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ABSTRACT

Objectives: Current best evidence has reported that therapeutic exercise programs that are designed to treat patellofemoral pain (PFP) should include both hip and knee specific exercises. The purpose of this review was to 1) examine the quality/comprehensiveness of exercise reporting in this field; 2) quantify the extent to which individual exercises comprised task-specific elements (single limb stance; eccentric control of the hip; rotational z-axis control) most likely to address key pathomechanics associated with PFP.

Design: Systematic review: a systematic survey of RCTs

Methods: PubMed, CINAHL, Medline, Physiotherapy Evidence Database (PEDro) and SPORT Discus databases were searched for randomized controlled trials that addressed PFP utilizing a proximal control hip focused rehabilitation paradigm. The therapeutic exercise programs were evaluated, and each individual exercise was extracted for analysis. Quality assessments included the PEDro Scale and the Consensus on Exercise Reporting Template (CERT) was utilized to score the reporting of the interventions.

Results: 19 studies were included in the final analysis. 178 total exercises were extracted from the proximal hip and knee rehabilitation programs. The exercises were analyzed for the inclusion of elements that align with reported underlying biomechanical mechanisms.

Conclusions: The vast majority of the exercises were sagittal plane, concentric, non-weight bearing exercises, whereas multiplanar exercises, single limb weightbearing, and exercises where loading was directed around the longitudinal z-axis, were considerably under-represented. Current exercises for PFP utilize simplistic frameworks that lack progression into more task specific exercise, and are not reflective of the complex injury etiology.

Keywords: Exercise, Hip, Knee, Patellofemoral Pain, Proximal Muscle Rehabilitation, Sports

1 **1. Introduction**

2 Patellofemoral Pain (PFP) is a common condition affecting individuals of all ages and activity
3 levels.¹⁻³ The prevalence of PFP varies by population but may be as high as 20-25% in active
4 populations.^{2,4} This condition affects females more than males, and almost two thirds of runners
5 with PFP are female.⁵

6
7 Exercise is a central component of PFP management.⁶⁻⁸ Initial interventions were limited to local
8 strengthening of the knee,^{3,9} but have since progressed to incorporate ‘proximal exercises’
9 targeting the hip and pelvis.² Whilst randomized clinical trials (RCTs) show that proximal
10 rehabilitation often results in short term improvement to pain and function,¹⁰⁻¹³ the long-term
11 prognosis of PFP remains poor.¹⁴ Over 50% of patients with PFP have unfavorable recovery at 5-
12 8 year follow ups,¹⁵ with others reporting that 90% of patients have residual pain and dysfunction
13 four years post-diagnosis.¹⁶ The effect of exercise rehabilitation on PFP patient’s quality of life
14 (QOL) is also unclear and may be comparable to control interventions.^{15,17}

15
16 PFP etiology is complex¹⁸⁻²⁰ but a primary factor associated with its poor long-term prognosis, is
17 the lack of consensus on an optimal exercise regimen.²¹ Many clinicians favor proximal exercises,
18 but the clinical interpretation of ‘proximal’ varies considerably, from simple hip-focused
19 strengthening exercises, to more generalized dynamic warm-up activities.²¹ There is a concern
20 that either extreme is suboptimal, as they cannot fully address key pathomechanics associated
21 with PFP,^{19,22,23} such as excessive or uncontrolled internal rotation of the femur (in relation to the
22 patella), particularly under high load and/or single limb conditions [Fig. 1].^{2,20,24}

23
24 Optimal rehabilitation requires a task specific approach, whereby exercises are progressed via
25 specificity and optimal loading principles.²⁵ This would include addressing the muscular deficits
26 affecting individuals with PFP, such as isometric, concentric and eccentric strengthening of the

