

**TITLE:** Objectively quantified lower limb strength recovery in people treated surgically or non-surgically after patellar dislocation: A systematic review

## **ABSTRACT**

**Objective:** Synthesize evidence on objectively quantified lower limb strength recovery in people treated surgically or non-surgically after patellar dislocation.

**Methods:** MEDLINE, EMBASE, Cochrane Library, SPORTDiscus, PEDro, AMED and CINAHL databases were last searched on July 30th 2020 for randomized controlled trials and observational studies that objectively quantified lower limb strength in people (any age or sex) treated surgically or non-surgically after patellar dislocation.

**Results:** 24 studies were included (877 participants, median age 20.7). All assessed knee extension strength, 11 knee flexion strength, three hip abduction strength, two hip external rotation strength, and one hip flexion, extension, adduction, and internal rotation strength. One randomized controlled trial judged at high risk of bias and two cohort studies with methodological limitations compared lower limb strength recovery between surgically and non-surgically treated people, with conflicting findings. After surgery, median long-term (>8 months) knee extension strength was 82.5% (IQR 78.5-88.2; 13 studies) of the unaffected leg and knee flexion strength was 91.5% (IQR 90.7-96.9; five studies). After non-surgical treatment, median long-term knee extensor strength was 86% (IQR 79.3-87.4; four studies) and mean flexion strength ranged from 95.2-96.7% (two studies). Hip strength was always >90% (two studies). Two redislocations during eccentric isokinetic knee testing and knee pain during isokinetic knee extension testing were reported as adverse events.

**Conclusions:** Available evidence indicates that after patellar dislocation, knee extension strength deficits in the affected limb are frequently observed and can persist long term, but this remains uncertain due to the limitations of relevant included studies. Whether lower limb strength recovery differs between people treated surgically and those treated non-surgically after patellar dislocation also remains uncertain.

Trial registration: (PROSPERO CRDX)

**Keywords:** kneecap; patellofemoral; muscle; conservative

**Word count:** 4000

## INTRODUCTION

Patellar dislocations account for 3% of sporting knee injuries.<sup>29</sup> The reported incidence of first-time patellar dislocations is 42 per 100,000 person years, equal between sexes, and highest in adolescents.<sup>16</sup> Treatment is either surgical or non-surgical. Surgery usually addresses soft-tissue injuries, abnormal bony morphology, or soft-tissue or bony alignment.<sup>55</sup> Non-surgical treatment usually involves initial immobilization, advice, and exercise.<sup>40</sup> Though surgery results in fewer recurrent dislocations at two to five years, recovery after both approaches is often incomplete.<sup>55</sup> Common problems include recurrent dislocation and instability, later surgery, reduced activity levels, and reduced knee function.<sup>28,55</sup>

To aid recovery, patients are often prescribed lower limb strengthening exercises, particularly those targeting the gluteals and quadriceps.<sup>24,40</sup> Adequate strength of these muscles is considered important for a safe return to sport.<sup>37</sup> During dynamic activities, these muscles absorb external hip and knee moments by eccentrically contracting. On single-leg landing, reduced hip and quadriceps strength has been associated with increased knee valgus in healthy females and reduced knee flexion in patients after anterior cruciate ligament reconstruction, respectively.<sup>13,45</sup> As these movement patterns are implicated in the patellar dislocation mechanism of injury,<sup>17</sup> restoring lower limb strength could reduce reinjury risk. Higher quadriceps strength also protects against patellofemoral cartilage loss,<sup>2</sup> which is important as patellar dislocation increases the risk of developing patellofemoral osteoarthritis.<sup>52</sup>

Only one systematic review has synthesized lower limb strength outcomes after patellar dislocation, finding evidence of incomplete knee extension strength recovery in the affected limb.<sup>58</sup> However, studies of surgically treated participants were excluded, limiting the generalizability of the findings, and some included studies measured strength using manual muscle testing and observed atrophy, which are inappropriate for detecting between limb strength deficits.<sup>9</sup> Furthermore, no included study assessed hip strength. Therefore, uncertainty remains over lower limb strength recovery in people treated surgically and non-surgically after patellar dislocation.

This systematic review aimed to synthesize the available evidence on objectively quantified lower limb strength recovery in people treated surgically or non-surgically after patellar dislocation. Primary outcomes were to identify which lower limb muscle groups undergo strength assessment in people after patellar dislocation, and to compare lower limb strength recovery between surgically and non-surgically treated people. Secondary outcomes were to compare lower limb strength recovery between people with a first-time patellar dislocation and those with recurrent dislocations, and to report adverse events related to the objective assessment of lower limb strength in people with a previous patellar dislocation.

## **MATERIALS AND METHODS**

The review protocol was registered on PROSPERO (CRDX). Reporting adheres to PRISMA guidelines.<sup>39</sup>

### **Search strategy**

One reviewer searched the EMBASE, MEDLINE, Cochrane Library, SPORTDiscus, PEDro, AMED, and CINAHL databases, and the following trial registries: ClinicalTrials.gov, UK clinical trials gateway, WHO International Clinical Trials Registry Platform, and ISRCTN registry. To identify additional potentially eligible studies, we screened the reference lists of included studies and relevant systematic reviews, and contacted corresponding authors of included studies published within the last 10 years. The initial search was conducted on June 21st 2019 and updated on July 30th 2020. Additional search strategy details are presented in appendix 1.

### **Eligibility criteria**

Randomized controlled trials (RCTs) and observational studies, except single-patient case reports, were included. Published and unpublished studies, including abstracts, were eligible. Participants could be any age or sex, with a previous first-time or recurrent patellar dislocation treated surgically or non-surgically, who underwent lower limb strength assessment. Studies only needed to report participants had a previous patellar dislocation to be eligible. All patellar stabilization surgeries and all non-surgical treatments were considered. Studies including participants with patellar subluxation, anterior knee pain, or patellofemoral pain, with no previous patellar dislocation, or participants with a patellar dislocation and previous patellofemoral or tibiofemoral arthroplasty, were excluded. Studies of participants with mixed knee conditions were only considered if data for participants with a patellar dislocation were presented separately or were obtainable from the corresponding author. Lower limb strength had to be quantified objectively with instrumented measurement. There were no restrictions on timeframe of strength assessments or year of publication. English, and non-English language studies that could be translated with Google Translate, were eligible. If the accuracy of translated studies was uncertain, these were excluded.

### **Study selection**

Search results were exported to EPPI-Reviewer 4 (University of London, London, UK) and duplicates removed. One reviewer screened all titles and abstracts and another independently screened a random 10% of records to assess the reliability of this process. Agreement was assessed using percentage agreement and Cohen's Kappa.<sup>10</sup> Full-texts were screened independently in duplicate. One reviewer screened all full-texts and three reviewers screened one third each. Disagreements were resolved by consensus or by another reviewer if required. Author correspondence (Richard Hawkins 2019, Marc Tompkins 2019) confirmed all participants in Tompkins et al<sup>64</sup> had recurrent patellar dislocations so this study was

included, but strength outcome data for Hawkins et al<sup>19</sup> were inaccessible, so this study was excluded.

### **Data extraction**

Two reviewers independently extracted data on study characteristics (authors, publication year, location, study design, single/multicenter, sample size, intervention details, follow-up time points), participant characteristics (age, sex, primary/recurrent dislocation, attrition (strength assessment only)), and strength assessment procedures (device, contraction type, joint motion, joint position/angular velocity, participant position, number of repetitions performed by participants, results, measurement unit, adverse events (defined as any unfavorable sign/symptom related to lower limb strength assessment)). Discrepancies were resolved by consensus or by another reviewer if needed. In Rauschning et al<sup>48</sup> and Sakuraba et al,<sup>51</sup> lower limb strength outcome data only presented graphically was extracted by one reviewer using WebPlotDigitizer (version 4.2, San Francisco, California, USA). To identify multiple study reports, we compared author names, locations, intervention details, participant characteristics, and durations of reports, as recommended by the *Cochrane Handbook for Systematic Reviews of Interventions*.<sup>20</sup> If multiple reports were identified, data were extracted separately then combined. Author correspondence (Heikki Mäenpää 2019, Krzysztof Malecki 2020 ) confirmed the same participants were included in in Mäenpää et al<sup>26,27</sup> and some of the same participants were included in Malecki et al.<sup>30–32</sup> Combining data from Mäenpää et al,<sup>26,27</sup> and Malecki et al,<sup>30–32</sup> was not possible as participant characteristics and treatments were different between reports. Therefore, Mäenpää et al<sup>26</sup> and Malecki et al<sup>31,32</sup> were excluded as these reports had smaller sample sizes and did not provide additional important outcome data.

### **Study appraisal**

We appraised RCTs using version 2 of the Cochrane risk-of-bias tool,<sup>61</sup> which provides an overall risk-of-bias judgement following assessment of bias arising from ‘the randomization process’, ‘deviations from intended interventions’, ‘missing outcome data’, ‘measurement of the outcome’, and ‘selection of the reported result’.

We appraised observational studies using an amended version of the Newcastle-Ottawa Scale.<sup>67</sup> We removed the questions ‘demonstration that outcome of interest was not present at start of study’ for cohort studies and ‘same method of ascertainment for cases and controls’ for case-control studies, as these do not apply to lower limb strength outcomes and to ensure similar application of the tool across study designs. For case series, we adopted the approach used in a similar systematic review by Moiz et al,<sup>40</sup> by removing the questions on selection of the non-exposed cohort and comparability of cohorts. Cohort and case-control studies could score a maximum of eight stars and case series a maximum of five.

Two reviewers independently appraised studies at the outcome level (lower limb strength). One reviewer appraised all included studies and two reviewers appraised half each. Disagreements were resolved by consensus. The overall strength of the

evidence was assessed based on the designs of included studies, methodological quality, and consistency of observed results.

### **Analysis**

Due to methodological and clinical heterogeneity, meta-analyses were not conducted for relevant outcomes. Instead, findings were synthesized narratively.

Lower limb strength comparisons between participants treated surgically and non-surgically, and between participants with a first-time dislocation and those with recurrent dislocations, were based on treatment and injury status at enrolment, respectively.

Population characteristics and strength outcomes, excluding healthy controls, were summarized using the median (interquartile range (IQR)) of individual study means. If studies with multiple treatment groups did not report aggregate means for relevant data, we used the mean of group means when the number of participants in treatment groups were equal and weighted means when the number of participants in treatment groups were unequal. Weighted means were calculated as described by Bland and Kerry,<sup>8</sup> using Excel version 2013 (Microsoft Corp. Redmond, Washington).

Strength outcomes are reported as % Limb Symmetry Index ((LSI) affected limb value divided by unaffected limb value x 100). If the LSI was not reported but data were available, the LSI was calculated. Strength outcomes were stratified by follow-up duration (time from dislocation for non-surgically treated participants and time from surgery for surgically treated participants) into short-term: ≤4 months, medium-term: >4-8 months, and long-term: >8 months, as physical therapy after acute patellar dislocation commonly lasts less than three months,<sup>56</sup> and return to sport after medial patellofemoral ligament (MPFL) surgery is often recommended at 4-6 months.<sup>24,70</sup>

There were insufficient data to conduct the planned adult/children subgroup analysis for the outcome comparing lower limb strength between people treated surgically with those treated non-surgically. There were also insufficient data to conduct; planned sensitivity analyses that involved removing RCTs at high risk of bias and removing studies that did not use isokinetic dynamometry for knee strength assessments, for relevant comparisons.

### **Changes from protocol**

Our systematic review protocol stated that patellar dislocations had to be diagnosed by a clinician or self-reported by participants. However, diagnostic criteria were often unreported. Therefore, studies only had to report participants had a previous patellar dislocation to be eligible.

We intended to contact authors for missing data but due to the extent of missingness this was considered unfeasible.

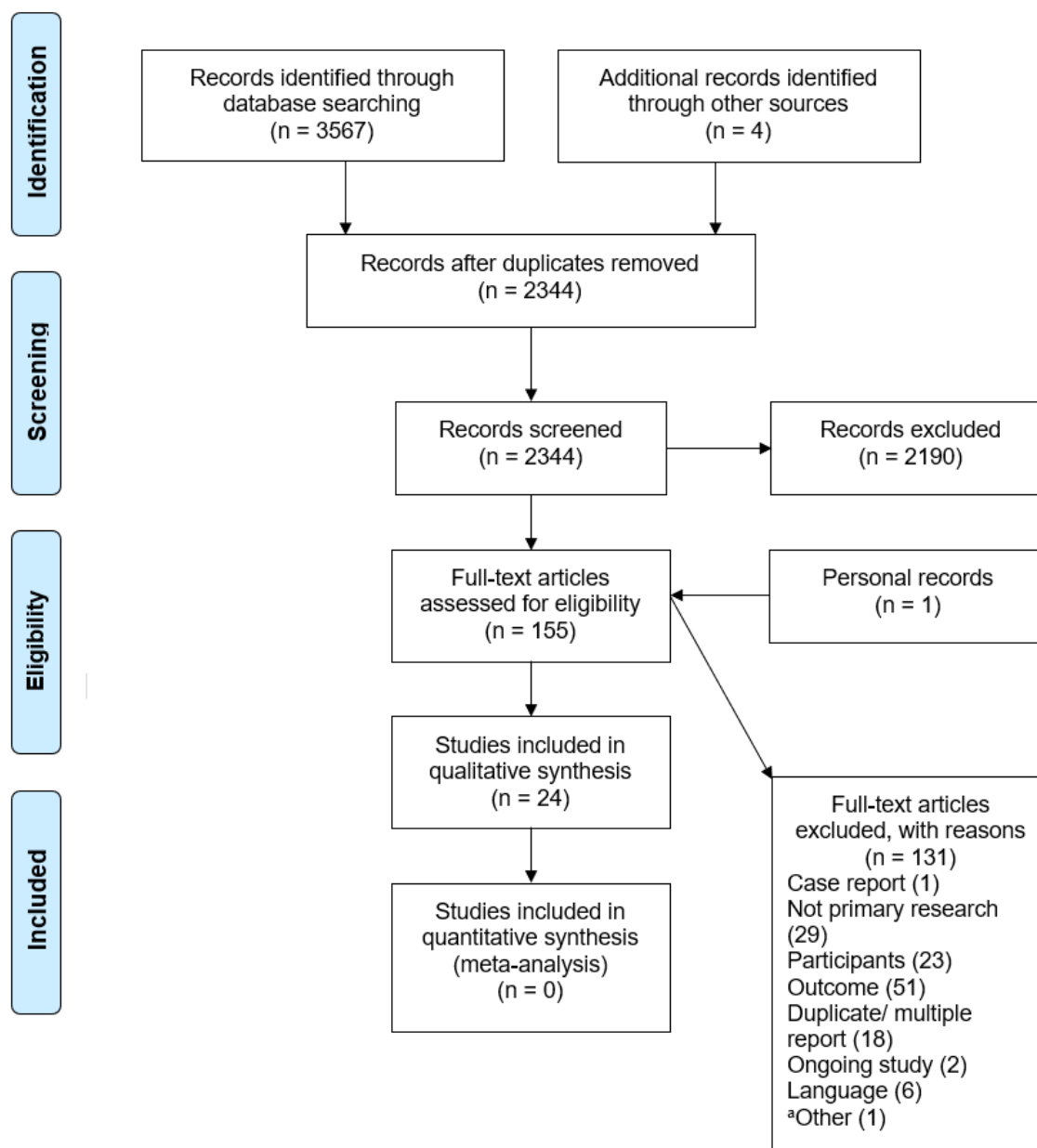
We planned to appraise RCTs using the Cochrane risk-of-bias tool,<sup>20</sup> but version 2 of the Cochrane risk-of-bias tool<sup>61</sup> was published shortly after protocol registration, so this was used to appraise included RCTs instead.

After data extraction, data indicated lower limb strength recovery after surgical and non-surgical treatment could be described separately. Due to potential clinical relevance, this was completed. To explore the impact of distal realignment surgery (procedures involving the tibial tuberosity or a Roux-Goldthwait procedure) on lower limb strength, we separately analyzed thigh muscle strength recovery in surgically treated participants excluding those who underwent isolated or concomitant distal realignment procedures. Distal realignment involves the extensor mechanism and typically requires more protective rehabilitation protocols than other patellar stabilization procedures,<sup>62</sup> potentially delaying thigh muscle strength recovery.

## **RESULTS**

### **Study characteristics**

Our search strategy identified 3571 records. After duplicate removal, 2344 titles and abstracts were screened. Agreement on independent duplicate screening of 10% of titles and abstracts from our initial search was 91% (214/236) and Kappa was 0.46. 155 reports underwent full-text screening and 24 studies were included in the review (figure 1). One included German-language study<sup>23</sup> could not be translated accurately with Google Translate, so data were extracted from the English-language abstract only.



**Figure 1.** PRISMA flow chart. <sup>a</sup>Outcome data available for one participant only

The characteristics of included studies are summarized in table 1; individual study characteristics are presented in appendix 2.

