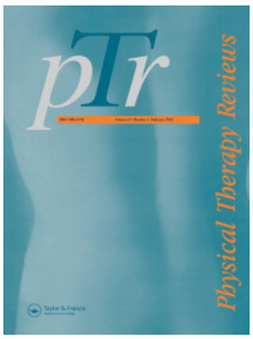

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Patellofemoral pain subgroups: a systematic scoping review of the evidence and clinical potential

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ABSTRACT

Introduction: Patellofemoral Pain (PFP) remains challenging to manage, with high rates of symptom recurrence. Subgrouping has been suggested as a strategy to enhance treatment effectiveness.

Objectives: This scoping review aimed to map the emerging literature on PFP subgroups and their evolution over time. Specifically, it explored study designs, stratification methods, subgroup classifications, and discussed their methodological rigor and clinical applicability.

Methods: Searches were conducted in seven databases. The review followed the PRISMA Extension for Scoping Reviews (PRISMA-ScR) guidelines. Critical appraisal was performed using JBI checklists.

Results: Forty-six studies were included. While efforts to stratify individuals with PFP date back to the 1990s, 90% of the studies were published after 2010. Most were observational cross-sectional designs (52.17%), and 17.39% were interventional. Twenty research groups proposed novel subgrouping approaches, but only four were replicated in subsequent studies. Many methods relied on imaging and biomechanical assessments, potentially limiting clinical use.

Conclusion: Subgrouping in PFP research has increased notably since 2010. Despite growing interest, few models have been tested in intervention studies, and their dependence on specialized assessments may hinder routine clinical implementation. Importantly, the most cited approach uses simple, low-cost clinical tests to classify individuals into three subgroups.

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KEYWORDS
Patellofemoral pain; subgroups; rehabilitation; physiotherapy

Introduction

Patellofemoral pain (PFP) is a common form of knee pain and is characterized by pain around or behind the patella [1]. This condition is typically exacerbated by weightbearing activities that stress the patellofemoral joint, particularly those involving knee flexion, such as squatting and stair climbing [1,2]. The study by Smith et al. showed that PFP has an annual incidence of 22.7% in the general population and has high prevalence and disability levels, concluding that PFP should be an urgent research priority. This is further supported by the fact that PFP management is challenging due to its poor response to treatment [3–5].

The most common type of treatment described in the literature for individuals with PFP is primarily conservative through physiotherapy and is based on a multimodal approach, where the main interventions are focused on quadriceps and hip abductors strengthening exercises, stretching, patellar taping, and foot orthoses [6,7]. However, a longitudinal study showed that 57% of patients had an unfavorable recovery and continued to experience symptoms five to eight years after treatment [8]. Furthermore, a multicenter observational study using data from 310 individuals with PFP showed that more than half of the participants had an unfavorable recovery after three months, and 40% after 1 year [9]. This problem has been attributed by several authors to the substantial inter-individual variability in biomechanical, psychological, and demographic factors among those affected by PFP [6,10–12]. To address this issue, many authors began to propose stratifying individuals with PFP into subgroups to offer better targeting of treatment and optimizing outcomes.

Research on PFP subgroups has been ongoing since the 1990s in different ways and has been growing ever

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Table 1. Search strategy for Medline *via* PubMed.

Search number	Query	Results
22	#12 AND #21	1,586
21	#13 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20	842,259
20	'Classification'[Title/Abstract]	441,107
19	'sub-group*'[Title/Abstract]	15,225
18	'stratification'[Title/Abstract]	97,299
17	'personal* treatment*'[Title/Abstract]	226
16	'TIPPs'[Title/Abstract]	40
15	'Target* intervention*'[Title/Abstract]	292
14	'Target* treatment*'[Title/Abstract]	764
13	'Subgroup*'[Title/Abstract]	330,258
12	#1 OR #2 OR #3 OR #4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11	41,162
11	'chondropathy'[Title/Abstract]	306
10	'chondromalacia patellae'[Title/Abstract]	296
9	'patella dysfunction'[Title/Abstract]	2
8	'anterior knee pain syndrome'[Title/Abstract]	56
7	'Knee joint'[Title/Abstract]	26,310
6	'Chondromalacia'[Title/Abstract]	1,092
5	'patella'[Title/Abstract]	12,502
4	'anterior knee pain'[Title/Abstract]	2,310
3	'retropatellar pain'[Title/Abstract]	62
2	'runners knee'[Title/Abstract]	9
1	'Patellofemoral pain'[Title/Abstract]	2,090

Note: TIPPS: Target Interventions for Patellofemoral Pain Syndrome.

since [13–17]. This trend aligns with the growing recognition of the multifactorial nature of PFP and the corresponding need for targeted treatment approaches according to subgroups [5]. However, it is not clear in the literature which stratification approaches show most promise, including the robustness of analysis, effectiveness of subgroup treatment-based approaches in interventional studies, and whether the subgroups generated are replicable in clinical practice. Therefore, a comprehensive review is needed to synthesize the various approaches, critically evaluate their strengths and limitations, and assess their clinical feasibility. Considering that research on PFP subgroups is relatively recent, we observed a wide variety of study designs and considerable heterogeneity in methodologies in a preliminary survey of the literature. Given this context, we determined that a scoping review would be the most appropriate approach to systematically map the current evidence in PFP subgroups.

Therefore, the objective of this scoping review was to map the literature on PFP subgroups and their development over time, identifying the types of study design, and stratification methods used. Additionally, this review also aimed to discuss the methodological rigor and clinical applicability of the proposed methods.

Methods

Protocol and registration

This scoping review was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR). The published protocol is available on the Open Science Framework (https://osf.io/t8w54).

Eligibility criteria

All documents that addressed PFP subgroups, whether as a primary or secondary objective, through experimental or theoretical approaches, or by simply referencing the topic were considered eligible for inclusion in this review. All study designs and type of evidence were included as the aim of this review was to map the existing literature on PFP subgroups. No restrictions were placed on publication date or language. Additionally, documents that did not meet the eligibility criteria or for which access to the full text could not be obtained after contacting the authors were excluded.

Information sources and search

A systematic search was carried out in the databases PubMed (Medline), Embase, Scopus, PEDro, LILCACS, Cochrane Library, and Web of Sciences. The search strategy was developed in discussion between the authors and reviewed by an experienced researcher in patellofemoral pain to be as broad as possible. An example of the complete search strategy is presented for Medline (*via* PubMed) in Table 1. All documents that met the inclusion criteria for full-text review underwent backward citation tracking of their references lists. A gray literature search was also carried out on Google and Google Scholar searches in the first ten search results pages. The searches were conducted on 7 February 2024, and an update was performed on 23 April 2025. In the absence of full text of the documents retrieved in the search, the authors were contacted by email.

Selection of sources of evidence

All documents were initially imported into EndNote software (version 21, Clarivate Analytics, Philadelphia,

PA, EUA), where duplicates were removed. Subsequently, the documents were imported to Rayyan [18] for the first phase of screening, which involved the review of titles and abstracts. Documents that passed the initial phase were then retrieved in full text in the second phase, where eligibility was further assessed against the inclusion criteria. Both phases of screening were conducted independently by two reviewers who were masked (ALC and VHVC). Any discrepancies between the reviewers in the selection of the documents were documented and standardized in an Excel spreadsheet and resolved by a third reviewer (JR).

Data charting process

A data charting template was created to extract data from the included studies. Before starting extraction, we piloted five studies and discussed aspects of our tool and the data to be extracted to ensure consistency in data reporting. Data mapping was done independently by two authors (ALC and VHVC). Discrepancies on the data mapping were resolved by the third author (JR) and subsequently discussed among the team [19]. The data charting template included the following data:

- Author and Year
- Country
- Journal/book
- Title of the document
- Study design and Type of evidence
- Objective
- Sample characteristics (if applicable)
- Subgroup suggested or using of existing subgroup (if applicable)
- Subgroups derived or used/Key points about subgroup described in the document (if applicable)
- What was the stratification based on? (if applicable)
- Instrumentation and equipment required for stratification of subgroups (if applicable)
- Limitations of each study

Critical appraisal of individual sources of evidence

To assess the methodological quality of the included studies, the checklists provided by the Joana Briggs Institute (JBI) were used [20]. The most appropriate checklist was chosen for each study design or type of evidence (https://jbi.global/critical-appraisal-tools) and was made by consensus among the authors after a detailed reading and discussion of the documents. For opinion studies with literature reviews, the 'Textual Evidence: Expert Opinion' checklist was used. For observational cross-sectional studies, the 'Analytical Cross-Sectional Studies' checklist was used. For interventional studies, the 'Quasi-Experimental Studies' or 'RCT' checklist was used. For cohort studies, the 'Cohort Studies' checklist was used. Then, the analysis of the individual studies was performed independently by two authors of this review (ALCSC and VHVC), and disagreements were resolved by a third author (JRS). The items of each checklist were scored 1 when they met the established criteria (Y: Yes) and 0 when they were not met, were unclear or the item was not applicable (N: No; U: Unclear; N/A: Not applicable). The total methodological quality score was obtained by adding the item scores divided by the number of items in the respective checklist. Studies that obtained scores above 66.6% were considered to have a low risk of bias. Those that obtained scores between 33.3% and 66.6% were considered to have a moderate risk of bias, and finally, studies that obtained scores below 33.3% were considered to have a high risk of bias.

Synthesis of results

After the selection of sources and critical appraisal results, the evidence was presented in three parts. In the first part, the documents were grouped based on the year of publication, study design and number of documents over the years. Secondly, all studies that suggested a new method of stratification of individuals with PFP into subgroups were compiled, in addition to the studies that referenced these existing subgroups. These two analyses were used to map the literature on a timeline and to identify how many stratification methods exist and which subgroups have been the cited by other studies to date. In the third part, an evidence table with the results of all the individual studies were presented with the data described previously in the Data Charting process section.

Results

Selection of sources of evidence

The PRISMA flow diagram illustrating the selection process is presented in Figure 1. Forty-six of 3,341 documents were included, and three disagreements were resolved by the third author (JR) during the selection of sources phase and two during the data mapping phase.

