26 37 41 45 46</sup>

### Exercise prescription and mechanobiological analysis

Results of exercise prescription and mechanobiological analysis are shown in [tables 2](#) and [3](#), respectively. Three of the 14 included studies<sup>23 38 44</sup> were considered to have evaluated the same exercise approach as stated in their title and methodology. Commonly (10 of 14 studies), studies reported evaluation of a strength protocol, despite exercise programmes being considered to be of an intensity to evoke strength-endurance<sup>24 37 39 42 45 46</sup> or neuromuscular<sup>25 26 40 43</sup> activation changes. In one study, the description of exercise prescribed was unclear and could not be interpreted.<sup>41</sup> Analysis of mechanobiological descriptors of exercise prescription from within the 14 included studies highlighted the absence of all ‘classical descriptors’ (eg, load magnitude, % of maximum) and rest period between sets (s/min) in all but one study<sup>39</sup> ([table 3](#)). The seven new descriptors proposed by Toigo and Boutellier<sup>47</sup> were absent, in their entirety, in the methodology of all included studies. Inclusion of the 13 descriptors in future studies is reported to be imperative for the delivery of effective and tailored exercise prescription.<sup>47</sup>

### Effects of proximal rehabilitation

Proximal rehabilitation—compared with—control

#### Pain and function

One LQ study<sup>26</sup> compared proximal rehabilitation in PFP patients to a control group receiving only Omega-3 and calcium supplementation in the short term ([figure 2](#)). Very limited evidence (1 LQ study<sup>26</sup>) with large effect indicated proximal rehabilitation, using exclusively open kinetic chain (OKC) exercises with

progressively higher resistant elastic band (see online supplementary file 2 for further programme details), reduces pain (VAS) (SMD, 95% CI 2.80, 1.71 to 3.88), and improves function (Western Ontario and McMaster osteoarthritis index (WOMAC)) (SMD, 95% CI 2.88, 1.78 to 3.98) in the short term.

Proximal rehabilitation—compared with—quadriceps rehabilitation

#### Pain

Three HQ<sup>42–44</sup> and one LQ study<sup>24</sup> compared proximal rehabilitation to quadriceps rehabilitation in the short and medium term (see online supplementary file 3 for further programme details; [figure 3](#)). Moderate evidence (3 HQ<sup>42–44</sup> and 1 LQ<sup>24</sup> study) of a small effect indicated greater pain reduction following a proximal rehabilitation programme compared with a quadriceps rehabilitation protocol in the short term ( $I^2=81\%$ ,  $p=0.001$ ; SMD, 95% CI 0.36, 0.13 to 0.59). In the medium term, there was strong evidence (2 HQ studies<sup>43 44</sup>) of a medium effect indicating greater pain reduction following a proximal rehabilitation programme compared with a quadriceps rehabilitation protocol ( $I^2=45\%$ ,  $p=0.18$ ; SMD, 95% CI 1.07, 0.55 to 1.59).

#### Function

Moderate evidence (3 HQ<sup>42–44</sup> and 1 LQ<sup>24</sup> study) indicated no difference in functional patient-reported outcome measures (Lower Extremity Functional Scale, LEFS; Anterior Knee Pain Score; AKPS and WOMAC) within a pooled group of statistically heterogeneous studies comparing proximal and quadriceps rehabilitation protocols in the short term ( $I^2=69\%$ ,  $p=0.02$ ; SMD, 95% CI 0.18, -0.05 to 0.42). In the medium term, strong evidence (2 HQ studies<sup>43 44</sup>) of medium effect indicated proximal rehabilitation improves functional patient-reported outcome measures (LEFS and WOMAC) when compared with quadriceps rehabilitation protocols ( $I^2=0\%$ ,  $p=0.54$ ; SMD, 95% CI 0.87, 0.36 to 1.37). Limited evidence (1 HQ study<sup>44</sup>) of a medium effect indicated improved objective function, as measured by single leg hop performance, following proximal compared to quadriceps rehabilitation in the short term.

Proximal combined with quadriceps rehabilitation—compared with—quadriceps rehabilitation

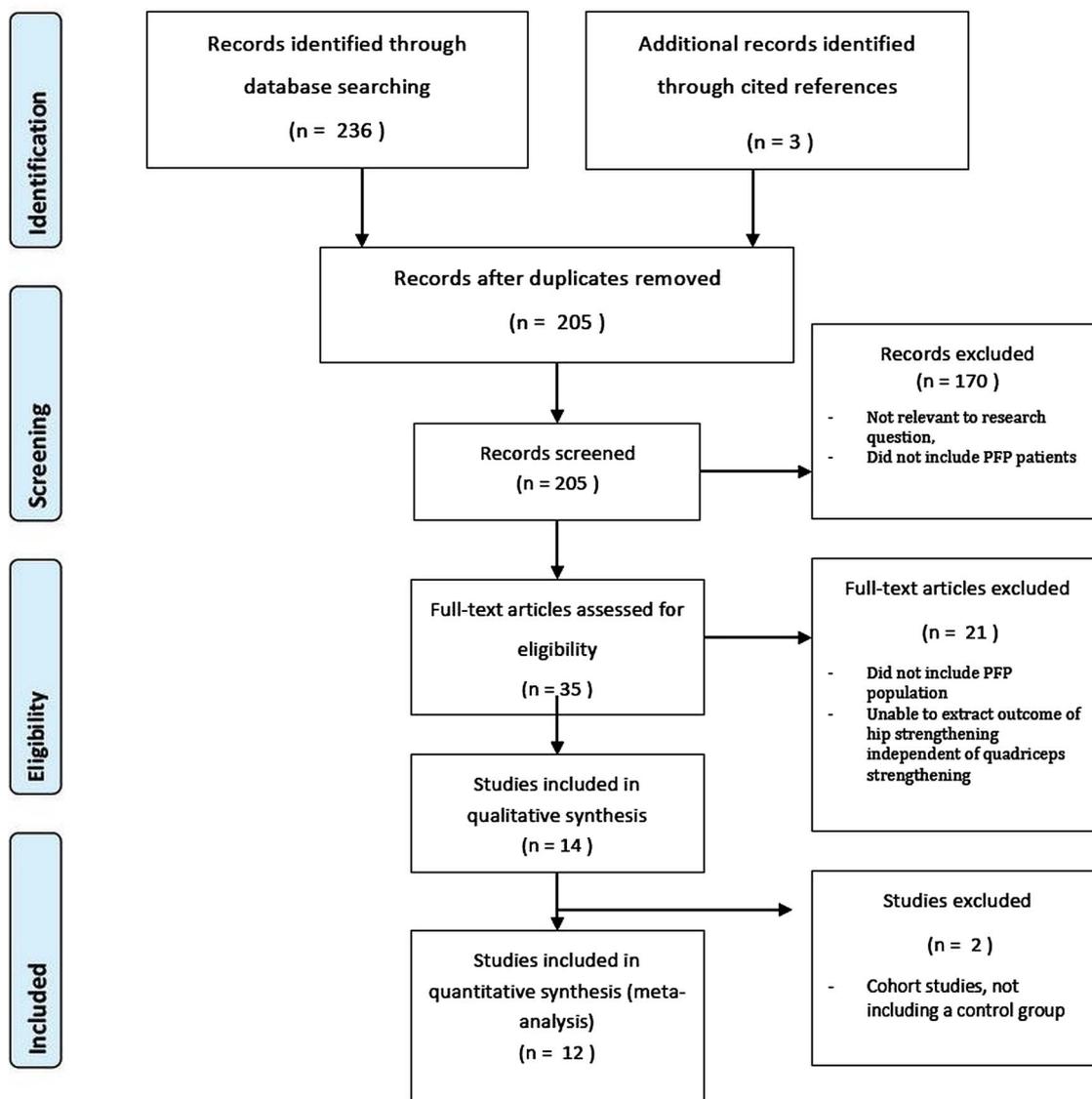
Four HQ<sup>23 38–40</sup> and three LQ<sup>24 37 41</sup> studies compared proximal combined with quadriceps rehabilitation to quadriceps

**Table 2** Analysis of programme design and aims

Author	Stated exercise aim (title)	Method exercise aim (within text)	Reviewers' interpretation of actual exercise aim	Fit of stated exercise aim (in text) and actual exercise	Outcome measure suitability for reviewer defined exercise aim and comment
Nakagawa <i>et al</i> <sup>40</sup>	Str	Str	NM	0	1 No patient capacity specific loading; no additional load; Assessed muscle EMG and isokinetic strength
Ismail <i>et al</i> <sup>39</sup>	Str	Str	StrEnd	1	2 Proximal rehabilitation performed at 60% of 10 RM; No patient specific training intensity for CKC exercises reported
Fukuda <i>et al</i> <sup>23</sup>	Str	Str	Str	2	1 Programme used 70% of 'estimated 1 RM' that could be performed pain free
Fukuda <i>et al</i> <sup>38</sup>	Str	Str	Str	2	1 Programme used 70% of 'estimated 1 RM' that could be performed pain free
Razeghi <i>et al</i> <sup>37</sup>	Str	Str	StrEnd	1	2 McQueen method of load progression used
Dolak <i>et al</i> <sup>24</sup>	Str	Str	StrEnd	1	2 Load progression as % of body weight, not of muscle capacity
Ferber <i>et al</i> <sup>46</sup>	Str	Str	StrEnd	1	1 Progression offered if exercise performed 'too easily', definition of 'too easily' not reported
Ferber <i>et al</i> <sup>42</sup>	Str	NM	StrEnd	1	1 Clinician led load prescription, ensuring last 3 of 10 repetitions were 'challenging'
Khayambashi <i>et al</i> <sup>26</sup>	Str	Str	NM	0	2 Resistance progression was generic, 3×20–25 repetitions were performed for each exercise
Baldon <i>et al</i> <sup>44</sup>	NM/Str	NM/Str	NM/Str	2	2 NM programme 20 repetitions plus isometric holds; Str performed at 75% 1 RM 3×12 repetitions
Khayambashi <i>et al</i> <sup>43</sup>	Str	Str	NM	0	1 Generic progression of resistance, 3×20–25 repetitions were performed for each exercise
Avraham <i>et al</i> <sup>41</sup>	Str	Str	Unclear	Unclear	Unclear Programme not clearly defined, repetitions dependent on patient 'capability'; no additional load described
Tyler <i>et al</i> <sup>45</sup>	Not stated	Str	StrEnd/NM/P	0	1 Programme described as 'progressive resistive exercise' but exact number of repetitions and load not described
Earl and Hoch <sup>25</sup>	Str	NM	NM	1	1 Assessed kinematic change, but also assessed strength

0=No, 1=In part, 2=Yes.