**Table 1** Summary of study characteristics

**Year published (no. of studies)**

2016-2020	8
2011-2015	5
2006-2010	5
2001-2005	1
1996-2000	3
1991-1995	1

≤1990	1
<b>Study design (no. of studies)</b>	
Case series	11
Surgical intervention(s) only	10
Non-surgical intervention only	1
Cohort	8
Surgical interventions only	5
Surgical and non-surgical interventions	3
Case-control	3
Surgical intervention only	1
Non-surgical intervention only	2
RCT	2
Surgical and non-surgical interventions	1
Non-surgical interventions only	1
<b><sup>a</sup>Participants</b>	
<sup>b</sup> Total (median; IQR) (N = 23)	877 (28; 20-53)
Knees (median; IQR) (N = 23)	853 (30; 20-47)
Primary/recurrent dislocations (participants) (N = 21)	362/455
<sup>c</sup> Age median (IQR) (N = 17)	20.7 (15.1-23)
Sex (male: female) (N = 20)	281: 396
<b><sup>d,e</sup>Surgical interventions (no. of studies)</b>	
MPFL reconstruction	9
Multiple proximal soft tissue realignment procedures and distal realignment	6
Multiple proximal soft tissue realignment procedures	5
Tibial tuberosity transfer	4
Lateral release and distal realignment	3
MPFL repair, MPFL reconstruction and distal realignment	2
MPFL repair and distal realignment, lateral release	1
<b><sup>e</sup>Non-surgical interventions (no. of studies)</b>	
Not reported	2
Immobilization only; initial immobilization and lower limb strengthening exercise; initial immobilization, quadriceps strengthening, and general rehabilitation; initial immobilization, strengthening, and knee range of movement exercise; initial immobilization and range of movement exercise	1

Studies that did not report means for relevant data were excluded from summary calculations; <sup>a</sup>Participants at enrolment/initial treatment not just those who underwent strength assessment; <sup>b</sup>Number of participants exceeds number of knees as different studies included in summary calculations; <sup>c</sup>Age at injury for non-surgically treated participants and age at surgery for surgically treated participants; <sup>d</sup>Surgical interventions at enrolment/initial treatment; <sup>e</sup>Some studies had more than one treatment so the number of treatments exceeds the number of studies; IQR, Interquartile range; MPFL, Medial patellofemoral ligament; N, Number of studies in summary calculation; RCT, Randomized controlled trial

In total, there were 877 participants (23 studies), 281 males and 396 females (20 studies), and the median age was 20.7 years (IQR 15.1-23; 17 studies). 362 participants had a first-time dislocation and 455 had a recurrent dislocation (21 studies). There were 11 case series, eight cohort studies, three case-control studies and two RCTs. 16/24 (66.7%) studies assessed lower limb strength after surgical treatment only, 4/24 (16.7%) studies assessed strength after non-surgical treatment only, and 4/24 (16.7%) studies assessed strength after surgical and non-surgical treatment. Surgical treatment could be categorized into nine different types, with isolated MPFL reconstruction most common (9/24 studies, 37.5%). Reported non-



surgical treatments involved immobilization only (1/8 studies, 12.5%) or initial immobilization then exercise (5/8 studies, 62.5%).

Strength assessment procedures are summarized in table 2; strength assessment procedures of individual studies are presented in appendix 3. Lower limb strength was quantified isokinetically in 18/24 studies (75%) and isometrically in 7/24 studies (29.2%), with one study using both isokinetic and isometric assessments.<sup>35</sup>

Assessment procedures varied widely between studies. In addition, information necessary to reproduce strength assessment procedures was often inadequately reported or missing, for example, the number of repetitions performed by participants was not reported in 9/24 (37.5%) studies, and for isokinetic assessments the contraction type and angular velocity was not reported or unclear in 10/18 (55.5%) studies and 4/18 (22.2%) studies, respectively. Fifteen different outcome measures were used to report results, with the LSI used in 12/24 studies (50%).

**Table 2** Summary of strength assessment procedures

**<sup>a</sup>Joint motion(s) assessed (no. of studies)**

Knee extension	24
Knee flexion	11
Hip abduction	3
Hip external rotation	2
Hip flexion, extension, adduction, internal rotation	1

**<sup>a</sup>Contraction type (no. of studies)**

Isokinetic	18
Knee extension	
Concentric	6
Concentric & eccentric	2
NR/UC	10
Knee flexion	
Concentric	3
Concentric & eccentric	1
NR/UC	7
Hip abduction	
NR	1
Isometric	7
Knee extension	7
Knee flexion	0
Hip abduction & external rotation	2
Hip adduction, flexion, extension, internal rotation	1

**<sup>a</sup>Angular velocity of isokinetic assessments (°/sec) (no. of studies)**

Knee	
60	9
180, 90, NR/UC	4
120	2
6, 12, 30, 240, 300	1
Hip	
120	1

**<sup>a</sup>Number of repetitions performed by participants (no. of studies)**

Isokinetic	
5, NR/UC	7
10	3
3, $\geq 3$	1
Isometric	
3, NR	2
5, one 5 second contraction, one 10 second contraction	1
<b><sup>a</sup>Reported outcome measures (no. of studies)</b>	
Isokinetic	
PT/BW	5
LSI of PT, PT, <sup>b</sup> LSI	4
Average PT	3
Total work output, average power	2
Deficit of torque of affected compared to unaffected limb, LSI of mean PT, LSI of mean power, H/Q ratio, angle of PT, post-operative improvement index, LSI of PT/BW	1
Isometric	
<sup>b</sup> LSI	2
Maximum force affected limb, force of affected limb, average torque to body weight, PT/BW, post-operative improvement index	1
<b><sup>c</sup>Duration of follow-up (strength assessment)</b>	
Total median (IQR) (N = 21)	36.4 (13-51.6) months

<sup>a</sup>Some studies report more than one variable for this parameter, so the number of variables exceeds the number of included studies; <sup>b</sup>Strength outcome measure used for LSI calculation not reported; <sup>c</sup>Follow-up is duration after surgery for surgical interventions and after dislocation for non-surgical interventions, if both surgical and non-surgical treatment provided, duration from initial treatment used, studies that did not provide mean follow-up for participants were excluded; H/Q, Hamstrings to quadriceps; IQR, Interquartile range; LSI, Limb symmetry index; N, Number of studies in summary calculation; NR, Not reported; PT, Peak torque; PT/BW, Peak torque to body weight; UC, Unclear; ( $^{\circ}$ /sec), Degrees per second

## Study appraisal

The two included RCTs, Askenberger et al<sup>5</sup> and Smith et al,<sup>57</sup> were judged to be overall at high risk of bias.

Six case series<sup>6,35,42,43,50,69</sup> scored the maximum of five stars and five case series<sup>4,23,34,48,59</sup> scored four stars on the amended Newcastle-Ottawa Scale. Four case series<sup>4,34,48,59</sup> lost a star for the domain assessing 'follow-up', as they either did not report if participants were enrolled consecutively or the number of eligible participants, or follow-up was below 80%. One cohort study<sup>21</sup> scored seven stars, one<sup>66</sup> scored six, two<sup>41,64</sup> scored five, three<sup>27,30,38</sup> scored four, and one<sup>51</sup> scored two. No cohort study controlled for both age and sex, and six lost a star for the domain assessing 'follow-up'. One case-control study<sup>54</sup> scored seven stars, one<sup>25</sup> scored six, and one<sup>3</sup> scored five. All lost a star for representativeness of cases. The appraisal of individual domains of version 2 of the Cochrane risk-of-bias tool and the amended Newcastle-Ottawa Scale are presented in appendix 4.

## Lower limb muscle groups assessed

Knee extension strength was assessed in all 24 studies; 11 of these also assessed knee flexion strength.<sup>5,6,66,21,27,30,38,41,42,51,54</sup> Hip abduction strength was assessed in three studies,<sup>3,25,54</sup> hip external rotation was assessed in two studies,<sup>3,25</sup> and hip

flexion, extension, adduction and internal rotation strength were assessed in one study.<sup>3</sup>

### **Lower limb strength recovery**

#### *Surgical Compared to Non-surgical Treatment*

Three studies compared lower limb strength between surgically and non-surgically treated people. Detailed results are presented in table 3.

Askenberger et al<sup>5</sup> compared thigh muscle strength between participants aged 9-14 years with a first-time patellar dislocation randomized to MPFL repair (n=37) or non-surgical treatment (n=37). Post-surgical rehabilitation and non-surgical treatment were similar and involved four weeks full weightbearing in a knee splint then lower limb strengthening exercise. At two years, there was no statistically significant difference in isokinetic knee extension or flexion strength between groups.

Moström et al<sup>41</sup> retrospectively compared thigh muscle strength between participants aged 9-14 with a first-time patellar dislocation treated surgically (seven participants) with osteochondral fragment fixation or removal and proximal soft tissue realignment (some participants also received distal realignment), and those treated non-surgically (44 participants) with immobilization then exercise. At mean 7.5 years, similar isokinetic knee extension and flexion strength scores were achieved by participants treated surgically and those treated non-surgically at enrolment, however no statistical comparison of strength between groups was completed.

Sakuraba et al<sup>51</sup> compared thigh muscle strength of the injured leg between females (mean age 20, 20 knees per treatment group, number of participants not reported) with recurrent patellar dislocations treated surgically with tibial tuberosity anteromedialization and those who received unspecified non-surgical treatment. Isokinetic concentric knee extension strength measured at an angular velocity of 30°/second was significantly higher in surgically treated participants. For all other assessments, mean strength scores were higher for surgically treated participants than non-surgically treated participants, but no statistical comparisons between groups were reported.

Reported lower limb strength outcomes for all studies are presented in appendix 5.

#### *First-time Compared to Recurrent Patellar Dislocations*

No study compared lower limb strength between participants with a first-time patellar dislocation and those with recurrent patellar dislocations.

**Table 3** Isokinetic lower limb strength in studies comparing surgically and non-surgically treated people

Study	Number of participants; females	Age (years)	Follow-up timepoint	Joint motion	Angular velocity (°/sec)	Strength outcome measure; Contraction type	Knee	Surgical participants	Non-surgical participants	P value
Askenberger et al <sup>5</sup>	Surg: 37; 18 Non-surg: 37; 20	Surg: 13.19 (1.08) Non-surg: 13.03 (1.14)	2 years	Knee ext	90	PT; Conc	<sup>a</sup> Injured (Nm)	107 (92-149)	118 (105-158)	0.252
					240			81 (69-107)	86 (71-110)	0.484
					90		<sup>a</sup> Uninjured (Nm)	137 (121-171)	132 (113-178)	0.730
					240			99 (81-116)	92 (82-126)	0.879
					90		<sup>a</sup> LSI (%)	83 (72-95)	93 (84-97)	0.093
					240			91 (77-97)	95 (86-100)	0.300
				Knee flex	90	<sup>a</sup> Injured (Nm)		65 (49-78)	59 (53-97)	0.661
					240			50 (39-61)	48 (39-71)	0.940
					90		<sup>a</sup> Uninjured (Nm)	68 (58-86)	68 (56-96)	0.993
					240			53 (44-60)	52 (41-73)	0.827
					90		<sup>a</sup> LSI (%)	95 (85-103)	98 (85-112)	0.215
					240			96 (89-104)	97 (90-111)	0.866
Moström et al <sup>41</sup>	Surg: 7; 4 Non-surg: 44; 25	Surg: 12.6 (2.3) Non-surg: <sup>b</sup> 13.5	7.5 (1.6) years	Knee ext	90	PT/BW; Conc	Injured (Nm/kg)	195.6 (57.4)	<sup>b</sup> 179.7	NR
							LSI (%)	89 (15)	<sup>b</sup> 84.8	NR
				Knee flex	90	PT/BW; Conc	Injured (Nm/kg)	103.6 (31.7)	<sup>b</sup> 108.2	NR
Sakuraba et al <sup>51</sup>	<sup>c</sup> Surg: 20 knees <sup>c</sup> Non-surg: 20 knees All females	20	NR	Knee ext	30	PT/BW; Conc	Injured (Nm/kg)	169 (52)	96 (34)	<0.01
						PT/BW; Ecc		218 (59)	146 (48)	NR
					90	PT/BW; Conc		<sup>d</sup> 130.4 (44.7)	<sup>d</sup> 74.3 (29.3)	NR
						PT/BW; Ecc		<sup>d</sup> 239.4 (69.2)	<sup>d</sup> 165.8 (49.8)	NR
				Knee flex	30	PT/BW; Conc		<sup>d</sup> 97.4 (36.6)	<sup>d</sup> 65.6 (17.4)	NR
						PT/BW; Ecc		<sup>d</sup> 137.6 (49.4)	<sup>d</sup> 99.7 (30.6)	NR
					90	PT/BW; Conc		<sup>d</sup> 78.8 (33.8)	<sup>d</sup> 56.7 (21.1)	NR
						PT/BW; Ecc		<sup>d</sup> 139.1 (50)	<sup>d</sup> 113.5 (34.1)	NR

Data are mean (standard deviation) unless otherwise stated; <sup>a</sup>Data are median (interquartile range); <sup>b</sup>Value is a weighted mean; <sup>c</sup>Number of participants not reported; <sup>d</sup>Obtained from graph using WebPlotDigitizer software; (°/sec), Degrees per second; Conc, Concentric; Ecc, Eccentric; Ext, Extension; Flex, Flexion; LSI, Limb symmetry index; Nm, Newton meter; Nm/kg, Newton meter per kilogram; Non-surg, Participants treated non-surgically at enrolment; NR, Not reported; PT, Peak torque; PT/BW, Peak torque to body weight ; Surg, Participants treated surgically at enrolment

## Adverse events

Mostrom et al<sup>41</sup> reported two patellar redislocations in the first five participants who underwent eccentric isokinetic knee testing on average 7.5 years after first-time patellar dislocation (participants were aged 9-14 years at time of injury). Concentric contractions were subsequently used. At the time of testing, 18/55 participants had undergone surgery and 27/55 had experienced a recurrent dislocation.

Rauschning et al<sup>48</sup> reported average knee pain on a nine-point Likert scale experienced by 18 females and two males (mean age 29.5 (range 17-42) years at time of surgery) during isokinetic knee extension testing. All participants had recurrent patellar dislocations and were treated surgically with lateral release and tibial tuberosity anteromedialization. Testing was conducted on average 19.8 (standard deviation (SD) 6.4) months after surgery. They found increased pain with slower angular velocities: 6°/second pain pre-surgery = 3.4, post-surgery = 1; 12°/second pain pre-surgery = 2.9, post-surgery = 1.2; and 60°/second pain pre-surgery = 1.7, post-surgery = 0.6.

Four studies<sup>3,21,25,51</sup> did not report any adverse events and it was unclear if adverse events were reported in Liebau et al<sup>23</sup> as the full-text was not translated. In the remaining 17 studies, no reported adverse events related to lower limb strength assessments.

## Additional analyses

Lower limb strength recovery, reported as a LSI, is presented in table 4. An LSI could not be calculated for any joint motion in 7/24 (71%) studies.<sup>21,23,25,48,51,57,59</sup> LSI data from Watanabe et al<sup>66</sup> was excluded as the number of participants was unclear.