27 hip and knee musculature.²⁶ Also, specific neuromuscular control exercises to enhance the rate of
28 muscular force development,²⁶ and isometric force steadiness focused training.²⁷ It is therefore
29 pragmatic that PFP rehabilitation eventually exposes patients to conditions involving: single limb
30 loading, eccentric hip strengthening, external perturbations around multiple planes, particularly
31 about the z-axis.²¹ Although nearly 100 reviews on PFP management have been published none
32 have considered the individual content and design of each rehabilitation exercise.⁶ A recent study
33 stated that exercise prescriptions in RCTs for PFP are poorly reported, and the authors suggested
34 adding the Consensus on Exercise Reporting Template (CERT) in future reviews.²⁸ The aim of
35 this systematic review is to include the CERT tool, in order to assess the exercise content
36 employed within randomized controlled trials (RCTs) implementing a proximal approach to the
37 treatment of PFP. Our key objectives were to:

- 38 1). examine the quality/comprehensiveness of exercise reporting in this field
- 39 2). quantify the extent to which individual exercises incorporate complex, task-specific elements
40 (single limb stance; eccentric control of the hip; rotational z-axis control) relevant to key
41 pathomechanics associated with PFP.

42

43 **2. Methods**

44 A systematic literature review was conducted after consulting the Preferred Reporting Items for
45 Systematic Reviews and Meta-Analysis (PRISMA) statement and the checklist completed.²⁹ The
46 review was registered at PROSPERO (CRD42017076115). Since the time of registration several
47 deviations from the original submission to PROSPERO occurred. A systematic literature search
48 of the PubMed, CINAHL, Medline, Physiotherapy Evidence Database (PEDro) and
49 SPORTDiscus databases was performed in March 2020 to obtain relevant studies for the review.
50 The date ranges utilized for the review were from database inception to the date the search was
51 conducted. The search strategy included filters to only include publications in the English

52 language and including only human participants. In addition, the study archives of the authors
53 were manually searched, and the reference lists of retrieved articles were hand searched for
54 possible information on trials of interest. Search terms included keywords or utilized Medical
55 Subject Headings (MeSH) where appropriate: “hip”, “knee”, “joint” combined with the terms
56 “patellofemoral”, “patella”, “strength*”. Google scholar was also searched using a combination
57 of the aforementioned key words. The PRISMA flow document detailing the search can be found
58 as an online Supplementary File 1.

59

60 The inclusion criteria was as follows; the authors: 1) clearly stated that the therapeutic exercises
61 that were being prescribed were specific to the hip and/or surrounding lumbopelvic musculature;
62 2) studies with male or female participants who were diagnosed with patellofemoral pain
63 syndrome or anterior knee pain were included in this review; 3) Only randomized and/or
64 controlled trials (RCTs) utilizing proximal hip muscle exercises in combination with or without
65 knee exercises were included. Considering many hip focused exercises load the quadriceps
66 simultaneously (e.g. single leg squats, step ups)³⁰ the hip and knee exercises were analyzed
67 together in this review. Feasibility studies or protocol papers, post-surgical rehabilitation,
68 editorial letters, case reports, commentaries, abstracts without full text and articles without a
69 description of the exercises, and the authors could not be reached to identify the exercises utilized
70 were ultimately excluded.

71

72 The identification of relevant articles, titles and abstracts were downloaded into EndNote X8.2
73 (Thomson Reuters, USA), where duplicates were removed. To identify relevant articles, titles
74 and abstracts of all the captured citations were independently screened by at least two authors
75 (SLD, DTT, AAW) applying the *a priori* inclusion criteria. Full text articles were then retrieved if
76 the abstract provided insufficient information to determine eligibility for inclusion. In the case of
77 differing assessments of the retrieved studies between the reviewing authors, the specific study

78 was collaboratively discussed amongst the three authors. All criteria were again independently
79 applied by two authors (SLD, AAW) to the full-text of the articles that passed the initial
80 screening process. If a consensus could not be reached on the decision for final inclusion, a fourth
81 author (CMB) was consulted.

82

83 Physiotherapy Evidence Database (PEDro) Scale

84 Two reviewers (SLD, DTT) independently assessed the methodological quality of each included
85 study using the Physiotherapy Evidence Database (PEDro) scale for randomized controlled
86 trials.³¹ The PEDro scale consists of 11 binary (yes/no) questions and it is a widely accepted
87 measurement tool for rating the methodological quality of randomized clinical intervention
88 studies.³² The tool has a maximum score of 10, as the first item is not given a point value. Any
89 discrepancies were resolved by utilizing a third reviewer (AAW) as needed. The PEDro scale of
90 each reviewed study was evaluated and reported in Supplementary File 2.