CKC, closed kinetic chain; EMG, electromyography; NM, neuromuscular (>20 repetitions, <30% 1 RM); P, power (85–100% 1 RM or 0–60% 1 RM at explosive velocity); RM, repetition maximum; Str, strength (≥70% 1 RM); StrEnd, strength endurance (30–70% 1 RM).



**Figure 1** Flow chart of included studies. PFP, patellofemoral pain.

rehabilitation alone (see online supplementary file 4 for further programme details), covering short,<sup>23 24 37 39-41 46</sup> medium,<sup>23 24</sup> and longer<sup>23</sup> follow-up (figures 4 and 5).

### Pain

Strong evidence (3 HQ<sup>38-40</sup> and 2 LQ studies<sup>24 37</sup>) of a small effect indicated greater pain reduction favouring proximal combined with quadriceps rehabilitation using both OKC and CKC exercises compared to a quadriceps rehabilitation alone in the short term ( $I^2=14\%$ ,  $p=0.33$ ; SMD, 95% CI 0.55, 0.22 to 0.88). In the medium term, there was moderate evidence (1 HQ<sup>23</sup> and 1 LQ study<sup>24</sup>) of a large effect indicating greater pain reduction following proximal combined with quadriceps rehabilitation using OKC and CKC compared to quadriceps rehabilitation alone in the medium term ( $I^2=92\%$ ,  $p=0.0003$ ; SMD, 95% CI 1.36, 0.83 to 1.90). Within the same HQ study, at 6 months, there was limited evidence (1 HQ study<sup>23</sup>) of a large effect indicating greater reduction in pain following proximal combined with quadriceps rehabilitation compared to quadriceps rehabilitation alone (SMD, 95% CI 2.58, 1.81 to 3.35).

In the longer term, there was limited evidence (1 HQ study<sup>23</sup>) of a large effect indicating greater pain reduction

following proximal combined with quadriceps rehabilitation compared to quadriceps rehabilitation alone (SMD, 95% CI 2.99, 2.16 to 3.83).

### Function

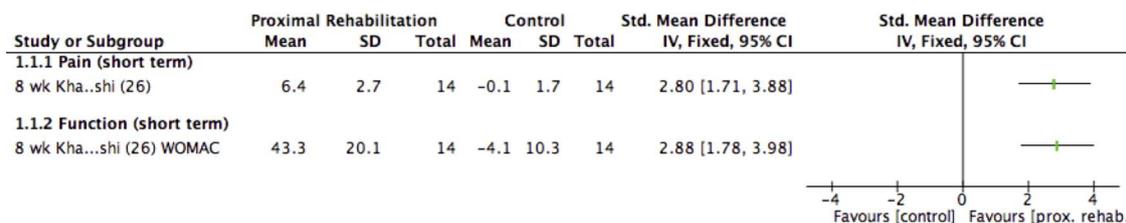
Strong evidence (2 HQ<sup>38 39</sup> and 1 LQ<sup>24</sup> study) of a small effect indicated greater functional patient-reported improvement (how measured) following proximal combined with quadriceps rehabilitation compared to quadriceps rehabilitation alone in the short term ( $I^2=18\%$ ,  $p=0.30$ ; SMD, 95% CI 0.42, 0.03 to 0.81). Limited evidence (1 HQ study<sup>38</sup>) indicated no difference in functional performance measured with the single leg hop test scores (SMD, 95% CI 0.32, -0.30 to 0.93) in the short term.

In the medium term, moderate evidence (1 HQ<sup>23</sup> and 1 LQ<sup>24</sup> study) of a large effect indicated increased patient reported function, measured by LEFS ( $I^2=96\%$ ,  $p<0.00001$ ; SMD, 95% CI 1.32, 0.75 to 1.89). Limited evidence (1 HQ study<sup>23</sup>) of a large effect indicated increased patient-reported function measured by AKPS (SMD, 95% CI 1.86, 1.18 to 2.54). Limited evidence (1 HQ study<sup>23</sup>) of large effect indicates increased performance-based function, measured by single leg hop scores (SMD, 95% CI 1.54, 0.89 to 2.18). Within the same study, at

**Table 3** Analysis of specific descriptors of exercise prescription

Author	Classical set of descriptors						New set of descriptors						
	Load magnitude	Repetitions (n)	Sets (n)	Rest in-between sets ([s] or [min])	Number of exercise interventions (per [day] or week)	Duration of the experimental period ([day] or weeks)	Fractional and temporal distribution of the contraction modes per repetition and duration [s] of one repetition	Rest in-between repetitions ([s] or [min])	Time under tension ([s] or [min])	Volitional muscular failure	Range of motion	Recovery time in-between exercise sessions ([h] or [d])	Anatomical definition of the exercise (exercise form)
Nakagawa <i>et al</i> <sup>40</sup>	X	Y	Y	X	Y	Y	X	X	X	X	Y	X	Y
Ismail <i>et al</i> <sup>39</sup>	Y	Y	Y	Y	Y	Y	Y	X	X	X	Y	X	X
Fukuda <i>et al</i> <sup>23</sup>	Y	Y	Y	X	Y	Y	X	X	X	X	Y	X	X
Fukuda <i>et al</i> <sup>38</sup>	Y	Y	Y	X	Y	Y	X	X	X	X	Y	X	X
Razeghi <i>et al</i> <sup>37</sup>	X	Y	X	X	X	Y	X	X	X	X	X	X	X
Dolak <i>et al</i> <sup>24</sup>	Y	Y	Y	X	Y	Y	X	X	X	X	X	X	X
Ferber <i>et al</i> <sup>46</sup>	X	Y	Y	X	Y	Y	Y	X	X	X	X	X	X
Ferber <i>et al</i> <sup>42</sup>	X	Y	Y	X	Y	Y	X	X	X	X	X	X	Y
Khayambashi <i>et al</i> <sup>26</sup>	X	Y	Y	X	Y	Y	X	X	X	X	Y	X	X
Baldon <i>et al</i> <sup>44</sup>	Y	Y	Y	X	Y	Y	X	X	X	X	X	X	X
Khayambashi <i>et al</i> <sup>43</sup>	X	Y	Y	X	Y	Y	X	X	X	X	Y	X	X
Avraham <i>et al</i> <sup>41</sup>	X	X	X	Y	Y	Y	X	Y	X	X	Y	X	X
Tyler <i>et al</i> <sup>45</sup>	X	X	X	X	Y	Y	X	X	X	X	X	X	X
Earl and Hoch <sup>25</sup>	X	Y	Y	X	Y	Y	X	X	X	X	X	X	Y

Y=Incorporated in study, X=Not incorporated in study.



**Figure 2** Proximal rehabilitation compared with control group for pain and function (WOMAC, Western Ontario and McMaster osteoarthritis index; 'short term', <3 months; IV, inverse variance; Std., standard mean difference).

6 months, limited evidence (1 HQ study<sup>23</sup>) of a large effect indicated increased patient-reported function, as measured by LEFS (SMD, 95% CI 2.49, 1.73 to 3.25), AKPS (SMD, 95% CI 1.86, 1.18 to 2.54), and performance-based function measured as single leg hop scores (SMD, 95% CI 1.85, 1.17 to 2.52).

In the longer term, limited evidence (1 HQ study<sup>23</sup>) of a large effect indicated greater patient-reported functional improvement as measured by LEFS (SMD, 95% CI 2.65, 1.86 to 3.43), AKPS (SMD, 95% CI 1.76, 1.09 to 2.42), and performance-based function measured with the single leg hop (SMD, 95% CI 2.06, 1.36 to 2.77) at 12 months, with proximal and quadriceps rehabilitation compared to quadriceps rehabilitation alone.

### Mechanisms of proximal rehabilitation

Ten<sup>24–26 37 39 40 42 44–46</sup> of the 14 studies explored variables with potential to explain proximal rehabilitation effects in the short term. No studies investigated mechanisms of effect at medium or longer-term follow-up.

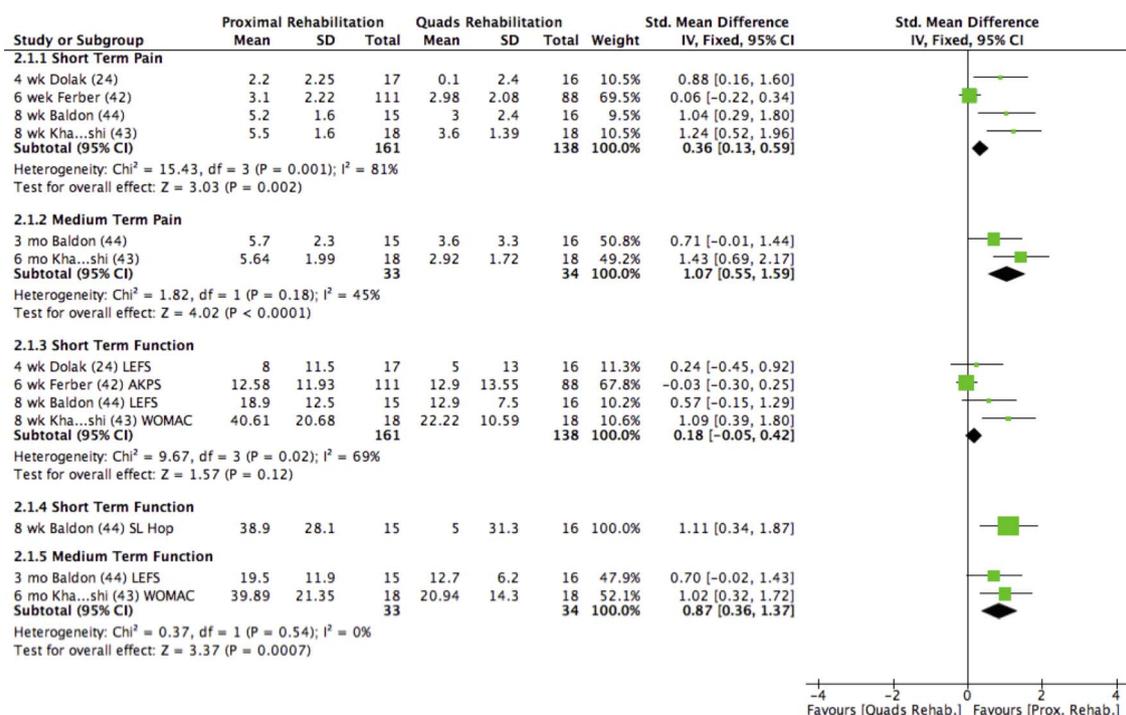
### Proximal rehabilitation—compared with—control

Limited evidence (2 LQ study<sup>26 46</sup>) of a large effect indicated that proximal rehabilitation using OKC band exercises increased isometric hip abduction strength ( $I^2=81\%$ ,  $p<0.00001$ ; SMD,