Short-term knee extension strength LSI was assessed by three studies,<sup>3,4,6</sup> and knee flexion strength LSI was assessed by one study.<sup>6</sup> After surgery mean knee extension strength was 59.8% (SD 39.5).<sup>4</sup> After non-surgical treatment, mean knee extension strength was 85.2%<sup>3</sup> and 79% (range 20-108),<sup>6</sup> and knee flexion strength was 85% (range 4-111).<sup>6</sup>

Medium-term knee extension strength LSI was assessed by three studies,<sup>4,6,35</sup> and knee flexion strength LSI was assessed by one study.<sup>6</sup> After surgery, mean knee extension strength was 67.9% (SD 23.5)<sup>4</sup> and 54.5%.<sup>35</sup> After non-surgical treatment, mean knee extension and flexion strength was 92% (range 39-118) and 95% (range 55-135), respectively.<sup>6</sup>

Long-term knee extension strength LSI was assessed by 14 studies<sup>4,5,50,54,64,69,27,30,34,35,38,41-43</sup> and knee flexion strength LSI was assessed by six studies.<sup>5,27,30,38,42,54</sup> After surgery, median knee extension strength was 82.5% (IQR 78.5-88.2; 13 studies)<sup>4,5,54,64,69,30,34,35,38,41-43,50</sup> and knee flexion strength was 91.5% (IQR 90.7-96.9; five studies).<sup>5,30,38,42,54</sup> If participants who underwent isolated or concomitant distal realignment procedures were excluded,<sup>30,34,38,41,43,64</sup> median post-surgical knee extension strength was 80.6% (IQR 75.4-84.4; eight studies)<sup>4,5,30,35,50,54,64,69</sup> and knee flexion strength was 91.5% (IQR 91.1-94.7; three

studies).<sup>5,30,54</sup> After non-surgical treatment, median knee extension strength was 86% (IQR 79.3-87.4; four studies),<sup>5,27,41,69</sup> and mean knee flexion strength LSI was  $\geq 95\%$  (two studies).<sup>5,27</sup>

In all studies where both a knee flexion and extension strength LSI could be calculated (using the criteria described in the footnote of table 4), the knee flexion LSI was higher.<sup>5,6,27,30,38,42,54</sup>

One study assessed short-term hip strength LSI and reported LSIs  $>90\%$  in all six hip movements assessed.<sup>3</sup> One study assessed long-term hip abduction LSI and found a value of 116.2%.<sup>54</sup>

**Table 4** Lower limb strength recovery reported as a Limb Symmetry Index

Study	Strength measure used for LSI calculation; strength assessment; contraction type	Surgical intervention(s)/non-surgical intervention	<sup>a</sup> Angular velocity (°/sec)/ <sup>b</sup> joint position (°)	Time of strength assessment	LSI (%) Surgical treatment		LSI (%) Non-surgical treatment	
					Knee ext	Knee flex	Knee ext	Knee flex
Short-term (≤4 months)								
<sup>c</sup> Arrebola et al <sup>3</sup>	Mean max force to body weight; isometric; N/A	NR	60 knee flex	9.27 (4.16) weeks	-	-	85.2	-
Atkin et al <sup>6</sup>	NR; isokinetic; NR	Immobilization, strengthening and knee ROM exercise	NR	12 weeks	-	-	79	85
<sup>d</sup> Asaeda et al <sup>4</sup>	NR; isometric; N/A	MPFL reconstruction	NR	3 months	59.8	-	-	-
Medium-term (>4-8 months)								
Atkin et al <sup>6</sup>	NR; isokinetic; NR	Immobilization, strengthening and knee ROM exercise	NR	24 weeks	-	-	92	95
Asaeda et al <sup>4</sup>	NR; isometric; N/A	MPFL reconstruction	NR	6 months	67.9	-	-	-
<sup>d</sup> Matsushita et al <sup>35</sup>	UC; isokinetic; NR	MPFL reconstruction	60	6 months	54.5	-	-	-
Long-term (>8 months)								
<sup>d</sup> Asaeda et al <sup>4</sup>	NR; isometric; N/A	MPFL reconstruction	NR	12 months	52.1	-	-	-
Shams et al <sup>54</sup>	PT/BW; isokinetic; conc	MPFL reconstruction	300	385 (189) days	88.4	90.7		
Askenberger et al <sup>5</sup>	PT; isokinetic; conc	MPFL repair/immobilization and lower limb strengthening exercise	90	2 years	83.1	91.5	88	96.7
<sup>d</sup> Matsushita <sup>35</sup>	UC; isokinetic; NR	MPFL reconstruction	60	2 years	78.5	-	-	-
Woods et al <sup>69</sup>	Mean PT; isokinetic; NR	Lateral release	90	27 (range 24-43) months	79.8	-	63	-
Mikashima et al <sup>38</sup>	Mean power; isokinetic; NR	Elmslie-Trillat, Elmslie-Trillat and MPFL reconstruction	NR	36.4 months	71.1	77.5	-	-
Tompkins et al <sup>64</sup>	Average torque to body weight; isometric; N/A	MPFL reconstruction, MPFL repair (8/14 participants also underwent tibial tuberosity anteromedialization)	60 knee flex	Minimum 2 years (range 24-75 months)	88.2	-	-	-
Ronga et al <sup>50</sup>	Average PT; isokinetic; conc	MPFL reconstruction	60	3.1 (range 2.5-4) years	66.1	-	-	-
Oliva et al <sup>43</sup>	Average PT; isokinetic; conc	Lateral release, vastus medialis advancement, and medial transfer of medial patellar tendon	60	3.8 (range 2.5-6) years	82.5	-	-	-
Malecki et al <sup>30</sup>	PT; isokinetic; NR	MPFL reconstruction, multiple proximal soft tissue realignment procedures and Roux-Goldthwait procedure	60	5.6 (range 3-15) years	84.8	96.9	-	-

**Table 4** Lower limb strength recovery reported as a Limb Symmetry Index

Study	Strength measure used for LSI calculation; strength assessment; contraction type	Surgical intervention(s)/non-surgical intervention	<sup>a</sup> Angular velocity (°/sec)/ <sup>b</sup> joint position (°)	Time of strength assessment	LSI (%) Surgical treatment		LSI (%) Non-surgical treatment	
					Knee ext	Knee flex	Knee ext	Knee flex
Marsh et al <sup>34</sup>	NR; isokinetic; conc	Lateral release and Roux-Goldthwait procedure	NR	6.2 (range 2-13) years	95	-	-	-
Moström et al <sup>41</sup>	PT; isokinetic; conc	Multiple proximal soft tissue realignment procedures (some also underwent a Roux-Goldthwait or Elmslie-Trillat procedure)/immobilization and ROM exercise	90	7.5 (1.6) years	89	-	84.8	-
Niedzielski et al <sup>42</sup>	PT; isokinetic; NR	Multiple proximal soft tissue realignment procedures and Roux-Goldthwait procedure	60	8.1 (range 5-15) years	79.1	105.8	-	-
Mäenpää et al <sup>27</sup>	PT; isokinetic; NR	Immobilization only	60	13 (5) years			87.2	95.2
<b>Median (IQR)</b>					82.5 (78.5-88.2)	91.5 (90.7-96.9)	86 (79.3-87.4)	
<b>Long-term (&gt;8 months) in surgical participants who did not undergo distal realignment</b>								
<sup>d</sup> Asaeda et al <sup>4</sup>	NR; isometric; N/A	MPFL reconstruction	NR	12 months	52.1	-	-	-
Shams et al <sup>54</sup>	PT/BW; isokinetic; conc	MPFL reconstruction	300	385 (189) days	88.4	90.7	-	-
Askenberger et al <sup>5</sup>	PT; isokinetic; conc	MPFL repair	90	2 years	83.1	91.5	-	-
<sup>d</sup> Matsushita <sup>35</sup>	UC; isokinetic; NR	MPFL reconstruction	60	2 years	78.5	-	-	-
Woods et al <sup>69</sup>	Mean PT; isokinetic; NR	Lateral release	90	27 (range 24-43) months	79.8	-	-	-
Tompkins et al <sup>64</sup>	Average torque to body weight; isometric; N/A	MPFL reconstruction	60 knee flex	Minimum 2 years (range 24-75 months)	95.3	-	-	-
Ronga et al <sup>50</sup>	Average PT; isokinetic; conc	MPFL reconstruction	60	3.1 (range 2.5-4) years	66.1	-	-	-
Malecki et al <sup>30</sup>	PT; isokinetic; NR	MPFL reconstruction	60	5.6 (range 3-15) years	81.3	97.8	-	-
<b>Median (IQR)</b>					80.6 (75.4-85.4)	91.5 (91.1-94.7)	-	-
					Hip ext	Hip flex	Hip ext	Hip flex
<b>Short-term (≤4 months)</b>								
<sup>c</sup> Arrebola et al <sup>3</sup>	Mean max force to body weight; isometric; N/A	NR	0 hip flex	9.27 (4.16) weeks	-	-	100	-



**Table 4** Lower limb strength recovery reported as a Limb Symmetry Index

Study	Strength measure used for LSI calculation; strength assessment; contraction type	Surgical intervention(s)/non-surgical intervention	<sup>a</sup> Angular velocity (°/sec)/ <sup>b</sup> joint position (°)	Time of strength assessment	LSI (%) Surgical treatment		LSI (%) Non-surgical treatment	
			90 hip flex	9.27 (4.16) weeks	-	-	-	97.3
					Hip ER	Hip IR	Hip ER	Hip IR
<b>Short-term (≤4 months)</b>								
<sup>c</sup> Arrebola et al <sup>3</sup>	Mean max force to body weight; isometric; N/A	NR	90 hip flex	9.27 (4.16) weeks	-	-	93.3	98.3
			0 hip flex	9.27 (4.16) weeks	-	-	97.2	98.1
					Hip abd	Hip add	Hip abd	Hip add
<b>Short-term (≤4 months)</b>								
<sup>c</sup> Arrebola et al <sup>3</sup>	Mean max force to body weight; isometric; N/A	NR	UC abd	9.27 (4.16) weeks	-	-	99.8	-
			0 abd	9.27 (4.16) weeks	-	-	N/A	96.6
<b>Long-term (&gt;8 months)</b>								
Shams et al <sup>54</sup>	PT/BW; isokinetic; NR	MPFL reconstruction	120	385 (189) days	116.2	-	-	-

For studies that reported multiple strength values per joint motion: isokinetic and slowest angular velocity values were used where applicable, the longest follow-up duration within follow-up stratifications was used, and concentric contraction and peak torque values were used where possible, as these were the most commonly reported contraction type and outcome measure used for LSI calculations, respectively of included studies; Data are mean (standard deviation) unless otherwise stated; Median only calculated if strength values from ≥3 studies available; <sup>a</sup>Only applicable to isokinetic assessments; <sup>b</sup>Only applicable to isometric assessments; <sup>c</sup>Only participants with a unilateral patellar dislocation (n = 27/44); <sup>d</sup>Participants assessed pre-surgery were not included in the non-surgical column as it was unclear if they had previous surgery; (°/sec), Degrees per second; Abd, Abduction; Add, Adduction; Conc, Concentric; ER, External rotation; Ext, Extension; Flex, Flexion; IQR, Interquartile range; IR, Internal rotation; LSI, Limb symmetry index; MPFL, Medial patellofemoral ligament; N/A, Not applicable; NR, Not reported; PT, Peak torque; PT/BW, Peak torque to body weight; ROM, Range of movement; UC, Unclear

## DISCUSSION

This is the first systematic review of lower limb strength recovery after patellar dislocation including surgically and non-surgically treated people. Knee extension and flexion strength are regularly assessed after this injury, but hip strength assessment is rare. The available evidence indicates that after patellar dislocation, knee extension strength deficits in the affected limb are frequently observed and can persist in the long-term. However, the clinical and methodological characteristics, strength testing procedures, and quality of included studies was highly variable, limiting the certainty of this finding.

Only three studies compared lower limb strength recovery between surgically and non-surgically treated people, with conflicting findings.<sup>5,41,51</sup> These studies had methodological limitations. Askenberger et al<sup>5</sup> was judged to be at high risk of bias, and Mostrom et al<sup>41</sup> and Sakuraba et al<sup>51</sup> were non-randomized studies that lost three and six stars respectively on the amended Newcastle-Ottawa Scale. Sakuraba et al<sup>51</sup> also did not report the sample size, participant identification and statistical analysis methods, and follow-up duration. In addition, mean differences with 95% confidence intervals were not reported, limiting interpretation of the magnitude and precision of any between group differences in lower limb strength. Due to the methodological limitations, poor reporting, and inconsistent results of relevant studies, no inferences about the comparative effect of surgical and non-surgical treatment on lower limb strength recovery after patellar dislocation could be made.

No study compared lower limb strength recovery between people after first-time patellar dislocation and those with recurrent dislocations, therefore it is uncertain if lower limb strength recovery differs between these patient groups.

The only reported adverse events related to lower limb strength assessments were knee pain during isokinetic knee extension<sup>48</sup> and two redislocations during isokinetic knee testing.<sup>41</sup> Because torque typically increases as angular velocity decreases,<sup>7</sup> the slow angular velocities (6°/second, 12°/second and 60°/second) used in Rauschning et al<sup>48</sup> could explain why participant reported pain that was worse with slower angular velocities. As patients after patellar dislocation will likely have lateral patellar instability, due to anatomical variants and/or MPFL injury,<sup>46,71</sup> the high - and laterally directed - forces generated during eccentric isokinetic knee extension testing could increase redislocation risk. We know of one other report of patellar dislocation during eccentric isokinetic knee testing which occurred in the uninvolved knee of a 24-year-old female after extensive knee surgery.<sup>33</sup> Subsequent magnetic resonance imaging revealed a femoral sulcus angle of 160°. Overall though, reported adverse events were rare, indicating lower limb strength assessments appear safe in these patients. However, caution is required during eccentric isokinetic knee testing due to a possible increased redislocation risk.

In healthy athletic populations<sup>12,49</sup> and adult members of the public,<sup>36</sup> between limb differences in knee extension and flexion strength are normally less than 10%. Only two included studies reported knee extension deficits less than 10% in the unaffected limb (using the criteria in the footnote in table 4) at any follow-up timepoint.<sup>6,34</sup> This finding is in keeping with a systematic review by Smith et al<sup>58</sup> which found evidence of reduced knee extension strength in the affected limb after non-surgical treatment for patellar dislocation. In contrast, long-term knee flexion strength symmetry appears restored to within normal limits; only one study reported a deficit greater than 10% of the unaffected limb.<sup>38</sup> Knee flexion strength recovery in the short- and medium-term remains uncertain as this was only evaluated by Atkin et al.<sup>6</sup> Distal realignment did not seem to affect long-term thigh muscle strength recovery compared to other surgical procedures, but inferences could not be made as this was not compared in any randomized studies. In included studies, there was a consistent trend of greater between limb strength deficits in the knee extensors than the knee flexors. Given the quadriceps muscles' insertion on the patella, this is clinically anticipated. However, confidence in this finding remains guarded due to the methodological and clinical heterogeneity of included studies.

Hip strength of the affected limb appeared restored in studies where this was evaluated.<sup>3,54</sup> However, in a high-quality case-control study, Shams et al<sup>54</sup> used an angular velocity of 120°/second to assess hip abduction peak torque. This may be suboptimal to detect between limb strength deficits because peak torque occurs at 0-60°/second and decreases as angular velocity increases.<sup>7</sup> In Arrebola et al,<sup>3</sup> counter-resistance during most isometric hip assessments appeared to rely mainly on assessors' arm strength. This is considered suboptimal as testers may be unable to adequately resist large forces,<sup>63</sup> which reduces hand-held dynamometry reliability.<sup>65</sup> Strength values were also not normalized to lever arm length, so, amongst participants with equal maximum strength, those with shorter limb segments would record lower strength scores. This study also had methodological limitations, losing three stars on the amended Newcastle-Ottawa Scale. Given the limitations and small number of studies that evaluated hip strength, hip strength recovery after patellar dislocation remains uncertain. As strong hip muscles are thought to increase patellofemoral stability by controlling lower limb kinematics<sup>47</sup> and hip strengthening is routinely prescribed after this injury,<sup>24,40</sup> more research evaluating hip strength and its role in recovery appears warranted.

Knee extension strength symmetry in most studies was below the 85-90% that has been recommended for return to sport,<sup>37</sup> even in the long-term. This indicates time-based return-to-sport criteria may be inappropriate after patellar dislocation and objective lower limb strength assessment should be considered during rehabilitation as strength may be overestimated. Though the effect of improving lower limb strength on outcomes after patellar dislocation has not been evaluated, it seems reasonable to assume – until such research is conducted – that restoring lower limb strength may be beneficial, based on research findings in other knee conditions.<sup>11,15</sup> Specific rehabilitation recommendations cannot be made as the optimal rehabilitation

after patellar dislocation is unknown.<sup>24,40</sup> Only one RCT has compared exercise-based interventions after this injury,<sup>57</sup> in comparison, a recent systematic review included 10 RCTs that compared surgical and non-surgical treatment.<sup>44</sup> This highlights the need for RCTs evaluating rehabilitation programs after this injury.

The methodological quality and reporting, of included studies was poor. Future studies should adhere to relevant reporting guidelines to facilitate interpretation of their results.<sup>14</sup> When reporting strength assessment procedures, authors could consider using the parameters in appendix 3 in future work. We also recommend researchers use outcomes that allow comparison of lower limb strength between participants such as, LSI of peak torque to body weight, to enable pooling of data in future reviews.

This review has some limitations. We used an amended version of the Newcastle-Ottawa Scale to appraise observational studies. The Newcastle-Ottawa Scale has been criticized for its lack of validation,<sup>60</sup> attribution of equal weight to individual tool domains,<sup>60</sup> and low inter-rater reliability.<sup>18</sup> However, to our knowledge no other existing appraisal tool accounts for the different observational study designs in this review. Relevant articles could have been missed, as non-English language studies that were not adequately translated with Google Translate were excluded, and agreement on independent screening of 10% of titles and abstracts was 0.46 (Kappa), which is considered moderate.<sup>1</sup> By screening reference lists of included studies and relevant systematic reviews, and contacting authors of included studies published in the last 10 years, the risk of missing eligible studies was minimized. We used the LSI to assess lower limb strength recovery, which can overestimate lower limb strength recovery of the injured limb if strength of the uninjured limb has deteriorated over time.<sup>68</sup> Finally, two studies were excluded as it was unclear if all participants had a previous patellar dislocation and attempts to contact the authors were unsuccessful.<sup>22,53</sup> The results of these studies are broadly consistent with our findings and their inclusion would unlikely affect our results.

