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Review Article

Prevalence of patellofemoral joint osteoarthritis after anterior cruciate ligament injury and associated risk factors: A systematic review

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A R T I C L E I N F O

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A B S T R A C T

Background: The prevalence of patellofemoral joint (PFJ) osteoarthritis (OA) after anterior cruciate ligament (ACL) injury was inconsistently reported in the literature. This review summarises the reported prevalence of PFJ OA and risk factors of PFJ OA after ACL injury.

Methods: PubMed, Embase, WoS, and MEDLINE (OVID) were searched up to 1 March 2019. A modified version of the Coleman methodology score was used to assess the methodological quality of the included studies. Prevalence of PFJ OA was pooled depended on different interventions in ACL injured populations.

Results: Thirty-eight studies were included. Five different radiographic classification methods were used: the Kellgren and Lawrence Grade 2, IKDC Grade B, Fairbank Grade 1, joint space narrowing of Grade 2 based on OARSI, and Ahlbäck Grade 1. One included study used MRI Osteoarthritis Knee Score to evaluate PFJ degenerative changes. The overall prevalence of PFJ OA after ACL injury in included studies varied between 4.5% and 80%. The large variation of PFJ OA prevalence is mainly because of different follow-up period and surgical techniques. The pooled data showed that bone-patellar tendon-bone graft, single-bundle ACL reconstruction (ACLR), and delayed ACLR are likely associated with PFJ degenerative changes after ACL injury. ACLR, delayed ACLR, body mass index (BMI), meniscectomy, patellofemoral chondral lesions, age at surgery, and TFJ OA were identified in the literature inducing PFJ OA after ACL injury.

Conclusions: Large variations of PFJ OA after ACL injury are associated with different follow-up period and surgical techniques. ACL reconstructed population with bone-patellar tendon-bone graft, single-bundle reconstruction, and delayed operation time has a high prevalence of PFJ OA.

The translational potential of this article: This review focuses more on the effect of surgical technique factors on the degenerative changes on PFJ. The results reveal that BPTB, single-bundle reconstruction, and delayed ACLR are more likely associated with PFJ degenerative changes after ACL injury. These findings imply that awareness of PFJ problems after surgical intervention will remind of surgeons taking PFJ into consideration in operations, which is likely to reduce the incidences of anterior knee pain, patellar maltracking, and over-constrained patella in the early stage after surgery.

Introduction

Patellofemoral joint (PFJ) osteoarthritis (OA) is identified on radiographs as osteophytes and loss of articular cartilage on patella or in the femoral trochlear groove [1]. PFJ OA is an important source of knee symptom after ACL injury. Symptoms of anterior knee pain, swelling, and functional limitations such as difficult to go up and down stairs, squatting or rising from a seated position are disabilities found in patients with PFJ OA [2,3]. In recent years, many papers reported that the prevalence of PFJ OA after ACL injury is increased, regardless of whether ACL reconstruction (ACLR) is performed [4,5]. This early onset of OA and its associated pain and functional limitations pose a particular challenge to younger adults when compared with an older OA population. Lee et al. reported that 17.4% of patients had newly developed PFJ OA after ACLR

Abbreviations: PFJ, Patellofemoral Joint; OA, Osteoarthritis; ACL, Anterior Cruciate Ligament; ACLR, Anterior Cruciate Ligament Reconstruction; TFJ, Tibiofemoral Joint; KL, Kellgren and Lawrence; JSN, Joint Space Narrowing; OARSI, Osteoarthritis Research Society International; BPTB, Bone-Patellar Tendon-Bone; HS, Hamstring; CI, Confidence Interval; MOAKS, MRI Osteoarthritis Knee Score; IKDC, International Knee Documentation Committee; CMS, Coleman methodology score; ORs, odd ratios.

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(38.9 ± 5.4 months of follow-up) [6]. A study reported that the prevalence of PFJ is 72% (15-years-follow-up) and 80% (20-years-follow-up) after ACLR [7]. A review by Culvenor et al. reported that radiographic PFJ OA after ACLR, with a prevalence ranging from 11% to 90% (median 36%), 2–15 years after surgery [4]. For comparison, the overall crude prevalence of radiographic PFJ OA was 17% in healthy individuals [8]. These emerging evidences suggest that although less well recognized compared with tibiofemoral joint (TFJ) OA, PFJ OA after ACL injury should be paid more attention to alleviate joint symptoms and functional limitations. However, the modifiable factors in treatment to alleviate degenerative changes in the PFJ after ACL injury remain unknown. Targeted interventions need to be developed to alleviate joint symptoms and functional limitations of PFJ OA after ACL injury. Therefore, we would like to conduct a systematic review to synthesize these evidences, assess the quality of the studies we found, and formulate conclusions and recommendations based on study findings. Besides, the reported prevalence of PFJ OA after ACL deficiency in the literature has large variations and has no consensus, likely reflecting different radiographic diagnostic criteria used, different surgical procedures, different follow-up period after surgery, and heterogeneous populations. Therefore, the overall prevalence of PFJ OA after ACL deficiency based on different radiographic diagnostic criteria, surgical procedures, follow-up period, and populations via systematic search remains unknown.

Many studies have reported the OA outcome in the knee after ACL injury [9–11]. However, many of them either did not specify the OA compartment in the knee, or focused on TFJ only. The PFJ has different biomechanical features from the TFJ and could be affected by ACLR in a different manner. Kim et al. reported that despite a clinically satisfactory ACLR (with negative anteroposterior drawer and pivot shift tests), patients showed at least one region with increased T2 value of the PFJ cartilage 3 years after ACLR, especially at the medial compartment of the trochlear cartilage [12]. The risk factors associated with PFJ OA after ACL injury have not been systematically summarised. Identification of the risk factors may assist in preventing or reducing PFJ OA after ACL injury in future studies to improve clinical outcome. Targeted interventions need to be developed to reduce the burden of early-onset OA following ACLR.

The published paper presented two questions: What is the prevalence of PFJ OA after ACL injury reported in the literature? which risk factors are associated with the development of degenerative changes on the PFJ after ACL injury? This review will do a systematic search, systematically summarise the reported prevalence of PFJ OA in populations on the base of study quality assessment, and identify what risk factors and elements that less recognized in the literature are associated with the development of PFJ OA after ACL injury.

Methods

Search strategies

We performed a comprehensive search in databases including MEDLINE (OVID), Pubmed, Embase, and WoS and up to 1 March 2019. The key search terms are as shown in Table 1. We only included studies evaluating PFJ OA with or without TFJ OA after ACL injury. Whether descripted the specified compartment of TFJ OA or not would not have an influence in the study selection. Similar search strategies were used in WoS, Embase, and MEDLINE (OVID). In addition, other relevant publications from reference lists were also included.