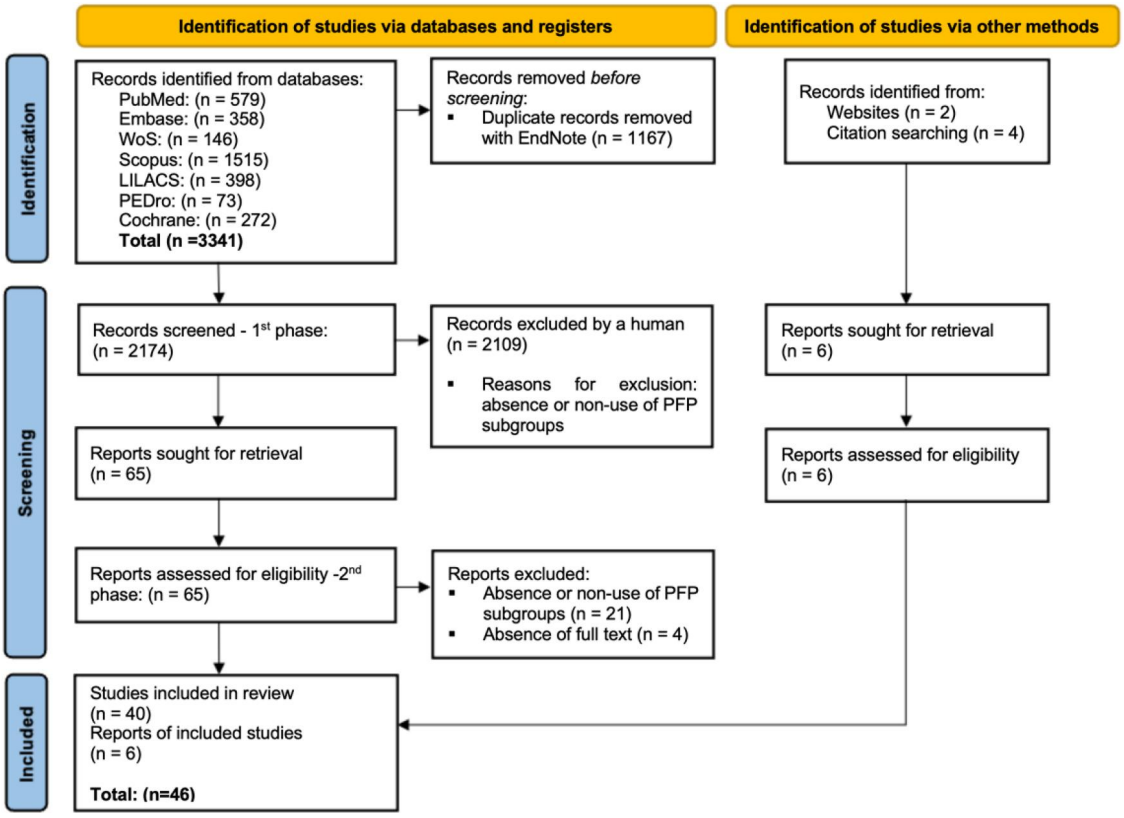

Figure 1. PRISMA flow diagram.

Characteristics of sources of evidence

Year of publication and study design

The stratification of individuals with PFP began to be addressed in 1998 [13,14] and the last publication on the subject was in 2024 [21]. Furthermore, of the 46 documents included in this review, several different study designs were found and were reported in different ways (peer-reviewed articles, poster presentations, book chapters, and conference reports). After a pairwise analysis and discussion between the team regarding the study design of the included studies, the documents were classified into seven categories according to the methodological approaches of the documents. The relationship between these categories, the number of documents, year of publications and study design of the included studies are presented in Figure 2.

The observational category contains nineteen cross-sectional studies, three retrospective studies and two prospective studies. Among the interventional studies, five were quasi-experimental studies, one was a randomized controlled feasibility study, one was a randomized controlled parallel-group trial, and one was a randomized, non-concurrent, multiple-baseline single-case design. The literature review category included four opinion studies with literature reviews, one systematic review with meta-analysis, two book chapters, and one Critically Appraised Topic (CAT). Consensus documents were categorized separately based on the

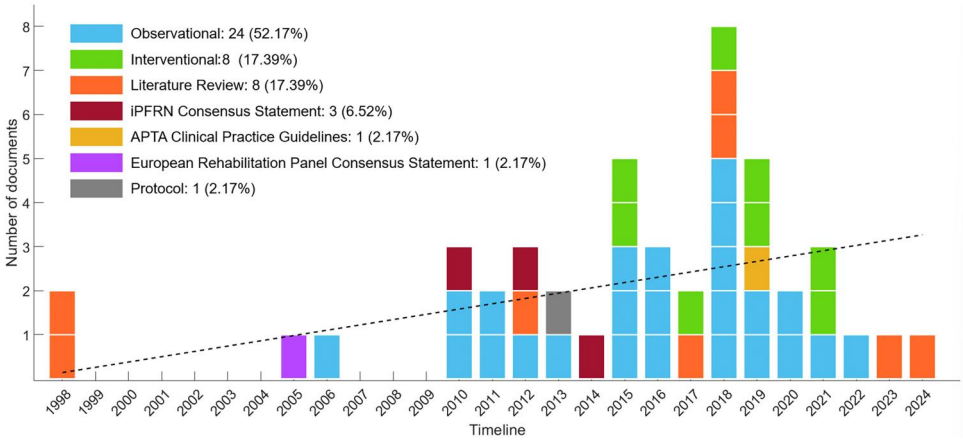

Figure 2. Relationship between categories, number of documents, year of publication and study design of the included documents.

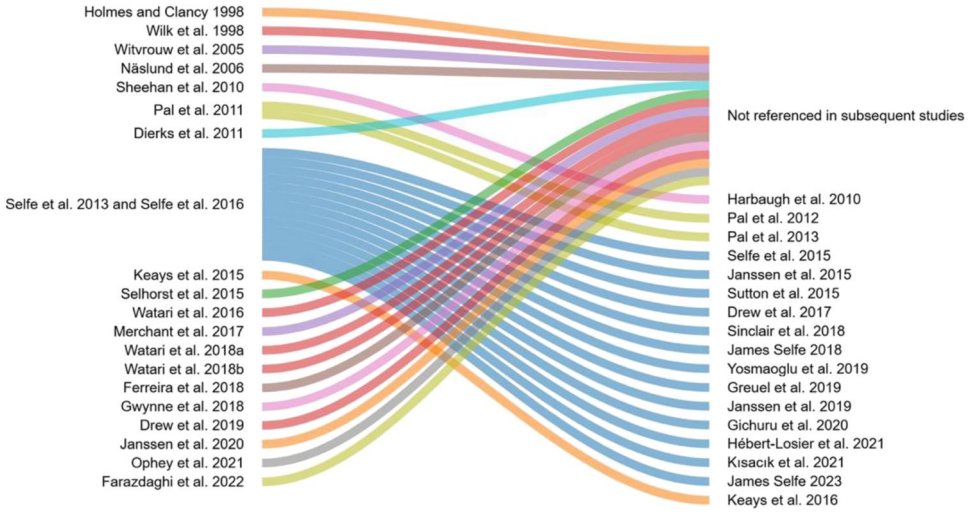

Figure 3. Relationship between studies that proposed original methods for stratifying individuals with PFP and subsequent studies that referenced these methods.

author group responsible for the development, and one was a protocol from one of the included studies.

Methods of stratification of patients with PFP

In this session all the studies that proposed new methods of stratification of individuals with PFP into subgroups were considered, in addition to the documents that referenced these methods in subsequent studies. Of the 46 documents included, twenty are original research that suggested new PFP subgroups. Four methods were replicated in subsequent studies [22–26]. Three of them were reproduced a maximum of two times [22,23,26], and one method was referenced in some way in thirteen other documents [25]. Figure 3 illustrates the relationship between the original subgroup documents and the studies that were carried out with these subgroups already described in the literature.

Critical appraisal within sources of evidence

Thirty-nine documents were evaluated, of which twenty-seven were considered to have low risk of bias (above 66.6%), twelve were considered to have moderate risk of bias (between 33.3% and 66.6%), and no studies were considered to have high risk of bias. The studies of Davis and Powers; Powers et al.; Callaghan; Selfe et al.; Witvrouw et al.; Willy et al.; and Selfe were not subject to critical appraisal due to the type of document (research retreat, book chapter, guideline and protocol) [6,10–12,16,17,24]. No studies were excluded based on quality, since one of the objectives of this review was to map and discuss all studies on the topic (Table 2).

Results of individual sources of evidence

The results of all the individual studies are summarized in Table 3.

Discussion

Summary of evidence

This scoping review aimed to map the literature on patellofemoral pain (PFP) subgroups and their development over time, identifying study designs, stratification methods that have been described and referenced in subsequent studies. Additionally, this study also aimed to discuss the methodological rigor and clinical applicability of the proposed methods. Our findings revealed a growing research interest in PFP subgrouping from 2010 onwards. Of the 46 studies included, over 50% were cross-sectional observational designs, while eight were interventional. Twenty studies introduced original subgrouping methods, but only four were cited in subsequent research. Three of them in no more than two articles, and one in thirteen articles.

PFP subgroups over time and study designs

The stratification of PFP into subgroups aims to improve treatment outcomes and became more prominent in the literature from the year 2010 according to our findings. One factor that may have contributed to this was the publication of the first consensus statement from the International Patellofemoral Research Network (iPFRN), published in 2010 [10]. The statement emphasized the need to identify subgroups of individuals with PFP to improve treatment strategies. This discussion continued during the second and third retreats organized by this research group in 2012 and 2014, respectively. Furthermore, both the European Rehabilitation Panel consensus published in 2006, and the Clinical Practice Guidelines of the American Physical Therapy Association (APTA) in 2019 describe the same narrative, highlighting that subgroups of PFP may exist. Therefore, the overall trend suggests that the interest in the topic has

Table 2. Results of critical appraisal of the included studies separated according to each JBI checklist used.