## CONCLUSIONS

Knee extension and flexion strength is regularly assessed after patellar dislocation but hip strength assessment is rare. The available evidence indicates that after patellar dislocation, knee extension strength deficits in the affected limb are frequently observed and can persist in the long-term, but this remains uncertain due to the limitations of relevant included studies. Hip strength recovery after patellar dislocation is unclear, as this was only evaluated in two studies. It was not possible to determine if lower limb strength recovery differs between people treated surgically with those treated non-surgically, due to a lack of high-quality trials. Lower limb strength assessment after a patellar dislocation appears safe, but caution may be required if using eccentric isokinetic knee testing. Better reporting of future studies will enable pooling of results in future reviews.



## REFERENCES

1. Altman DG. *Practical Statistics for Medical Research*. First edit. London: Chapman & Hall; 1991.
2. Amin S, Baker K, Niu J, et al. Quadriceps strength and the risk of cartilage loss and symptom progression in knee osteoarthritis. *Arthritis Rheum*. 2009;60(1):189-198. doi:10.1002/art.24182.
3. Arrebola LS, Smith T, Silva FF, et al. Hip and Knee Weakness and Ankle Dorsiflexion Restriction in Individuals Following Lateral Patellar Dislocation. *Clin J Sport Med*. 2019;00. doi:10.1097/jsm.0000000000000815.
4. Asaeda M, Deie M, Fujita N, et al. Knee biomechanics during walking in recurrent lateral patellar dislocation are normalized by 1 year after medial patellofemoral ligament reconstruction. *Knee Surgery, Sport Traumatol Arthrosc*. 2016;24(10):3254-3261. doi:10.1007/s00167-016-4040-2.
5. Askenberger M, Bengtsson Moström E, Ekström W, et al. Operative Repair of Medial Patellofemoral Ligament Injury Versus Knee Brace in Children With an Acute First-Time Traumatic Patellar Dislocation: A Randomized Controlled Trial. *Am J Sports Med*. 2018;46(10):2328-2340. doi:10.1177/0363546518770616.
6. Atkin DM, Fithian DC, Marangi KS, et al. Characteristics of Patients With Primary Acute Lateral Patellar Dislocation and Their Recovery Within the First 6 Months of Injury. *Am J Sports Med*. 2000;28(4):472-479. doi:https://doi.org/10.1177/03635465000280040601.
7. Baltzopoulos V, Brodie D. Isokinetic dynamometry. Applications and limitations. *Sport Med*. 1989;8:101-116.
8. Bland JM, Kerry SM. Weighted comparison of means. *BMJ*. 1998;316:129. doi:https://doi.org/10.1136/bmj.316.7125.129.
9. Bohannon RW. Manual muscle testing: Does it meet the standards of an adequate screening test? *Clin Rehabil*. 2005;19(6):662-667. doi:10.1191/0269215505cr873oa.
10. Cohen J. A coefficient of agreement for nominal scales. *Educ Psychol Meas*. 1960;20(1):37-46.
11. Coudeyre E, Jegu AG, Giustanini M, Marrel JP, Edouard P, Pereira B. Isokinetic muscle strengthening for knee osteoarthritis: A systematic review of randomized controlled trials with meta-analysis. *Ann Phys Rehabil Med*. 2016. doi:10.1016/j.rehab.2016.01.013.
12. Dervisevic E, Hadzic V. Quadriceps and hamstrings strength in team sports: Basketball, football and volleyball. *Isokinet Exerc Sci*. 2012;(20):293-300. doi:10.3233/ies-2012-00483.
13. Dix J, Marsh S, Dingenen B, Malliaras P. The relationship between hip muscle strength and dynamic knee valgus in asymptomatic females: A systematic review. *Phys Ther Sport*. 2019;37:197-209. doi:10.1016/j.ptsp.2018.05.015.
14. Enhancing the QUALity and Transparency Of health Research. www.equator-

network.org. Accessed January 5, 2020.

15. Flosadottir V, Roos EM, Ageberg E. Muscle function is associated with future patient-reported outcomes in young adults with ACL injury. *BMJ Open Sport Exerc Med*. 2016;2(1):e000154. doi:10.1136/bmjsem-2016-000154.
16. Gravesen KS, Kallemose T, Blønd L, Troelsen A, Barfod KW. High incidence of acute and recurrent patellar dislocations: a retrospective nationwide epidemiological study involving 24.154 primary dislocations. *Knee Surgery, Sport Traumatol Arthrosc*. 2018;26(4):1204-1209. doi:10.1007/s00167-017-4594-7.
17. Greiwe RM, Saifi C, Ahmad CS, Gardner TR. Anatomy and biomechanics of patellar instability. *Oper Tech Sports Med*. 2010;18(2):62-67. doi:10.1053/j.otsm.2009.12.014.
18. Hartling L, Milne A, Hamm MP, et al. Testing the Newcastle Ottawa Scale showed low reliability between individual reviewers. *J Clin Epidemiol*. 2013;66(9):982-993. doi:10.1016/j.jclinepi.2013.03.003.
19. Hawkins RJ, Bell RH, Anisette G. Acute patellar dislocations. The natural history. *Am J Sports Med*. 14(2):117-120. doi:10.1177/036354658601400204.
20. Higgins J, Green S (editors). Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 [updated March 2011]. Available from [www.handbook.cochrane.org](http://www.handbook.cochrane.org).
21. Keilani M, Palma S, Crevenna R, et al. Functional outcome after recurrent patellar dislocation: Comparison of two surgical techniques—Medial patellofemoral ligament reconstruction (MPFL) vs. Elmslie Trillat procedure. *Wien Klin Wochenschr*. 2019;131:614-619. doi:10.1007/s00508-019-01570-3.
22. Krych AJ, O'Malley MP, Johnson NR, et al. Functional testing and return to sport following stabilization surgery for recurrent lateral patellar instability in competitive athletes. *Knee Surgery, Sport Traumatol Arthrosc*. 2018;26(3):711-718. doi:10.1007/s00167-016-4409-2.
23. Liebau C, Merkel M, Merk H, Neumann HW. Die Medialisierung der Tuberositas tibiae zur Behandlung habitueller Patellaluxationen. *Chirurg*. 1999;70(11):1307-1314. doi:10.1007/s001040050784.
24. Lightsey HM, Wright ML, Trofa DP, Popkin CA, Ahmad CS, Redler LH. Rehabilitation variability following medial patellofemoral ligament reconstruction. *Phys Sportsmed*. 2018;46(4):441-448. doi:10.1080/00913847.2018.1487240.
25. Lucas KCH, Jacobs C, Lattermann C, Noehren B. Gait deviations and muscle strength deficits in subjects with patellar instability. *Knee*. 2020;27(4):1285-1290. doi:10.1016/j.knee.2020.05.008.
26. Mäenpää H, Huhtala H, Lehto MUK. Recurrence after patellar dislocation. Redislocation in 37/75 patients followed for 6-24 years. *Acta Orthop Scand*. 1997;68(5):424-426. doi:10.3109/17453679708996255.
27. Mäenpää H, Latvala K, Lehto MUK. Isokinetic thigh muscle performance after long-term recovery from patellar dislocation. *Knee Surgery, Sport Traumatol*

- Arthrosc.* 2000;8(2):109-112. doi:10.1007/s001670050196.
28. Magnussen RA, Verlage M, Stock E, et al. Primary patellar dislocations without surgical stabilization or recurrence: how well are these patients really doing? *Knee Surgery, Sport Traumatol Arthrosc.* 2017;25(8):2352-2356. doi:10.1007/s00167-015-3716-3.
  29. Majewski M, Susanne H, Klaus S. Epidemiology of athletic knee injuries: A 10-year study. *Knee.* 2006;13(3):184-188. doi:10.1016/j.knee.2006.01.005.
  30. Malecki K, Fabis J, Flont P, Lipczyk Z, Niedzielski K. Preliminary results of two surgical techniques in the treatment of recurrent patellar dislocation. *Int Orthop.* 2016;40(9):1869-1874. doi:10.1007/s00264-016-3119-1.
  31. Malecki K, Fabis J, Flont P, Niedzielski KR. The results of adductor magnus tenodesis in adolescents with recurrent patellar dislocation. *Biomed Res Int.* 2015;2015. doi:10.1155/2015/456858.
  32. Małecki K, Niedzielski K, Flont P, Fabis-Strobin A, Fabis J. Bilateral Hidden Isokinetic Quadriceps Performance before and after MPFL Reconstruction in Pediatric Patients. *J Knee Surg.* 2020;1(212). doi:10.1055/s-0039-3402031.
  33. Maletius W, Gillquist J, Messner K. Acute patellar dislocation during eccentric muscle testing on the Biodex dynamometer. *Arthroscopy.* 1994;10(4):473-474. doi:10.1016/S0749-8063(05)80203-8.
  34. Marsh JS, Daigneault JP, Sethi P, Polzhofer GK. Treatment of recurrent patellar instability with a modification of the Roux-Goldthwait technique. *J Pediatr Orthop.* 2006;26(4):461-465. doi:10.1097/01.bpo.0000217711.34492.48.
  35. Matsushita T, Araki D, Matsumoto T, Niikura T, Kuroda R. Changes in knee extensor strengths before and after medial patellofemoral ligament reconstruction. *Phys Sportsmed.* 2019;47(2):220-226. doi:10.1080/00913847.2018.1547086.
  36. Meldrum D, Cahalane E, Conroy R, Fitzgerald D, Hardiman O. Maximum voluntary isometric contraction : Reference values and clinical application. *Amyotroph Lateral Scler.* 2007;(8):47-55. doi:10.1080/17482960601012491.
  37. Ménétrey J, Putman S, Gard S. Return to sport after patellar dislocation or following surgery for patellofemoral instability. *Knee Surgery, Sport Traumatol Arthrosc.* 2014;22(10):2320-2326. doi:10.1007/s00167-014-3172-5.
  38. Mikashima Y, Kimura M, Kobayashi Y, Asagumo H, Tomatsu T. Medial patellofemoral ligament reconstruction for recurrent patellar instability. *Acta Orthop Belg.* 2004:545-550.
  39. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ.* 2009;339(b2535). doi:10.1136/bmj.b2535.
  40. Moiz M, Smith N, Smith TO, Chawla A, Thompson P, Metcalfe A. Clinical Outcomes After the Nonoperative Management of Lateral Patellar Dislocations: A Systematic Review. *Orthop J Sport Med.* 2018;6(6):1-17. doi:10.1177/2325967118766275.



41. Moström EB, Mikkelsen C, Weidenhielm L, Janarv PM. Long-term follow-up of nonoperatively and operatively treated acute primary patellar dislocation in skeletally immature patients. *Sci World J*. 2014. doi:10.1155/2014/473281.
42. Niedzielski KR, Malecki K, Flont P, Fabis J. The results of an extensive soft-tissue procedure in the treatment of obligatory patellar dislocation in children with ligamentous laxity: a post-operative isokinetic study. *Bone Joint J*. 2015;97-B(1):129-133. doi:10.1302/0301-620X.97B1.33941.
43. Oliva F, Ronga M, Longo UG, Testa V, Capasso G, Maffulli N. The 3-in-1 procedure for recurrent dislocation of the patella in skeletally immature children and adolescents. *Am J Sports Med*. 2009;37(9):1814-1820. doi:10.1177/0363546509333480.
44. Pagliuzzi G, Napoli F, Previtali D, Filardo G, Zaffagnini S, Candrian C. A Meta-analysis of Surgical Versus Nonsurgical Treatment of Primary Patella Dislocation. *Arthrosc - J Arthrosc Relat Surg*. 2019;35(8):2469-2481. doi:10.1016/j.arthro.2019.03.047.
45. Palmieri-Smith RM, Lepley LK. Quadriceps strength asymmetry after anterior cruciate ligament reconstruction alters knee joint biomechanics and functional performance at time of return to activity. *Am J Sports Med*. 2015;43(7):1662-1669. doi:10.1177/0363546515578252.
46. Parikh SN, Lykissas MG, Gkias I. Predicting Risk of Recurrent Patellar Dislocation. *Curr Rev Musculoskelet Med*. 2018;11(2):253-260. doi:10.1007/s12178-018-9480-5.
47. Post WR, Fithian DC. Patellofemoral Instability: A Consensus Statement From the AOSSM/PFF Patellofemoral Instability Workshop. *Orthop J Sport Med*. 2018;6(1):1-5. doi:10.1177/2325967117750352.
48. Rauschning W, Nordesjö LO, Nordgren B. Isokinetic knee extension strength and pain before and after advancement osteotomy of the tibial tuberosity. *Arch Orthop Trauma Surg*. 1983;102(2):95-101. doi:10.1007/BF02498723.
49. Risberg MA, Steffen K, Nilstad A, et al. Normative quadriceps and hamstring muscle strength values for female, healthy, elite handball and football players. *J Strength Cond Res*. 2018;32(8):2314-2323. doi:10.1519/jsc.0000000000002579.
50. Ronga M, Oliva F, Longo UG, Testa V, Capasso G, Maffulli N. Isolated medial patellofemoral ligament reconstruction for recurrent patellar dislocation. *Am J Sports Med*. 2009;37(9):1735-1742. doi:10.1177/0363546509333482.
51. Sakuraba K, Yamauchi Y, Ikeda H. Isokinetic torque of knee extensors and flexors in patients with recurrent patellar dislocations. *J Orthop Surg*. 1993;1(1):23-26.
52. Sanders TL, Pareek A, Johnson NR, Stuart MJ, Dahm DL, Krych AJ. Patellofemoral Arthritis after Lateral Patellar Dislocation: A Matched Population-Based Analysis. *Am J Sports Med*. 2017;45(5):1012-1017. doi:10.1177/0363546516680604.
53. Saper MG, Fantozzi P, Bompadre V, Racicot M, Schmale GA. Return-to-Sport

- Testing After Medial Patellofemoral Ligament Reconstruction in Adolescent Athletes. *Orthop J Sport Med*. 2019;7(3):1-7. doi:10.1177/2325967119828953.
54. Shams K, DiCesare CA, Grawe BM, et al. Biomechanical and Functional Outcomes After Medial Patellofemoral Ligament Reconstruction: A Pilot Study. *Orthop J Sport Med*. 2019;7(2):1-10. doi:10.1177/2325967119825854.
  55. Smith T, Donell S, Song F, Hing C. Surgical versus non-surgical interventions for treating patellar dislocation. *Cochrane Database Syst Rev*. 2015;(2). doi:10.1002/14651858.CD008106.pub3.
  56. Smith TO, Chester R, Clark A, Donell ST, Stephenson R. A national survey of the physiotherapy management of patients following first-time patellar dislocation. *Physiotherapy*. 2011;97(4):327-338. doi:10.1016/j.physio.2011.01.003.
  57. Smith TO, Chester R, Cross J, Hunt N, Clark A, Donell ST. Rehabilitation following first-time patellar dislocation: A randomised controlled trial of purported vastus medialis obliquus muscle versus general quadriceps strengthening exercises. *Knee*. 2015;22(4):313-320. doi:10.1016/j.knee.2015.03.013.
  58. Smith TO, Davies L, Chester R, Clark A, Donell ST. Clinical outcomes of rehabilitation for patients following lateral patellar dislocation: A systematic review. *Physiotherapy*. 2010;96(4):269-281. doi:10.1016/j.physio.2010.02.006.
  59. Smith TO, Mann CJ V, Donell ST. Does knee joint proprioception alter following medial patellofemoral ligament reconstruction? *Knee*. 2014;21(1):21-27. doi:10.1016/j.knee.2012.09.013.
  60. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *Eur J Epidemiol*. 2010;25(9):603-605. doi:10.1007/s10654-010-9491-z.
  61. Sterne JAC, Savović J, Page MJ, et al. RoB 2: A revised tool for assessing risk of bias in randomised trials. *BMJ*. 2019;366:1-8. doi:10.1136/bmj.l4898.
  62. Thompson P, Metcalfe AJ. Current concepts in the surgical management of patellar instability. *Knee*. 2019;26(6):1171-1181. doi:10.1016/j.knee.2019.11.007.
  63. Thorborg K, Bandholm T, Hölmich P. Men are stronger than women-Also in the hip. *J Sci Med Sport*. 2013;16(5):3-5. doi:10.1016/j.jsams.2013.03.018.
  64. Tompkins M, Kuenze CM, Diduch DR, Miller MD, Milewski MD, Hart JP. Clinical and Functional Outcomes following Primary Repair versus Reconstruction of the Medial Patellofemoral Ligament for Recurrent Patellar Instability. *J Sports Med*. 2014;2014:1-8. doi:10.1155/2014/702358.
  65. Wadsworth CT, Nielsen DH, Corcoran DS, Phillips CE, Sannes TL. Interrater reliability of hand-held dynamometry: Effects of rater gender, body weight, and grip strength. *J Orthop Sports Phys Ther*. 1992;16(2):74-81. doi:10.2519/jospt.1992.16.2.74.
  66. Watanabe T, Muneta T, Ikeda H, Tateishi T, Sekiya I. Visual analog scale assessment after medial patellofemoral ligament reconstruction: With or

- without tibial tubercle transfer. *J Orthop Sci.* 2008;13(1):32-38.  
doi:10.1007/s00776-007-1196-0.
67. Wells G, Shea B, O'Connell D, et al. Newcastle - Ottawa Quality Assessment Scale. [http://www.ohri.ca/programs/clinical\\_epidemiology/nosgen.pdf](http://www.ohri.ca/programs/clinical_epidemiology/nosgen.pdf). Accessed January 3, 2020.
  68. Wellsandt E, Failla M, Snyder-Mackler L. Limb Symmetry Indexes Can Overestimate Knee Function After ACL Injury. *J Orthop Sports Phys Ther.* 2017;47(1):334-338. doi:10.2519/jospt.2017.7285.
  69. Woods GW, Elkousy HA, O'Connor DP. Arthroscopic release of the vastus lateralis tendon for recurrent patellar dislocation. *Am J Sports Med.* 2006;34(5):824-831. doi:10.1177/0363546505282617.
  70. Zaman S, White A, Shi WJ, Freedman KB, Dodson CC. Return-to-Play Guidelines After Medial Patellofemoral Ligament Surgery for Recurrent Patellar Instability: A Systematic Review. *Am J Sports Med.* 2018;46(10):2530-2539. doi:10.1177/0363546517713663.
  71. Zhang GY, Zhu HX, Li EM, et al. The correlation between the injury patterns of the medial patellofemoral ligament in an acute first-time lateral patellar dislocation on MR imaging and the incidence of a second-time lateral patellar dislocation. *Korean J Radiol.* 2018;19(2):292-300. doi:10.3348/kjr.2018.19.2.292.