Table 1
Search strategies in MEDLINE.

1	Anterior cruciate*[tw] OR acl[tw];
2	injur* [tw] OR tear* [tw] OR ruptur* [tw] OR deficien* [tw] OR tear* [tw]
3	(osteoarthrit*[tw] OR osteo-arthrit*[tw] OR osteoarthro*[tw] OR osteo-arthro [tw] OR arthrosis[tw] OR arthroses[tw] OR arthrot*[tw] OR gonarthro*[tw] OR degen*[tw])
4	(risk*[tw] OR factor*[tw] OR risk factor *[tw] OR population at risk OR populations at risk OR prevalence[MeSH]

Study selection

The searched studies were assessed based on the following inclusion criteria:

Full text available;

Written in English;

Study design could be as follows: randomised controlled trial, prospective cohort study, and retrospective study;

ACL reconstructed patients who had accepted primary ACLR; use of an arthroscopic and use of hamstring tendon/bone-patellar tendon-bone (BPTB)/allografts;

ACL injury patients with conservative treatment;

The number of included subjects must be more than 20;

OA outcomes including: radiographic OA, OA findings on MRI/during arthroscopy;

Follow-up period of at least 2 years;

Animal studies, cadaveric studies, case series, letters, case reports, and reviews were excluded. Studies including patients without skeletally immature knees were also excluded.

Data extraction and analysis

To evaluate the reported prevalence of PFJ OA, results from the radiologic and MRI assessments were extracted from the included studies. For the cut off value in defining PFJ OA, In the present review, after comparing the grading of different classification system, Kellgren and Lawrence (KL) Grade 2, IKDC Grade B, Fairbank Grade 1, Ahlbäck Grade 1, joint space narrowing based on OARSI Grade 2 or higher (or a sum of osteophyte grades of ≥2, or Grade 1 JSN in combination with a Grade 1 osteophyte), and MRI Osteoarthritis Knee Score (MOAKS) Grade 1 was used to define as PFJ degenerative changes. The reason we used such grading to define PFJ OA was that these grading from different system share similar severity of degenerative changes in the PFJ: definite osteophytes and/or possible JSN. Meta-analysis for proportions with random effects model were performed using MedCalc for Windows, V.16.8 to calculate pooled prevalence of PFJ OA and (odd ratios) ORs of associated risk factors. Heterogeneity tests were also conducted and interpreted as follows: $I^2<25\%$, low heterogeneity; $25\% \leq I^2 \leq 75\%$, moderate heterogeneity; and $I^2>75\%$, high heterogeneity. Data were pooled based on the following study populations: (1) ACL reconstructed population with BPTB graft; (2) ACL reconstructed population with HS graft; (3) ACL reconstructed population with single-bundle graft; (4) ACL reconstructed population with double-bundle graft; (5) ACL deficient population with conservative treatment (non-ACL reconstruction); (6) Early ACL reconstruction; (7) Delayed ACL reconstruction. (8) Follow-up periods: 2–5 years; 6–10 years; over 10 years. We also calculated the pooled ORs of incurring PFJ OA between ACL reconstructed populations and conservative treatment populations. In addition, funnel plots generated by Medcalc (V.16.8) was used to visually inspect the existence of publication biases and/or between study heterogeneity. In the absence of biases and/or between study heterogeneity, funnel plot will be a symmetrical inverted funnel in shape. Funnel plots of ORs of ACLR inducing PFJ OA were made to inspect the existence of publication biases.

Study quality assessment

A modified version of the Coleman methodology score (CMS) was used to assess the methodological quality of the included studies (Appendix 1) [13]. The CMS originally consisted of 10 criteria with a total score ranging from 0 to 100. A score of 100 indicated the most high-quality study with no confounding factors or other biases. The criteria were based on the Consolidated Standards of Reporting Trials

(CONSORT) statement for randomised controlled trials. The CMS was originally developed for surgical treatment of tendinopathy, but modified versions of the CMS have been used in other reviews [14,15].The following criteria were altered for part A: (1) "Mean of follow-up (yrs)" (question 2) was altered from mean follow up (mths) and the range of follow up is modified accordingly, (2) "type of study" (question 4) was altered to give both prospective cohort studies and randomised controlled trials the highest score, (3) "description of postoperative treatment" (question 7) was removed. Part A gave a total score of 50. The following modifications were included in part B: (1) "Outcome criteria" (question 1) was altered; the original criterion concerning sensitivity was removed, and the score was given to studies that reported interrater or intrarater reliability for the radiologic assessments. Part B gave a total score of 40. The maximum score of the modified CMS was therefore 90. The modified CMS is listed in Appendix 1. The methodological quality of the included studies was assessed by 2 independent reviewers (Wenhan HUANG and Tim-Yung ONG). Conflicting scores for the various items were discussed until consensus was reached. It is suggested in the literature that a score of more than 55% of total score for other checklists is to be considered as a high-quality study [16].

Results

Identification and selection of the literature

The search resulted in 1454 studies, for which all abstracts were reviewed. Twenty-five additional studies from relevant reference lists were also included. After screening of the abstracts, 59 were identified as possibly relevant, and full texts were retrieved. After review of the full texts, 38 met all the inclusion criteria (Figure 1).

There were no disagreements on inclusions. The references of the 2 studies were reviewed and 4 additional studies meeting the inclusion criterion were identified. The characteristics of the included studies are presented in Table 2. Among them, 16 prospective studies and 22 retrospective studies were included in this systematic review. Four of the prospective studies were randomised controlled studies [17–20].

Totally 4254 subjects were included in the studies, with samples ranging from 22 to 589. The mean follow-up time is 9.48 ± 5.67 years. In 5 studies, not only PFJ were radiologically assessed in ACL deficient population with conservative treatment, but radiologically assessed in ACL reconstructed population [17,21–24]. Surgical procedures for the ACLR reported in the studies were using hamstring, BPTB grafts, or iliotibial tract with or without augmentations. Preoperative PFJ OA was reported in 5 studies. Particularly, preoperative radiographic assessment was included in 10 studies.