91

92 Consensus on Exercise Reporting Template (CERT)

93 Two blinded reviewers (SLD, DTT) independently extracted intervention data from each included
94 study using the CERT reporting form with guidance from the Explanation and Elaboration
95 Statement document.³³ The CERT is a 16-item checklist developed and endorsed by an
96 international panel of exercise experts designed to assess the quality/comprehensiveness of
97 reporting of exercise and contains seven categories: materials, provider, delivery, location,
98 dosage, tailoring and compliance.³⁴ Following data extraction, any differences between reviewers
99 were discussed and a final score was reached via a consensus meeting, a third reviewer (AAW)
100 was consulted when consensus could not be met initially.

101

102 All therapeutic exercises were extracted for data analysis from the included studies. The elements
103 of each exercise were chosen to reflect the underlying pathomechanics described earlier

104 including: single limb loading, eccentric hip strengthening, and external loading directed around
105 multiple planes, specifically about the z-axis.

106

107 Exercise analysis attempted to determine the authors exact intention for delivering a specific
108 exercise as accurately as possible based on provided exercise descriptions, corresponding figures,
109 and terminology. Three reviewers (SLD, AAW, DTT) with a combined 68 years of clinical
110 experience initially analyzed the exercises, and exercises that needed a fourth reviewer (CMB),
111 with 20 years of clinical experience, facilitated a final decision. The exercises were categorized
112 utilizing the following elements and the *a priori* definitions that were used to categorize each
113 element:

114 1. *Multipplanar & Triplanar*

115 The exercise must include primary movement within two or more of the three cardinal planes. If
116 an exercise was scored as multipplanar, then the two or three planes were also identified in the
117 analysis. Once identified as multipplanar, the multipplanar box was checked, and then the two or
118 three planes were then also identified in the analysis. The final score did not include the
119 “multipplanar” box, because the total number of planes included were tallied into the final score. If
120 all three cardinal planes were included in the primary purpose of the exercise, then a score of 3,
121 indicating a triplanar exercise, would be added to the remaining fields to be analyzed.

122

123 2. *Sagittal Plane*

124 The primary intent of the exercise utilized movement that occurred primarily within the sagittal
125 plane. A supine straight leg raise is an example of isolated movement about the sagittal plane.

126

127 3. *Frontal Plane*

128 The primary movement of the exercise occurred within the frontal plane. An example of an
129 isolated exercise to the frontal plane would be a sidelying straight leg raise.

130

131 4. *Transverse Plane*

132 The primary movement of the exercise occurred within the transverse plane. Seated external
133 rotation is an isolated transverse plane exercise. Exercises that are more difficult to categorize,
134 such as the “clam” were put into transverse and frontal if the author reported it as utilizing two
135 planes of motion, if not, it was scored as transverse plane only.

136

137 5. *Z-axis Rotation*

138 The exercise needed to deliver a rotary perturbation that would induce an internal rotation of the
139 femur about the longitudinal z-axis of the body as illustrated in Figure 1. The hip and knee must
140 be in an extended position as if the body is in a upright weight bearing alignment. Hip external
141 rotation in a single leg stance, is an example of an isolated z-axis rotation exercise.

142

143 6. *Bilateral Weight Bearing*

144 The primary movement of the exercise had both lower extremities contacting the ground in a long
145 axis position where the hip was in a position of extension with the acetabulum over the femur in
146 an upright bipedal position. Quadruped exercises were not considered bilateral weight-bearing for
147 this reason. A forward lunge was considered to be a bilateral weight bearing exercise because
148 both feet were on the ground during the intentional phase of the exercise.

149

150 7. *Single Limb Stance*

151 The exercise was performed on one lower extremity that was full weight bearing and contacting
152 the ground. Several exercises were delivered in a sequential movement, whereas one foot moved
153 in a step by step fashion. These exercises were scored as having both phases of stance. An

154 exercise such as a side-stepping monster walk, was scored as having both bilateral and unilateral
155 weightbearing. A single leg squat was scored as a single limb stance exercise.