## Appendix 1: search strategy

One reviewer developed the search strategy with two health science librarians, one of whom reviewed the final search strategy.

<b>MEDLINE via Ovid (1946 to present)</b>
1. exp Patellar Dislocation/
2. exp Patella/
3. exp Patellofemoral Joint/
4. (patell* or Kneecap* or "knee cap*" or PFJ).tw.
5. 2 or 3 or 4
6. exp Joint Instability/ or exp Joint Dislocations/
7. (Dislocat* or Instability or Unstable or Sublux*).tw.
8. 6 or 7
9. 5 and 8
10. 1 or 9
11. exp Muscle Strength/
12. exp Muscle Strength Dynamometer/
13. exp Muscle Weakness/
14. (strength* or torque or isokinetic* or Power or musc* or weak* or Dynamomet* or Isometric* or isotonic* or force or eccentric* or concentric*).tw.
15. 11 or 12 or 13 or 14
16. 10 and 15
17. limit 16 to humans

<b>EMBASE via Ovid (1974 to present)</b>
1. exp patella dislocation/
2. exp patella/
3. exp patellofemoral joint/
4. (patell* or Kneecap* or "knee cap*" or PFJ).tw.
5. 2 or 3 or 4
6. exp dislocation/
7. exp joint instability/
8. (Dislocat* or Instability or Unstable or Sublux*).tw.
9. 6 or 7 or 8
10. 5 and 9
11. 1 or 10
12. exp dynamometer/ or exp dynamometry/
13. exp muscle strength/
14. exp muscle weakness/
15. (strength* or torque or isokinetic* or power or musc* or weak* or dynamomet* or isometric* or isotonic* or force or eccentric* or concentric*).tw.

16. 12 or 13 or 14 or 15
17. 11 and 16
18. limit 17 to human

<b>AMED via Ovid (1985 to present)</b>	
1. exp patella/	
2. (patell* or Kneecap* or "knee cap*" or PFJ).af.	
3. 1 or 2	
4. exp Dislocations/	
5. exp Joint instability/	
6. (Dislocat* or Instability or Unstable or Sublux*).af.	
7. 4 or 5 or 6	
8. 1 and 7	

<b>Cochrane library (inception to present)</b>	
1	MeSH descriptor: [Patellar Dislocation] this term only
2	MeSH descriptor: [Patella] this term only
3	MeSH descriptor: [Joint Dislocations] this term only
4	MeSH descriptor: [Joint Instability] this term only
5	#3 OR #4
6	#2 AND #5
7	#1 OR #6
8	Patell* OR Kneecap* OR "knee cap*" or PFJ
9	Dislocat* OR Instability OR Unstable OR Sublux*
10	#8 AND #9
11	#7 OR #10
12	MeSH descriptor: [Muscle Strength Dynamometer] this term only
13	MeSH descriptor: [Muscles] this term only
14	MeSH descriptor: [Torque] this term only
15	#12 OR #13 OR #14 (2029)
16	Strength* OR Torque OR Isokinetic* OR Power* OR Musc* OR Weak* Or Dynamomet* OR Quad* OR Isometric* OR Glute* OR Isotonic* OR Force OR Eccentric* OR Concentric*
17	#15 or #16
18	#11 AND #17

<b>CINAHL via EBSCOhost (inception to present)</b>	
S16	S10 and S15
S15	S11 or S12 or S13 or S14
S14	TX strength* OR TX torque* OR TX isokinetic* OR TX power OR TX musc* OR TX weak* OR TX dynamomet* OR TX isometric* OR TX isotonic* OR TX eccentric* OR TX concentric*
S13	(MH "Muscle Weakness+")
S12	(MH "Exercise Test, Muscular+")

S11	(MH "Muscle Strength+")
S10	S1 or S9
S9	S4 and S8
S8	S5 or S6 or S7
S7	TX dislocat* OR TX instability OR TX unstable OR TX sublux*
S6	(MH "Joint Instability+")
S5	(MH "Dislocations+")
S4	S2 or S3
S3	TX patell* OR TX Kneecap* OR TX "Knee cap*" OR TX PFJ
S2	(MH "Patella")
S1	(MH "Patella Dislocation")

<b>SPORTDiscus (inception to present)</b>	
S11	S7 and S10
S10	S8 or S9
S9	TX strength* OR TX torque OR TX isokinetic* OR TX power OR TX musc* OR TX weak* OR TX dynamomet* OR TX isometric* OR TX isotonic* OR TX eccentric* OR TX concentric*
S8	((DE "MUSCLE strength" OR DE "GRIP strength" OR DE "KRAUS-Weber test" OR DE "MUSCLE strength testing" OR DE "MUSCLE strength measurement") OR (DE "DYNAMOMETER")) OR (DE "MUSCLE weakness")
S7	S3 and S6
S6	S4 or S5
S5	TX dislocat* OR TX instability OR TX unstable OR TX sublux*
S4	DE "DISLOCATIONS (Anatomy)" OR DE "ANKLE dislocation" OR DE "BONESETTERS" OR DE "DISLOCATIONS in children" OR DE "ELBOW dislocation" OR DE "FINGER dislocation" OR DE "WRIST dislocations" OR DE "DISLOCATIONS in children" OR DE "SUBLUXATION"
S3	S1 or S2
S2	TX patell* OR TX kneecap* OR TX "Knee cap*" OR TX PFJ
S1	DE "PATELLA" OR DE "PATELLOFEMORAL joint"

<b>PEDro (inception to present)</b>	
1	Patell* Dislocat*
2	Patell* Instability
3	Patell* Unstable
4	Patell* Sublux*
5	Kneecap* Dislocat*
6	Kneecap* instability
7	Kneecap* Unstable
8	Kneecap* Sublux*
9	"Knee cap*" Dislocat*
10	"Knee cap*" instability
11	"Knee cap*" Unstable
12	"Knee cap*" Sublux*
13	PFJ Dislocat*

14	PFJ Instability
15	PFJ Unstable
16	PFJ Sublux*
	Combine all search terms AND, title and abstract

<b>Trial registries (search terms)</b>	
<b>ClinicalTrials.Gov:</b> ((Patella OR Kneecap) AND (Dislocation))	
<b>UK clinical trials gateway:</b> ((patella* OR kneecap) AND (dislocation))	
<b>WHO International Clinical Trials Registry Platform:</b> (Patella AND dislocation)	
<b>ISRCTN registry:</b> (Patella AND dislocation)	

## Appendix 2: individual study characteristics

Authors and year (country)	Design	Single/multicenter	Participants [per treatment group where applicable]; <sup>a</sup> age (years); sex (males/females); primary/recurrent dislocations	Treatment groups	Surgical intervention(s)	Non-surgical intervention(s)
Asaeda et al <sup>4</sup> 2016 (Japan)	Case series	Single center	26 [Surg: 11, non-surg: 15 (healthy controls)]; <sup>b</sup> Age pre-surgery = 21.2 (7.6); <sup>b</sup> Sex = 3/8; <sup>b</sup> Primary/recurrent = 0/11	<sup>b</sup> 1	MPFL reconstruction using semitendinosus graft. 5 participants also had a lateral release.  Post-surgery: immobilized for 2 weeks in a soft knee brace and completed isometric quadriceps exercises and unspecified strengthening exercises for other joints. At 3 weeks allowed PWB and started ROM exercises. At 6 weeks allowed FWB. Return to sport allowed at 6 months.	N/A
Arrebola et al <sup>3</sup> 2019 (Brazil)	Case-control	Single center	88 [Surg: 0, non-surg: 88 (non-surgically treated participants: 44, healthy controls: 44)]; <sup>b</sup> Age = 20; <sup>b</sup> Sex = 14/30; <sup>b</sup> Primary/recurrent = NR	<sup>b</sup> 1	N/A	NR
Askenberger et al <sup>5</sup> 2018 (Sweden)	Parallel RCT	Single center	74 [Surg: 37, non-surg: 37 (all non-surg participants underwent diagnostic arthroscopy)]; Age at injury = Surg: 13.19 (1.08), non-surg: 13.03 (1.14); Sex = Surg: 19/18, non-surg: 17/20; Primary/recurrent = 74/0	2	Arthroscopic MPFL repair.  Post-surgery: FWB in soft knee splint for 4 weeks then a program of strengthening and functional training from physical therapists with specialist knowledge of pediatric patellofemoral rehabilitation. This included unspecified gluteal and core muscle training.	As per post-surgery treatment
Atkin et al <sup>6</sup> 2000 (USA)	Case series	Single center	74 [Surg: 0, non-surg: 74] Age = 19.9 (range 11-56); Sex = 37/37; Primary/recurrent = 74/0	1	N/A	Initially WBAT with crutches in knee immobilizer. Progressed to patella-stabilizing brace and encouraged to begin closed-chain resistance exercises and passive ROM as able. Return to stressful activities and sports allowed when full passive ROM, no effusion and quadriceps muscle strength was ≥80% of unaffected limb. Participants encouraged to wear patella-stabilizing braces for pivoting activities and sports.



Authors and year (country)	Design	Single/multicenter	Participants [per treatment group where applicable]; <sup>a</sup> age (years); sex (males/females); primary/recurrent dislocations	Treatment groups	Surgical intervention(s)	Non-surgical intervention(s)
Keilani et al <sup>21</sup> 2019 (Austria)	Cohort	Single center	12 [Surg:12 (MPFL reconstruction: 6, Elmslie-Trillat: 6), non-surg: 0]; Age = MPFL reconstruction: median 33 (range 18-38), Elmslie-Trillat: median 26 (range 19-32); Sex = 12/0; Primary/recurrent = 0/12	2	MPFL reconstruction usually using a hamstring tendon or allograft Post-surgery: NR	Elmslie-Trillat procedure Post-surgery: NR
Liebau et al <sup>23</sup> 1999 (Germany)	Case series	Single center	88 [Surg: 88, non-surg: 0]; Age = UC; Sex = UC; Primary/recurrent = 0/88	1	Medial tibial tuberosity transfer. 21 participants also had a lateral release. Post-surgery: UC	N/A
Lucas et al <sup>25</sup> 2020 (USA)	Case-control	Single center	32 [Surg: 0, non-surg: 32 (non-surgically treated participants: 16, healthy controls: 16); <sup>b</sup> Age = 21.1 (4.2); <sup>b</sup> Sex = 3/13; <sup>b</sup> Primary/recurrent = 10/6	<sup>b</sup> 1	N/A	NR
Mäenpää et al <sup>27</sup> 2000 (Finland)	Cohort	NR	82 [Surg: 0, <sup>c</sup> non-surg: 82 (non-surg no redislocation: 32, surg for redislocation: 34, surg for anterior knee pain/subluxations: 16)]; Age at testing = Non-surg no redislocation: 39 (12), surg for redislocation: 30 (8), surg for anterior knee pain/subluxations: 37 (10); Sex = 32/50 (Non-surg no redislocation: 12/20, surg for redislocation: 14/20, surg for anterior knee pain/subluxations: 6/10); Primary/recurrent = 82/0	3	Proximal realignment (Helfet method): 20 participants, proximal and distal realignment (Elmslie-Roux-Trillat): 4 participants, proximal and distal realignment (Hauser method): 2 participants Post-surgery: NR	Initially all participants immobilized for 3 (2) weeks.
Malecki et al <sup>30</sup> 2016 (Poland)	Cohort	NR	56 (65 knees) [Surg: 56 (MPFL reconstruction: 28 (32 knees), soft tissue realignment: 28 (33 knees)), non-surg: 0]; Age = Median 14 (range 6-18), per treatment group NR; Sex = MPFL reconstruction: 9/19, soft tissue realignment: 3/25; Primary/recurrent = 0/56	2	MPFL reconstruction using adductor magnus tendon. Post-surgery: immobilized for 6 weeks. Locked at 10° flexion for first 2 weeks, 0-30° for next 2 weeks, and 0-60° for last 2 weeks. FWB allowed 4 weeks after surgery.	Soft tissue realignment: retinacular plasty (lateral release of capsule, medial capsular tightening), vastus medialis advancement, and Roux-Goldthwait procedure. Post-surgery: placed in plaster cast for 6 weeks.

Authors and year (country)	Design	Single/multicenter	Participants [per treatment group where applicable]; <sup>a</sup> age (years); sex (males/females); primary/recurrent dislocations	Treatment groups	Surgical intervention(s)		Non-surgical intervention(s)
Marsh et al <sup>34</sup> 2006 (Germany)	Case series	Single center	24 (34 knees) [Surg: 24 (34 knees), non-surg: 0]; Age = 14.2 (range 3-18); Sex = 10/14; Primary/recurrent = 0/24	1	Roux-Goldthwait procedure and lateral release. Post-surgery: immobilized for 4 weeks in a knee immobilizer then PWB for 2 more weeks. Unspecified physical therapy began between weeks 4-6. All participants completed 8-12 weeks of physical therapy.		N/A
Matsushita et al <sup>35</sup> 2019 (Japan)	Case series	Single center	20 [Surg: 20, non-surg: 0]; Age = 20 (7.5); Sex = 2/18; Primary/recurrent = 0/20	1	Pre-surgery: unspecified physical therapy. MPFL reconstruction with semitendinosus graft. 12 participants also underwent lateral release. Post-surgery: PWB in a knee brace. At day 3 post-surgery, electrical stimulation of the quadriceps was used. At 1 week, brace removed and participants started ROM exercise. At week 5 ergometer started. At week 8 half squatting started. Jogging and sport allowed at 3 and 6 months post-surgery respectively.		N/A
Mikashima et al <sup>38</sup> 2004 (Japan)	Cohort	NR	40 [Surg: 40 (Elmslie-Trillat: 20, Elmslie-Trillat and MPFL reconstruction: 20), non-surg: 0]; Age = Elmslie-Trillat: 26.4 (9.7), Elmslie-Trillat and MPFL reconstruction: 26 (10); Sex: Elmslie-Trillat: 5/15, Elmslie-Trillat and MPFL reconstruction: 6/14; Primary/recurrent = 0/40	2	Elmslie-Trillat procedure. Post-surgery: NR	Elmslie-Trillat procedure and MPFL reconstruction. Post-surgery: NR	N/A
Moström et al <sup>41</sup> 2014 (Sweden)	Cohort	Single center	72 [Surg: 7 (Surg during acute phase), non-surg: 44 (Non-surg at testing: 33, surg due to recurrence: 11)]; Age at injury = Surg during acute phase: 12.6 (2.3), non-surg at testing: 13.5 (1.3), surg due to recurrence: 13.3 (1.5); Sex = Surg: 3/4, non-surg: 19/25 (non-surg at testing: 17/16, surg due to recurrence: 2/9); Primary/recurrent = At enrolment: 51/0, at testing: 18/33 (Demographic data only available for 51 participants)	3	Surgery during acute phase involved refixation or removal of large osteochondral fragment ≥1cm and proximal realignment (vastus medialis advancement, medial reefing, lateral release if patellar tilt present). Skeletally immature participants underwent a Roux-Goldthwait procedure and those with quadriceps angle ≥20° underwent a Roux-Elmslie-Trillat procedure. Post-surgery: FWB in cast for 4 weeks then commenced physiotherapy. Allowed free active ROM, and returned to	Surgery due to recurrence: as per surgery during acute phase except removal/fixation of osteochondral fragment. Post-surgery: NR	Patella-stabilizing knee brace for 4 weeks then physiotherapy for 2 months with active ROM of the knee and a gradual return to sports.