Methodological quality

The results of the study quality assessments are presented in Table 3. Thirty-one studies can be regarded as high-quality studies based on the modified CMS. For part A, "type of study" and "number of treatment procedures" gave the lowest scores. For part B, the lowest scores were achieved for "outcome criteria" and "description of subject selection process." None of the studies fulfilled all the criteria (modified CMS of

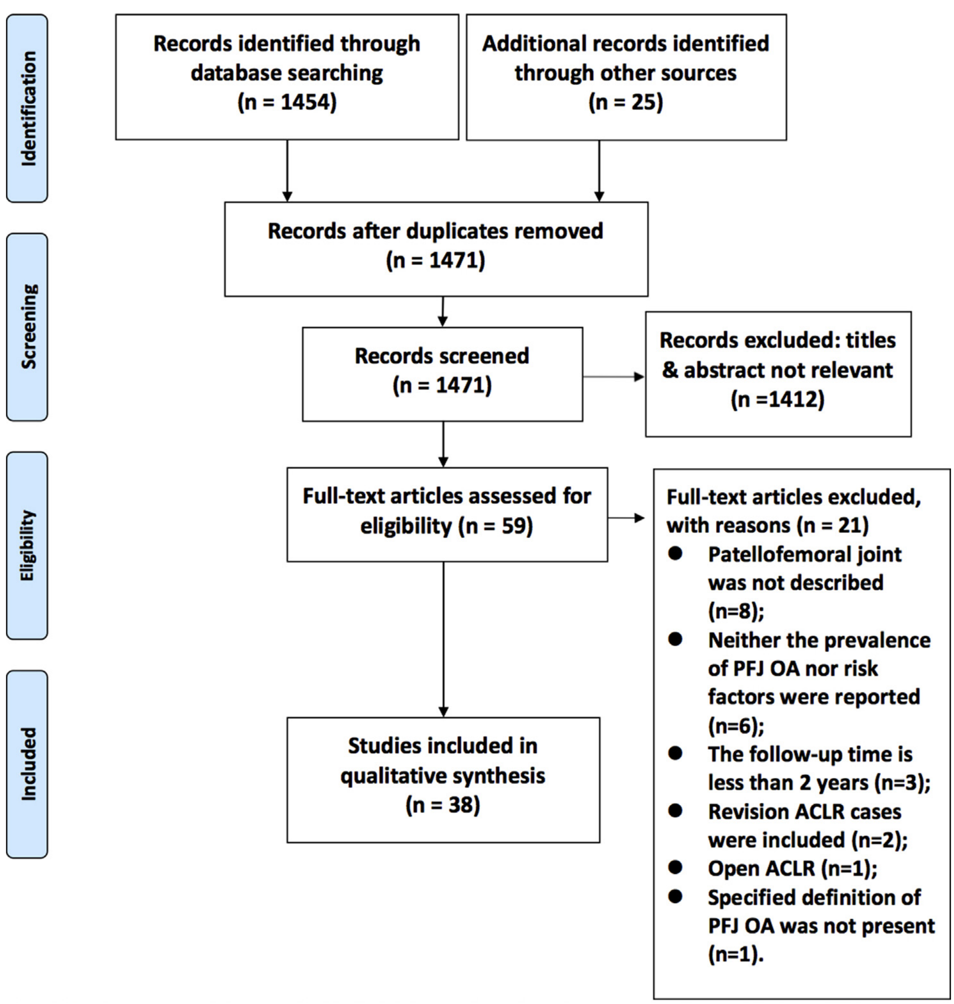

Figure 1. Flow-chart of studies included in the current systematic review.

Table 2
Summary of the main characteristics of the included studies.

	Additional information	N	Years since ACLR	Grading system	PFJ OA prevalence (%)			Surgical procedure	Reported risk factors	
					Mild	Mod	Severe		Significant	Nonsignificant
Barenius et al. [18] 2014	ACLR with BPTB ACLR with HS	69 65	14	KL	22(≥Mild) 25(≥Mild)	NA	NA	Arthroscopic BPTB + HS	BMI; medial meniscus resection	Age at injury; graft type; sex; overweight, time between injury and reconstruction, lateral meniscus resection
Culvenor et al. [29] 2013	ACLR with HS	70	7	OARSI	47(≥Mild)	NA	NA	Arthroscopic HS	Articular cartilage lesions; late duration to ACLR	Meniscus injury; intermediate duration to ACLR
Øiestad et al. [25] 2012[b]	ACLR with BPTB	181	12	KL	19	5.5	1	Arthroscopic BPTB	Increased age; TFJ OA	knee laxity; self-reported knee function; quadriceps strength; Hop tests up to two years postoperatively
Neuman et al. [40] 2008	ACLR with BPTB Non-ACLR	22 60	15	OARSI	47(≥Mild) 8.3(≥Mild)	NA	NA	Arthroscopic BPTB	ACLR	Meniscal injury
Lohmander et al. [22] 2004	ACLR with BPTB/HS Non-ACLR	31 26	12	OARSI	20(≥Mild) 3.8(≥Mild)	NA	NA	Arthroscopic BPTB + HS	ACLR	Symptoms; activity level
Meer et al. [23] 2016	ACLR with BPTB/HS Non-ACLR	93 50	2	KL	11.8 8	NA	NA	Arthroscopic BPTB + HS	Meniscectomy during the first year after ACL trauma	Age at operation; sex; BMI; Tegner activity score; effusion; meniscal tear
Frobell et al. [17] 2013	Early ACLR Delayed ACLR Non-ACLR	58 29 26	5	KL	24(≥Mild) 21(≥Mild) 7.7(≥Mild)	NA	NA	Arthroscopic BPTB + HS		ACLR
Culvenor et al. [39] 2016[b]	ACLR-15-year follow-up ACLR-20-year follow-up	181	15 20	KL	72(≥Mild) 80(≥Mild)	NA	NA	Arthroscopic BPTB		Anterior knee pain
Cantin et al. [48] 2016	ACLR	589	12	IKDC	8(≥Mild)	2	0	Arthroscopic BPTB + ITB + HS		
Risberg et al. [9] 2016	ACLR-15-year follow-up ACLR-20-year follow-up	168	15 20	KL	21(≥Mild)	NA	NA	Arthroscopic BPTB + HS		
Ahn et al. [37] 2011	ACLR with BPTB	117	10	IKDC	49	9	3	Arthroscopic BPTB		
Breitfuss et al. [32] 1996	ACLR with BPTB	41	2	Fairbank	25(≥Mild)	NA	NA	Arthroscopic BPTB		
Cohen et al. [28] 2007	ACLR with BPTB	62	11	Fairbank	52	23	0	Arthroscopic BPTB		
Järvelä et al. [43] 2001	ACLR with BPTB	100	7	IKDC	34	12	1	Arthroscopic BPTB		
Keays et al. [49] 2007[a]	ACLR with HS ACLR with BPTB	27 29	6	Modified KL	41.3 29.6	0 0	0 0	Arthroscopic BPTB + HS		
Murray et al. [11] 2012		83	13	IKDC	65	10	1	Arthroscopic BPTB		
Sajovic et al. [19] 2006	ACLR with HS ACLR with BPTB	28 26	5	IKDC	17(≥Mild) 50(≥Mild)	NA NA	NA NA	Arthroscopic BPTB		
Salmon et al. [50] 2006	ACLR with BPTB	49	13	IKDC	26	0	0	Arthroscopic BPTB		
Bourke et al. [51] 2012	ACLR with HS	118	15	IKDC	11	0	1	Arthroscopic HS		
Hertel et al. [52] 2005	ACLR with BPTB	67	10	IKDC	6	0	0	Arthroscopic BPTB		
Karikis et al. [20] 2016	ACLR with single-bundle ACLR with double-bundle	41 46	5	Fairbank	23 9	3 4	0 0	Arthroscopic HS		
Tsoukas et al. [24] 2016	ACLR with BPTB/HS Non-ACLR	32 13	10.1	IKDC	64 60	NA	NA	Arthroscopic BPTB + HS		
Mascarenhas et al. [53] 2012	ACLR with BPTB ACLR with HS	36 47	5	KL	57 26	NA	NA	Arthroscopic BPTB + HS		
Li et al. [54] 2011	ACLR with BPTB/HS	249	7.8	KL	10	1	0	Arthroscopic BPTB + HS		
Hui et al. [55] 2011	ACLR with BPTB	50	15	IKDC	14	2	0	Arthroscopic BPTB		
Keays et al. [10] 2010[a]	ACLR with HS ACLR with BPTB	29 27	6	KL	41.3 29.6	0 0	0 0	Arthroscopic BPTB + HS		
Fithian et al. [56] 2005	Non-ACLR Early ACLR	113 63	6.6	IKDC	57 76	NA	NA	Arthroscopic BPTB		