Individual studies	Items of the textual evidence: Expert opinion and narrative JBI checklists						Score
	1	2	3	4	5	6	
Holmes and Clancy [13]	Y	U	Y	Y	Y	N	4/6: 66.6%
Wilk et al. [14]	Y	U	Y	Y	Y	U	4/6: 66.6%
Witvrouw et al. [47]	Y	U	Y	Y	Y	Y	5/6: 83.3%
Merchant et al. [52]	Y	Y	Y	Y	Y	N	5/6: 83.3%
Selfe et al. [64]	Y	Y	Y	Y	Y	N	5/6: 83.3%
Selfe [65]	Y	Y	Y	Y	N	U	4/6: 66.6%

	Items of the Systematic Reviews and Research Syntheses checklist											
	1	2	3	4	5	6	7	8	9	10	11	
Saltychev et al. [66]	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	10/11: 90.90%
Meade et al. [21]	Y	Y	U	U	Y	U	U	N/A	N	Y	Y	5/11: 45.45%

	Items of the Cross-sectional JBI checklist								
	1	2	3	4	5	6	7	8	
Näslund et al. [48]	Y	N	Y	Y	N	N	Y	Y	5/8: 62.5%
Sheehan et al. [22]	Y	N	Y	Y	N	N	Y	Y	5/8: 62.5%
Dierks et al. [34]	Y	Y	Y	Y	N	N	Y	Y	6/8: 75%
Selfe et al. [25]	Y	Y	Y	Y	N	N	Y	Y	6/8: 75%
Ferreira et al. [37]	Y	Y	Y	Y	N	N	Y	Y	6/8: 75%
Gwynne et al. [67]	Y	Y	U	Y	N	N	U	Y	4/8: 50%
Watari et al. [36]	Y	Y	Y	Y	U	N	Y	Y	6/8: 75%
Janssen et al. [68]	Y	Y	U	Y	N	N	U	U	3/8: 37.5%
Hébert-Losier et al. [46]	Y	Y	U	Y	N	N	U	U	3/8: 37.5%
Farazdaghi et al. [39]	Y	Y	Y	Y	U	N	Y	Y	6/8: 75%
Janssen et al. [42]	Y	Y	Y	Y	Y	Y	Y	Y	8/8: 100%
Selfe et al. [41]	Y	Y	Y	Y	N	N	Y	Y	6/8: 75%
Sutton et al. [43]	Y	Y	Y	Y	N	N	Y	Y	6/8: 75%
Gichuru et al. [45]	Y	Y	Y	Y	U	N	Y	Y	6/8: 75%
Pal et al. [23]	Y	Y	Y	Y	U	N	Y	Y	6/8: 75%
Pal et al. [50]	Y	Y	Y	Y	N	N	Y	Y	6/8: 75%
Pal et al. [51]	Y	Y	Y	Y	N	N	Y	Y	6/8: 75%
Harbaugh et al. [49]	Y	U	Y	Y	U	N	Y	Y	5/8: 62.5%
Watari et al. [40]	Y	U	Y	Y	U	N	Y	Y	5/8: 62.5%
Watari et al. [35]	Y	Y	Y	Y	U	N	Y	Y	6/8: 75%
Janssen et al. [44]	Y	Y	Y	Y	U	N	Y	Y	6/8: 75%

	Items of the RCT JBI checklist													
	1	2	3	4	5	6	7	8	9	10	11	12	13	
Drew et al. [30]	Y	U	Y	N	N	Y	U	Y	Y	Y	Y	Y	Y	9/13: 69.23%
Kısacık et al. [32]	Y	Y	Y	U	N	Y	U	Y	Y	U	U	Y	Y	8/13: 61.53%

	Items of the quasi-experimental JBI checklist									
	1	2	3	4	5	6	7	8	9	
Keays et al. [26]	Y	N	N	N	Y	Y	Y	U	Y	5/9: 55.5%
Sinclair et al. [31]	Y	N	U	Y	Y	Y	Y	U	Y	6/9: 66.6%
Greuel et al. [27]	Y	N	Y	Y	Y	Y	Y	N/A	Y	7/9: 77.7%
Selhorst et al. [28]	Y	N	U	N/A	Y	Y	Y	N	Y	5/9: 55.5%
Yosmaoğlu et al. [29]	Y	N	Y	Y	Y	Y	Y	Y	Y	8/9: 88.8%
Ophey et al. [33]	Y	N	Y	Y	Y	Y	N	Y	U	6/9: 66.6%

	Items of the cohort JBI checklist											
	1	2	3	4	5	6	7	8	9	10	11	
Keays et al. [69]	Y	N/A	Y	N	N	Y	Y	Y	Y	N/A	Y	7/11: 63.63%
Drew et al. [38]	Y	Y	Y	Y	Y	Y	Y	Y	N/A	N/A	Y	9/11: 81.81%

Y: yes; N: no; U: unclear; N/A: Not applicable; RCT: Randomized Controlled Trial; JBI: Joanna Briggs Institute.

grown, with more researchers contributing to this field over the years.

With this increase in interest, various study designs have been used making it challenging to summarize results. The consideration of whether targeted treatments for specific subgroups of PFP are effective can only be explored through interventional studies. However, more than 50% of the included studies were cross-sectional observational studies and only eight were interventional studies, with one of these not evaluating the effects of a treatment regimen [27]. However, the findings from the interventional studies with a subgroup-based approach support the idea that considering patient subgroups with distinct characteristics leads to more effective outcomes compared to treating all individuals with PFP as a single and homogeneous group.

Interventional studies using PFP subgroups

Selhorst et al. concluded that a sequential treatment approach using a PFP treatment algorithm resulted in clinically significant improvements in function in 100% of patients who completed the protocol [28]. Keays et al. demonstrated that supplementing local knee-focused treatment tailored to address each patient's specific deficits led to further significant improvements in pain and function [26]. The study

Table 3. Evidence table with the individual results of the documents included in this review.

First author and year	Country	Journal/book	Title of the document	Study design and type of document	Aim	Sample characteristics	Subgroup suggestion or use of existing subgroup	Subgroups derived or used / key points about subgroup described in the document	What was the stratification based on?	Instrumentation or equipment required for stratification of subgroups***
Holmes and Clancy 1998 [13]	USA	Journal of Orthopaedic & Sports Physical Therapy	Clinical Classification of Patellofemoral Pain and Dysfunction	Literature Review/Clinical commentary Research article	'This article discusses previously published classification systems for patellofemoral disorders and outlines the rationale for and diagnostic categories of the patellofemoral classification system we are currently using.'	N/A	Suggestion	Three broad categories: - Patellofemoral instability - PFP with malalignment but no episodes of instability - PFP without malalignment *Subclassifications: 60 subgroups in total	Literature review	Radiographic imaging device****
Wilk et al. 1998 [14]	USA	Journal of Orthopaedic & Sports Physical Therapy	Patellofemoral Disorders: A Classification System and Clinical Guidelines for Nonoperative Rehabilitation	Literature Review/ Clinical commentary Research article	'The purpose of this article is to introduce a classification system that may be used as the foundation for treatment strategies and interventions for nonsurgical management of patients with patellofemoral pain.'	N/A	Suggestion	Eight major groups: - Patellar compression syndromes - Patellar instability - Biomechanical dysfunction - Direct patellar trauma - Soft tissue lesions - Overuse syndromes - Osteochondritis diseases - Neurologic disorders *Subdivisions: 26 subgroups in total	Literature review	Goniometers Tape measures Calipers
Witvrouw et al. 2005 [47]	Belgium	Knee Surgery, Sports Traumatology, Arthroscopy	Clinical classification of patellofemoral pain syndrome: guidelines for non-operative treatment	Literature Review/ Consensus Statement (European Rehabilitation Panel) Research article	'The aim of this study with a classification system was to guide the clinician through clinical examination in order to develop a nonoperative treatment protocol, specific for each individual with PFPS.'	N/A	Suggestion	- Malalignment • Malalignment of entire leg • Malalignment of PF joint ○ Non-muscular origin ○ Muscular origin - Muscular dysfunction • Strength deficit ○ Vastus medialis obliquus (VMO) ○ Quadriceps • Neuromuscular dysfunction ○ VMO/vastus lateralis timing dysfunction • Flexibility ○ Hamstrings, quadriceps, gastrocnemius, iliotibial band	- Consensus of meetings and discussions reached by the European Rehabilitation Panel - Clinical observation - Literature review	- Tape measure - Goniometer - Measuring rod - Radiographic imaging device****
Näslund et al. 2006 [48]	Sweden	Physiotherapy Theory and Practice	Comparison of symptoms and clinical findings in subgroups of individuals with patellofemoral pain	Observational Cross-sectional study Research article	'The aim of the present study was to investigate if commonly used symptoms and clinical findings are useful in diagnosing subgroups of individuals with PFPS, according to findings in radiological examinations.'	- 75 PFP 20-49y GA: 19 F/10M GB:15F/14M GC: 12 F/5M - 48 Control 20-49y 30F/18M	Suggestion	- IAKP - Slow bone turnover disease - Diagnoses of pathology	- Radiographic examination - Scintigraphy - Patient history - Clinical tests	- Radiographic imaging device - Scintillation camera - Goniometer
Davis and Powers 2010 [10]	EUA	Journal of Orthopaedic & Sports Physical Therapy	Patellofemoral Pain Syndrome: Proximal, Distal, and Local Factors. An International Research Retreat	Consensus statement Conference report	'The mission of this first international research retreat was to bring scientists together from around the world who were conducting research aimed at understanding the factors that are related to the development, and consequently the treatment, of PFPS.'	N/A	N/A	- 'Identification of subgroups of people with PFPS is needed. Features of an individual that may influence response to treatment include age (adolescents, adults, etc), patellofemoral joint stability (e.g. subluxation/instability), chronicity, contributing factors (biomechanics, muscle function, alignment), contributing factors (local, proximal, distal), and source of pain. - 'High-quality randomized clinical trials for novel interventions (e.g. gait retraining) are strongly encouraged. However, these treatments should either be targeted to those subgroups of people who are most likely to	N/A	N/A

(*continued*)

Table 3. Continued.