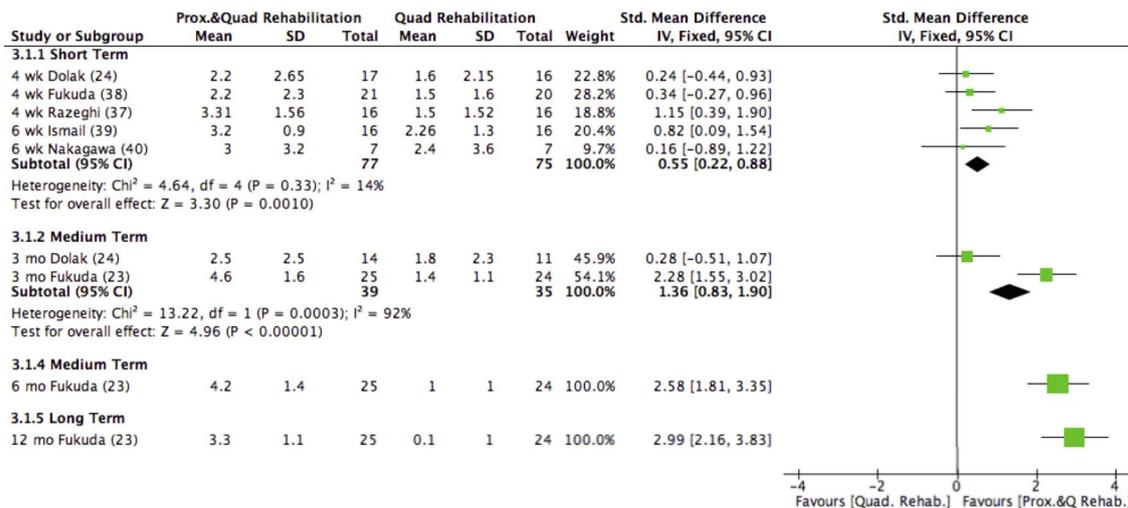
95% CI 1.69, 1.03 to 2.36) (figure 6). Very limited evidence (1 LQ study<sup>26</sup>) of a large effect indicated increased isometric hip external rotation strength in the OKC rehabilitation group in both the left (SMD, 95% CI 2.45, 1.43 to 3.46) and right (SMD, 95% CI 2.73, 1.66 to 3.80) hip. Very limited evidence (1 LQ study<sup>46</sup>) of a large effect indicated OKC proximal rehabilitation reduced the degree of knee valgum variability during consecutive footfalls while running (SMD, 95% CI 2.68, 1.54 to 3.82), but did not change peak knee genu valgum angles while running (SMD, 95% CI 0.83, -0.01 to 1.67).

### Proximal rehabilitation—compared with—quadriceps rehabilitation

Moderate evidence (1 HQ and 1 LQ study<sup>24 42</sup>) indicated no difference in maximal isometric strength for hip abduction ( $I^2=60\%$ ,  $p=0.11$ ; SMD, 95% CI 0.18, -0.08 to 0.44), external rotation ( $I^2=0\%$ ,  $p=0.44$ ; SMD, 95% CI 0.11, -0.15 to 0.37) or knee extension ( $I^2=0\%$ ,  $p=0.33$ ; SMD, 95% CI 0.09, -0.17 to 0.35) following a proximal (OKC) rehabilitation programme, as compared to a quadriceps (OKC/CKC) rehabilitation programme (figure 7). Limited evidence (1 HQ study<sup>42</sup>) indicated no difference in hip extension (SMD, 95% CI 0.09, -0.19 to 0.37) or internal rotation (SMD, 95% CI 0.02, -0.26



**Figure 3** Proximal rehabilitation compared with quadriceps rehabilitation for pain and function (LEFS, Lower Extremity Functional Score; AKPS, Anterior Knee Pain Score; 'short term', <3 months; IV, inverse variance; Std., standard mean difference).



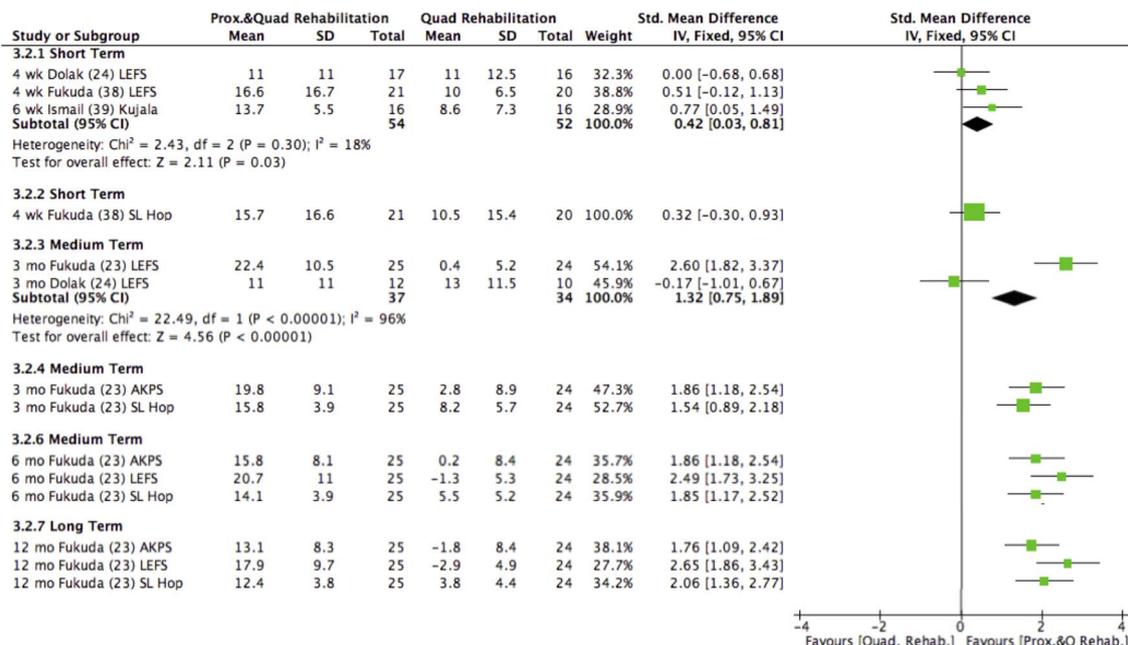
**Figure 4** Proximal and quadriceps rehabilitation compared with quadriceps rehabilitation for pain ('short term', <3 months; 'medium term', 3–12 months; 'longer term', ≥12 months; IV, inverse variance; Std., standard mean difference).

to 0.30) strength when comparing an OKC proximal with a CKC quadriceps rehabilitation programme.

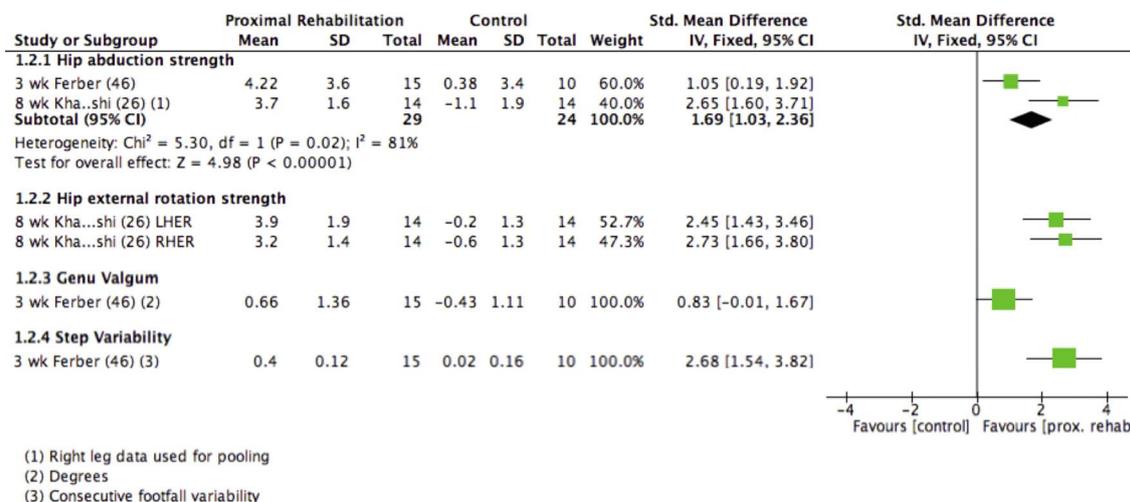
Limited evidence (1 HQ study<sup>44</sup>) indicated proximal rehabilitation using CKC exercises, when compared with a CKC quadriceps rehabilitation protocol, increased the degree of pelvis anteversion (SMD, 95% CI 1.21, 0.43 to 1.98), hip flexion (SMD, 95% CI 1.16, 0.39 to 1.92), trunk contralateral inclination (SMD, 95% CI 0.90, 0.16 to 1.65), pelvis elevation (SMD, 95% CI 0.94, 0.19 to 1.68), hip abduction (SMD, 95% CI 2.20, 1.28 to 3.11), and knee adduction (SMD, 95% CI 0.81, 0.07 to 1.55) during a single leg squatting task. Additionally, anterior (SMD, 95% CI 2.03, 1.14 to 2.92), lateral (SMD, 95% CI 2.50, 1.53 to 3.46), and posterior (SMD, 95% CI 1.54, 0.73 to 2.36) trunk endurance (seconds), and proximal abductor (SMD, 95% CI 1.24, 0.47 to 2.02) and knee

extensor (SMD, 95% CI 0.97, 0.22 to 1.72) torque (nm/kg) increased in the proximal rehabilitation group when compared with quadriceps rehabilitation.<sup>44</sup>

Proximal combined with quadriceps rehabilitation—compared with—quadriceps rehabilitation alone  
Strong evidence (2 HQ studies<sup>39 40</sup>) indicated no difference in isokinetic, concentric and eccentric hip abduction, and external rotation strength following a proximal (OKC) combined with quadriceps (CKC) rehabilitation programme when compared to a quadriceps rehabilitation (CKC) programme alone (figure 8). Very limited evidence (1 LQ study<sup>24</sup>) indicated no difference in isometric hip abduction (SMD, 95% CI 0.54, -0.16 to 1.23) or external rotation (SMD, 95% CI 0.63, -0.07 to 1.33) strength following a proximal combined with quadriceps rehabilitation



**Figure 5** Proximal and quadriceps rehabilitation compared with quadriceps rehabilitation for function (LEFS, Lower Extremity Functional Score; AKPS, Anterior Knee Pain Score; 'short term', <3 months; 'medium term', 3–12 months; 'longer term', ≥12 months; IV, inverse variance; Std., standard mean difference).