(continued on next page)

Table 2 (*continued*)

	Additional information	N	Years since ACLR	Grading system	PFJ OA prevalence (%)			Surgical procedure	Reported risk factors	
					Mild	Mod	Severe		Significant	Nonsignificant
	Late ACLR	33			60					
Wang et al. [35] 2003	ACLR with BPTB	44	4.8	Ahlback	11.4	NA	NA	Arthroscopic BPTB		
Edwards et al. [57] 2000	ACLR with BPTB/HS	45	8	IKDC	22.2	8.9	0	Arthroscopic BPTB + HS		
Jarvela et al. [58] 1999	Early ACLR	48	7	IKDC	41.6	6.3	0	Arthroscopic BPTB		
	Delayed ACLR	43			28.8	13.3	0			
Thompson et al. [59] 2015	ACLR with BPTB	80	20	IKDC	18	13	0	Arthroscopic BPTB		
Ruffilli et al. [60] 2014	ACLR with single-bundle	20	12.1	IKDC	20	20	0	Arthroscopic HS		
	ACLR with double-bundle	31			22	0	0			
Franceschi et al. [33] 2013	ACLR with anteromedial portal	46	5	Fairbank	7.1	NA	NA	Arthroscopic HS		
	ACLR with transtibial portal	42			15.2					
Holm et al. [61] 2012	Open ACLR	25	12	KL	20	NA	NA	Arthroscopic & Open BPTB		
	Arthroscopic ACLR	28			36					
Suomalainen et al. [41] 2012	Double-bundle ACLR with bioabsorbable screw fixation	20	5	KL	25	0	0	Arthroscopic HS		
	Single-bundle ACLR with bioabsorbable screw fixation	21			38	0	0			
	Single-bundle ACLR with metallic screw fixation	24			25	0	0			
Sim et al. [38] 2015		67	3.6	IKDC	4.5	0	0	Arthroscopic HS		
Sward et al. [31] 2013	ACL injured with varus alignment	36	15	OARSI	22	0	0	NA		
	ACL injured with valgus/neutral alignment	29			7	0	0			
Liden et al. [34] 2008	ACLR with HS	41	7.2	Fairbank	5	0	0	Arthroscopic BPTB + HS		

N, number of included subjects; IKDC, International Knee Documentation Committee; KL, Kellgren and Lawrence; OARSI, Osteoarthritis Research Society International; NA, not applicable; PFJ, patellofemoral joint; TFJ, tibiofemoral joint; BPTB: bone-patellar tendon-bone; HS, hamstring.

[a] The same group patients were reported in these two studies by Keays et al. and same prevalence were reported.

[b] The same group patients were reported in these two studies by Oiestad et al. and Culvenor et al. in different follow-up periods.

90). The mean modified CMS was 58.89 ± 11.54, which corresponds to a CMS of 65.43 when transferred to a 0 to 100 score. The lowest score achieved was 39, and the highest score is 80 found in two studies [9,25]. The prospective studies achieved a mean modified CMS of 70.06, with the highest score of 80 and the lowest score of 52. The retrospective studies correspondingly achieved a mean modified CMS of 59.3, with the highest score of 58 and the lowest score of 39.

Prevalence reported in included studies

Because the definition for PFJ varied in different studies, various cutoff values for defining PFJ OA in the included studies were used to define as PFJ OA. The cut–off values chosen was described in methods section. The cut-off point used in the current systematic review was consistent with previous studies [26,27]. The overall prevalence of PFJ OA in the included studies varied between 4.5% and 80% (Table 2). Only 4 studies reported the PFJ OA alone and rest of the included studies focus on both PFJ and TFJ.

ACL reconstructed population

In ACL reconstructed population with BPTB graft, the overall prevalence of PFJ OA from 20 studies was (mean proportion: (95% CI)) 38.9% (29.4–48.9%) (Figure 2). In ACL reconstructed population with HS graft, the overall prevalence of PFJ OA from 13 studies was 23.0% (15.7–31.3%). In ACL reconstructed population with single-bundle graft, the overall prevalence of PFJ OA from 3 studies was 31.6% (23.3–40.6%). In ACL reconstructed population with double-bundle graft, the overall prevalence of PFJ OA from 3 studies was 19.1% (12.1–27.4%). In early ACL reconstructed population, the overall prevalence of PFJ OA from 2 studies was 8.1% (3.9–13.5%). In delayed ACL reconstructed population, the overall prevalence of PFJ OA from 2 studies was 40.3% (8.2–78.2%). In ACL reconstructed population with different follow-up, the overall prevalence of PFJ OA is 20.4% (14.8–26.5%, 2–5 years), 32.5% (20.9–45.3%, 6–10 years), and 31.8% (22.0–42.5%, over 10 years), respectively.