Authors and year (country)	Design	Single/multicenter	Participants [per treatment group where applicable]; <sup>a</sup> age (years); sex (males/females); primary/recurrent dislocations	Treatment groups	Surgical intervention(s)	Non-surgical intervention(s)
Niedzielski et al <sup>42</sup> 2015 (Poland)	Case series	Single center	11 [Surg: 11, non-surg: 0]; Age = 13.8 (range 12-15); Sex = 4/7; Primary/recurrent = 0/11	1	sports following physiotherapy consultation. Vastus medialis advancement, lateral release, Roux-Goldthwait procedure, and Galeazzi semitendinosus tenodesis. Post-surgery: immobilized in a cylinder cast for 6 weeks then began unspecified strength and ROM exercises.	N/A
Oliva et al <sup>43</sup> 2009 (UC)	Case series	UC	25 [Surg: 25, non-surg: 0]; Age = 13.5±3.8; Sex = 18/7; Primary/recurrent = 0/25	1	Lateral release, vastus medialis advancement, and transfer of the medial third of the patella tendon to the upper tibia and medial collateral ligament. Post-surgery: PWB in a straight-knee splint for 2 weeks then progressed to FWB. At 6 weeks the splint was removed and participants commenced static cycling, progressively lowering the seat, and unspecified concentric thigh muscle and proprioception exercise. At 8 weeks commenced gentle jogging on a trampoline. At 12 weeks gradually returned to normal activities and commenced sport specific rehabilitation. Return to sport was planned at 6 months	N/A
Rauschning et al <sup>48</sup> 1983 (Sweden)	Case series	Single center	20 [Surg: 20, non-surg: 0]; Age = 29.5 (range 17-42); Sex = 2/18; Primary/recurrent = 0/20	1	Lateral release and anteromedialization of tibial tuberosity. Post-surgery: passive and active ROM exercises with leg elevated were commenced immediately. FWB with crutches commenced on day 2. No physiotherapy provided apart from pre-surgery instructions (NR). The screw from the tibial tuberosity anteromedialization was removed at 8 weeks as an outpatient procedure.	N/A
Ronga et al <sup>50</sup> 2009 (UC)	Case series	UC	28 [Surg: 28, non-surg: 0]; Age = 32.5±11.4; Sex = 21/7; Primary/recurrent = 0/28	1	MPFL reconstruction using gracilis or semitendinosus tendon. Post-surgery: PWB in a straight-knee splint for 2 weeks then progressed to FWB. At 6 weeks the splint was removed and participants commenced static cycling, progressively lowering the seat, and unspecified concentric thigh muscle and proprioception exercise. At 8 weeks commenced gentle jogging on a trampoline. At 12 weeks gradually returned to normal activities and commenced sport specific rehabilitation. Return to sport was planned at 6 months	N/A
Sakuraba et al <sup>51</sup> 1993 (Japan)	Cohort	NR	UC (60 knees) [Surg: UC (20 knees), non-surg: UC (40 knees: 20 healthy controls and 20 non-surgical participants)]; Age = 20; Sex = <sup>b</sup> 0/UC (40 knees); Primary/recurrent = <sup>b</sup> 0/UC (40 knees)	<sup>b</sup> 2	Anteromedialization of the tibial tuberosity using 'crosse hockey' technique. Post-surgery: NR	NR. It is unclear if this was the surgical participants before surgery or represents a separate cohort.

Authors and year (country)	Design	Single/multicenter	Participants [per treatment group where applicable]; <sup>a</sup> age (years); sex (males/females); primary/recurrent dislocations	Treatment groups	Surgical intervention(s)	Non-surgical intervention(s)
Shams et al <sup>54</sup> 2019 (USA)	Case-control	Single center	31 [Surg: 16, non-surg: 15 (healthy controls)]; <sup>b</sup> Age = 16.1 (2.74) at testing; <sup>b</sup> Sex = 6/10; Primary/recurrent = UC	<sup>b</sup> 1	MPFL reconstruction. Post-surgery: completed rehabilitation and cleared to return to sport (Participants were recruited from referrals from multiple clinicians therefore surgical procedures and rehabilitation unlikely standardized)	
Smith et al <sup>59</sup> (UK)	Case series	Single center	30 [Surg: 30, non-surg: 0]; Age = 23 (6.4); Sex = 16/14; Primary/recurrent = 0/30	1	MPFL reconstruction using a semitendinosus or gracilis graft. Post-surgery: initially provided with crutches but encouraged to progress off these as able. No restrictions on ROM or weightbearing. Advised to start unspecified ROM and strengthening exercises as soon as tolerable. Outpatient physiotherapy commenced in the first week and involved unspecified ROM and strengthening exercises.	
Smith et al <sup>57</sup> (UK)	Parallel RCT	Multicenter	50 [Surg: 0, non-surg: 50 (Vastus medialis: 25, General quads: 25)]; Age = Vastus medialis: 23.9 (7.5), General quads: 23 (6.9); Sex = Vastus medialis: 14/11, General quads: 14/11; Primary/recurrent = 50/0	2	N/A	Vastus medialis exercise: wall sit squeezing cushion in neutral rotation and isometric wall sit, single leg dips, and isometric knee extension at 40° in internal rotation. Median 3 (IQR 2-4) sessions lasting median 6 (IQR 4-6) weeks. General quads: isometric wall sit, straight leg raise, single leg dips, and isometric knee extension in neutral lower limb rotation. Median 4 (IQR 2-6) sessions lasting median 6 (IQR 5-7) weeks.  Both groups completed 7 reps, 3 times per day. Treatments commenced immediately after randomization and were progressed by physiotherapists. Participants also received standard treatment of immobilization in knee

Authors and year (country)	Design	Single/multicenter	Participants [per treatment group where applicable]; <sup>a</sup> age (years); sex (males/females); primary/recurrent dislocations	Treatment groups	Surgical intervention(s)	Non-surgical intervention(s)
Tompkins et al <sup>64</sup> 2014 (USA)	Cohort	Single center	20 (23 knees) [Surg: 20 (MPFL repair: 12 (14 knees), MPFL reconstruction: 8 (9 knees)), non-surg: 0]; Age = MPFL repair: 20.1, MPFL reconstruction: 19.8; Sex = MPFL repair: 3/9, MPFL reconstruction: 4/4; Primary/recurrent = 0/20	2	MPFL repair using suture anchors or imbrication without anchors to tighten the MPFL in those without tears but chronic stretching. 8 participants also underwent anteromedialization of the tibial tuberosity. Post-surgery: WBAT in brace locked in extension. First 6 weeks participants completed NWB ROM exercise then closed chain strengthening for the next 6 weeks. At 3 months commenced open chain strengthening. At 5-6 months returned to sport once they passed an unspecified functional assessment.	MPFL reconstruction: using hamstring graft. Post-surgery: as per MPFL repair group.
Watanabe et al <sup>66</sup> 2008 (Japan)	Cohort	Multicenter	40 (42 knees) [Surg: 40 (MPFL reconstruction: UC (29 knees), MPFL reconstruction and tibial tuberosity transfer: UC (13 knees)), non-surg: 0]; Age = MPFL reconstruction: 19 (range 11-36), MPFL reconstruction and tibial tuberosity transfer: 20 (range 14-32); Sex = MPFL reconstruction: UC (9/20 knees), MPFL reconstruction and tibial tuberosity transfer: UC (3/10 knees); Primary/recurrent = 0/40	2	MPFL reconstruction using semitendinosus or gracilis tendon graft. 6 knees also underwent a lateral retinacular release. Post-surgery: day 1 isometric quadriceps exercises and PWB as tolerated in a knee extension brace. ROM exercises and mobilizing with crutches from day 3. Participants discharged from	MPFL reconstruction as described in adjacent column and medialization of tibial tuberosity. 12 knees also underwent a lateral retinacular release. Post-surgery: as described in adjacent column but participants were required to use a brace or crutches until bony union.

Authors and year (country)	Design	Single/multicenter	Participants [per treatment group where applicable]; <sup>a</sup> age (years); sex (males/females); primary/recurrent dislocations	Treatment groups	Surgical intervention(s)	Non-surgical intervention(s)
					acute care when knee flexion was >90° and then followed up as an outpatient. Most participants could FWB at 2-4 weeks. Return to jogging was allowed at 3 months if sufficient ROM, muscle strength, and stability. Return to sports was at 6 months.	
Woods et al <sup>69</sup> 2006 (USA)	Case series	Single center	24 [Surg: 24, non-surg: 0]; Age = Aggregate age NR, females 20.7±6.6, males 26.2±14.6; Sex = 7/17; Primary/recurrent = 0/24	1	Isolated lateral release of vastus lateralis ensuring tendon retraction ≤2.5cm.  Post-surgery: WBAT using crutches. Participants attended up to 4 weeks of rehabilitation, usually this was ≤1 week. Rehabilitation involved quadriceps control during weightbearing, isometric quadriceps strengthening, and static cycling. Participants finished rehabilitation once they could cycle for 10 minutes consecutively. Participants were advised to continue cycling twice per day for 4 months, increasing to 30 minutes cycling as able.	N/A

Data are mean (SD) unless otherwise stated; <sup>a</sup>Age at time of injury for non-surgically treated participants and age at time of surgery for surgically treated participants unless otherwise stated; <sup>b</sup>Patellar dislocation participants only; <sup>c</sup>Non-surgical participants subsequently divided into 3 groups based on recovery; FWB, Full weightbearing; MPFL, Medial patellofemoral ligament; N/A, Not applicable; Non-surg, Non-surgical; NR, Not reported; NWB, Non-weightbearing; PWB, Partial weightbearing; RCT, Randomized controlled trial; ROM, Range of movement; Surg, Surgical; UC, Unclear; WBAT, Weightbearing as tolerated

### Appendix 3: strength assessment procedures of individual studies

Study	Strength assessment; contraction type; device	Joint motion assessed; <sup>a</sup> joint ROM (°)	Participant position	<sup>a</sup> Angular velocity (°/sec)/ <sup>b</sup> test joint position (°): no. of repetitions performed by participants	Reported outcome measure(s)	<sup>c</sup> Time of strength assessment
Asaeda et al <sup>4</sup>	Isometric; N/A; HHD	Knee ext; N/A	Seated, hands behind back, feet off the ground, HHD placed on distal tibia	NR: NR	<sup>d</sup> LSI	<sup>e</sup> Pre-surgery, 3, 6 & 12 months
Arrebola et al <sup>3</sup>	Isometric; N/A; HHD	Knee ext; N/A Hip flex, ext, abd, add, IR & ER; N/A	Knee ext: seated on edge of plinth, back supported, HHD attached to plinth leg, stabilizing belt around HHD and participant's distal tibia Hip flex: seated on edge of plinth, HHD at distal thigh, counter resistance applied by researcher Hip ext: prone, 90° knee flexion, HHD at distal thigh, counter resistance applied by researcher Hip abd: side-lying, test leg uppermost, knee extended, HHD proximal to ankle, counter resistance applied by researcher Hip add: side-lying, test leg bottommost, knee extended, HHD proximal to ankle, counter resistance applied by researcher Hip ER (0° hip flex): supine, knee of test leg flexed to 90° over edge of plinth, HHD proximal to medial malleolus, counter resistance applied by researcher Hip ER (90° hip flex): seated on edge of plinth, back unsupported, 90° knee flex, HHD proximal to medial malleolus, counter resistance applied by researcher Hip IR (0° hip flex): supine, knee of test leg flexed to 90° over edge of plinth, HHD proximal to lateral malleolus, counter resistance applied by researcher Hip IR (90° hip flex): seated on edge of plinth, back unsupported, 90° knee flex, HHD proximal to lateral malleolus, counter resistance applied by researcher	Knee ext 60: 3 Hip flex 90 (hip flex): 3 Hip ext 0 (hip flex): 3 Hip abd UC (abd): 3 Hip add 0 (abd): 3 Hip IR 0 & 90 (hip flex): 3 Hip ER 0 & 90 (hip flex): 3	Mean maximum force to body weight affected limb (all participants), mean maximum force to body weight affected and unaffected limb (participants with unilateral dislocations)	9.27 (4.16) weeks
Askenberger et al <sup>5</sup>	Isokinetic; conc; ID	Knee flex & ext; 10-90	NR	90: 5 240: 10	PT both limbs, LSI of PT	2 years post baseline
Atkin et al <sup>6</sup>	Isokinetic; NR; ID	Knee flex & ext; NR	NR	NR: NR	<sup>d</sup> LSI	12 & 24 weeks
Keilani et al <sup>21</sup>	Isokinetic; NR; ID	Knee flex & ext; NR	Participant seated and stabilized with straps at abdomen, shoulders and thigh. Axis of rotation of knee and dynamometer aligned.	60: 5	PT/BW of affected leg	MPFL reconstruction: 47 months; Elmslie-Trillat: 43 months

Study	Strength assessment; contraction type; device	Joint motion assessed; <sup>a</sup> joint ROM (°)	Participant position	<sup>a</sup> Angular velocity (°/sec)/ <sup>b</sup> test joint position (°): no. of repetitions performed by participants	Reported outcome measure(s)	<sup>c</sup> Time of strength assessment
Liebau et al <sup>23</sup>	Isokinetic; UC; ID	Knee ext; NR	UC	UC: UC	Deficit of torque of affected compared to unaffected limb	4.9 years
Lucas et al <sup>25</sup>	Isometric; N/A; HHD	Knee ext; N/A Hip abd & ER; N/A	Knee ext: seated, HHD at anterior tibia 5cm proximal to medial malleolus Hip abd: side lying, HHD 5cm proximal to knee joint line Hip ER: seated, HHD 5cm proximal to medial malleolus (HHD position maintained by a stabilization strap for all tests)	Knee ext NR: 3 Hip abd UC (abd): 3 Hip ER 90 (hip flex): 3	Average PT/BW of affected leg	NR (last patellar dislocation was >1 year ago)
Mäenpää et al <sup>27</sup>	Isokinetic; NR; ID	Knee flex & ext; 0-90	Stabilized with straps at the chest, pelvis, thigh, and malleoli. Axes of rotation of the dynamometer and knee aligned	60: 5 180: 5	LSI of PT	13 (5) years
Malecki et al <sup>30</sup>	Isokinetic; NR; ID	Knee flex & ext; NR	NR	60: NR 180: NR NR: NR	PT both limbs, LSI of PT	5.6 (range 3-15) years
Marsh et al <sup>34</sup>	Isokinetic; conc & ecc; ID	Knee ext; NR	NR	NR: NR	<sup>d</sup> LSI	6.2 (range 2-13) years
Matsushita et al <sup>35</sup>	Isometric; N/A; ID Isokinetic; NR; ID	Knee ext; NR	Isometric: NR Isokinetic: NR	Isometric 60: 5, 90: 5 Isokinetic 60: 5, 180: 5 NR: NR	Isometric & isokinetic: PT/BW of both limbs, post-operative improvement index of both limbs, <sup>d</sup> LSI	<sup>e</sup> Pre-surgery, 6 months, 1 & 2 years
Mikashima et al <sup>38</sup>	Isokinetic; NR; ID	Knee flex & ext; NR	NR	NR: NR	LSI of mean power	Elmslie-Trillat: 41 (8.7) months; MPFL reconstruction and Elmslie-Trillat: 31.7 (10.5) months
Moström et al <sup>41</sup>	Isokinetic; conc; ID	Knee flex & ext; 10-90	NR	90: 5	PT/BW knee flex & ext affected limb, H/Q ratio of PT affected limb, LSI of PT of knee ext	7.5 (1.6) years
Niedzielski et al <sup>42</sup>	Isokinetic; NR; ID	Knee flex & ext; NR	NR	60: 10 180: 10	Angle of PT, PT both limbs, LSI of PT	8.1 (range 5-15) years
Oliva et al <sup>43</sup>	Isokinetic; conc; ID	Knee ext; NR	NR	60: 5 120: 5	Average PT, total work output, average power of both limbs	3.8 (range 2.5-6) years