First author and year	Country	Journal/book	Title of the document	Study design and type of document	Aim	Sample characteristics	Subgroup suggestion or use of existing subgroup	Subgroups derived or used / key points about subgroup described in the document	What was the stratification based on?	Instrumentation or equipment required for stratification of subgroups***
								benefit, or the randomized clinical trials should be sufficiently powered to enable the development of clinical prediction rules.' - 'Today's scientific insight in this pathology tends to show us that not every patient with PFPS has the same "abnormalities." Therefore, a standard treatment for PFPS does not exist, and a tailor made approach is preferred.' - 'PFP does not have a homogenous presentation.' - 'Future research should focus on the identification of subgroups of people with PFP, and the efficacy of targeted interventions for these subgroups.'		
Sheehan et al. 2010 [22]	USA	Clinical Orthopaedics and Related Research	Q-angle and J-sign. Indicative of Maltracking Subgroups in Patellofemoral Pain	Observational Cross-sectional study Research article	'The primary objective was to test the hypothesis that increased Q-angle, lateral hypermobility, and the presence of a J-sign are correlated with the patellar lateral position, relative to the femur, in terminal extension. The secondary objective was to explore whether more than one maltracking pattern could be discriminated, based on PF displacements and rotations.'	- 19 PFP (30 knees) • Lateral maltrackers: 29.3 y, 14 F/3M • Non-lateral maltrackers: 27.9 y, 12 F/1M - 28 control (37 knees) 26.3y 22F,15M	Suggestion	- Nonlateral maltrackers - Lateral maltrackers	Dynamic 3D Magnetic Resonance Imaging	Magnetic Resonance Imaging scanner
Harbaugh et al. 2010 [49]	USA	Journal of Orthopaedic Research	Correlating Femoral Shape with Patellar Kinematics in Patients with Patellofemoral Pain	Observational Cross-sectional Retrospective study Research article	'Quantify femoral and patellar shape in the context of 3D PF kinematics of asymptomatic subjects and patients with PF pain and maltracking ("maltrackers") to test three hypotheses: 1) femoral and patellar shape parameters are different between these cohorts; 2) these same parameters differ between kinematicallyunique subgroups within the maltrackers; and 3) the influence of femoral shape on PF kinematics differs between kinematically-unique subgroups of maltrackers.'	- 30 PFP knees Maltrackers: 27.6 y, 26 F/4M • Non-lateral maltrackers: 27.9 y, 12 F/1M • Lateral maltrackers: 27.4 y, 14 F/3M - 33 Control 24.9y 16F,17M	Existing subgroup [22]	- Non-lateral maltrackers - Lateral maltrackers	3D dynamic MRI	Magnetic Resonance Imaging scanner
Pal et al. 2011 [23]	USA	American Journal of Sports Medicine	Patellar Maltracking Correlates With Vastus Medialis Activation Delay in Patellofemoral Pain Patients	Observational Cross-sectional Case control study Research article	'The purpose of this study was to determine if classifying patellofemoral pain patients into subgroups would lend insight into the large variation in VM activation delay.'	- 40 PFP 28.9y 19F, 21 M - 15 control 28.2y 8F, 7 M	Suggestion	- Normal trackers - Maltrackers: tilt or bisect offset - Maltrackers: tilt and bisect offset	Patellar tracking measures obtained using weightbearing Magnetic Resonance Imaging (MRI)	Magnetic Resonance Imaging scanner

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First author and year	Country	Journal/book	Title of the document	Study design and type of document	Aim	Sample characteristics	Subgroup suggestion or use of existing subgroup	Subgroups derived or used / key points about subgroup described in the document	What was the stratification based on?	Instrumentation or equipment required for stratification of subgroups***
Dierks et al. 2011 [34]	USA	Medicine & Science in Sports & Exercise	Lower Extremity Kinematics in Runners with Patellofemoral Pain during a Prolonged Run	Observational Cross-sectional study Research article	'The purpose of this study was to investigate the influence of exerted state running on lower extremity kinematics during the stance phase in runners with PFP while compared with controls.'	- 20 PFP 24.1 y 15F,5M - 20 control 22.7y 15F, 5 M	Suggestion	- PFP valgus - PFP Hip Abd - PFP other	3D Kinematic data	3D Motion Capture System
Callaghan 2012 [16]	UK	Sports Injuries (Book)	Will Sub-classification of Patellofemoral Pain Improve Physiotherapy Treatment?	Literature Review Book chapter	'In order to ascertain the success of non-operative treatments, a detailed literature search was performed between 1950 and August 2009.'	N/A	N/A	- 'It is becoming more accepted amongst experts in the diagnosis and conservative treatment PFPS that there may be subgroups of patients who display several characteristics known to be associated with this condition.' - 'Future trials are urgently required to evaluate targeted treatments for patellofemoral pain to establish if subclassifying PFPS in order to provide the appropriate treatment makes any difference to the outcome.' - 'To date there has not been a study to fully attempt subclassification followed by an RCT that tailors conservative treatment to the patient depending on their subgroup characteristics. Such a study using a blinded, randomised controlled design would have to ascertain if patients who are sub-classified with certain characteristics of PFPS demonstrated improvement from a specific 'tailored' approach to physiotherapy treatment rather than from the usual 'generalised' approach.'	N/A	N/A
Pal et al. 2012 [50]	USA	Journal of Orthopaedic Research	Patellar tilt correlates with vastus lateralis:vastus medialis activation ratio in maltracking patellofemoral pain patients	Observational Cross-sectional study Research article	'The purpose of this study was develop a method for classifying PF pain subjects using patellar tracking measures obtained under weightbearing conditions.'	- 39 PFP 28.4y - 15 control 30.9y	Existing subgroup [23]	- -Normal trackers - -Maltrackers	Patellar tracking measures obtained using weightbearing Magnetic resonance (MRI)	Magnetic Resonance Imaging scanner
Powers et al. 2012 [11]	USA (first author) Ghent (Host of the conference)	Journal of Orthopaedic & Sports Physical Therapy	Patellofemoral Pain: Proximal, Distal, and Local Factors: 2nd International Research Retreat	Consensus statement Conference Report	'The mission of the second International Patellofemoral Pain Research Retreat was to bring together scientists and clinicians from around the world who are conducting research aimed at understanding the factors that contribute to the development, and consequently the treatment, of PFP.'	N/A	N/A	- 'One potential source for this inter-subject variability is the likely presence of subgroups 47,53 within the general population of individuals experiencing maltracking.' - 'These studies should make every attempt to explain the pathway to pain for each subject (or subgroup of patients) within the study, as opposed to assuming that individuals who do not fit within the primary theories being tested are "outliers" and can be eliminated from the analysis or ignored in discussing the results.' - 'Clinically this may be related to a subgroup of patients whose pain is associated with low environmental temperatures and poor rehabilitation outcomes' - 'Clinical prediction rules are needed to identify a subgroup of individuals who may have developed PFP from altered hip neuromechanics.'	N/A	N/A

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First author and year	Country	Journal/book	Title of the document	Study design and type of document	Aim	Sample characteristics	Subgroup suggestion or use of existing subgroup	Subgroups derived or used / key points about subgroup described in the document	What was the stratification based on?	Instrumentation or equipment required for stratification of subgroups***
Pal et al. 2013 [51]	USA	Journal of Orthopaedic Research	Patellar maltracking is prevalent among patellofemoral pain subjects with patella alta: an upright, weightbearing MRI study	Observational Cross-sectional study Research article	'The purpose of this study was to investigate the relationship between patella height and patella tracking in PF pain subjects.'	- 37 PFP 30.9y 20F,17M - 15 control 28.4y 8F,7M	Existing subgroup [23]	- Normal trackers - Maltrackers with patella alta - Maltrackers with normal patella height	Patellar tracking measures and height obtained using weightbearing Magnetic resonance (MRI)	Magnetic Resonance Imaging scanner
Selfe et al. 2013 [24]	UK	BMJ Open	Targeted interventions for patellofemoral pain syndrome (TIPPS): classification of clinical subgroups	Study Protocol	'To provide information on the clinical utility of subgrouping patients with PFP.'	N/A	Suggestion (Protocol of Selfe et al. 2016) [25]	- Strong subgroup - Weak and Tight subgroup - Pronated feet subgroup	- TIPPs clinical tests: Hip abductor weakness Quadriceps weakness Patellar hypomobility Patellar hypermobility Pronated foot posture Lower limb biarticular muscle tightness	- Handheld dynamometer (Lafayette Instrument Company, model 01165, Lafayette, IN, USA) - Stabilization strap - Tape measure - Pen - Digital inclinometer
Witvrouw et al. 2014 [12]	Qatar (First author) Canada (Conference)	British Journal of Sports Medicine	Patellofemoral pain: consensus statement from the 3rd International Patellofemoral Pain Research Retreat held in Vancouver, September 2013	Consensus statement Conference report	'The mission of the 3rd International Patellofemoral Research Retreat was to improve our understanding concerning the factors that contribute to the development and consequently to the treatment of PFP.' 'The aim was to provide clinicians with updated knowledge of PFP, thus enabling them to integrate this knowledge into their clinical practice.'	N/A	N/A	- 'Identification of different subgroups of people with PFP remains a goal. These subgroups could be based on pain types (e.g. nociceptive pain or central sensitisation), or on different structural or biomechanical features. Investigations could then investigate whether different subgroups influence the large individual variation in outcome results after a physiotherapy programme.' - 'Similar to the recommendations for local factors, identification of subgroups remains the 'holy grail' for PFP research. These studies could yield insights into the pathophysiology of PFP and provide targets for treatment (i.e. addressing strength or gait impairments).' - 'There have been initial attempts to classify patients by aetiological subgroup. Additional work should continue in this area to attempt to classify patients for targeted interventions.'	N/A	N/A
Keays et al. 2015 [26]	Australia	Physiotherapy Research International	Individualized Physiotherapy in the Treatment of Patellofemoral Pain	Interventional Quasi-experimental study Research article	'The aim of this study was establish the effect of supplementing local treatment for PFP with individualized treatment targeted to each patient's specific global deficit and possible underlying cause of PFP. Secondarily, we aimed to sub-group our patients according to their deficits.'	41 PFP (60 knees) 13–82 y 26F,15M	Suggestion	- Hypermobile stance group - Dynamic knee valgus group - Hypomobile group - Patellofemoral osteoarthritis group	- Global measures based on clinical findings and Radiographic examination	- Cybex II dynamometer (Cybex, a division of Lumex, Inc, Ronkonkoma, NY, USA) - Goniometer - Radiographic imaging device
Selfe et al. 2015 [41]	UK	Physiotherapy	Targeted intervention for patellofemoral pain (TIPPS): identifying potential clinical subgroups	Observational Cross-sectional study Poster presentation	'The main purpose of this study was to describe the distribution of PFP patients into different subgroups using six routine clinical assessment test criteria.'	127 PFP 26y 66%F, 34%M	Existing subgroup [25]	- Strong subgroup - Weak and Tight subgroup - Pronated feet subgroup	- TIPPs Clinical tests: Hip abductor weakness Quadriceps weakness Patellar hypomobility Patellar hypermobility Pronated foot posture	- Handheld dynamometer (Lafayette Instrument Company, model 01165, Lafayette, IN, USA)