ACL deficient population with conservative treatment

In ACL deficient population with conservative treatment, the overall prevalence of PFJ OA from 7 studies was 20.3% (95% CI: 6.5–39.1%). We also investigated the relationship between the prevalence of PFJ OA and modified CMS (Figure 3). No obvious trend was found between them but large prevalence variations were shown in lower quality studies. In the two studies with highest MCS score, the prevalence is 21% [9] and 25% [25], separately. For the prospective study, the prevalence of PFJ OA is

Table 3
Modified Coleman methodology score for included studies.

Section Score (Maximum)	Mean (SD)
Part A	
Study size (10)	8.74
Mean duration follow-up(5)	4.89
No. of treatment procedures (10)	0.53
Type of study (15)	5.92
Diagnostic certainty (5)	5
Description of surgical procedure (5)	3.84
Part B	
Outcome criteria (10)	**5.74**
Outcome measured clearly (4)	4
Reported interrater or intrarater reliability (3)	0.95
Use of outcome criteria that has reported good reliability (3)	0.79
Procedure for assessing outcomes (15)	**12.60**
Subjects recruited (5)	5
Investigator independent of surgeon/therapist (4)	2.00
Written assessment (3)	2.84
Completion of assessment by subjects themselves with minimal investigator assistance (3)	2.76
Description of subject selection process (15)	**11.89**
Selection criteria reported and unbiased (5)	3.68
Recruitment rate reported (≥80% = 5; <80% = 3)	4.26
Eligible subjects not included in the study accounted for (5)	3.95
Total part A (50)	28.66(6.94)
Total part B (40)	30.23 (5.72)
Total score (90)	59.89(11.54)

SD, standard deviation.

between 10.7% and 80%, among them the randomised controlled study reported as between 13% and 26%. For the retrospective study, the figure is between 4.5% and 75%. One study evaluated the association between meniscectomy in ACLR population and PFJ OA and the prevalence reported is 75% [28].

Radiologic classification methods

Five different radiologic classification methods were used in the 37 included studies. Only one reported the PFJ OA prevalence of 11.8% after ACL injury using MOAKS [23]. Seventeen studies used the IKDC classification system (Figure 4). The reported prevalence of PFJ OA in these studies was between 4.5% and 65%. The KL classification system was used in 11 studies. The reported prevalence of PFJ OA in these studies was between 21% and 80%. The OARSI classification system was used to grade JSN and osteophytes in 4 studies with a reported prevalence of PFJ OA from 20% to 47%, respectively [21,22,29–31]. One study used the KL to grade OA in TFJ; however, the researchers did not specify radiologic classification system but used JSN and osteophyte formation [17]. This study reported a prevalence of 17% of PFJ OA. Five studies used the Fairbank classification system with a reported prevalence of PFJ OA between 11.4% and 52% [20,28,31–34]. The KL showed variant prevalence of PFJ OA, which made the prevalence inconsistent (21%–80%). JSN by OARSI also exhibited inconsistent prevalence of PFJ OA. Only one study used the Ahlbäck classification system with a reported prevalence of 11.4% in PFJ OA [35]. Most of the studies reported that the radiographs were performed with the patients in the standing position with full weight bearing (n = 27) and with a knee flexion angle of 15°–45° (n = 21).

Risk factors inducing PFJ OA after ACLR

Seven risk factors were identified inducing PFJ OA after ACL injury (Table 2). Among them, ACLR was the most frequently reported risk factors. The odds ratios of risk of incurring PFJ OA varied between 0.81 and 9.62 in five studies that included both ACLR population and non-ACLR population after ACL rupture [17,21–24]. The pooled ORs of incurring PFJ OA between ACL reconstructed populations and conservative treatment populations is 2.1 (95% CI: 1.1 to 3.9) (Figure 5).

Identification of risk factors using logistic regression analysis was conducted in 6 studies to determine the effect of each potential risk factor on the odds of a patient having PFJ OA. Risk factors identified in these 6 studies were BMI [18], delayed ACLR [29], meniscectomy, patellofemoral chondral lesions, and age at surgery [25], more TFJ OA [29]. In the remaining studies, risk factors were identified using Poisson regression and discriminant analysis. Risk factors reported were ACLR [21], age at the time of operation [25] and presence of chondral injury [29]. One study not only evaluated the odds ratios of PFJ OA in both ACLR population and non-ACLR population after ACL rupture, but performed logistic regression to determine odds ratios of the candidate risk factors in relevant factors [22].

Publication bias was assessed by visual inspection of funnel plots for ORs of ACLR inducing PFJ OA (Figure 6). The plots demonstrate that some asymmetry was found regarding the ORs of ACLR incurring PFJ OA.

Discussion

Prevalence of PFJ OA after ACL injury

The overall prevalence of PFJ OA in included studies varied between 4.5% and 80%. For comparison, the overall crude prevalence of isolated radiographic PFJ OA was 7% in community-based populations in a systematic review [8]. The reported prevalence of PFJ OA is between 11.8% and 80% for the prospective studies with a modified CMS of 49–74. For the retrospective studies, the prevalence varied between 4.5% and 76% with a modified CMS of 37–59. All the 38 included studies reported the PFJ OA for subjects with or without concomitant meniscectomy in ACL reconstructed populations, and none of them reported in an isolated ACLR population. Specially, some studies reveal that menisci in different regions plays a different role in the development of PFJ OA. Meer et al. show that medial meniscal injury/meniscectomy influences PFJ OA while lateral meniscal injury/meniscectomy does not [36].

The pooled prevalence of PFJ OA based on different follow-up period showed that in the early stage, the prevalence is low (20.4%); afterwards, it increased by 10% in the following 5 years. However, the pooled data showed that no obvious increase after that and even a little decrease was shown. It might be caused by the increasing sample size with the increase of follow-up, which enables us to get a smaller margin of error and get the true prevalence.

Radiologic grading systems

Five different radiologic classification methods based on evaluation of osteophyte formation, JSN, or both were used in the 37 included studies. One study graded PFJ OA according to the description of MOAKS with MRI. We admit that there are some mild differences of pathological stages among different classification system. Despite of these variations, the selected cutoff values can be representative of moderate to severe degenerative changes in the PFJ, we believe that the definition for PFJ OA is consistent and may not be a large concern. After we categorising the prevalence of PFJ OA based on different systems, no obvious underestimation or overestimation was found under different systems. It indicates that radiographic classification system variations might not have a great impact on the reporting prevalence of PFJ OA. The cutoff grade for defining PFJ OA using different grading systems is various in the included 38 studies. IKDC was used in 17 included studies, with parameters graded as normal (A), nearly normal (B), abnormal (C), or severely abnormal (D). Only two studies defined PFJ OA clearly [37,38]. The onset of OA was defined as Grade C or D in patients whose preoperative grade was A or B in the study by Ahn et al. [37], while Grade B, C, and D were