**Figure 6** Proximal rehabilitation compared with control group for strength and biomechanics in the short term (<3 months) (LHER, left proximal external rotation; RHER, right proximal external rotation; IV, inverse variance; Std., standard mean difference).

programme compared to quadriceps rehabilitation alone. Moderate evidence (2 LQ studies<sup>24, 37</sup>) indicated no difference in isometric knee extension strength (I<sup>2</sup>=0%, p=0.37; SMD, 95% CI 0.07, -0.42 to 0.56) following comparison of proximal and quadriceps rehabilitation with quadriceps rehabilitation alone.

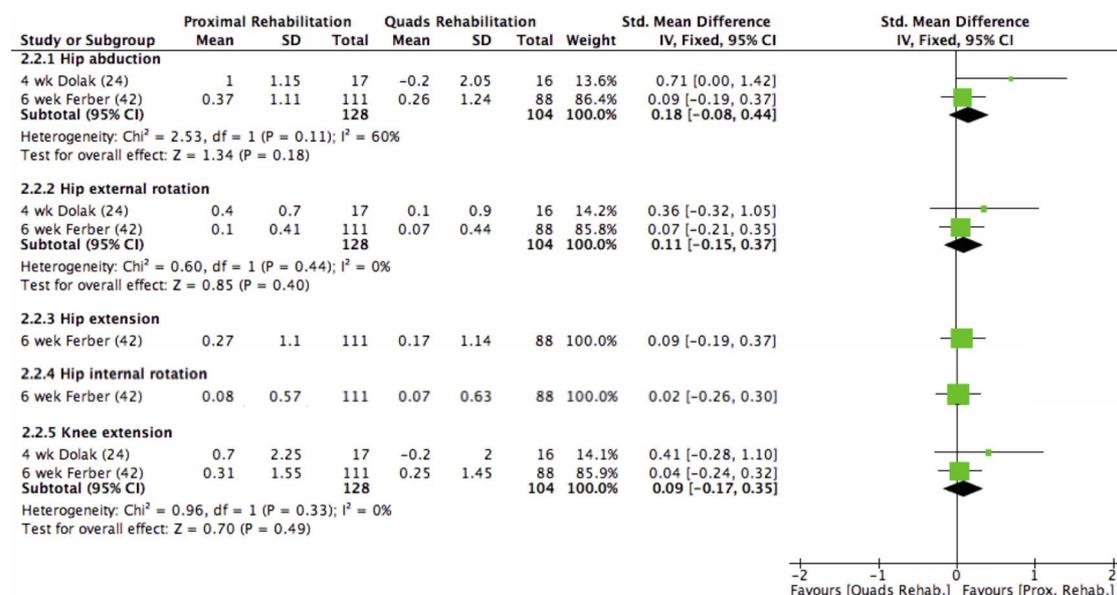
#### Proximal rehabilitation alone

One LQ study<sup>45</sup> divided their cohort into 'successful' ( $\geq 1.5$  cm reduction in VAS) and 'unsuccessful' groups, reporting an improvement in isometric proximal abduction and adduction strength was unrelated to success. Very limited evidence (1 LQ study<sup>25</sup>) indicated an improvement in lateral core endurance (p=0.001), hip abduction (p=0.008) and external rotation (p=0.03) isometric strength, and knee abduction internal moments (p=0.05) after an 8-week OKC and CKC neuromuscular activation intervention directed at the proximal musculature. A trend in increased anterior (p=0.06) and posterior

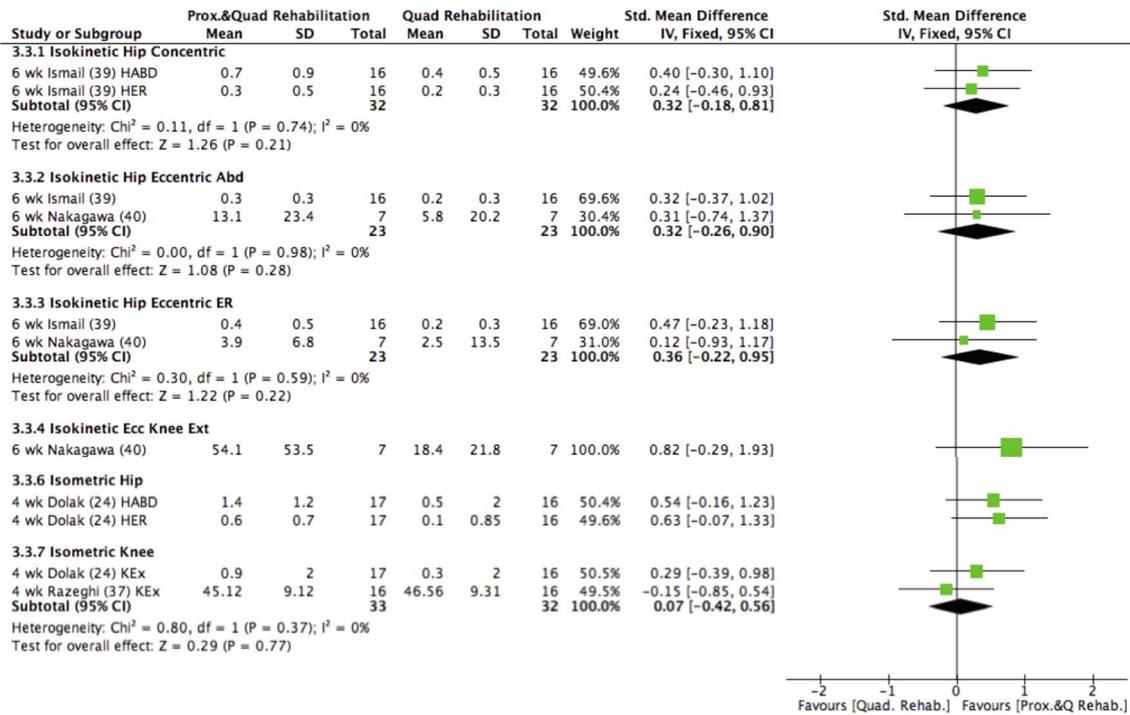
(p=0.1) core endurance, and hip abduction moment (p=0.06) was reported in the same study.<sup>25</sup> However, no change in rear foot eversion, knee abduction, hip adduction and internal rotation angles, rear foot inversion or hip external rotation moments were reported during a running task.<sup>25</sup>

#### DISCUSSION

This systematic review and meta-analysis evaluated the effects of proximal muscle rehabilitation on pain and function in individuals with PFP and the potential mechanisms for effectiveness. Fourteen studies of varying quality were identified, including 11 RCTs.<sup>23, 24, 26, 37-44</sup> In the short term, strong evidence indicates proximal combined with quadriceps rehabilitation is significantly better at reducing pain than quadriceps rehabilitation alone,<sup>23, 24, 37, 39-41, 46</sup> moderate evidence indicates proximal rehabilitation is better at improving pain compared to quadriceps rehabilitation alone,<sup>24, 42-44</sup> and very limited evidence indicates proximal rehabilitation reduces pain compared to a no



**Figure 7** Proximal rehabilitation compared with quadriceps rehabilitation for isometric strength in the short term (<3 months) (IV, inverse variance; Std., standard mean difference).



**Figure 8** Proximal and quadriceps rehabilitation compared with quadriceps rehabilitation for strength in the short term (<3 months) (Abd, abduction; ER, external rotation; Ecc, eccentric; Ext, extension; HABD, hip abduction; HER, hip external rotation; IV, Inverse variance; Std., standard mean difference).

intervention control.<sup>26</sup> In the medium term, strong and moderate evidence indicates proximal and proximal combined with quadriceps rehabilitation, respectively, is more effective at reducing pain than quadriceps rehabilitation alone.<sup>23 43 44</sup> In the longer term, limited evidence indicates proximal combined with quadriceps rehabilitation is more effective at reducing pain than quadriceps rehabilitation alone.<sup>23</sup> Greater improvements in function were also reported for proximal, and proximal combined with quadriceps rehabilitation compared with quadriceps rehabilitation alone in the short (strong evidence), medium (strong to moderate evidence) and longer (limited evidence) term.<sup>23 24 38 39</sup> Put together, these findings support the implementation of proximal muscle rehabilitation programmes for the management of PFP in clinical practice.

## Effects of proximal rehabilitation

### Pain

Strong evidence suggests that a combined proximal and quadriceps rehabilitation protocol using both OKC and CKC exercises results in superior short term outcomes of pain reduction when compared to CKC quadriceps rehabilitation alone. This pooled result is, however, driven by one LQ study<sup>37</sup> that reported significant improvement in pain. In contrast, three<sup>24 38 40</sup> of the five pooled studies reported no greater short-term pain reduction when compared to a quadriceps rehabilitation programme. An important consideration when interpreting these findings is that the CKC quadriceps exercises adopted within the three equivocal studies<sup>24 38 40</sup> would also facilitate activation of proximal musculature and as such, could also be considered a combined proximal and quadriceps intervention. A similar story emerges when comparing proximal and quadriceps rehabilitation. Specifically, within a pooled group of heterogeneous studies that evaluated proximal compared with quadriceps rehabilitation, a large multicentre trial that compared an OKC proximal to a CKC quadriceps protocol demonstrated no

significant differences in pain reduction between groups, but reported significant pain reduction within both groups in the short term.<sup>42</sup> Adding proximal rehabilitation to quadriceps appears to offer the most favourable short-term outcome; however, it is clear that further research to identify the most effective rehabilitation programme design is required to maximise effectiveness.

In the medium term, pooled results indicate proximal rehabilitation more effectively reduced pain when compared to quadriceps rehabilitation alone. Among the pooled studies, exercise programme design differed significantly, with one utilising exclusively neuromuscular OKC<sup>43</sup> and the other using neuromuscular and strength CKC<sup>44</sup> exercises. Of these protocols, the neuromuscular OKC protocol resulted in the greatest positive symptom change, but further research directly comparing these different protocols is needed. Proximal combined with quadriceps rehabilitation was more effective than quadriceps rehabilitation in reducing pain in the medium and longer term, with treatment effects of large magnitude. The single study reporting significant pain reduction in the long-term used a combination of both OKC and CKC at an intensity assessed to be sufficient to evoke strength changes (ie, >70% 1 RM).<sup>23</sup> These exercise parameters may be relevant to the successful outcome given that OKC exercises are commonly used clinically to allow for specific isolation of proximal musculature<sup>48</sup> while attempting to reduce loading of the PFJ. These preliminary findings require further research to determine the most efficacious protocol to reduce pain, in the medium and long term.