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First author and year	Country	Journal/book	Title of the document	Study design and type of document	Aim	Sample characteristics	Subgroup suggestion or use of existing subgroup	Subgroups derived or used / key points about subgroup described in the document	What was the stratification based on?	Instrumentation or equipment required for stratification of subgroups***
									Lower limb biarticular muscle tightness	- Stabilization strap - Tape measure - Pen - Digital inclinometer
Janssen et al. 2015 [42]	UK	Physiotherapy	Targeted intervention for patellofemoral pain (TIPPS): psychosocial characteristics of clinical subgroups	Observational Cross-sectional study Poster presentation	'The main objective of this study was to explore interactions between demographic, clinical and psychosocial characteristics and clinical subgroups.'	127 PFP 26y 66%F, 34%M	Existing subgroup [25]	- Strong subgroup - Weak and Tight subgroup - Pronated feet subgroup	- TIPPs Clinical tests: Hip abductor weakness Quadriceps weakness Patellar hypomobility Patellar hypermobility Pronated foot posture Lower limb biarticular muscle tightness	- Handheld dynamometer (Lafayette Instrument Company, model 01165, Lafayette, IN, USA) - Stabilization strap - Tape measure - Pen - Digital inclinometer
Sutton et al. 2015 [43]	UK	Trials	Identification of strata for a trial of a targeted multimodal physiotherapy intervention in patellofemoral pain patients	Observational Cross-sectional study Poster presentation	'It has been proposed that there are PFP patient strata, classified based on clinical tests, who would respond to modes of interventions targeted at the individual's stratum.'	127 PFP 26y 66%F, 34%M	Existing subgroup [25]	- Strong subgroup - Weak and Tight subgroup - Pronated feet subgroup	- TIPPs Clinical tests: Hip abductor weakness Quadriceps weakness Patellar hypomobility Patellar hypermobility Pronated foot posture Lower limb biarticular muscle tightness	- Handheld dynamometer (Lafayette Instrument Company, model 01165, Lafayette, IN, USA) - Stabilization strap - Tape measure - Pen - Digital inclinometer
Selhorst et al. 2015 [28]	USA	The International Journal of Sports Physical Therapy	Evaluation of a treatment algorithm for patients with patellofemoral pain syndrome: a pilot study	Interventional Randomized controlled pilot trial Research article	'The purpose of this pilot study was to determine the feasibility of (1) Appropriately delivering the PFPS algorithm in the clinic setting; (2) Recruiting enough patients to perform a full RCT; (3) Outcome measures appropriate to assess the outcomes of a full RCT.'	21 PFP 14.10 y 14F, 7 M	Suggestion	- Fear of avoidance subgroup - Lower extremity flexibility subgroup - Functional malalignment subgroup - Strengthening subgroup	Classification system (PFPS algorithm) based on the patient's clinical presentation	- Digital inclinometer - Goniometer
Keays et al. 2016 [69]	Australia	Clinical Journal of Sport Medicine	Three-Year Outcome After a 1-Month Physiotherapy Program of Local and Individualized Global Treatment for Patellofemoral Pain Followed by Self-Management	Observational Prospective Cohort study Research article	'The primary aim of this 3-year study was to establish whether the improvement in 7 outcome measures after a 1-month program, targeting both local and individual global deficits, would be maintained. Secondarily, this study aimed to assess long-term return-to-sport activities and recurrence of pain. In addition, it aimed to assess exercise compliance. The final aim was to determine whether long-term outcomes were related to the initial local treatment grouping, the global physical subgroups, or to gender, laterality, age, or chronicity.'	37 PFP (55 knees) 13–82 y 23F,14M	Existing subgroup [26]	- Hypermobile stance group - Dynamic knee valgus group - Hypomobile group - Patellofemoral osteoarthritis group	Global measures based on clinical findings	- Cybex II dynamometer (Cybex, a division of Lumex, Inc, Ronkonkoma, NY, USA) - Goniometer - Radiographic imaging device

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First author and year	Country	Journal/book	Title of the document	Study design and type of document	Aim	Sample characteristics	Subgroup suggestion or use of existing subgroup	Subgroups derived or used / key points about subgroup described in the document	What was the stratification based on?	Instrumentation or equipment required for stratification of subgroups***
Watari et al. 2016 [40]	Canada	Clinical Biomechanics	Determination of patellofemoral pain sub-groups and development of a method for predicting treatment outcome using running gait kinematics	Observational Cross-sectional Retrospective study Research article	'The purpose of this study was to use baseline 3-dimensional (3D) running gait kinematic data and self-reported pain and function measures to classify recreationally active individuals experiencing PFP with respect to whether they were Responders or Non-responders to a 6-week rehabilitation protocol.'	- 41 PFP 29F,12M - 26 PFP 30.7y 14F, 12 M - 31 Control 17F, 14 F	Suggestion	- Responders - Non-responders • Greater ankle dorsiflexion during swing phase • Greater knee abduction during swing phase • Greater hip flexion during swing phase - Greater ankle inversion during stance phase	3D gait analysis	-Gait Analysis Systems (Inc., Calgary, Alberta, Canada)
Selfe et al. 2016 [25]	UK	British Journal of Sports Medicine	Are there three main subgroups within the patellofemoral pain population? A detailed characterization study of 127 patients to help develop targeted intervention (TIPPs)	Observational Cross-sectional study Research article	'Four objectives were identified: 1. To determine the relative frequency with which the patients fell into each of the potential subgroups defined by the à priori test thresholds. 2. To assess whether the potential subgroups defined by the à priori test thresholds were mutually exclusive or whether, and how frequently, patients fell into two or more subgroups. 3. To ascertain whether other approaches such as hierarchical clustering and latent profile analysis, offered additional insights into subgrouping of patients with PFP using data from the same clinical assessment tests. 4. To report differences in patient-related characteristics (demographic, clinical and psychosocial) across subgroups.'	127 PFP 26y 66%F, 34%M	Suggestion	- Strong subgroup - Weak and Tight subgroup - Pronated feet subgroup	- TIPPs Clinical tests: Hip abductor weakness Quadriceps weakness Patellar hypomobility Patellar hypermobility Pronated foot posture Lower limb biarticular muscle tightness	- Handheld dynamometer (Lafayette Instrument Company, model 01165, Lafayette, IN, USA) - Stabilization strap - Tape measure - Pen - Digital inclinometer
Merchant et al. 2017 [52]	USA	The American Journal of Orthopedics	The Diagnosis and Initial Treatment of Patellofemoral Disorders	Literature Review Research article	'Our purpose is to provide simple guidelines for the diagnosis and early care of patellofemoral disorders.'	N/A	Suggestion	- Vastus medialis obliquus deficiency - Medial patellofemoral ligament laxity - Lateral retinaculum tightness - Increased quadriceps angle - Hip abductor weakness - Patella *alta* - Trochlear dysplasia	Clinical classification based on etiology	Radiographic imaging device
Drew et al. 2017 [30]	UK	BMC Musculoskeletal Disorders	The effect of targeted treatment on people with patellofemoral pain: a pragmatic, randomised controlled feasibility study	Interventional Randomised Controlled Feasibility study Research article	'The primary purpose of this study was therefore to explore the feasibility of treatment matched to the specific clinical criteria of a selected subgroup	- 14 PFP (MT group) 29.1y 7F, 7 M - 12 PFP (UC group) 29.3y 8F, 4 M	Existing subgroup [25]	-Hip weakness	Hip abductor strength	Biodex isokinetic system 4 (IRPS Mediquipe, UK).

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First author and year	Country	Journal/book	Title of the document	Study design and type of document	Aim	Sample characteristics	Subgroup suggestion or use of existing subgroup	Subgroups derived or used / key points about subgroup described in the document	What was the stratification based on?	Instrumentation or equipment required for stratification of subgroups***
					compared to usual care (UC) management to inform a future stratified approach to PFP treatment. The a priori selection of a subgroup with a specific characteristic such as hip abductor weakness also provides the opportunity, as a secondary aim, to explore the mechanism of effect as this has also been recently advocated for trials of physical interventions.'					
Selfe et al. 2018 [64]	UK	Annals of Joint	Anterior knee pain subgroups: the first step towards a personalized treatment	Literature Review Research article	'This paper reviews early attempts at PFP subgrouping and introduces readers to some of the modern methodological approaches employed to derive subgroups.'	N/A	N/A	- 'High quality empirical studies confirm that a multimodal approach confers some benefits to patients such as improved pain, function and quality of life, in the short term. However, there is limited evidence to support the longer-term outcomes of a multimodal treatment approach. In view of the limited benefit and lack of evidence of the long-term success of the multimodal approach, support for the idea of subgrouping patients with PFP has grown in recent years, especially as this approach has proved effective for optimizing management in other musculoskeletal conditions, such as, low back pain'	N/A	N/A
Watari et al. 2018 [35]	Canada	BMC Musculoskeletal disorders	Runners with patellofemoral pain demonstrate sub-groups of pelvic acceleration profiles using hierarchical cluster analysis: an exploratory cross-sectional study	Observational Cross-sectional study Research article	'The purpose of this exploratory study was to determine if running gait patterns in PFP runners could be clustered into homogeneous sub-groups using pelvic acceleration data, using a large dataset of males and females with PFP. A secondary purpose was to analyze kinematic differences between the sub-groups, by comparing lower limb peak angles that are considered important in the pathomechanics of PFP and thereby investigate the practical and clinical implications of clustering these subjects based on 3D pelvic acceleration data.'	110 PFP 66F, 44 M Physically active	Suggestion	Running gait sub-groups: - C1 - C2	Pelvic acceleration patterns during running	- 8 high-speed digital video cameras (MX3/ Nexus, Vicon, Oxford, UK) - Treadmill
Ferreira et al. 2018 [37]	Brazil	Gait and Posture	Which is the best predictor of excessive hip internal rotation in women with patellofemoral pain: Rearfoot eversion or hip	Observational Cross-sectional study Research article	'The aim of this study was: (i) to investigate if the peak rearfoot eversion during stair ascent and/or the peak concentric abductor	37 PFP 22y 37F	Suggestion	- Excessive rearfoot eversion subgroup - Non-excessive rearfoot eversion subgroup	3D motion analysis	- 3D motion analysis system (Vicon Motion Systems Inc.; Denver EUA) - Force plate