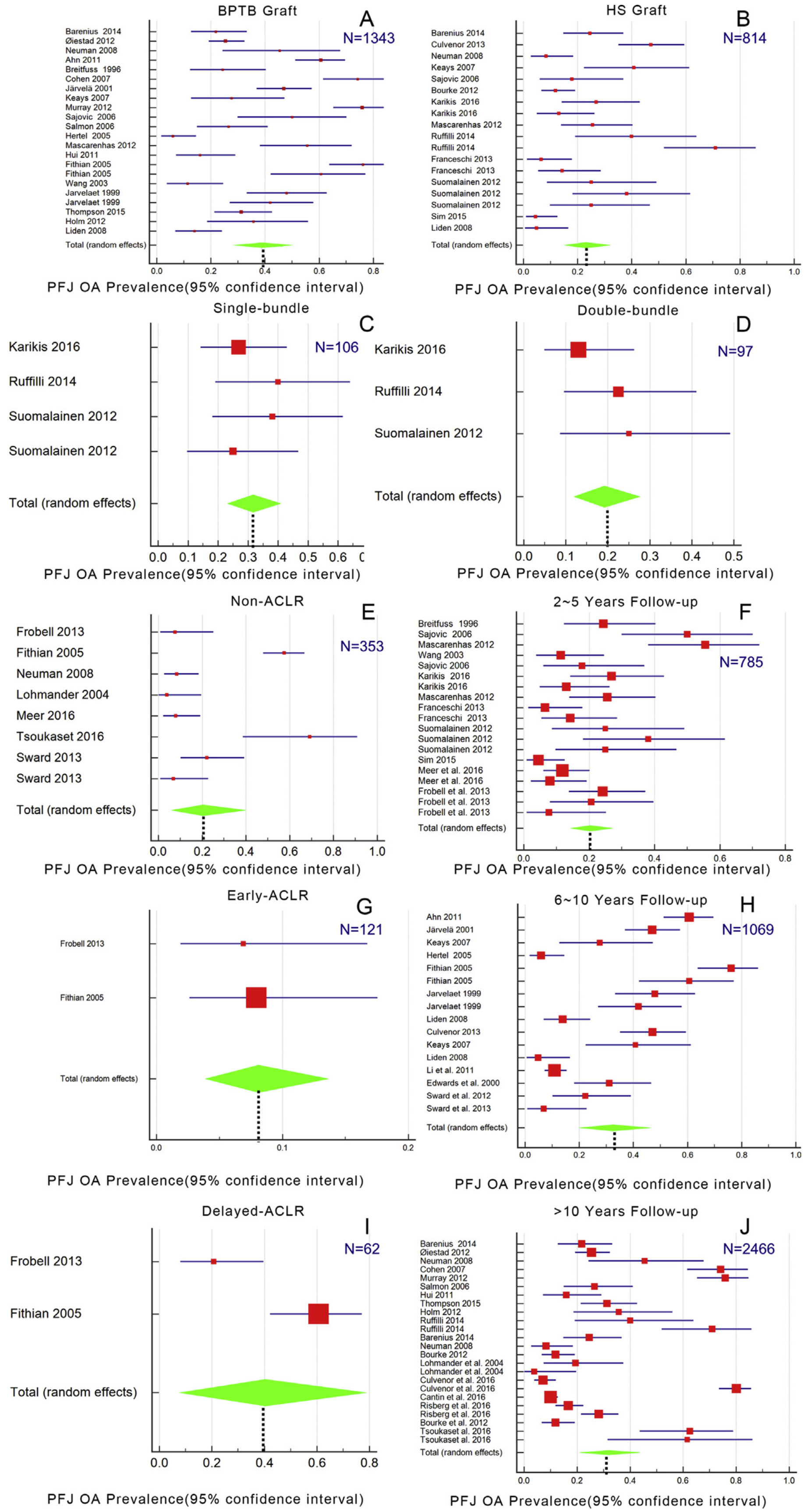

Figure 2. Prevalence of PFJ OA in ACL reconstructed population with BPTB/HS grafts, double-bundle/single-bundle reconstruction, non-ACLR/early ACLR/delayed ACLR. BPTB, bone-patellar tendon-bone; HS, hamstring; CI, confidence interval; PFJ, patellofemoral joint; OA, osteoarthritis; ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction.

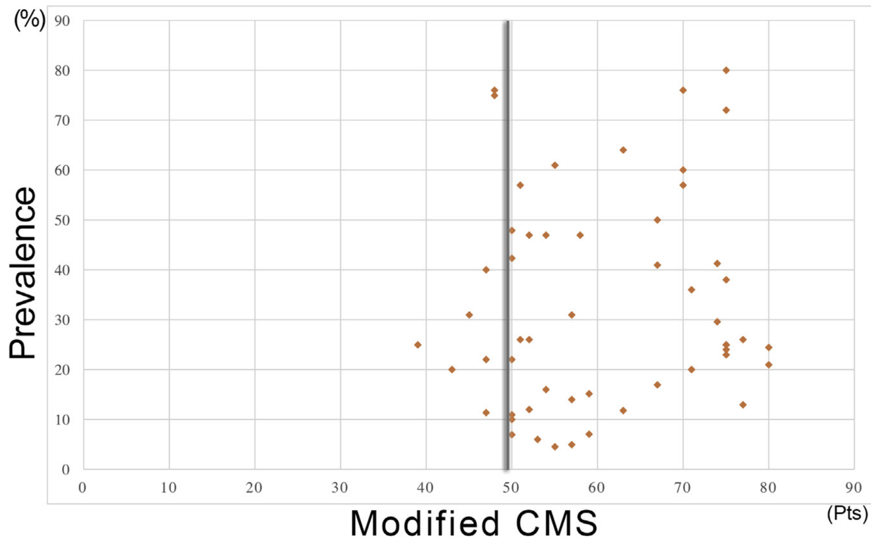

Figure 3. The overall prevalence scatter plots of included studies with corresponding modified CMS. CMS, Coleman methodology score.

regarded as degenerative arthritis changes in the study by Sim et al. [38]. The KL classification was used in 11 studies with Grade 0–4. Four studies used Grade 2 as the cutoff for the presence of radiographic PFJ OA [9,18,25,39]. Fairbank was used in 5 studies with Grade 0–4 and no definition for PFJ OA was given in these included studies. Besides, these studies did not report the criteria they used for different grade levels. Osteophytes and JSN were scored in PFJ using the OARSI in four studies [17,22,29,40]. In these four studies, the definition for PFJ OA is consistent and JSN of Grade 2 or higher, sum of osteophyte grades ≥2 or grade 1 JSN in combination with a Grade 1 osteophyte was defined as PFJ OA. Only one study used Alhback with grade classification [35]. Neither definition of PFJ OA nor the classification was given in this study. Particularly, one study identified early degenerative changes by assessment on MRI according to the description of MOAKS reported by Meer et al. [23]. The features are categorized from grad 0 to 3 in cartilage lesions, osteophytes, and bone marrow lesions.