### Function

Fewer studies evaluated the effects of proximal muscle rehabilitation on functional outcomes, which limits the conclusions that can be drawn. Greater improvements in self-reported measures (WOMAC, LEFS, AKPS) and performance-based measures (Single Leg hop test) of function were observed in the short

term following proximal rehabilitation compared to a no intervention control; and following proximal combined with quadriceps rehabilitation compared to quadriceps rehabilitation. Moderate evidence indicated no difference in function when comparing proximal with quadriceps rehabilitation, which differs from findings related to pain. It is possible that interventions that address the deficits in gluteal strength<sup>20 19</sup> and activation<sup>21</sup> and quadriceps strength<sup>19</sup> that are evident in individuals with PFP could be sufficient to result in the short-term improvement of function, but not in the medium and longer term. Importantly, greater functional improvements are provided by proximal compared to quadriceps rehabilitation (strong evidence), and a combined proximal and quadriceps rehabilitation compared to quadriceps rehabilitation alone (limited to moderate evidence) in the medium and longer term. It is possible that superior pain outcomes with proximal compared to quadriceps rehabilitation in the short-term results from the quadriceps loading causing irritation to the PFJ, although further research documenting pain levels during exercise is needed to clarify this. These findings suggest that incorporating proximal rehabilitation into the management of PFP is beneficial to functional outcomes. However, considering the currently limited to moderate supporting evidence, further high quality studies are needed to confirm these positive results.

### Mechanisms of proximal rehabilitation

This review evaluated potential short-term mechanisms of treatment effect, with studies reporting improvement in isometric<sup>24 26 46</sup> and isokinetic strength,<sup>39 40</sup> eccentric torque,<sup>44</sup> trunk muscle endurance,<sup>44</sup> single leg squat kinematics,<sup>44</sup> reduced knee joint motion variability,<sup>46</sup> and reduced peak knee abduction internal moments.<sup>25</sup> Changes in strength were measured in 10 of the 14 included studies. Limited evidence of large effect indicated greater improvement in isometric hip abduction strength in the short-term following a neuromuscular or strength-endurance resistance band intervention when compared to no intervention, offering a potential mechanism for changes in pain and function.<sup>26 46</sup> However, given the absence of significant difference in maximal isometric hip abduction, extension, external and internal rotation, and knee extension strength when comparing OKC proximal rehabilitation to CKC quadriceps rehabilitation,<sup>42</sup> it is also plausible that the positive effects of a rehabilitation intervention are not exclusively derived through changes in strength, but through a combination of more global lower limb strength changes, a change in lower limb biomechanics, possible central or systemic mechanisms,<sup>49</sup> or most likely a combination of these factors.

Three studies exploring kinematic and/or kinetic change resulting from proximal rehabilitation reported small but significant changes about the hip and knee<sup>25 44 46</sup> that offer potential mechanisms for treatment effects. Increased hip adduction and internal rotation has been identified previously as a risk factor for and is associated with PFP symptoms.<sup>5 14</sup> Consequently interventions that demonstrate capacity to modify these parameters warrant further investigation. Although some evidence reports clinical measures are able to identify individuals with movement deficits and detect biomechanical change of small magnitude,<sup>50</sup> it is important to ensure clinical tools are sufficiently sensitive to direct intervention choice and determine treatment effects.

Further exploration of the mechanisms for treatment effects following a rehabilitation intervention on muscle structure, neural innervation, systemic systems and biomechanics is needed to guide a tailored exercise approach to address patient-specific deficits and predict outcomes in individuals with PFP.

### Clinical implications

Interventions that aim to improve strength, strength-endurance and neuromuscular activity of proximal musculature are effective in the management of PFP, and should be incorporated in clinical practice. From within the largest high quality study that explored the effect of proximal compared with quadriceps rehabilitation, OKC proximal rehabilitation in isolation was not more effective at reducing pain than a CKC quadriceps rehabilitation programme<sup>42</sup> in the short term. These findings suggest CKC quadriceps rehabilitation is as effective at increasing proximal strength as an isolated OKC proximal rehabilitation programme and have potentially important clinical implications for exercise intervention design. These suggest that clinicians could choose different treatment approaches and achieve the same or similar strength gains. Subsequently, this would allow clinicians to be guided by patient response, preference or available equipment, without negatively impacting on patient care.

Proximal rehabilitation combined with quadriceps rehabilitation using both OKC and CKC exercises produced better pain and functional outcomes in the short,<sup>44</sup> medium and longer term<sup>23</sup> compared to quadriceps rehabilitation alone. Therefore, therapists treating PFP should aim to prescribe exercise interventions targeting the quadriceps and proximal musculature in individuals with PFP using a combination of OKC and CKC exercises.

Rehabilitation exercises from studies included in this review were completed between 3 and 7 times per week, with the intensity of the programmes varying significantly. Exercise frequency did not appear to be dependent on the type and intensity of the rehabilitation protocols prescribed. Given established guidelines<sup>33</sup> that indicate neuromuscular training has greater effect if performed frequently (daily) and strength training less frequently (2–3× per week) on physiological adaptation, the specificity of exercise frequency in the management of PFP is lacking within the current evidence base and requires further research.

Given that the primary goal of PFP treatment is often pain reduction, utilising exercise parameters that do not aggravate symptoms is important. Consequently, utilising OKC exercises in the short term or CKC exercises within finite pain limits throughout the rehabilitation process is advocated by the current evidence.<sup>23 24 44</sup> It is unclear at present whether these parameters are essential for a successful outcome; further research is required to determine the most effective protocol design. Furthermore, identification of individuals who are more likely to respond to a specific proximal intervention approach is an important consideration given the dearth of evidence exploring indicators for proximal intervention success.<sup>51</sup>

### Limitations

There are limitations that need to be considered when interpreting the results of this review. Variability in study design, type of protocol (OKC or CKC), and differing outcome measures limited further data pooling. Where pooling was possible, heterogeneity of rehabilitative exercise prescription remained evident in both exercise frequency and intensity. Nonetheless, given the paucity of available evidence, we felt that data pooling was valuable to strengthening the findings of the review. Non-English language publications were not sought in this review. While it is arguable that high-quality RCTs would aim to be published in higher impact journals written in the English language, identification of further trial data may have influenced the outcomes of analysis. Assessment of methodological quality

was completed using the PEDro scale. It was identified that only 43% of the included 11 studies blinded the assessor to the intervention delivered and only one study attempted to blind the participants to their group allocation. Given growing evidence for proximal intervention efficacy, future studies should aim to blind the participants and researchers to the allocated group. Finally, it has been identified that mechanobiological determinants of exercise prescription are poorly reported or defined within the included rehabilitation studies. To ensure clinical utility and consistency of exercise parameter reporting within future studies, these determinants must be detailed.

## CONCLUSION

The best available evidence indicates that proximal rehabilitation with or without simultaneous quadriceps rehabilitation is beneficial to pain and function in individuals with PFP in the short and medium term. While fewer studies have evaluated long-term effects, the limited evidence available indicates proximal and quadriceps rehabilitation combined has greater positive benefit on pain and function than quadriceps rehabilitation alone. A combination of both OKC and CKC exercise are most likely to result in favourable outcomes. Given variability in rehabilitation protocols within the current literature, further studies designed to identify the most effective protocol by considering exercise type, load and dose are required. To improve clinical applicability, these studies must detail specific exercise descriptors. Regardless, proximal rehabilitation should be incorporated into clinical reasoning paradigms for the management of PFP.

## Summary box

- ▶ Proximal combined with quadriceps rehabilitation reduces pain and improves function more than quadriceps rehabilitation in the short, medium and long term.
- ▶ Proximal rehabilitation is more effective than quadriceps rehabilitation in decreasing pain in the short term, and decreasing pain and improving function in the medium term.
- ▶ Maximum hip muscle isometric strength can be increased by proximal rehabilitation compared to no exercise controls, but not significantly more than a closed kinetic chain quadriceps focused rehabilitation programme.

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**Competing interests** None declared.

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Author	Sample Size		Gender (F:M)		Age Range (mean age)		Height (m)		Weight (kg)	
	INT	CON	INT	CON	INT	CON	INT	CON	INT	CON
Nakagawa et al. <a href="#">40</a>	7	7	10:4		17-40 (23.6 ± 5.9)		NR	NR	NR	NR
Fukuda et al. <a href="#">23</a>	25	24	25:0	24:0	20-40 (22.0 ± 3.0)	20-40 (23.0 ± 3.0)	1.59 ± 0.10	1.60 ± 0.30	60.0 ± 2.6	61.5 ± 3.6
Ferber et al. <a href="#">46</a>	15	10	10:5	6:4	NR (35.2 ± 12.2)	NR (29.9 ± 8.3)	1.65 ± 0.34	1.73 ± 0.41	69.1 ± 11.6	73.1 ± 15.7
Avraham et al. <a href="#">41</a>	10, 10, 10		NR	NR	NR	NR	NR	NR	NR	NR
Tyler et al. <a href="#">45</a>	35 (45k)		29:6		NR (33 ± 16)		NR		NR	
Khayambashi et al. <a href="#">26</a>	14	14	14:0	14:0	NR (28.9 ± 5.8)	NR (30.5 ± 4.8)	1.582 ± 0.058	1.609 ± 0.046	60.8 ± 10.4	62.6 ± 10.6
Earl & Hoch <a href="#">25</a>	19		19:0		16-40 (22.68 ± 7.19)		1.64 ± 0.07		60.2 ± 7.35	
Razeghi et al. <a href="#">37</a>	16 (28k)*	16 (24k)	16:0	16:0	18-30 (22.62 ± 2.67)		NR	NR	NR	NR
Fukuda et al. <a href="#">38</a> (KHE)	21	23	21:0	23:0	NR (25.0 ± 7.0)	NR 24.0 ± 7.0)	1.62 ± 0.6	1.60 ± 0.5	61.3 ± 8.1	57.8 ± 6.2
Fukuda et al. <a href="#">38</a> (KE)	20	23	20:0	23:0	NR (25.0 ± 6.0)	NR 24.0 ± 7.0)	1.64 ± 0.6	1.60 ± 0.5	57.1 ± 7.3	57.8 ± 6.2
Dolak et al. <a href="#">24</a>	17	16	17:0	16:0	NR (25 ± 5)	NR (26 ± 6)	1.66 ± 0.08	1.66 ± 0.08	NR	NR
Ismail et al. <a href="#">39</a>	16	16	12:4	11:5	18-30(20.8±2.7)	18-30 (21.2±3.2)	1.64 ± 0.85	1.66 ± 0.53	64.5±9.6	66.6±9.8
Baldon et al. <a href="#">44</a>	15	16	15:0	16:0	18-30 (21.3±2.6)	18-30 (22.7±3.2)	1.60 ± 0.1	1.66 ± 0.1	58.3 ± 7.3	57.1 ± 8.2
Khayambashi et al. <a href="#">43</a>	18	18	9:9	9:9	NR (28.2 ± 7.9)	NR (27.3 ± 6.7)	1.71 ± 0.89	1.71 ± 0.99	70.6 ± 11.5	66.7 ± 14.7
Ferber et al. <a href="#">42</a>	111	88	133:66		NR (29±7.1)		170.4± 0.94		67.7 ± 9.5	