156

157 8. *Eccentric Emphasis of the Hip*

158 The authors of this review acknowledge that most any exercise or movement has both a
159 concentric and eccentric phase. The intent of the exercise being analyzed needed to explicitly
160 state that the exercise was to be performed in a deceleratory manner or other language that made
161 it clear that the goal was to accentuate or focus on the eccentric portion of the exercise. Exercises
162 with a commonly accepted clinical focus to be eccentric, such as lateral step downs, were scored
163 as having an eccentric focus at the hip. This analysis targets the deceleratory responsibility of the
164 hip, specifically femoral internal rotation of the lower extremity. The analysis is attempting to
165 identify if there was an emphasis placed on the eccentric control of the hip external rotators.
166 Although, the muscle group that was targeted with the eccentric focus of the intervention was also
167 noted during analysis (e.g. quadriceps, gluteus medius/maximus, external rotators of the hip).

168

169 As each exercise was analyzed it was determined how many of the above elements were
170 accounted for within each individual exercise. Each exercise was scored out of 6 total possible
171 points. The multiplanar column was not added into the final score for each individual exercise,
172 because each individual plane was accounted for in the total score. Similarly, if an exercise was
173 either bilateral or unilateral, only a score of 1 was given for being a weight bearing exercise.

174

175 **3. Results**

176 The initial search captured potentially relevant papers, and after removal of duplicates 2506
177 articles remained to be screened. After screening based on title and abstract, 2396 articles were
178 excluded. The remaining 110 full text articles were obtained and reviewed by two authors (SLD

179 & AAW). Ninety-one were excluded after review of the full text, leaving 19 studies fulfilling the
180 eligibility criteria.

181

182 Physiotherapy Evidence Database (PEDro) Scale:

183 The scores on the PEDro scale for the 19 included RCTs ranged from three to ten, out of a
184 possible ten points. The most common limitation noted was the lack of blinding in the studies of
185 both subjects and therapists. The overall average score for the included studies was 6.2 indicating
186 a level of moderate to high quality for the included RCTs.^{2,35}

187

188 Consensus on Exercise Reporting Template (CERT):

189 The CERT reporting form results (Supplementary File 3) ranged from 0 to 16 (19 total possible
190 points) with an average score of 8.0. Most shortcomings concerned item 2 (qualification of
191 exercise instructor), item 6 (motivation strategies), item 14b (how exercises are individualized),
192 and item 16a (assessment of fidelity). For calculation of the completeness of the exercise
193 descriptions, a single score was calculated for CERT for each study. Items 8 and 14a scored the
194 highest; exercise description(s) and generic or individually tailored, both scoring affirmative in 17
195 of the 19 studies. None of the studies completed all items in the checklist.

196

197

4. Exercise Analysis

198 The total number of extracted exercises from the included studies was 178 (Table 1). Multiplanar
199 exercises consisted of a total of 39/178, representing 21.9% of all exercises analyzed. The planes
200 that were most frequently incorporated into the multiplanar exercises were sagittal/frontal
201 representing 58.9% of all multiplanar exercises. Sagittal/transverse and frontal/transverse
202 represented only 5 and 6 exercises respectively. All three planes of movement, sagittal/
203 frontal/transverse, were included in 5 triplanar exercises. Sagittal plane exercises were the most
204 predominantly utilized and represented a total of 120 out of 178 and accounted for 67.4% of the

205 total exercises analyzed. The most common exercise isolated to the sagittal plane was standing
206 hip extension in the open kinetic chain. Exercises on the frontal plane represented a total of 69 out
207 of 178 exercises and accounted for 38.8% of all exercises analyzed. The most common exercise
208 prescribed that was isolated to the frontal plane was open chain hip abduction. The total number
209 of exercises in the transverse plane was 36 out of 178 representing 20.2% of the total exercises.
210 The most commonly prescribed exercise isolated to the transverse plane was a seated external
211 rotation exercise.