Risk factors inducing PFJ OA after ACL injury

Eight studies identified the risk factors inducing PFJ OA after ACL injury, including ACLR, delayed ACLR, BMI, meniscectomy, patellofemoral chondral lesions, and age at surgery, more TFJ OA. Among them, ACLR was the most frequently reported risk factor. For studies not only evaluating the OR in ACLR population but in non-ACLR population after ACL injury, we found that the OR values varied between 0.81 and 9.62. Moreover, among these studies, the highest quality studies reported that the prevalence of PFJ OA after ACLR after 14-years follow-up was 23% (average age at end point: 40 years old) [18] and 2-year follow-up 20.5% (single bundle reconstruction; average age at end point: 38 years old) & 24% (double bundle reconstruction) [41], respectively. The pooled prevalence of PFJ OA in normal subjects aged 40 is not reported in the literature; however, for comparison, the pooled prevalence of PFJ OA in normal subjects aged 60 is 21.9% (95% CI: 16.9%-27.8) [42]. It means that for a same prevalence of PFJ OA, the age of ACLR population is 20 years earlier than that of normal subjects. In addition, all these studies had the subject inclusion criteria including the time from injury to the beginning of the treatment, and thus, the time was the same in the ACLR population and non-ACLR population in each study. It means that the PFJ condition was similar in these two populations before treatment; however, due to surgery, the ACLR population has higher chance for the development of PFJ OA.

Generally, the prevalence of PFJ OA in ACLR group is higher than that in non-ACLR group, which indicates that ACLR is essentially a risk factor inducing PFJ OA (Figure 3-H). As a risk factor, ACLR has many

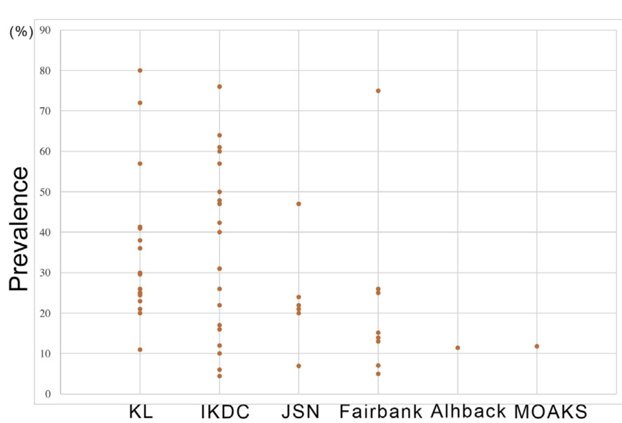

Figure 4. The overall prevalence scatter plots of included studies using different radiologic classification systems: MOAKS, MRI Osteoarthritis Knee Score; YS, years. KL, Kellgren and Lawrence; JSN, joint space narrowing; IKDC, International Knee Documentation Committee; MOAKS, MRI Osteoarthritis Knee Score.

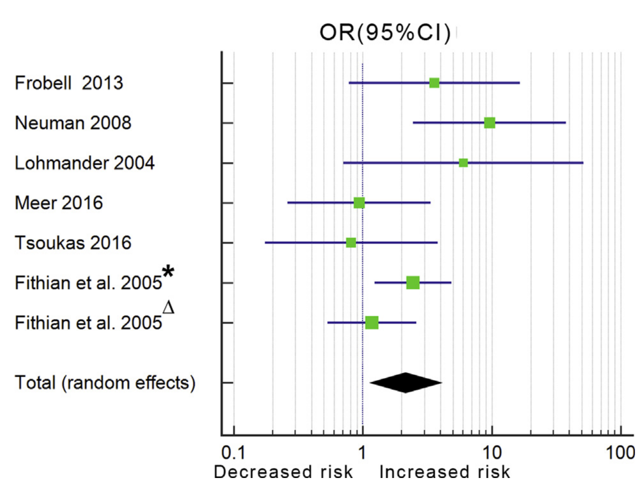

Figure 5. Forest plot of comparison: Risk factors and associations with conservative treatment and ACLR. OR, odds ratio; CI, confidence interval; ACLR, anterior cruciate ligament reconstruction.

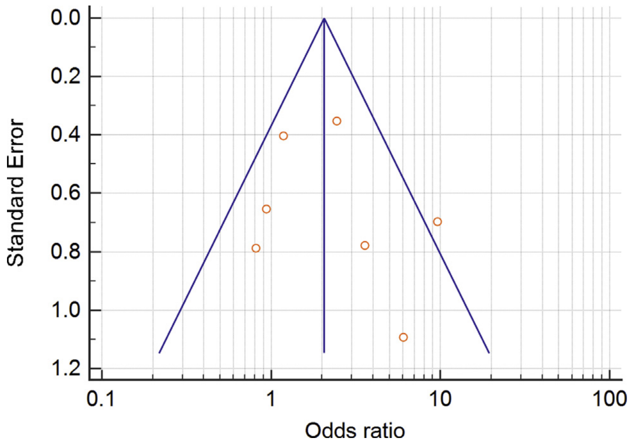

Figure 6. Funnel plots of the standard error (SE) and odd ratio (OR) for ACLR (*: early ACL reconstruction in study by Fithina et al., 2005; Δ: late ACL reconstruction in study by Fithina et al., 2005). ACLR, anterior cruciate ligament reconstruction.

contributors, including graft types [43]; single-bundle and double-bundle techniques [20]; PFJ biomechanical changes caused by graft tension. In a recent study, it is reported that all patients (10/10) showed at least one region with increased T2 value of the PFJ cartilage 3 years after ACLR, especially at the medial compartment of the trochlear cartilage [44]. The forest plots show that BPTB, single-bundle reconstruction, and delayed ACLR are more likely to be associated with PFJ degenerative changes after ACL injury when compared to hamstring tendon, double-bundle reconstruction, and early ACLR.