Study	Strength assessment; contraction type; device	Joint motion assessed; <sup>a</sup> joint ROM (°)	Participant position	<sup>a</sup> Angular velocity (°/sec)/ <sup>b</sup> test joint position (°): no. of repetitions performed by participants	Reported outcome measure(s)	<sup>c</sup> Time of strength assessment
Rauschning et al <sup>48</sup>	Isokinetic; NR; ID	Knee ext; 90-full ext	Fixed to a table with straps around the thighs and trunk	6: at least 3 12: at least 3 60: at least 3	PT of affected limb	<sup>e</sup> Pre-surgery, 19.8± <sup>f</sup> 6.4 months
Ronga et al <sup>50</sup>	Isokinetic; conc; ID	Knee ext; NR	NR	60: 5 120: 5	Average PT, total work output, average power of both limbs	3.1 (range 2.5-4) years
Sakuraba et al <sup>51</sup>	Isokinetic; conc & ecc; ID	Knee flex & ext; NR	NR	30: NR 90: NR	PT/BW affected limb	NR
Shams et al <sup>54</sup>	Isokinetic; knee: conc, hip: NR; ID	Knee flex & ext; 0-100 Hip abduction; 0-45	Knee: seated, trunk perpendicular to the floor, hip and knee flexed to 90° Hip: standing, trunk perpendicular to the floor, axes of rotation of hip and dynamometer aligned, used bilateral upper limb support	Knee 300: 10 Hip 120: 10	PT/BW both limbs	385 (189) days
Smith et al <sup>59</sup>	Isometric; N/A; HHD	Knee ext; N/A	Seated on edge of plinth, arms across body and feet off the ground. HHD held by researcher who applied counter resistance	0, 40, 80: One 5 second contraction	Maximum force of affected limb	Pre-surgery (inpatient admission), 6 weeks, 3 & 12 months
Smith et al <sup>57</sup>	Isometric; N/A; HHD	Knee ext; N/A	NR	0, 30, 60, 90: NR	Force of affected limb	Baseline, 6 weeks, 6 & 12 months
Tompkins et al <sup>64</sup>	Isometric; N/A; ID	Knee ext; N/A	Seated and secured with straps. Trunk, hip, and knee position standardized	30: one 10 second contraction 60: one 10 second contraction	Average torque to body weight both limbs	MPFL reconstruction: 29.2± <sup>f</sup> 15.9 months; MPFL repair: 43± <sup>f</sup> 19.9 months
Watanabe et al <sup>66</sup>	Isokinetic; NR; ID	Knee flex & ext; NR	NR	60: NR	<sup>d</sup> LSI	4.3 years (range 1.5-8.1)
Woods et al <sup>69</sup>	Isokinetic; NR; ID	Knee ext; NR	NR	90: 3	Mean PT of both limbs, LSI of mean PT	Pre-surgery (day of surgery), 27 (range 24-43) months

Numbers are mean (SD) unless otherwise stated; <sup>a</sup>Only applicable to isokinetic assessments; <sup>b</sup>Only applicable to isometric assessments and refers to knee flexion angle unless otherwise stated; <sup>c</sup>Duration post-surgery for surgical interventions and post injury for non-surgical interventions unless otherwise stated, aggregate time points are used where available; <sup>d</sup>Strength outcome measure used for LSI calculation not reported; <sup>e</sup>Duration pre-surgery not reported; <sup>f</sup>Measure of dispersion unclear; (°/sec), degree per second; Abd, Abduction; Add, Adduction; Conc, Concentric; Ecc, Eccentric; ER, External rotation; Ext, Extension; Flex, Flexion; HHD, Hand-held dynamometer; H/Q, Hamstrings to quadriceps; ID, Isokinetic dynamometer; IR, Internal rotation; LSI, Limb symmetry index; MPFL, Medial patellofemoral ligament; N/A, Not applicable; NR, Not reported; PT, Peak torque; PT/BW, Peak torque to body weight; ROM, Range of movement; UC, Unclear

## Appendix 4: appraisal of individual domains of version 2 of the Cochrane risk-of-bias tool and Newcastle Ottawa Scale

Version 2 of the Cochrane risk-of-bias tool for randomized controlled trials						
Study	Overall risk of bias	Bias arising from the randomization process	Bias due to deviations from intended interventions	Bias due to missing outcome data	Bias in measurement of the outcome	Bias in selection of the reported result
Askenberger et al <sup>5</sup>	High	High	High	High	High	Some concerns
Smith et al <sup>57</sup>	High	Low	Low	Some concerns	Low	Some concerns

Amended Newcastle-Ottawa Scale scores for observational studies									
Study	Representativeness of the exposed cohort	<sup>a</sup> Selection of the non-exposed cohort	Ascertainment of exposure	<sup>a</sup> Study controls for age	<sup>a</sup> Study controls for sex	Assessment of outcome	Was follow-up long enough for outcomes to occur	Adequacy of follow-up of cohorts	Number of stars (Cohorts maximum of 8, case series maximum of 5)
<b>Case series</b>									
Asaeda et al <sup>4</sup>	✓	-	✓	-	-	✓	✓	x	4
Atkin et al <sup>6</sup>	✓	-	✓	-	-	✓	✓	✓	5
Liebau et al <sup>23</sup>	x	-	✓	-	-	✓	✓	✓	4
Marsh et al <sup>34</sup>	✓	-	✓	-	-	✓	✓	x	4
Matsushita et al <sup>35</sup>	✓	-	✓	-	-	✓	✓	✓	5
Niedzielski et al <sup>42</sup>	✓	-	✓	-	-	✓	✓	✓	5
Oliva et al <sup>43</sup>	✓	-	✓	-	-	✓	✓	✓	5
Rauschning et al <sup>48</sup>	✓	-	✓	-	-	✓	✓	x	4
Ronga et al <sup>50</sup>	✓	-	✓	-	-	✓	✓	✓	5
Smith et al <sup>59</sup>	✓	-	✓	-	-	✓	✓	x	4
Woods et al <sup>69</sup>	✓	-	✓	-	-	✓	✓	✓	5
<b>Cohort studies</b>									
Keilani et al <sup>21</sup>	✓	✓	✓	x	✓	✓	✓	✓	7
Mäenpää et al <sup>27</sup>	✓	x	✓	x	x	✓	✓	x	4
Malecki et al <sup>30</sup>	✓	x	✓	x	x	✓	✓	x	4
Mikashima et al <sup>38</sup>	✓	x	✓	x	x	✓	✓	x	4
Moström et al <sup>41</sup>	✓	✓	✓	x	x	✓	✓	x	5
Sakuraba et al <sup>51</sup>	x	x	x	x	✓	✓	x	x	2
Tompkins et al <sup>64</sup>	✓	✓	✓	x	x	✓	✓	x	5
Watanabe et al <sup>66</sup>	✓	✓	✓	x	x	✓	✓	✓	6

Number of stars (Case-controls maximum of 8)	Non-response rate	Ascertainment of exposure	Comparability of cases and controls (age)	Comparability of cases and controls (sex)	Definition of controls	Selection of controls	Representativeness of the cases	Is the case definition adequate?
<b><u>Case-control studies</u></b>								
5	✓	✓	✓	✓	x	x	x	✓
6	✓	✓	✓	✓	✓	x	x	✓
7	✓	✓	✓	✓	✓	✓	x	✓

<sup>a</sup>Not applicable for case series

## Appendix 5: reported lower limb strength outcomes of individual studies

Study	Strength outcome (measurement unit); assessment method	Joint action; <sup>a</sup> angular velocity (°/sec)/ <sup>b</sup> joint position (°)	Injured	Uninjured	LSI % (SD)	Joint action; <sup>a</sup> angular velocity (°/sec)/ <sup>b</sup> joint position (°)	Injured	Uninjured	LSI % (SD)
		<b>Surgical intervention(s)</b>				<b>Non-surgical intervention(s)</b>			
<sup>c</sup> Asaeda et al <sup>4</sup>	<sup>d</sup> LSI; isometric	<b>3 months</b> Knee ext; NR	NR	NR	59.8 (39.5)	N/A	N/A	N/A	N/A
		<b>6 months</b> Knee ext; NR	NR	NR	67.9 (23.5)	N/A	N/A	N/A	N/A
		<b>12 months</b> Knee ext; NR	NR	NR	52.1 (24.3)	N/A	N/A	N/A	N/A
Arrebola et al <sup>3</sup>	Mean maximum force to body weight x 100 (kgf/kg); isometric	N/A	N/A	N/A	N/A	<b>9.27 (4.16) weeks (all participants n = 44)</b>			
		N/A	N/A	N/A	N/A	Knee ext; 60	40.44 (12.33)	N/A	N/A
		N/A	N/A	N/A	N/A	Hip flex; 90	30.82 (7.76)	N/A	N/A
		N/A	N/A	N/A	N/A	Hip ext; 0	27.14 (7.85)	N/A	N/A
		N/A	N/A	N/A	N/A	Hip abd; UC	17.53 (4.04)	N/A	N/A
		N/A	N/A	N/A	N/A	Hip add; 0	15.46 (4.77)	N/A	N/A
		N/A	N/A	N/A	N/A	Hip ER; 0 hip flex	12.51 (3.55)	N/A	N/A
		N/A	N/A	N/A	N/A	Hip ER; 90 hip flex	14.09 (3.76)	N/A	N/A
		N/A	N/A	N/A	N/A	Hip IR; 0 hip flex	11.48 (3.5)	N/A	N/A
		N/A	N/A	N/A	N/A	Hip IR; 90 hip flex	17.11 (5.68)	N/A	N/A
		N/A	N/A	N/A	N/A	<b>Unilateral dislocators (n = 27)</b>			
		N/A	N/A	N/A	N/A	Knee ext; 60	40.14 (12.99)	47.12 (12.88)	85.2
		N/A	N/A	N/A	N/A	Hip flex; 90	31.3 (8.26)	32.17 (9.12)	97.3
		N/A	N/A	N/A	N/A	Hip ext; 0	28.18 (7.41)	28.04 (8.13)	100
		N/A	N/A	N/A	N/A	Hip abd; UC	17.71 (3.81)	17.74 (4.35)	99.8
		N/A	N/A	N/A	N/A	Hip add; 0	16.48 (4.6)	17.06 (4.64)	96.6
		N/A	N/A	N/A	N/A	Hip ER; 0 hip flex	12.26 (3.45)	12.61 (4.22)	97.2
		N/A	N/A	N/A	N/A	Hip ER; 90 hip flex	14.15 (3.38)	15.16 (3.51)	93.3
		N/A	N/A	N/A	N/A	Hip IR; 0 hip flex	10.73 (2.64)	10.94 (3.04)	98.1
		N/A	N/A	N/A	N/A	Hip IR; 90 hip flex	16.41 (4.96)	16.69 (5.29)	98.3

	Strength outcome (measurement unit); assessment method	Joint action; <sup>a</sup> angular velocity (°/sec)/ <sup>b</sup> joint position (°)				Joint action; <sup>a</sup> angular velocity (°/sec)/ <sup>b</sup> joint position (°)				
Study			Injured	Uninjured	LSI % (SD)		Injured	Uninjured	LSI % (SD)	
		Surgical intervention(s)				Non-surgical intervention(s)				
Askenberg et al <sup>5</sup>	PT (Nm) & LSI of PT; isokinetic	2 years				2 years				
		Knee ext; 90	107 (92-149)	137 (121-171)	83 (72-95)	Knee ext; 90	118 (105-158)	132 (113-178)	93 (84-97)	
		Knee ext; 240	81 (69-107)	99 (81-116)	91 (77-97)	Knee ext; 240	86(71-110)	92 (82-126)	95 (86-100)	
		Knee flex; 90	65 (49-78)	68 (58-86)	95 (85-103)	Knee flex; 90	59 (53-97)	68 (56-96)	98 (85-112)	
		Knee flex; 240	50 (39-61)	53 (44-60)	96 (89-104)	Knee flex; 240	50 (39-61)	52 (41-73)	97 (90-111)	
Atkin et al <sup>6</sup>	<sup>d</sup> LSI; isokinetic	12 weeks				12 weeks				
		N/A	N/A	N/A	N/A	Knee ext; NR	NR	NR	79 (range 20-108)	
		N/A	N/A	N/A	N/A	Knee flex; NR	NR	NR	85 (4-111)	
		N/A	N/A	N/A	N/A	24 weeks				
		N/A	N/A	N/A	N/A	Knee ext; NR	NR	NR	92 (39-118)	
Keilani et al <sup>21</sup>	PT/BW (Nm/kg); isokinetic	MPFL recon: 47 months; Elmslie-Trillat: 43 months								
		Knee ext; 60	MPFL recon: median 205 (range 179-275) Elmslie-Trillat: median 210 (range 195-297)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Knee flex; 60	NR	N/A	N/A	N/A	N/A	N/A	N/A	
Liebau et al <sup>23</sup>	<sup>e</sup> Torque (Nm); isokinetic	4.9 years								
		Knee ext; UC	N/A	N/	Deficit of 19 Nm	N/A	N/A	N/A	N/A	
Lucas et al <sup>25</sup>	Average PT/BW (Nm/kg); isometric	NR (last patellar dislocation was > 1 year ago)				NR (last patellar dislocation was > 1 year ago)				
		N/A	N/A	N/A	N/A	Knee ext; NR	14.5 (4.1)	N/A	N/A	
		N/A	N/A	N/A	N/A	Hip abd; UC	12.1 (2)	N/A	N/A	
Mäenpää et al <sup>27</sup>	LSI of PT (Nm); isokinetic	N/A	N/A	N/A	N/A	Hip ER; UC	5.5 (1.9)	N/A	N/A	
		N/A	N/A	N/A	N/A	13 (5) years				
		N/A	N/A	N/A	N/A	Knee ext; 60	NR	NR	A: 91 (11) B: 88 (8) C: 78 (12)	
		N/A	N/A	N/A	N/A	Knee ext; 180	NR	NR	A: 97 (15) B: 95 (10) C: 90 (10)	

Study	Strength outcome (measurement unit); assessment method	Joint action; <sup>a</sup> angular velocity (°/sec) <sup>b</sup> joint position (°)	Surgical intervention(s)			Non-surgical intervention(s)			
			Injured	Uninjured	LSI % (SD)	Injured	Uninjured	LSI % (SD)	
		N/A	N/A	N/A	N/A	Knee flex; 60	NR	NR	A: 96 (18) B: 95 (13) C: 94 (11)
		N/A	N/A	N/A	N/A	Knee flex; 180	NR	NR	A: 99 (11) B: 97 (3) C: 96 (18)
Malecki et al <sup>30</sup>	PT (Nm) & LSI of PT; isokinetic	5.6 (range 3-15) years							
		Knee ext; 60	D: 99 (36.1) E: 81 (35.6)	D: 117.3 (43.6) E: 89.9 (35.3)	D: 81.3 (11.5) E: 88.2 (27.4)	N/A	N/A	N/A	N/A
		Knee ext; 180	D: 69.5 (27.3) E: 54.6 (23.3)	D: 76.8 (26.9) E: 60.1 (23.8)	D: 87.1 (12.8) E: 91.5 (30)	N/A	N/A	N/A	N/A
		Knee flex; 60	D: 52.9 (23.3) E: 41.3 (16.8)	D: 54.5 (20.6) E: 42.9 (14.9)	D: 97.8 (14.3) E: 96 (29.2)	N/A	N/A	N/A	N/A
		Knee flex; 180	D: 40.9 (14.1) E: 27.5 (12.5)	D: 40 (15.9) E: 28.6 (10.3)	D: 104.6 (16) E: 100.3 (49.3)	N/A	N/A	N/A	N/A
Marsh et al <sup>34</sup>	<sup>e</sup> Strength (N) & <sup>d</sup> LSI; isokinetic	6.2 (range 2-13) years							
		Knee ext; con; NR	303	319	95	N/A	N/A	N/A	N/A
		Knee ext; ecc; NR	320	400	80	N/A	N/A	N/A	N/A
Matsushita et al <sup>35</sup>	PT/BW (Nm/kg), post-operative improvement index of both limbs, <sup>d</sup> LSI; isometric & isokinetic	6 months							
		Knee ext; 60 (isometric)	1.29 (0.6)	2.1 (0.77)	61.4	N/A	N/A	N/A	N/A
		Knee ext; 90 (isometric)	1.1 (0.57)	2.01 (0.66)	54.7	N/A	N/A	N/A	N/A
		Knee ext; 60 (isokinetic)	0.97 (0.55)	1.78 (0.6)	54.5	N/A	N/A	N/A	N/A
		Knee ext; 180 (isokinetic)	0.73 (0.43)	1.22 (0.73)	59.8	N/A	N/A	N/A	N/A
		1 year							
		Knee ext; 60 (isometric)	1.54 (0.56)	2.13 (0.53)	72.3	N/A	N/A	N/A	N/A
		Knee ext; 90 (isometric)	1.32 (0.57)	2 (0.6)	66	N/A	N/A	N/A	N/A
		Knee ext; 60 (isokinetic)	1.26 (0.42)	1.82 (0.4)	69.2	N/A	N/A	N/A	N/A
		Knee ext; 180 (isokinetic)	0.98 (0.33)	1.2 (0.4)	81.7	N/A	N/A	N/A	N/A