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First author and year	Country	Journal/book	Title of the document	Study design and type of document	Aim	Sample characteristics	Subgroup suggestion or use of existing subgroup	Subgroups derived or used / key points about subgroup described in the document	What was the stratification based on?	Instrumentation or equipment required for stratification of subgroups***
			muscle strength? Exploring subgroups		muscle strength can predict peak hip internal rotation during stair ascent in women with PFP.'					(Bertec Corporation, Columbus, OH, model FP4060) - Isokinetic dynamometer (Biodex System 4 Pro, New York, USA)
Gwynne et al. 2018 [67]	UK	Clinical biomechanics	Two-dimensional frontal plane projection angle can identify subgroups of patellofemoral pain patients who demonstrate dynamic knee valgus	Observational Cross-sectional study Research article	'The aim of the study was to assess for dynamic knee valgus in individuals with and without PFP by determining frontal plane knee alignment (2-D FPPA) during single limb stance and SLS.'	- 30 PFP 30.6y 18F, 12 M - 30 controls 29.9y 15F, 15 M	Suggestion	-Dynamic knee valgus	Clinical classification of two-dimensional frontal plane knee alignment	Two digital video cameras (Sony Handycam DCR-HC37, Tokyo, Japan)
Sinclair et al. 2018 [31]	UK	Physical Therapy in Sport	Effects of a 4-week intervention using semi-custom insoles on perceived pain and patellofemoral loading in targeted subgroups of recreational runners with patellofemoral pain	Interventional Quasi-experimental study Research article	'The current study aimed to explore the effects of a 4-week intervention using semi-custom foot insoles on pain symptoms and patellofemoral loading in subgroups of recreational runners.'	17 PFP in total 7F, 10 M —11 PFP strong 33.6y —6 PFP W&T 34.8y	Existing subgroup [25]	- Strong subgroup - Weak and tight subgroup	- TIPPs Clinical tests: Hip abductor weakness Quadriceps weakness Patellar hypomobility Patellar hypermobility Pronated foot posture Lower limb biarticular muscle tightness	- Handheld dynamometer (Lafayette Instrument Company, model 01165, Lafayette, IN, USA) - Stabilization strap - Tape measure - Pen - Digital inclinometer
Saltychev et al. 2018 [66]	Finland	Journal of Rehabilitation Medicine	Effectiveness of conservative treatment for patellofemoral pain syndrome: a systematic review and meta-analysis	Systematic Review with Meta-analysis Research article	'To evaluate the evidence regarding the effectiveness of conservative treatment in reducing patellofemoral pain.'	N/A	N/A	'Thus, the possibility of a particular treatment being effective for specific subgroups of patients with PFP should be taken into account.' 'Future studies should examine whether subgroups of patients with PFP with different characteristics might benefit differently from particular treatments.' 'There is limited evidence that some treatments modalities may be beneficial for some subgroups of patients with PFP.'	N/A	N/A
Selfe 2018 [65]	UK	NMU Commons	Patellofemoral subgroups, a low cost clinical approach with a surprise or two!	Keynote Lecture Abstract	This presentation summarises the results of the Targeted Interventions for Patellofemoral Pain (TIPPs) programme of research that has led to the development of a robust simple hierarchical algorithm.	N/A	Existing subgroup [25]	Strong (22% of participants) Weak and tight (39% of participants) Weak and pronated (39% of participants)	TIPPs Clinical tests	N/A
Watari et al. 2018 [36]	Canada	Clinical Biomechanics	Use of baseline pelvic acceleration during running for classifying response to muscle strengthening treatment in patellofemoral pain: A preliminary study	Observational Cross-sectional Retrospective study Research article	The primary aim of this study was to determine whether pelvic acceleration measures during running, in conjunction with clinical and demographic variables could classify PFP patients according to their response to muscle strengthening treatment following a 6-week hip/ core and knee	28 PFP (Responders) 28.5y 18F, 10 M 13 PFP (Non-Responders) 33y 11F, 2 M Physically active young adults	Suggestion	- Responders - Non-responders	Response to exercise-based treatment based on a combination of three components of the pelvic accelerations	- 8 high-speed digital video cameras (MX3/ Nexus, Vicon, Oxford, UK) - Treadmill

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Table 3. Continued.

First author and year	Country	Journal/book	Title of the document	Study design and type of document	Aim	Sample characteristics	Subgroup suggestion or use of existing subgroup	Subgroups derived or used / key points about subgroup described in the document	What was the stratification based on?	Instrumentation or equipment required for stratification of subgroups***
					exercise-based rehabilitation protocol. We also aimed to perform an exploratory analysis of the differences in baseline pelvic acceleration between those same sub-groups.					
Greuel et al. 2019 [27]	UK	The Knee	How does acute pain influence biomechanics and quadriceps function in individuals with patellofemoral pain?	Interventional Quasi-experimental study Research article	'This study aimed to investigate the direct effect of acute PFP on quadriceps strength and arthrogenic muscle inhibition, quadriceps and hamstrings co-contraction and hip and knee biomechanics.'	21 PFP 29.7y 10F, 11 M	Existing subgroup [25]	-Strong subgroup*	N/A	N/A
Drew et al. 2019 [38]	UK	Journal of Orthopaedic & Sports Physical Therapy	Toward the Development of DataDriven Diagnostic Subgroups for People with Patellofemoral Pain Using Modifiable Clinical, Biomechanical, and Imaging Features	Observational Prospective Cohort study Research article	'The primary aim of this study was to combine modifiable clinical, biomechanical, and imaging features to identify potential data-driven diagnostic subgroups within a PFP cohort. Based on data from a 12-month follow-up, the secondary aim was to explore the prognosis of these data-driven subgroups.'	70 PFP 31.03y 43F, 27 M	Suggestion	- Strong subgroup - Pronation and malalignment - Weak subgroup - Active and flexible subgroup	Clinical, biomechanical and MRI imaging features	- Magnetic resonance imaging - Digital inclinometer - Motion-capture system (Vicon Nexus Version 1.6; Oxford Metrics, Yarnton, UK) - Isokinetic Biodex System 4 (Biodex Medical Systems, Shirley, NY)
Yosmaoğlu et al. 2019 [29]	UK	Sports Health: A Multidisciplinary approach	Targeted Treatment Protocol in Patellofemoral Pain: Does Treatment Designed According to Subgroups Improve Clinical Outcomes in Patients Unresponsive to Multimodal Treatment?	Interventional Prospective Crossover study Research article	'The purpose of this study was to assess the clinical outcomes of targeted treatments designed according to the characteristics of these 3 subgroups of PFP patients.'	–61 PFP 27y	Existing subgroup [25]	- Strong subgroup - Weak and Tight subgroup - Pronated feet subgroup	- TIPPs Clinical tests: Hip abductor weakness Quadriceps weakness Patellar hypomobility Patellar hypermobility Pronated foot posture Lower limb biarticular muscle tightness	- Handheld dynamometer (Lafayette Instrument Company, model 01165, Lafayette, IN, USA) - Stabilization strap - Tape measure - Pen - Digital inclinometer
Janssen et al. 2019 [44]	UK	Physiotherapy Practice and Research	How useful is a single measurement of patellar mobility in the assessment of patients with patellofemoral pain?	Observational Cross-sectional study Research article	'Therefore, in this study, we examined the stability of the data from the medial-lateral patellar glide test across sequential measurements. Additionally, we aimed to measure patellar mobility in a group of young adults without a recent history of knee pain, to provide data for comparison with that of patellofemoral pain patients.'	22 Healthy 26 y 13F, 9 M 127 PFP 26 y 66%F, 33%M	Existing subgroup [25]	- Strong subgroup - Weak and Tight subgroup - Pronated feet subgroup	- TIPPs Clinical tests: Total medial-lateral patellar glide test	- Tape measure - Tape
Willy et al. 2019 [6]	USA	Journal of Orthopaedic & Sports Physical Therapy	Patellofemoral Pain Clinical Practice Guidelines Linked to the International Classification of Functioning, Disability and Health from the Academy of Orthopaedic Physical Therapy of the American	Literature Review/Consensus statement Guideline	'The objectives of these clinical guidelines are as follows: Describe evidence-based physical therapy practice, including diagnosis, prognosis, intervention, and assessment of outcome, for musculoskeletal disorders	N/A	N/A	- Future high-quality RCTs should utilize appropriately powered sample sizes to more clearly identify subgroups of people, such as individuals with painful resisted knee extension' - 'Multiple biomechanical and neuromusculoskeletal factors related to the knee, hip, ankle, and trunk/pelvis	N/A	N/A

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Table 3. Continued.