\* 1 subject lost to follow up in intervention group  
**INT**, intervention; **CON**, control; **F**, female; **M**, male; **NR**, not reported; **k**, knees; **KHE**, knee and proximal exercise; **KE**, knee exercise

Supplementary File 2 – Proximal rehabilitation compared to a control group study characteristics

<i>Author</i>	<i>Intervention</i>	<i>Control</i>	<i>Variables measured</i>	<i>Follow up</i>
<b><i>Proximal rehabilitation v Control Group</i></b>				
Khayambashi et al. <a href="#">26</a>	Bilateral proximal abductor & external rotator rehabilitation (n=14) 3xper week <ul style="list-style-type: none"> <li>• 5 minute walking warm up</li> <li>• Standing proximal abduction with band</li> <li>• Seated external rotation with band</li> <li>• Progressive band strength through sets and weeks</li> <li>• 20-25repetitions completed per exercise per set</li> <li>• All exercises performed bilaterally</li> <li>• 5minute walking cool down</li> </ul>	No exercise (n=14) <ul style="list-style-type: none"> <li>• 1000mg Omega-3 and 400mg calcium daily supplements</li> <li>• Pain relief medication as needed</li> </ul>	<ul style="list-style-type: none"> <li>• Pain</li> <li>• VAS</li> <li>• Health status</li> <li>• WOMAC</li> <li>• Strength</li> <li>• Proximal abduction</li> <li>• Proximal external rotation</li> </ul>	8 weeks & 6 months
Ferber et al. <a href="#">46</a>	Proximal abductor rehabilitation programme (n=15) <ul style="list-style-type: none"> <li>• Performed daily over 3weeks</li> <li>• Supervised initially and after 7-10 days to check technique</li> <li>• Standing proximal abduction and extension with the resistance of band 3x10repetitions on each leg, 2secs in each direction</li> </ul>	No exercise (n=10) <ul style="list-style-type: none"> <li>• Asymptomatic population</li> </ul>	<ul style="list-style-type: none"> <li>• Pain                             <ul style="list-style-type: none"> <li>• VAS</li> </ul> </li> <li>• Strength                             <ul style="list-style-type: none"> <li>• Proximal abduction strength</li> </ul> </li> <li>• Kinematics                             <ul style="list-style-type: none"> <li>• Peak knee genu valgum angle</li> <li>• Stride-to-stride knee-joint variability</li> </ul> </li> </ul>	3 weeks
VAS = Visual analogue scale, WOMAC = Western Ontario and McMaster osteoarthritis index				

Supplementary File 3 – Proximal rehabilitation compared to quadriceps rehabilitation group study characteristics

<i>Author</i>	<i>Intervention</i>	<i>Control</i>	<i>Variables measured</i>	<i>Follow up</i>
<b><i>Proximal rehabilitation v Quadriceps rehabilitation</i></b>				
Ferber et al. <sup>42</sup>	<p>Proximal and core focused exercises (n= 111)</p> <ul style="list-style-type: none"> <li>Performed 6xper week (3x per with trainer)</li> <li>6 week intervention period</li> </ul> <p>Week 1</p> <ul style="list-style-type: none"> <li>Proximal abduction – standing; Proximal external rotator – standing; Proximal external rotator – sitting; All 3x10repetitionss (resistance band)</li> </ul> <p>Week 2</p> <ul style="list-style-type: none"> <li>Proximal abduction – standing; Proximal external rotator – standing; Proximal internal rotator – standing; All 3x10reps (resistance band)</li> </ul> <p>Week 3</p> <ul style="list-style-type: none"> <li>Proximal abduction – standing; Proximal external rotator – standing; Proximal external rotator – sitting; All 3x10reps (stronger resistance band)</li> <li>Balancing 2 feet on Airex® pad 3x30-45seconds</li> </ul>	<p>Quadriceps exercise (n= 88)</p> <ul style="list-style-type: none"> <li>Performed 6xper week (3x per with trainer)</li> <li>6 week intervention period</li> </ul> <p>Week 1</p> <ul style="list-style-type: none"> <li>Isometric quadriceps setting Knee extensions—standing Double-legged, one-quarter squats; 3x10 repetitions</li> </ul> <p>Week 2</p> <ul style="list-style-type: none"> <li>Isometric quadriceps setting; Double-legged, one-half squats; Terminal knee extension w/ resistance band; 3x15 repetitions; Double-legged, one-quarter squats ; 3x30seconds</li> </ul> <p>Week 3</p> <ul style="list-style-type: none"> <li>Double-legged, one-half squats ; Single-legged, one-quarter squat; Double-legged, one-quarter wall squats; 3x10 repetitions;</li> <li>Terminal-knee extension w/ resistance band 3x10 repetitions with stronger band</li> </ul> <p>Week 4</p> <ul style="list-style-type: none"> <li>Single-legged, one-half squats ; Forward, one-quarter lunge; Lateral step-down (4-inch [3.6 cm] step), No.; Forward step-down (4-inch [3.6 cm] step), No. ; 3x10 repetitions;</li> <li>Double-legged, one-half wall squats;</li> </ul>	<ul style="list-style-type: none"> <li>Pain</li> <li>VAS</li> <li>Function <ul style="list-style-type: none"> <li>Anterior knee pain score</li> </ul> </li> <li>Strength <ul style="list-style-type: none"> <li>Proximal abduction</li> <li>Proximal extension</li> <li>Proximal internal rotation</li> <li>Proximal external rotation</li> <li>Knee extension</li> </ul> </li> </ul>	6 weeks

	<p>Week 4-6</p> <ul style="list-style-type: none"> <li>• Proximal extension 45° – standing; Proximal external rotator – standing; Proximal external rotator – sitting; All 3x10-15reps (resistance band)</li> <li>• Balancing 1 foot on Airex® pad 3x45-60seconds</li> </ul>	<p>3x30seconds</p> <p>Week 5-6</p> <ul style="list-style-type: none"> <li>• Double-legged wall squat (to max 90° knee flexion); 3x45-60seconds;</li> <li>• Lateral step-down (6–10 in [5.6–9.6 cm] step); Forward step-down (6–10 in [5.6–9.6 cm] step) ; Forward one-half full lunge (to maximum 90° of knee flexion); Single-legged one-half full squat (to maximum 90° of knee flexion); 3x15 repetitions</li> </ul>		
Dolak et al. <sup>24</sup>	<p>4 weeks initial proximal abduction and external rotation rehabilitation followed by 4 weeks weight bearing exercises (n=17)</p> <ul style="list-style-type: none"> <li>• Exercise completed 3xper week (1 supervised, 2 at home)</li> <li>• Seated hamstring stretch, standing quadriceps stretch and standing wall stretch for triceps surae for 3x30sec prior to rehabilitation</li> <li>• Progression made on an individual basis by the treating clinician within protocol limits</li> <li>• Side-lying proximal abduction/external rotation +/- 3-7% of body weight 3x10repetitions</li> <li>• Standing proximal abduction +/- 3-7% body weight 3x10repetitions</li> <li>• Seated proximal external</li> </ul>	<p>4 weeks initial quadriceps rehabilitation followed by 4 weeks weight bearing exercises (n=16)</p> <ul style="list-style-type: none"> <li>• Exercise completed 3xper week (1 supervised, 2 at home)</li> <li>• Seated hamstring stretch, standing quadriceps stretch and standing wall stretch for triceps surae for 3x30sec prior to rehabilitation</li> <li>• Progression made on an individual basis by the treating clinician within protocol limits</li> <li>• Quad sets</li> <li>• Short arc quads +/- 3-7% body weight</li> <li>• Straight leg raises +/- 3-7% body weight</li> <li>• Terminal knee extension with 3-7% body weight</li> </ul>	<ul style="list-style-type: none"> <li>• Pain</li> <li>• VAS</li> <li>• Function</li> <li>• LEFS</li> <li>• Strength</li> <li>• Isometric proximal abduction strength</li> <li>• Isometric proximal external rotation strength</li> <li>• Isometric knee extension strength</li> </ul>	4 Weeks

	<p>rotation +/- 3-7% body weight 3x10repetitions</p> <ul style="list-style-type: none"> <li>• Quadrupe hydrant +/-3% body weight 3x10repetitions</li> </ul>			
Khayambashi et al. <a href="#">43</a>	<p>8 weeks posterolateral proximal rehabilitation exercises</p> <ul style="list-style-type: none"> <li>• Exercise completed 3 times per week, supervised by a therapist</li> <li>• 5 min walking warm up</li> <li>• 20 mins resistance banding exercises for proximal abduction and external rotation – 3 sets of 20-25 reps using progressively increasing resistance banding</li> <li>• 5 min walking cool down</li> </ul>	<p>8 weeks quadriceps rehabilitation exercises</p> <ul style="list-style-type: none"> <li>• Exercise completed 3 times per week, supervised by a therapist</li> <li>• 5 min walking warm up</li> <li>• 20 mins resistance banding exercises – seated knee extension against resistance banding, and squatting - 3 sets of 20-25 reps using progressively increasing resistance banding</li> <li>• 5 in walking cool down</li> </ul>	<ul style="list-style-type: none"> <li>• Pain <ul style="list-style-type: none"> <li>• VAS</li> </ul> </li> <li>• Function <ul style="list-style-type: none"> <li>• WOMAC</li> </ul> </li> </ul>	8 weeks and 6 months
Baldon et al. <a href="#">44</a>	<p>8 weeks functional stabilisation exercises directed at the proximal and trunk</p> <ul style="list-style-type: none"> <li>• Exercises performed 3 times per week supervised</li> <li>• First 2 weeks – exercises focused at enhancing motor control at trunk and proximal – 20% of 1 repetition maximum – 2x20repetitions</li> <li>• Next 3 weeks – exercises to increase proximal strength and maintain motor control – 75% of 1 repetition maximum – 3x12 repetitions</li> <li>• Final 3 weeks – intensity increased whilst maintaining</li> </ul>	<p>8 week standard training programme focused on quadriceps rehabilitation</p> <ul style="list-style-type: none"> <li>• Exercises performed 3 times per week supervised</li> <li>• Comprised of combination of stretches, open and closed kinetic chain exercises</li> <li>• Included straight leg raise, knee extension, leg press, wall squats, step ups, single leg standing on unstable platform</li> <li>• First 2 weeks – exercises focused at enhancing motor – 20% of 1 repetition maximum – 2x20repetitions</li> <li>• Next 3 weeks – exercises to increase quadriceps strength and maintain motor control – 75% of 1 repetition maximum – 3x12 repetitions</li> <li>• Final 3 weeks – intensity increased whilst</li> </ul>	<ul style="list-style-type: none"> <li>• Pain <ul style="list-style-type: none"> <li>• VAS</li> </ul> </li> <li>• Function <ul style="list-style-type: none"> <li>• LEFS</li> <li>• Single leg triple hop</li> </ul> </li> <li>• Single leg squat kinematics <ul style="list-style-type: none"> <li>• Trunk, pelvis, proximal and knee</li> </ul> </li> <li>• Trunk endurance and eccentric torque</li> </ul>	8 weeks and 3 months