Methodological quality

The current systematic review showed that the mean modified CMS was 58.9 ± 11.5, which corresponds to a CMS of 65.4 when transferred to a 0 to 100 score. Another similar systematic review investigating knee OA after ACL deficiency revealed a mean CMS of 52 [14]. The CMS assesses the study quality of reporting, and it has been shown that the score correlated positively with the level-of-evidence rating [45]. The treatment procedure section in part A resulted in the lowest score in all included studies, as description or outcome of rehabilitation was seldom present. Only 11 studies reported either interrater or intrarater reliability, ranging from 0.51 to 0.78 that depends on specified outcome measurement system. These results are similar to those reported in other systematic review [14,45]. Ten studies scored 3 points in “use of outcome criteria that has reported good reliability”, as only in these 10 studies was the KL used. All included studies fulfilled the requirement in the following categories: mean follow-up, diagnostic certainty, and subjects recruited (results not taken from surgeons’ files). The two studies with highest modified CMS (80) are prospective non-randomised studies, and they scored in every section except treatment procedure in part A [9,25]. They are representatives of high assessment quality studies with standardised methods and recommended to present the true prevalence of PFJ OA after ACLR (21% and 25%, respectively) [46].

Regarding publication bias, multiple sources have been identified that may affect funnel plot asymmetry including reporting bias. In the present review, for ORs of ACLR inducing PFJ OA, the funnel plot asymmetry is mainly due to different timing of surgery (early or late ACLR) and different follow-up period (2–15 years). One study fall out of the 95% CI axis due to the significantly high OR (OR = 9.62) [40].

Summary

Although ACL injury and ACLR are well-established risk factors for the development of TFJ OA, PFJ OA after ACLR has gone largely unrecognised. In the present systematic review, PFJ OA after ACL deficiency was conducted in terms of epidemiological data, clinical definitions, and associated risk factors. The pooled prevalence of PFJ OA after ACL deficiency indicated us the prevalence of PFJ OA is a common clinical problem; The associated risk factors identified in this systematic review are crucial findings for the clinicians to reduce the prevalence of PFJ OA after ACL deficiency. In the present systematic review, the innovations are that that the overall prevalence of PFJ OA after ACL injury in the included studies varied between 4.5% and 80% based on different radiographic classification systems. The pooled prevalence of PFJ OA after ACL injury implied that we underestimated the degenerative changes in the PFJ after ACL injury with conservative or surgical treatment.

The substantial variation of PFJ OA prevalence is mainly due to the use of surgical techniques, and different follow-up periods. The pooled data showed that BPTB, single-bundle reconstruction, and delayed ACLR was more likely to induce PFJ degenerative changes after ACL injury compared to HS, double-bundle reconstruction, and early ACLR. In particular, ACLR itself, which is the main treatment to ACL injury, was a risk factor for the development of PFJ OA after ACL injury. These findings indicated that hamstring graft, double-bundle reconstruction, and early ACLR should be recommended to reduce the potential degenerative changes in the PFJ during ACLR. Modified rehabilitation strategies aimed to reduce PFJ OA after ACL injury should also be investigated in future studies to improve clinical outcome.

Some other findings from this review are that radiographic assessment should be done in standardized radiographic procedures. From this review, although we found that classification system variations did not have a significant impact on the reporting of the prevalence of PFJ OA, the KL should be recommended as a radiologic assessment to make outcome comparison easy based on its high interrater reliability. The X-rays taken, the baseline information of the included subjects, the technical issues with regard to taking patellofemoral X-rays, the results of opposite knee, and the recruitment rate should be reported, and attempts should be made to account for patients who are not included and those who are lost to follow-up. For patients undergone ACLR after ACL injury, the protocols and outcomes of rehabilitation should be reported. Due to lack of randomized controlled studies, future studies on the reported prevalence of PFJ OA should be randomized and controlled. Apart from the proposed improvement listed above, approaches to improve graft healing after ACLR such as intraoperative irrigation should also be systematically reviewed to evaluate if these approaches benefit the PFJ because some researchers found that the intraoperative irrigation had some improvement in knee laxity after ACLR [47].

This systematic review has some limitations. First, a customised definition of PFJ OA was present in this systematic review as there is no consistent criteria in published literature. This may generate selection bias with respect to reporting the prevalence of PFJ OA. Second, as some studies focused on outcome measurement under different kinds of intervention rather than focussing on PFJ OA, the presented risk factors may not be available in different studies. Third, the prevalence of PFJ OA in ACLR with or without meniscectomy or other concomitant injury was not reported. This is because the included studies did not evaluate the concomitant effect from other anatomical structures beside ACLR. Fourth, the methodological quality assessment, modified CMS, has shortages in assessing the methodological quality of studies involving both surgically and nonsurgically treated subjects with ACL injury. Fifth, this systematic review only included English-language studies, which may introduce a language bias and lead to erroneous conclusions.

Conflict of interest

The authors have no conflicts of interest to disclose in relation to this article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jot.2019.07.004.

Appendix 1. Modified Coleman methodology score[a]

Section	Number or factor	Score	Criteria
Part A			
Only one score to be given for each section Study size: number of patients	>60	10	
	41–60	7	
	20–40	4	
	<20, not stated	0	
Mean follow-up, y	>5	5	
	2–5	3	
	<2	0	
No. of different treatment procedures included in each reported outcome. More than 1 method may be assessed, but separate outcomes should be reported.	1 procedure	10	Surgical methods and/or nonoperative treatment methods
	More than 1 method but >90% of subjects undergoing the 1 procedure	7	
	Not stated, unclear, or <90% of subjects undergoing the 1 procedure	0	
Type of study	Prospective cohort study/randomized controlled trial	15	
	Retrospective cohort study/case series	0	
Diagnostic certainty	In all	5	Arthroscopy
	In >80%	3	
	In <80%	0	
Description of treatment given	Adequate (technique stated and necessary details of that type of procedure given)	5	
	Fair (technique only stated without 3 elaboration)	3	
	Inadequate, not stated, or unclear	0	
Part B			
Scores could be given for each option in each of the 3 sections			
Outcome criteria	Outcome measures clearly defined	4	Radiologic classification and standing position
	Reported either interrater or intrarater 3 reliability	3	
	Use of outcome criteria that has reported good reliability	3	Kellgren and Lawrence
Procedure for assessing outcomes	Subjects recruited (results not taken from surgeons' files)	5	Radiologic assessment performed
	Investigator independent of surgeon/therapist	4	Radiologist independent of the authors of the study
	Written assessment	3	Use of questionnaires for evaluation of osteoarthritis
	Complection of assessment by subjects themselvrs with minimal investigator assistance	3	WOMAC, KOOS, IKDC, Lysholm, Tegner/return-to- sport questionnaire
Description of subject selection process	Selection criteria reported and unbiased	5	Inclusion criteria
	Recruitment rate reported >80%	5	Radiologic assessment
	Recruitment rate reported <80%	3	Radiologic assessment
	Eligible subjects not included in the study satisfactorily accounted for, or 100% recruitment	5	Dropout analysis
Total score		90	

[a] The modified Coleman methodology score criteria used on the studies reporting PFJ OA after ACLR.

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