First author and year	Country	Journal/book	Title of the document	Study design and type of document	Aim	Sample characteristics	Subgroup suggestion or use of existing subgroup	Subgroups derived or used / key points about subgroup described in the document	What was the stratification based on?	Instrumentation or equipment required for stratification of subgroups***
			Physical Therapy Association		commonly managed by orthopaedic physical therapists; Classify and define common musculoskeletal conditions using the World Health Organization's terminology related to impairments of body function and body structure, activity limitations, and participation restrictions.'			have been reported to be associated with PFP. Similar to low back pain, clinicians recognize that PFP is not a homogeneous condition, and response to intervention varies. As a result, several classification systems with subcategories of PFP have been proposed for nonsurgical management of patients. Many of these classification systems are based on proposed pathoanatomical diagnoses, which rely on diagnostic imaging or surgical findings. These classification systems are of limited utility for physical therapists because they do not include clear diagnostic criteria for each subcategory, or they rely on imaging or surgical findings that may not always be available to the physical therapist at the initial encounter.'		
Gichuru et al. 2020 [45]	UK	Physiotherapy	Validation of presence of three main subgroups identified within a UK patellofemoral pain population (PFP) using a Turkish data set	Observational Cross-sectional study Poster presentation	'The objective of the study was to validate the presence of the previously identified three main subgroups within a UK patellofemoral pain population (PFP) using a Turkish PFP data set.'	85 PFP 26y 74%F, 26%M	Existing subgroup [25]	- Strong subgroup - Weak and Tight subgroup - Pronated feet subgroup	- TIPPs Clinical tests: Hip abductor weakness Quadriceps weakness Patellar hypomobility Patellar hypermobility Pronated foot posture Lower limb biarticular muscle tightness	- Handheld dynamometer (Lafayette Instrument Company, model 01165, Lafayette, IN, USA) - Stabilization strap - Tape measure - Pen - Digital inclinometer
Janssen et al. 2020 [68]	UK	Physiotherapy	Hot and cold knees: exploring differences in patella skin temperature in patients with patellofemoral pain	Observational Cross-sectional study Research article	'To investigate the distribution of patella skin temperature (Tsk) measurements and to explore the presence of temperature subgroups in patellofemoral pain (PFP) patients.'	- 232 PFP TIPPs: 26.5 y, 66%F, Turkish: 26.1 y, 74%F London: 30.7 y, 67%F - 58 Healthy 28.7y 38%F	Suggestion**	- Cold $\leq$ 30 °C - Normal 30–35.5 °C - Hot $\geq$ 35.5 °C	Skin temperature	- FORA IR19 infrared thermometer (ForaCare, Suisse, AG, Neugasse 55, 9000 St. Gallen, Switzerland)
Hébert-Losier et al. 2021 [46]	New Zealand	Musculoskeletal Science and Practice	An exploration of normative values in New Zealand to inform the Targeted Interventions for Patellofemoral Pain approach	Observational Cross-sectional test-retest study Research article	'Our primary aim was to explore the clinical assessment scores from a non-PFP population outside of the United Kingdom (Selfe et al.) and Turkey (Yosmaoğlu et al.), i.e. countries where previous work on TIPPs has been undertaken in PFP populations, whilst considering ethnicity and sex. Given that reliability of measures depends on sample characteristics (Matheson), our secondary aim was to revisit the inter-rater reliability of the individual clinical assessments of the TIPPs algorithm within this singular cohort of individuals.'	89 Healthy – normative database: 40F, 19.4 y 49M, 19.6 y 17 Healthy – interrater reability: 5F, 22 y 12M, 21.7 y	Existing subgroup [25]	- Strong subgroup - Weak and Tight subgroup - Pronated feet subgroup	- TIPPs Clinical tests: Hip abductor weakness Quadriceps weakness Patellar hypomobility Patellar hypermobility Pronated foot posture Lower limb biarticular muscle tightness	- Handheld dynamometer (Lafayette Instrument Company, model 01165, Lafayette, IN, USA) - Stabilization strap - Tape measure - Pen - Digital inclinometer

(*continued*)

Table 3. Continued.

First author and year	Country	Journal/book	Title of the document	Study design and type of document	Aim	Sample characteristics	Subgroup suggestion or use of existing subgroup	Subgroups derived or used / key points about subgroup described in the document	What was the stratification based on?	Instrumentation or equipment required for stratification of subgroups***
Kısacık et al. 2021 [32]	Turkey	Journal of Back and Musculoskeletal Rehabilitation	Short foot exercises have additional effects on knee pain, foot biomechanics, and lower extremity muscle strength in patients with patellofemoral pain	Randomized controlled parallel-group trial Research article	This study aimed to investigate the additional effects of SFE on knee pain, foot biomechanics, and lower extremity muscle strength in patients with PFP following a standard exercise program.	15 PFP (SFEG group) 39.60y 12F, 3 M 15 PFP (control group) 43.60y 13F, 2 M	Existing subgroup [25]	- Weak and pronated foot	- TIPPs Clinical tests: Pronated foot posture (Foot Posture Index – FPI)	N/A
Ophey et al. 2021 [33]	Netherlands	Journal of Bodywork & Movement Therapies	Short-term effectiveness of an intervention targeting lower limb range of motion on pain and disability in patellofemoral pain patients: A randomized, non-concurrent multiple-baseline study	Randomized, non-concurrent, multiple-baseline single-case design (MBD) Research article	The present study evaluates the short-term effectiveness of an intervention targeting LLROM on pain and disability in patients with PFP.	8 PFP 19y 5F, 3 M	Suggestion	Subgroup 1: quadriceps and iliopsoas related PFP Subgroup 2: patellofemoral joint related PF Subgroup 3: iliotibial tract related PFP Subgroup 4: normal LLROM	Lower limb range of motion (LLROM)	Goniometer Digital inclinometer (Baseline, White Plains, NY, USA)
Farazdaghi et al. 2022 [39]	Iran	Journal of Bodywork & Movement Therapies	Knee impairments: Comparison between new clinical classification by cluster analysis and movement system impairment model	Observational Cross-sectional study Research article	'Our main objective was to classify the patients based on signs and symptoms using PAM clustering method and compare the sub-clusters with MSI classification sub-groups.'	200 PFP 42y 71.5%F (143)	Suggestion	- Valgus with hypomobility sub-cluster - Valgus sub-cluster - Hypomobility sub-cluster - Hyperextension sub-cluster - Varus sub-cluster - Self-management sub-cluster	MSI model for knee impairments based on observation of functional tasks	N/A
Selfe 2023 [17]	UK	Anterior Knee Pain and Patellar Instability (Textbook)	Targeted treatment in anterior knee pain patients according to subgroups vs multimodal treatment	Literature Review Book chapter	'This chapter reviews the current state of knowledge for PFP subgrouping and introduces readers to some of the modern methodological approaches employed to derive subgroups.'	N/A	N/A	- 'There is limited evidence supporting the longer-term outcomes of a multimodal approach to therapy.' - 'There have been many attempts at producing PFP stratification frameworks and defining subgroups, however no consensus on these has been reached.'	N/A	N/A
Meade et al. 2024 [21]	USA	Journal of Sport Rehabilitation	Multimodal Rehabilitation Including Strengthening Exercise Is Effective in Improving Fear-Avoidance Beliefs in Individuals With Patellofemoral Pain: A Critically Appraised Topic	Critically Appraised Topic (CAT) Research article	Therefore, the potential findings of this critically appraised topic (CAT), which examines the influence of rehabilitation including strengthening exercises on FABs	N/A	N/A	- '(…) support the need for targeted, patient-specific, impairment-based interventions that incorporate the psychological realm to treat the patient with PFP.' - 'After performing this biopsychosocial evaluation early in the consultation process, clinicians may then subgroup participants into physically, psychologically, and socially deficit phenotypes to guide treatments, as has been previously explored in the literature.11 Such a subgrouping approach is valuable because individuals with PFP do not all experience the same impairments.' - 'Clinicians should perform an encompassing biopsychosocial evaluation early in the consultation process and work collaboratively with a multidisciplinary team of healthcare professionals to individualize treatment and target patient deficits.'	N/A	N/A

N/A: Not applicable. PFP: Patellofemoral pain. y: Years. F: Female. M: Male. IAKP: Idiopathic Anterior Knee Pain. PFPS: Patellofemoral Pain Syndrome. VMO: Vastus Medialis Obliquus. GA: Group A. GB: Group B. GC: Group C. MRI: Magnetic Resonance Imaging. 3D: Three-Dimensional. TIPPS: Targeted Interventions for Patellofemoral Pain Syndrome. RCT: Randomized Controlled Trial. MT: Multimodal Treatment. UC: Usual Care. SFE: Short foot exercises. LLROM: Lower limb range of motion. BJSM: British Journal of Sports Medicine. BMC: Biomedical Central. BMJ: British Medical Journal. PAM: Partitioning Around Medoids. MSI: Movement System Impairment.

*This study performed a post hoc analysis suggesting that their sample was part of the 'strong subgroup' described by Selfe et al. [25]

**Although this study was carried out within the scope of the Selfe et al. study [25], it suggested subgroups based on skin temperature.

***In this section we consider instrumentation necessary to stratify individuals into subgroups in addition to physical and clinical examination, such as functional or manual tests that do not require instrumentation.

****Instrumentation recommended but not mandatory.

by Yosmaoğlu et al. found that over 70% of non-responders to multimodal treatment demonstrated recovery after receiving targeted treatment designed according to their subgroup characteristics [29]. Drew et al. reported a greater improvement in the Global Rating of Change Scale and the Anterior Knee Pain Scale compared to the usual care group [30]. Sinclair et al. investigated the effects of semi-custom foot insoles in two subgroups of PFP and one of them exceeded the minimum clinically important difference (MCID) for KOOS-PF pain symptoms and had reductions in patellofemoral stress [31]. The results of Kısacık et al. study demonstrates that Short Foot Exercises (SFE) had significant effects on foot biomechanics and knee pain on the 'weak and pronated' subgroup of PFP compared to usual treatment (hip and knee strengthening and stretching exercises) [32]. Whereas Ophey et al. indicated that an intervention targeting lower limb range of motion may moderately reduce short-term pain and disability in patients with PFP [33]. However, it is still important to highlight that only one definitive randomized clinical trial [32] has been conducted considering the PFP subgroup approach to date. Furthermore, not all these studies used the same method of stratifying PFP subgroups and each of them has limitations regarding their own methodology.

Selhorst et al. conducted a study exclusively with pediatric patients [28], while the age range in the Keays et al. study ranged from 13 to 82 years [26], which limits the generalization of the results and consisted in a heterogeneous sample, respectively. Ophey et al. used a short intervention duration and was conducted with only eight patients [33]. The other four studies were conducted based on the same stratification method of individuals with PFP [29–32], in which three subgroups were described: a subgroup that had more muscle strength compared to the other subgroups, and two other subgroups where both had muscle weakness as a common characteristic, with one having foot pronation and the other having muscle stiffness in the lower limbs [25]. Drew et al. selected only patients who had hip muscle weakness, which makes it difficult to generalize the results since the other subgroups were not considered [30]. Whereas, Sinclair et al. identified two of these three subgroups ('strong' subgroup and 'weak and tight' subgroup), and offered a treatment (semi-custom insoles) that aimed to benefit the subgroup that was not included ('weak and pronated' subgroup) in their sample [31]. And, although Yosmaoğlu et al. study found the three subgroups and offered targeted treatment for each of them, the study is a cross-over that did not have a washout period, that is, all these patients had already received multimodal treatment, which may have been subject to residual effect bias from the first intervention [29]. Finally, Kısacık et al. reported on a sample that was 80% female which may not be fully representative [32]. Despite these limitations, the results still appear promising regarding symptom improvement in individuals with PFP. However, although the three subgroup method was the most reproduced, many stratification methods have been suggested.