	<p>good lower limb alignment - 75% of 1 repetition maximum</p> <ul style="list-style-type: none"> <li>• 1 repetition maximum assessed at 3 and 6 weeks</li> <li>• All exercises performed within 3/10 pain limits</li> </ul>	<p>maintaining good lower limb alignment - 75% of 1 repetition maximum</p> <ul style="list-style-type: none"> <li>• 1 repetition maximum assessed at 3 and 6 weeks</li> <li>• All exercises performed within 3/10 pain limits</li> </ul>		
WOMAC = Western Ontario and McMaster osteoarthritis index				

Supplementary File 4 – Proximal rehabilitation combined with quadriceps rehabilitation compared to quadriceps rehabilitation alone study characteristics

<b>Author</b>	<b>Intervention</b>	<b>Control</b>	<b>Variables measured</b>	<b>Follow up</b>
<b><i>Proximal rehabilitation &amp; Quadriceps rehabilitation v Quadriceps rehabilitation</i></b>				
Ismail et al. <a href="#">39</a>	<p>Closed Kinetic Chain and proximal exercise group (n = 16)</p> <ul style="list-style-type: none"> <li>• 18 supervised sessions</li> <li>• Static stretching hamstrings, iliotibial band, gastrocnemius, quadriceps 3x30sec</li> <li>• Mini wall squat with ball between knees 0°-40°, 6sec hold x10repetitions</li> <li>• Forward step up on 8inch step, 6sec hold x10repetitions</li> <li>• Lateral step up on 8inch step, 6sec hold x10repetitions</li> <li>• Terminal knee extension with resistance banding 0-30°, 6sec hold in full extension</li> <li>• Proximal abduction in sidelying with ankle weight*, 6sec hold,</li> </ul>	<p>Closed Kinetic Chain exercise group (n = 16)</p> <ul style="list-style-type: none"> <li>• 18 supervised sessions</li> <li>• Static stretching hamstrings, iliotibial band, gastrocnemius, quadriceps 3x30sec</li> <li>• Mini wall squat with ball between knees 0°-40°, 6sec hold x10repetitions</li> <li>• Forward step up on 8inch step, 6sec hold x10repetitions</li> <li>• Lateral step up on 8inch step, 6sec hold x10repetitions</li> <li>• Terminal knee extension with resistance banding 0-30°, 6sec hold in full extension</li> </ul>	<ul style="list-style-type: none"> <li>• Pain</li> <li>• VAS (0-10)</li> <li>• Kujala Score (0-100)</li> <li>• Strength</li> <li>• Isokinetic (60°/s) peak force/body mass index <ul style="list-style-type: none"> <li>▪ Centric proximal abduction</li> <li>▪ Eccentric proximal abduction</li> <li>▪ Centric proximal external rotation</li> <li>▪ Eccentric proximal external rotation</li> </ul> </li> </ul>	6 weeks

	<p>2x10repetitions</p> <ul style="list-style-type: none"> <li>Proximal external rotation in sitting with ankle weight*, 6sec hold, 2x10repetitions</li> </ul> <p>*load, 60% 10 repetition maximum</p>			
Fukuda et al. <a href="#">23</a>	<p>Knee and proximal exercise group (KHE) (n = 28)</p> <ul style="list-style-type: none"> <li>12 supervised sessions (nil at home)</li> <li>Therapist assisted stretching hamstrings, plantar flexors, quadriceps and ilitibial band 3x30s</li> <li>Seated knee extension 90°-45°, 3x10repetitions*</li> <li>Leg press 0°-45°, 3x10repetitions*</li> <li>Squatting 0°-45°, 3x10repetitions*</li> <li>Single-leg calf raises, 3x10repetitions*</li> <li>Prone knee flexion (maintaining patella off table) 3x10repetitions*</li> <li>Proximal abduction with weights (sidelying) 3x10repetitions*</li> </ul>	<p>Knee exercise group (KE) (n = 26)</p> <ul style="list-style-type: none"> <li>12 supervised sessions (nil at home)</li> <li>Therapist assisted stretching hamstrings, plantar flexors, quadriceps and ilitibial band 3x30s</li> <li>Seated knee extension 90°-45°, 3x10repetitions*</li> <li>Leg press 0°-45°, 3x10repetitions*</li> <li>Squatting 0°-45°, 3x10repetitions*</li> <li>Single-leg calf raises, 3x10repetitions*</li> <li>Prone knee flexion (maintaining patella off table) 3x10repetitions*</li> <li>*load, 70% of 1 pain free repetition maximum</li> </ul> <p>†maximum resistance that enables 10 repetitions</p>	<ul style="list-style-type: none"> <li>Pain <ul style="list-style-type: none"> <li>NPRS ascending stairs</li> <li>NPRS descending stairs</li> </ul> </li> <li>Function <ul style="list-style-type: none"> <li>LEFS (0-80)</li> <li>AKPS (0-100)</li> <li>Single-limb hop test (cm)</li> </ul> </li> </ul>	<p>3 months, 6 months &amp; 12 months</p>

	<ul style="list-style-type: none"> <li>• Proximal abduction against elastic band (standing) 3x10repetitions†</li> <li>• Proximal external rotation against elastic band (sitting) 3x10repetitions†</li> <li>• Proximal extension (machine) 3x10repetitions*</li> <li>• *load, 70% of 1 pain free repetition maximum</li> </ul> <p>†maximum resistance that enables 10 repetitions</p>			
Dolak et al. <a href="#">24</a>	<p>4 weeks initial proximal abduction and external rotation rehabilitation followed by 4 weeks weight bearing exercises (n=17)</p> <ul style="list-style-type: none"> <li>• Exercise completed 3xper week (1 supervised, 2 at home)</li> <li>• Seated hamstring stretch, standing quadriceps stretch and standing wall stretch for triceps surae for 3x30sec prior to rehabilitation</li> <li>• Progression made on an individual basis by the</li> </ul>	<p>4 weeks initial quadriceps rehabilitation followed by 4 weeks weight bearing exercises (n=16)</p> <ul style="list-style-type: none"> <li>• Exercise completed 3xper week (1 supervised, 2 at home)</li> <li>• Seated hamstring stretch, standing quadriceps stretch and standing wall stretch for triceps surae for 3x30sec prior to rehabilitation</li> <li>• Progression made on an individual basis by the treating clinician within</li> </ul>	<ul style="list-style-type: none"> <li>• Pain</li> <li>• VAS</li> <li>• Function</li> <li>• LEFS</li> <li>• Strength</li> <li>• Isometric proximal abduction strength</li> <li>• Isometric proximal external rotation strength</li> <li>• Isometric knee extension strength</li> </ul>	4 weeks, 8 weeks & 3 months

	<p>treating clinician within protocol limits</p> <ul style="list-style-type: none"> <li>• Side-lying proximal abduction/external rotation +/- 3-7% of body weight 3x10repetitions</li> <li>• Standing proximal abduction +/- 3-7% body weight 3x10repetitions</li> <li>• Seated proximal external rotation +/- 3-7% body weight 3x10repetitions</li> <li>• Quadruped hydrant +/-3% body weight 3x10repetitions</li> <li>• Single leg balance with front pull/diagonal pull/on airex pad/airex pad and diagonal pull 3x30sec</li> <li>• Wall slides with resistance/single leg mini squats/lunges to 20.3cm step/lunges to a 10cm step 3x10repetitions</li> <li>• Lateral step down 10cm step/15.25cm step/ 15.25cm step with resistance/20.3cm step 3x10repetitions</li> <li>• 2 leg calf raises/single leg calf raises/off step/on airex pad 3x10repetitions</li> </ul>	<p>protocol limits</p> <ul style="list-style-type: none"> <li>• Quad sets</li> <li>• Short arc quads +/- 3-7% body weight</li> <li>• Straight leg raises +/- 3-7% body weight</li> <li>• Terminal knee extension with 3-7% body weight</li> <li>• Single leg balance with front pull/diagonal pull/on airex pad/airex pad and diagonal pull 3x30sec</li> <li>• Wall slides with resistance/single leg mini squats/lunges to 20.3cm step/lunges to a 10cm step</li> <li>• Lateral step down 10cm step/15.25cm step/ 15.25cm step with resistance/20.3cm step</li> <li>• 2 leg calf raises/single leg calf raises/off Painstep/on airex pad</li> </ul>		
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<p>Fukuda et al. <a href="#">38</a></p>	<p>Knee and proximal exercise group (KHE) (n = 23)</p> <ul style="list-style-type: none"> <li>• 12 supervised sessions (nil at home)</li> <li>• Therapist assisted stretching hamstrings, plantar flexors, quadriceps and ilitibial band 3x30s</li> <li>• Iliopsoas rehabilitation in non-weight bearing, 3x10repetitions*</li> <li>• Seated knee extension 90°-45°, 3x10repetitions*</li> <li>• Leg press 0°-45°, 3x10repetitions*</li> <li>• Squatting 0°-45°, 3x10repetitions*</li> <li>• Proximal abduction against elastic band (standing) 3x10repetitions†</li> <li>• Proximal abduction with weights (sidelying) 3x10repetitions*</li> <li>• Proximal external rotation against elastic band (sitting) 3x10repetitions†</li> <li>• Side-stepping against</li> </ul>	<p>Knee exercise group (KE) (n = 22)</p> <ul style="list-style-type: none"> <li>• 12 supervised sessions (nil at home)</li> <li>• Therapist assisted stretching hamstrings, plantar flexors, quadriceps and ilitibial band 3x30s</li> <li>• Iliopsoas rehabilitation in non-weight bearing, 3x10repetitions*</li> <li>• Seated knee extension 90°-45°, 3x10repetitions*</li> <li>• Leg press 0°-45°, 3x10repetitions*</li> <li>• Squatting 0°-45°, 3x10repetitions*</li> <li>• *load, 70% of 1 pain free repetition maximum</li> </ul> <p>†maximum resistance that enables 10 repetitions</p>	<ul style="list-style-type: none"> <li>• Pain</li> <li>• NPRS ascending stairs</li> <li>• NPRS descending stairs</li> <li>• Function</li> <li>• LEFS (0-80)</li> <li>• AKPS (0-100)</li> <li>• Single-limb hop test (cm)</li> </ul>	<p>4 weeks</p>
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	<ul style="list-style-type: none"> <li>elastic band 3x1minute</li> <li>*load, 70% of 1 pain free repetition maximum</li> </ul> <p>†maximum resistance that enables 10 repetitions</p>			
Razeghi et al. <a href="#">37</a>	<p>Proximal &amp; knee rehabilitation exercise programme (n=16)</p> <ul style="list-style-type: none"> <li>Programme not explicitly described</li> <li>“Progressive resistive exercises for the proximal muscles”</li> <li>“Terminal and 90° to 50° resistive knee extension and mini squats for the quadriceps”</li> <li>“The McQueen progressive resistive technique was applied to increase exercise resistance”</li> </ul>	<p>Knee rehabilitation exercise programme (n=16)</p> <ul style="list-style-type: none"> <li>Programme not explicitly described</li> <li>“Terminal and 90° to 50° resistive knee extension and mini squats for the quadriceps”</li> <li>“The McQueen progressive resistive technique was applied to increase exercise resistance”</li> </ul>	<p>In case and control group:</p> <ul style="list-style-type: none"> <li>Pain</li> <li>VAS</li> <li>Successful/unsuccessful outcome</li> <li>Strength</li> <li>Knee extension strength</li> </ul> <p>In success /unsuccess groups only</p> <ul style="list-style-type: none"> <li>Strength <ul style="list-style-type: none"> <li>Proximal flexion strength</li> <li>Proximal extension strength</li> <li>Proximal abductor strength</li> <li>Proximal adductor strength</li> <li>Proximal internal rotation strength</li> <li>Proximal external rotation strength</li> <li>Knee extension strength</li> </ul> </li> </ul>	4 weeks
Nakagawa et al. <a href="#">40</a>	<p>Proximal and Knee Exercise Group (n = 7)</p> <ul style="list-style-type: none"> <li>All exercises performed in addition to the knee exercise group exercises</li> <li>Once per week supervised, 4 times per week independently at</li> </ul>	<p>Knee Exercise Group (n = 7)</p> <ul style="list-style-type: none"> <li>Once per week supervised, 4 times per week independently at home</li> <li>Stretches (all exercise sessions) 3 repetitions/30-second hold. Sitting</li> </ul>	<ul style="list-style-type: none"> <li>Pain <ul style="list-style-type: none"> <li>VAS – usual, worst, stair ascent and decent, squatting and prolonged sitting</li> </ul> </li> <li>Gluteal Electromyography <ul style="list-style-type: none"> <li>Max Voluntary Isometric Contraction (MVIC)</li> <li>Eccentric Contraction (EC)</li> <li>EC expressed as % of MVIC</li> </ul> </li> </ul>	6 weeks