Study	Strength outcome (measurement unit); assessment method	Joint action; <sup>a</sup> angular velocity (°/sec)/ <sup>b</sup> joint position (°)	Injured	Uninjured	LSI % (SD)	Joint action; <sup>a</sup> angular velocity (°/sec)/ <sup>b</sup> joint position (°)	Injured	Uninjured	LSI % (SD)
		<b>Surgical intervention(s)</b>				<b>Non-surgical intervention(s)</b>			
		<b>2 years</b>							
		Knee ext; 60 (isometric)	1.78 (0.65)	2.14 (0.71)	83.2	N/A	N/A	N/A	N/A
		Knee ext; 90 (isometric)	1.59 (0.56)	1.9 (0.54)	83.7	N/A	N/A	N/A	N/A
		Knee ext; 60 (isokinetic)	1.39 (0.46)	1.77 (0.6)	78.5	N/A	N/A	N/A	N/A
		Knee ext; 180 (isokinetic)	0.97 (0.37)	1.19 (0.39)	81.51	N/A	N/A	N/A	N/A
Mikashima et al <sup>38</sup>	LSI of mean power; isokinetic	<b>F: 41 (8.7) months; G: 31.7 (10.5) months</b>							
		Knee ext; NR	NR	NR	F: 66.8 (7.2) G: 75.3 (23.3)	N/A	N/A	N/A	N/A
		Knee flex; NR	NR	NR	F: 81.7 (13.8) G: 73.3 (26.7)	N/A	N/A	N/A	N/A
Moström et al <sup>41</sup>	<sup>f</sup> PT/BW knee ext & flex (Nm/kg), LSI of PT of knee ext; isokinetic	<b>7 (1.4) years</b>				<b>H: 7.7 (1.5) years; I: 7.3 (1.5) years</b>			
		Knee ext; 90	195.6 (57.4) Males: 242 (50) Females: 88 (20)	NR	89 (15)	Knee ext; 90	H: 187.2 (59.5) Males: 220 (43) Females: 152 (56) I: 157.9 (63.2) Males: 231 (30) Females: 142 (57)	NR	H: 86 (17) I: 81 (32)
		Knee flex; 90	103.6 (31.7) Males: 124 (36) Females: 88 (20)	NR	NR	Knee flex; 90	H: 106 (34.4) Males: 128 (26) Females: 83 (27) I: 113.8 (57.6) Males: 208 (77) Females: 93 (26)	NR	NR
Niedzielski et al <sup>42</sup>	PT (Nm); isokinetic	<b>8.1 (range 5-15) years</b>							
		Knee ext; 60	68.2 (40.2)	86.2 (49.1)	79.1	N/A	N/A	N/A	N/A
		Knee ext; 180	47 (23.1)	58.5 (29)	80.3	N/A	N/A	N/A	N/A
		Knee flex; 60	41.9 (18.4)	39.6 (22.4)	105.8	N/A	N/A	N/A	N/A
		Knee flex; 180	29.6 (16.2)	29.4 (13.2)	100.7	N/A	N/A	N/A	N/A
Oliva et al <sup>43</sup>	Average PT	<b>3.8 (range 2.5-6) years</b>							

Study	Strength outcome (measurement unit); assessment method	Joint action; <sup>a</sup> angular velocity (°/sec)/ <sup>b</sup> joint position (°)	Injured	Uninjured	LSI % (SD)	Joint action; <sup>a</sup> angular velocity (°/sec)/ <sup>b</sup> joint position (°)	Injured	Uninjured	LSI % (SD)
		<b>Surgical intervention(s)</b>				<b>Non-surgical intervention(s)</b>			
	(Nm), total work output (J), & average power (W); isokinetic	Knee ext; 60	Average PT: 94±31; total work output: 103±16; average power: 82±13	Average PT: 114±37; total work output: 105±14; average power: 108±10	Average PT: 82.5; total work output: 98.1; average power: 75.9	N/A	N/A	N/A	N/A
		Knee ext; 120	Average PT: 88±32; total work output: 86±13; average power: 108±45	Average PT: 96±42; total work output: 98±14; average power: 136±32	Average PT: 91.7; total work output: 87.8; average power: 79.4	N/A	N/A	N/A	N/A
<sup>c</sup> Rauschnig et al <sup>48</sup>	PT (Nm); isokinetic	<b>19.8 (6.4) months</b>				<b>Pre-surgery (duration pre-surgery NR)</b>			
		Knee ext; 6	Males: 212.5 Females: 130.3 (43.9)	NR	NR	Knee ext; 6	Males: 171.7 Females: 125.5 (48.5)	NR	NR
		Knee ext; 12	<sup>g</sup> 128 (45.52) Males: 205.5 Females: 131.7 (46.3)	NR	NR	Knee ext; 12	<sup>g</sup> 111.85 (48.11) Males: 162.0 Females: 117.8 (48.8)	NR	NR
		Knee ext; 60	Males: 161.2 Females: 107.9 (34.6)	NR	NR	Knee ext; 60	Males: 115.3 Females: 93.8 (30.9)	NR	NR
Ronga et al <sup>50</sup>	Average PT (Nm), total work output (J), & average power (W); isokinetic	<b>3.1 (range 2.5-4) years</b>							
		Knee ext; 60	Average PT: 118.3±47.8; total work output: 123.4± 45.3; average power: 94.7±19.3	Average PT: 178.5±37.3; total work output: 164.3±29.5; average power: 118.1±10.8	Average PT: 66.1; total work output: 75.1; average power: 80.2	N/A	N/A	N/A	N/A
		Knee ext; 120	Average PT: 94±49.7; total work output: 110±41.3; average power: 124.8±42.1	Average PT: 150±31; total work output: 150.6±33.2; average power: 166.4±39.2	Average PT: 62.7; total work output: 73; average power: 75	N/A	N/A	N/A	N/A
Sakuraba et al <sup>51</sup>	PT/BW (Nm/kg) x 100; isokinetic	<b>NR</b>				<b>NR</b>			
		Knee ext; conc; 30	169 (52)	NR	NR	Knee ext; conc; 30	96 (34)	NR	NR



Study	Strength outcome (measurement unit); assessment method	Joint action; <sup>a</sup> angular velocity (°/sec)/ <sup>b</sup> joint position (°)	Injured	Uninjured	LSI % (SD)	Joint action; <sup>a</sup> angular velocity (°/sec)/ <sup>b</sup> joint position (°)	Injured	Uninjured	LSI % (SD)
		<b>Surgical intervention(s)</b>				<b>Non-surgical intervention(s)</b>			
		Knee ext; ecc; 30	218 (59)	NR	NR	Knee ext; ecc; 30	146 (48)	NR	NR
		<sup>g</sup> Knee ext; conc; 90	130.4 (44.7)	NR	NR	<sup>g</sup> Knee ext; conc; 90	74.3 (29.3)	NR	NR
		<sup>g</sup> Knee ext; ecc; 90	239.4 (69.2)	NR	NR	<sup>g</sup> Knee ext; ecc; 90	165.8 (49.8)	NR	NR
		<sup>g</sup> Knee flex; conc; 30	97.4 (36.6)	NR	NR	<sup>g</sup> Knee flex; conc; 30	65.6 (17.4)	NR	NR
		<sup>g</sup> Knee flex; ecc; 30	137.6 (49.4)	NR	NR	<sup>g</sup> Knee flex; ecc; 30	99.7 (30.6)	NR	NR
		<sup>g</sup> Knee flex; conc; 90	78.8 (33.8)	NR	NR	<sup>g</sup> Knee flex; conc; 90	56.7 (21.1)	NR	NR
		<sup>g</sup> Knee flex; ecc; 90	139.1 (50)	NR	NR	<sup>g</sup> Knee flex; ecc; 90	113.5 (34.1)	NR	NR
Shams et al <sup>54</sup>	PT/BW (Nm/kg); isokinetic	<b>385 (189) days after surgery/235 (157) days after return to sport</b>							
		Hip abd; 120	0.79 (0.3)	0.69 (0.28)	116.2	N/A	N/A	N/A	N/A
		Knee ext; 300	0.76 (0.3)	0.86 (0.25)	88.4	N/A	N/A	N/A	N/A
		Knee flex; 300	0.49 (0.17)	0.54 (0.19)	90.7	N/A	N/A	N/A	N/A
Smith et al <sup>59</sup>	Maximum force (N); isometric	<b>6 weeks post-surgery</b>				<b>Inpatient admission pre-surgery</b>			
		Knee ext; 0	30.1 (14.4)	NR	NR	Knee ext; 0	32.1 (14.6)	NR	NR
		Knee ext; 40	50.3 (28.7)	NR	NR	Knee ext; 40	44.5 (28.6)	NR	NR
		Knee ext; 80	69.1 (33.3)	NR	NR	Knee ext; 80	60.1 (47.0)	NR	NR
		<b>3 months</b>				<b>N/A</b>			
		Knee ext; 0	44.2 (20.6)	NR	NR	N/A	N/A	N/A	N/A
		Knee ext; 40	63.2 (41.4)	NR	NR	N/A	N/A	N/A	N/A
		Knee ext; 80	88.3 (48.7)	NR	NR	N/A	N/A	N/A	N/A
		<b>12 months</b>				<b>N/A</b>			
		Knee ext; 0	57.9 (24.6)	NR	NR	N/A	N/A	N/A	N/A
		Knee ext; 40	85.2 (38.8)	NR	NR	N/A	N/A	N/A	N/A
		Knee ext; 80	101.0 (49.4)	NR	NR	N/A	N/A	N/A	N/A
Smith et al <sup>57</sup>	Force (N); isometric	N/A	N/A	N/A	N/A	<b>Baseline</b>			
		N/A	N/A	N/A	N/A	Knee ext; 0	GQ: 33.4 (43.8) VM: 35.8 (38.9)	NR	NR
		N/A	N/A	N/A	N/A	Knee ext; 30	GQ: 89.9 (50.5)	NR	NR

Study	Strength outcome (measurement unit); assessment method	Joint action; <sup>a</sup> angular velocity ( $^{\circ}$ /sec)/ <sup>b</sup> joint position ( $^{\circ}$ )	Surgical intervention(s)			Joint action; <sup>a</sup> angular velocity ( $^{\circ}$ /sec)/ <sup>b</sup> joint position ( $^{\circ}$ )	Non-surgical intervention(s)		
			Injured	Uninjured	LSI % (SD)		Injured	Uninjured	LSI % (SD)
		N/A	N/A	N/A	N/A	Knee ext; 60	VM: 85.9 (58.8) GQ: 116.2 (65.4)	NR	NR
		N/A	N/A	N/A	N/A	Knee ext; 90	VM: 97.9 (48.5) GQ: 118.3 (89.2) VM: 100.4 (64.9)	NR	NR
		N/A	N/A	N/A	N/A	<b>6 weeks</b> Knee ext; 0	GQ: 83.9 (38.4) VM: 93.5 (47.1)	NR	NR
		N/A	N/A	N/A	N/A	Knee ext; 30	GQ: 164.7 (70.2) VM: 167.1 (66.5)	NR	NR
		N/A	N/A	N/A	N/A	Knee ext; 60	GQ: 180.3 (74.1) VM: 172 (56.1)	NR	NR
		N/A	N/A	N/A	N/A	Knee ext; 90	GQ: 181.6 (75) VM: 177.6 (63.8)	NR	NR
		N/A	N/A	N/A	N/A	<b>6 months</b> Knee ext; 0	GQ: Median 94.4 (IQR 81.3-143.2); VM: median 110.9 (IQR 50.6-159.2)	NR	NR
		N/A	N/A	N/A	N/A	Knee ext; 30	GQ: median 170.5 (IQR 136.2-196.4); VM: median 177 (IQR 124.2-202.4)	NR	NR
		N/A	N/A	N/A	N/A	Knee ext; 60	GQ: median 204.5 (IQR 136.3-253); VM: median 216.9 (IQR 148.9-236.6)	NR	NR
		N/A	N/A	N/A	N/A	Knee ext; 90	GQ: median 245 (IQR 134.3-267.4); VM: median 189.8 (IQR 148.5-	NR	NR

Study	Strength outcome (measurement unit); assessment method	Joint action; <sup>a</sup> angular velocity ( $^{\circ}$ /sec)/ <sup>b</sup> joint position ( $^{\circ}$ )				Joint action; <sup>a</sup> angular velocity ( $^{\circ}$ /sec)/ <sup>b</sup> joint position ( $^{\circ}$ )			
		Injured	Uninjured	LSI % (SD)		Injured	Uninjured	LSI % (SD)	
		Surgical intervention(s)				Non-surgical intervention(s)			
						237.7)			
						<b>12 months</b>			
		N/A	N/A	N/A	N/A	Knee ext; 0	GQ: median 102.5 (IQR 83.6-136.5); VM: median 91.5 (IQR 75-126.5)	NR	NR
		N/A	N/A	N/A	N/A	Knee ext; 30	GQ: median 186.6 (IQR 146.1-250.5); VM: median 190.4 (IQR 178.2-236.1)	NR	NR
		N/A	N/A	N/A	N/A	Knee ext; 60	GQ: median 102.5 (IQR 83.6-136.5); VM: median 230.4 (IQR 158.8-267.1)	NR	NR
		N/A	N/A	N/A	N/A	Knee ext; 90	GQ: median 258.4 (IQR 172.2-286.6); VM: median 247.9 (IQR 178.8-281.1)	NR	NR
Tompkins et al <sup>64</sup>	Average torque to body weight (Nm/kg); isometric	<b>MPFL repair: 43±19.9months; MPFL recon: 29.2±15.9 months</b>							
		Knee ext; 30	MPFL repair: 1.09; MPFL recon: 1.07	MPFL repair: 1.18; MPFL recon: 1.16	MPFL repair: 92.4; MPFL recon: 92.2	N/A	N/A	N/A	N/A
		knee ext; 60	MPFL repair: 1.81; MPFL recon: 1.82	MPFL repair: 2.17; MPFL recon: 1.91	MPFL repair: 83.4; MPFL recon: 95.3	N/A	N/A	N/A	N/A
Watanabe et al <sup>66</sup>	<sup>d</sup> LSI; isokinetic	<b>4.3 (range1.5-8.1) years</b>							
		Knee ext; 60	N/A	N/A	MPFL recon: 86 MPFL recon and TTT: 87	N/A	N/A	N/A	N/A

Study	Strength outcome (measurement unit); assessment method	Joint action; <sup>a</sup> angular velocity (°/sec)/ <sup>b</sup> joint position (°)				Joint action; <sup>a</sup> angular velocity (°/sec)/ <sup>b</sup> joint position (°)			
			Injured	Uninjured	LSI % (SD)		Injured	Uninjured	LSI % (SD)
		<b>Surgical intervention(s)</b>				<b>Non-surgical intervention(s)</b>			
		Knee flex; 60	N/A	N/A	MPFL recon: 93 MPFL recon and TTT: 86	N/A	N/A	N/A	N/A
Woods et al <sup>69</sup>	Mean PT (Nm) & LSI of mean PT; Isokinetic	<b>27 (range 24-43) months post op</b> Knee ext; 90	41.5±12.9	52±13.5	79.8 (range 50-100)	<b>Pre-surgery (day of surgery)</b> Knee ext; 90	32.3±13.9	51.3±12.8	63 (range 50-100)

Values are mean (SD) unless otherwise stated; <sup>a</sup>Applies to isokinetic assessments; <sup>b</sup>Applies to isometric assessments; <sup>c</sup>Participants assessed pre-surgery were not included in the non-surgical column as some participants had previous surgery or it was unclear if participants had previous surgery; <sup>d</sup>Strength measure used for limb symmetry index calculation not reported; <sup>e</sup>Whether this is peak or mean torque/force is not reported; <sup>f</sup>Measurement unit not reported; <sup>g</sup>Obtained from graph using WebPlotDigitizer software; A, Non-surgical treatment no recurrence group; B, Surgical and non-surgical treatment for recurrent dislocation after initial non-surgical treatment group; C, Surgery for anterior knee pain after initial non-surgical treatment group; D, MPFL reconstruction group; E, Soft tissue realignment group; F, Elmslie-Trillat distal realignment group; G, MPFL reconstruction and Elmslie-Trillat distal realignment group; H, Non-surgical treatment group; I, Initial non-surgical treatment then subsequent surgery due to recurrence group; °/sec, Degrees per second; Abd, Abduction; Add, Adduction; Conc, Concentric; Ecc, Eccentric; ER, External rotation; Ext, Extension; Flex, Flexion; GQ, General quads treatment group; IQR, Interquartile range; IR, internal rotation J, Joule; kg, Kilogram; kgf, Kilograms of force; LSI, Limb symmetry index; MPFL; Medial patellofemoral ligament; N/A; Not applicable; N, Newton; Nm, Newton meter; Nm/kg, Newton meter per kilogram; NR, Not reported; PT, Peak torque; PT/BW, Peak torque to body weight; UC, Unclear; TTT, Tibial tuberosity transfer; Recon; Reconstruction; VM, Vastus medialis treatment group; W, Watt;