PFP subgrouping methods

To date, twenty studies proposed novel methods for stratifying individuals with PFP into subgroups. However, regarding methodological rigor, only nine studies were classified as low risk of bias based on the critical appraisal with scores above 66.6% [23,25,33–39]. In the study of Pal et al. patellar alignment (measured *via* static MRI) and activation timing (measured during walking/jogging) were acquired during separate activities, since it is not feasible to reproduce walking or jogging under MR surveillance. Additionally, the definition of the 75% confidence interval used as a maltracking threshold is subjective [23]. In the study of Ferreira et al. the subgroup analysis was post-hoc, meaning it was decided upon after the initial analysis and results were known, which can reduce the strength of the findings compared to an a priori hypothesis-driven subgroup analysis [37]. The inclusion criteria of the study of Farazdaghi et al. excluded patients with very low (<3) or high (>7) pain levels, potentially limiting the generalizability of the results [39]. The method described by Dierks et al. was based on predefined visual patterns rather than a purely data-driven clustering of all kinematic variables [34].

While the analysis used by Watari et al. (Principal Components) was shown to distinguish subtle differences, their clinical interpretation in terms of specific joint mechanics was complex. In addition, the classification model developed to predict treatment outcome was not validated with a new cohort of PFP patients. This presents a risk of overfitting the model to the specific dataset used, which limits its generalizability and ability to determine true predictive accuracy in a clinical setting [35,40]. In the study by Ophey et al., a core part of the methodology was a two-step intervention based on evaluating and subgrouping participants according to their lower limb range of motion (LLROM) using a modified test. Crucially, the cut-off values used to define 'normal' LLROM and classify participants into subgroups were based on clinical observations and not validated reference data from healthy subjects [33]. In the study by Selfe et al., although the subcategories were not mutually exclusive, the

use of normative data ±1 standard deviation to define initial subgroup criteria, followed by statistical clustering techniques to explore underlying patterns, provides a robust approach, and with a comparison of results from two different clustering methods offers internal validation [25]. Drew et al. utilized a rigorous two-stage cluster analysis. This approach combined variables from multiple domains and used specific information criterion to determine the optimal number of clusters. The interpretation of the clusters adds to the methodological strength [38].

PFP subgrouping methods referenced in subsequent studies

Four proposed methods were reproduced by subsequent studies, with three being reproduced a maximum of twice and all by the same research group as the original study [22,23,26] and one reproduced thirteen times [25]. However, many of these thirteen studies included authors from the research group as the original study [17,27,29–32,41–46]. Still, this method appears to be gaining traction and has been referenced and built upon by other authors. This subgrouping approach originally described by Selfe et al. identified three subgroups of patients with PFP. These subgroups were defined as 'strong,' 'weak and tighter,' and 'weak and pronated foot'. Stratification was done based on six simple clinical tests, specifically hip abductor and quadriceps weakness using a hand-held dynamometer, patellar hypo and hypermobility through the Patellar Glide Test, the pronated foot posture through the Foot Posture Index (FPI), and lower limb biarticular muscle tightness using a digital inclinometer, and later using a clinical goniometer [24,25].

Similar to the study of Selfe et al., the study of Drew et al. aimed to identify subgroups by combining modifiable clinical, biomechanical, and imaging features [25,38]. Drew et al. stated that their identified subgroups are consistent with and extended the subgroupings proposed by Selfe et al. Although it was not reproduced or tested in interventional studies and depends on imaging features, it was the study best evaluated through critical appraisal. They note that despite identifying only three groups, the results from Selfe et al. showed many similarities to their four subgroups. The 'strong' groups in both studies demonstrated high strength and were predominantly male. The 'weak' subgroup in Drew et al. shared similarities with the 'weak and tighter' group in Selfe et al. in terms of lower strength and physical activity. The 'pronation and malalignment' and 'active and flexible' subgroups in Drew et al. showed some similarities with the 'weak and pronated foot' group in Selfe et al. regarding a high Foot Pronation Index score and greater gastrocnemius flexibility. The differences between the studies are likely due to variations in statistical methodology and the inclusion of imaging and biomechanical features in the Drew et al. study, which were not part of the low-cost clinical tests used by Selfe et al., and could potentially reduce the ability to implement the methods described by Drew et al. in clinical settings.

Clinical applicability of the PFP subgrouping methods

The majority of the studies included used imaging features (radiographic examination, scintigraphy, MRI) and specialized biomechanical equipment (isokinetic dynamometry, 3D motion capture systems and accelerometers) in the classification of individuals with PFP [13,22,23,26,34,35,40,47–52]. This is a significant limitation for clinical practice since this kind of equipment has limited availability in most physiotherapy settings, making a subgrouping method that relies on it less universally applicable in practice. The classification system proposed by Selhorst et al. (PFPS algorithm) and Witvrouw et al. is intended to be clinically oriented but offers less detail on the specific tests and their broad accessibility [28,47]. Whereas Selfe et al. prioritized low-cost, simple clinical tests making their proposed subgroups potentially highly accessible in routine physiotherapy practice. Its study assessed therapist fidelity to the assessment process, indicating a focus on practical implementation [25]. Future research on PFP subgroups should prioritize the clinical validation of the existing stratification models.

Tailoring treatment according to PFP subgroups

In terms of treatment, it seems that the stratification method proposed by Selfe et al. offers a promising direction by dividing patients into three clinically distinct subgroups, each potentially benefiting from a more targeted intervention [25]. Two of these subgroups share muscle weakness as a key feature (one combined with foot pronation and the other with soft tissue stiffness) suggesting a clear therapeutic pathway involving strengthening exercises coupled with foot orthoses or stretching strategies, respectively. However, the third subgroup, characterized by preserved strength levels compared to the other subgroups, presents a clinical challenge. This 'strong' subgroup was somewhat unexpected, given that muscle weakness has been consistently reported as a feature of the general population of PFP in the literature. The identification of individuals with PFP who do not present with typical strength deficits, and do not have foot pronation or muscle stiffness, raises important questions about the underlying

mechanisms of pain in this subgroup and highlights a gap in current treatment paradigms. Although neuromuscular control exercises may be a promising avenue, it is rarely prescribed alone in clinical practice or in research. Therefore, further investigation is needed to determine which interventions may be most effective for this subgroup whose presentation deviates from the traditional profile of PFP.

Other trends and references on PFP subgroups

Although some studies were not eligible for this review, it is necessary to highlight some trends and references regarding PFP subgroups. Some authors have categorized PFP by pain duration (acute vs. chronic) [53–56] and by pain severity [57]. These studies compare PFP subgroups with each other and with healthy individuals to highlight differences in factors such as gait biomechanics, muscle function (strength, activation, endurance), and self-reported function. The results consistently show that individuals with PFP have deficits compared with healthy controls, and that some of these deficits may differ between acute and chronic subgroups. However, there are limitations to subgrouping strictly based on pain, including the lack of universal consensus on duration criteria and the cross-sectional nature of most research that prevents determining causality (whether pain causes deficits or vice versa). Furthermore, PFP is a multifactorial condition, meaning that pain alone may not be sufficient to capture all the nuances of different types of patients. Despite these limitations, the identification of distinct characteristics across pain subgroups suggests that rehabilitation strategies may need to be tailored to the individual's 'status,' whether focused on controlling pain intensity (which is a controllable and important factor in the early stages) or on interventions targeting specific biomechanical or muscular deficits found across subgroups.

Furthermore, although some studies were not conducted with PFP subgroups or did not fit within the mapping and scope of this review, they highlighted the importance of identifying subgroups among individuals with patellofemoral pain (PFP) to provide treatments tailored to the specific characteristics of each group [5,58–63]. This contributes to the growing trend of this approach that challenges the traditional multimodal treatment model and suggests that considering specific subgroup characteristics may lead to more effective clinical outcomes. Recognizing the heterogeneity of PFP and addressing it through targeted strategies may contribute to advances in clinical practice and promote a change in the way this condition is treated.

Critical appraisal within sources of evidence

The finding that 27 documents presented a low risk of bias, 12 had a moderate risk, and none had a high risk indicates a generally high methodological quality among the included studies. Importantly, each study was appraised using checklists appropriate to its specific design, ensuring that the assessment reflected the methodological rigor within each type of study. This overall quality strengthens the interpretation of the results and highlights that the existing gap in the literature, the recurrence of symptoms in the long term despite current interventions, cannot be attributed to poor-quality evidence. Instead, it suggests that new approaches, such as identifying and addressing specific subgroups within PFP, may be necessary to achieve more sustainable outcomes.

Limitations

This review has limitations inherent to the design of a scoping review. Despite a broad and systematic search in several databases and gray literature, some relevant studies may not have been retrieved. In addition, four authors were contacted to obtain the full text of inaccessible documents, but there was no response. Data extraction and categorization were performed by two reviewers independently, with some decisions resolved by a third, which may introduce subjective bias. Finally, methodological heterogeneity and the variety of approaches to defining and applying subgroups in individuals with PFP limit the possibility of definitive clinical conclusions.

Conclusions

There is a trend in the literature toward stratifying individuals with PFP into subgroups, which has intensified since 2010. However, most subgrouping models have been proposed in cross-sectional studies, with limited testing in interventional research. In addition, most studies use imaging methods and specialized biomechanical equipment, which may be a limitation for the clinical application of PFP subgroups. The most cited approach stratifies individuals into three subgroups ('Strong,' 'Weak and Pronated,' and 'Weak and Tighter') based on clinical assessments, which may offer the best approach for future implementation within physiotherapy settings, however further work is required to support this approach .

Author contributions statement

CRediT: **Ana Luiza Costa e Silva Cabral**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing; **Victor Hugo Vilarinho Carrijo**: Data curation, Formal analysis, Methodology, Software, Writing – review & editing; **Johan Robalino Salinas**: Data curation, Formal analysis, Methodology, Software; **João Paulo Vilas-Boas**: Conceptualization, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – review & editing; **Jim Richards**: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing – review & editing.

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