	<p>home</p> <p>Weeks 1 and 2 exercises; 2 sets of 15 repetitions/ 10-second hold</p> <ul style="list-style-type: none"> <li>• Transversus abdominus muscle contraction in the quadruped position</li> <li>• Isometric combined proximal abduction–lateral rotation in side-lying with the proximals and knees slightly flexed elastic resistance</li> <li>• Side-lying isometric proximal abduction with extended knee</li> <li>• Isometric combined proximal abduction–lateral rotation in the quadruped position</li> </ul> <p>Weeks 3 and 4 exercises; 2 sets of 15 repetitions/ 10-second hold or 3 sets of 10 repetitions</p> <ul style="list-style-type: none"> <li>• Pelvic drop exercise on a 20-cm step Upper extremity extension of the contralateral arm with elastic resistance performed in a single-leg stance</li> <li>• Rotation of the body in the</li> </ul>	<p>hamstring stretch. Sitting patellar mobilization. Standing quadriceps, calf and iliotibial band stretch.</p> <p>Weeks 1 and 2 exercises; 2-4 sets of 10 repetitions/ 10-second hold</p> <ul style="list-style-type: none"> <li>• Isometric quadriceps contractions while sitting with 90° of knee flexion</li> <li>• Straight-leg raise in supine</li> <li>• Mini squats to 40° of knee flexion</li> </ul> <p>Weeks 3 and 4 exercises; 3 sets of 10 repetitions</p> <ul style="list-style-type: none"> <li>• Wall slides (0–60° of knee flexion)</li> <li>• Steps-up and steps-down from a 20-cm step</li> <li>• Forward lunges (0–45° of knee flexion)</li> </ul> <p>Weeks 5 and 6 exercises, as for weeks 3 and 4 plus; 3 sets of 30-second hold each exercise</p> <ul style="list-style-type: none"> <li>• Balance exercises: unilateral stance on the floor and on an air-filled disc, with opened and closed eyes</li> <li>• Progressive walking or</li> </ul>	<ul style="list-style-type: none"> <li>• Eccentric Isokinetic Peak Torque <ul style="list-style-type: none"> <li>• Knee extensor</li> <li>• Proximal abductor</li> <li>• Proximal lateral rotator</li> </ul> </li> </ul>	
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	<p>direction of the contralateral side, holding an elastic resistance with the ipsilateral arm while maintaining the lower extremity static</p> <p>Weeks 5 and 6 exercises, as for weeks 3 and 4b</p> <ul style="list-style-type: none"> <li>• Additional elastic resistance around the affected leg in the forward lunges to encourage lateral rotation and abduction of the proximal</li> </ul>	running programme		
Avraham F et al. <a href="#">41</a>	<p>Proximal and quadriceps rehabilitation exercises (n = 10)</p> <p>Two treatment sessions/week in clinic, 4 sessions independently at home</p> <ul style="list-style-type: none"> <li>• 3 minutes Straight leg raises</li> <li>• 3 minutes Single leg squats</li> <li>• 3 minutes ITB stretches</li> <li>• 3 minutes hamstring stretches</li> <li>• 3 minutes proximal external rotators rehabilitation</li> <li>• 15minutes TENS</li> </ul>	<p>Quadriceps rehabilitation exercises (n = 10)</p> <p>Two treatment sessions/wk in clinic, 4 sessions independently at home</p> <ul style="list-style-type: none"> <li>• 7.5 minutes straight leg raises</li> <li>• 7.5 minutes single leg squats</li> <li>• 15 minutes TENS</li> </ul>	<ul style="list-style-type: none"> <li>• Pain</li> <li>• VAS (0-10)</li> <li>• Function</li> <li>• Patellofemoral evaluation scale (0-100)</li> </ul>	3 weeks

VAS – Visual analogue scale; NPRS – Numeric pain rating scale; LEFS – Lower extremity functional score; AKPS – Anterior knee pain score; TENS – Transcutaneous electrical nerve stimulation; ITB – Iliotibial band				

Supplementary File 5 – Proximal rehabilitation alone study characteristics

<i>Author</i>	<i>Intervention</i>	<i>Control</i>	<i>Variables measured</i>	<i>Follow up</i>
<b>Proximal rehabilitation alone</b>				
Earl & Hoch <a href="#">25</a>	Proximal & core muscle rehabilitation programme (n=19) <ul style="list-style-type: none"> <li>• 8-15 supervised sessions lasting 30-60minutes over 8 weeks</li> <li>• Additional 3xper home exercise programme</li> <li>• Hamstring, Quadriceps and calf stretches</li> <li>• Abdominal draw in</li> <li>• Side lying clamshell</li> <li>• Side lying straight leg raising</li> <li>• Supine arm/leg extension</li> <li>• Quadruped arm/leg extension</li> <li>• Isometric single leg stance +/- proximal abduction/quick kicks</li> <li>• Single leg column weights</li> <li>• Prone and side plank</li> <li>• Monster walks</li> <li>• Mini squats</li> <li>• Single leg stance with sport specific upper limb movements</li> </ul>	None	<ul style="list-style-type: none"> <li>• Pain               <ul style="list-style-type: none"> <li>• VAS</li> <li>• AKPS</li> </ul> </li> <li>• Strength               <ul style="list-style-type: none"> <li>• Isometric proximal abduction strength</li> <li>• Isometric proximal external rotation strength</li> <li>• Anterior, lateral and posterior core endurance</li> </ul> </li> <li>• Kinematics               <ol style="list-style-type: none"> <li>1. Peak internal joint moments during the stance phase of running</li> </ol> </li> <li>• Clinical measures               <ul style="list-style-type: none"> <li>• Joint range of motion</li> </ul> </li> </ul>	8 weeks

<p>Tyler et al. <a href="#">25</a></p>	<p>Proximal rehabilitation and flexibility programme (n=35, 43 Knees)</p> <ul style="list-style-type: none"> <li>• Home exercise programme performed daily</li> <li>• Progressive resisted exercise - Seated proximal flexion, adduction, extension, abduction</li> <li>• Stretching proximal flexors, quadriceps, iliotibial band</li> <li>• Manual therapy – patella mobs</li> <li>• Mini squats</li> <li>• Balance exercise</li> <li>• Step ups and step downs</li> <li>• Upper and lower extremity reaches</li> <li>• Plyometric/agility exercises</li> <li>• Lunges</li> <li>• Return to sport</li> </ul>	<p>None</p>	<ul style="list-style-type: none"> <li>• Pain <ul style="list-style-type: none"> <li>• During activities of daily living VAS</li> <li>• Exercise VAS</li> </ul> </li> <li>• Strength <ul style="list-style-type: none"> <li>• Proximal flexion strength</li> <li>• Proximal abduction strength</li> <li>• Proximal adduction strength</li> </ul> </li> <li>• Clinical Measures <ul style="list-style-type: none"> <li>• Obers test</li> <li>• Thomas test</li> </ul> </li> </ul>	<p>6 weeks</p>
<p>VAS – Visual analogue scale; AKPS – Anterior knee pain score</p>				

Supplementary File 6 - PFP diagnosis checklist

Author	Inclusion Items			Exclusion Items				Total Score
	Clear definition of location	Insidious onset unrelated to trauma	Symptoms consistent with diagnosis	Previous knee surgery	Internal derangement	Ligamentous instability	Other sources of anterior knee pain	
Tyler et al. <a href="#">45</a>	1	1	1	1	1	1	1	7
Razeghi et al. <a href="#">37</a>	1	1	1	1	1	1	1	7
Nakagawa et al. <a href="#">40</a>	1	1	1	1	1	1	1	7
Earl & Hoch <a href="#">25</a>	1	1	1	1	1	1	1	7
Dolak et al. <a href="#">24</a>	1	1	1	1	1	1	1	7
Ferber et al. <a href="#">42</a>	1	1	1	1	1	1	1	7
Baldon et al. <a href="#">44</a>	1	1	1	1	1	1	1	7
Ismail et al. <a href="#">39</a>	1	1	1	1	1	1	0	6
Khayambashi et al. <a href="#">26</a>	1	0	1	1	1	1	1	6
Khayambashi et al. <a href="#">43</a>	1	0	1	1	1	1	1	6
Fukuda et al. <a href="#">23</a>	1	0	1	1	1	1	1	6
Fukuda et al. <a href="#">38</a>	1	0	1	1	1	1	1	6
Ferber et al. <a href="#">46</a>	1	1	1	1	0	0	1	5
Avraham et al. <a href="#">41</a>	1	0	1	0	0	0	0	2