212

213 Exercises that met the a priori definition for the integration of the z-axis was the least represented
214 component in all of the exercises. The total number of exercises that included a z-axis component
215 was 12, representing 6.7% inclusion in all analyzed exercises. A closer look at the integration of
216 the z-axis into the exercises found it was the lone component utilized within 3 exercises; coupled
217 with single leg stance in 8 exercises; eccentric quadriceps for 1 exercise; and it was coupled with
218 eccentric hip external rotators in a single leg stance for 2 exercises. These 2 exercises met 5/6
219 criteria. Each of the exercises were only on two planes (sagittal/transverse and frontal/transverse)
220 and not considered to be triplanar. Almost half of the exercises analyzed (47%) only contained
221 one of the six possible elements, exercises that contained 5/6 represented 7% and not a single
222 exercise represented all 6 elements.

223

224 Eccentric exercises totaled 20/178, representing 11.2%. The analysis of the 20 eccentric exercises
225 found the most represented muscle group that had an eccentric focus was of the quadriceps (12),
226 gluteus medius (5), and hip external rotators (3). Bilateral weight bearing and single limb stance
227 each had 43 total exercises, representing 24.2% for each category respectively. Figure 2 offers a
228 visual representation of the results of the exercise analysis.

229

230 **5. Discussion**

231 The aim of this systematic review is to describe the exercise content employed within randomized
232 controlled trials (RCTs) implementing a proximal approach to the treatment of PFP. Previous
233 reviews have classified hip focused rehabilitation programs based on broad parameters such as
234 open vs. closed chain and exercise dosages;^{2,7,36} the next logical step was to analyze the content of
235 individual exercises. To our knowledge this was the first review to quantify the extent to which
236 individual exercises comprised task-specific elements (single limb stance; eccentric control of the
237 hip; rotational z-axis control) most likely to address key pathomechanics associated with PFP.
238 We analyzed an aggregate of 178 exercises, extracted from 19 RCTs. The number of exercises
239 employed within each trial varied considerably, with a range of 2-21 and a median of 6 exercises
240 per program. Most exercises reflected an isolated, reductionist approach to rehabilitation, with the
241 majority based on sagittal plane movements with concentric loading, undertaken in a non-weight
242 bearing position.

243

244 During walking or running, the hip musculature must quickly (50-200ms)²⁶ decelerate the lower
245 limb, and plays a key role in controlling the internally rotating femur.^{24,37-39} Weakness and/or
246 delayed activation of the hip and pelvis musculature is common in PFP,^{2,26,40-45} and may
247 contribute to uncontrolled or excessive internal rotation of the femur during single limb loading.
248 Female individuals with PFP demonstrate lower maximal muscle strength and decreased rate of
249 force development at the hip and knee.²⁶ That said, it is pragmatic that PFP rehabilitation should
250 therefore include strengthening of the proximal hip musculature, with a specific focus on
251 neuromotor control,^{27,46} speed of contractions,^{26,46} and eccentrically loading the gluteals and the
252 deep hip lateral rotators.⁴⁷ However, our review found that most strengthening exercises were
253 limited to open chain and were concentric, with only three exercises out of 178 (< 0.0%)
254 challenging the hip external rotators with an eccentric emphasis. We also found that strengthening
255 was typically undertaken in either the sagittal (hip extension) or frontal plane (hip abduction),
256 with transverse plane exercises (rotation) being the least represented (20.2%).

257

258 Although open chain, concentric strengthening represents an important stage of PFP
259 rehabilitation, exercise interventions must be progressed to reflect the nature of the intended
260 task.^{46,48} Failing to maximally challenge PFP patients, might explain the often poor long-term
261 prognosis associated with this condition.^{14-16,46} Future interventions must incorporate more task
262 specific loading of the hip musculature.⁴⁶ Primarily, this should include more intensive exercises
263 designed to increase power⁴⁶, as well as, additional eccentric loading across all planes of
264 movement.^{37,49-53} Establishing triplanar control of the hip and pelvis is essential to improving both
265 task specific neuromotor control of the proximal muscles,^{27,46} and will limit contralateral pelvic
266 drop, femoral adduction and internal rotation.⁵² It is also essential that PFP rehabilitation include
267 hip rotation, as this specifically reflects loading forces and can enhance the activity of key
268 musculature such as the gluteus medius and minimis.⁵⁴

269

270 Optimal rehabilitation is underpinned by progression, whereby exercises become increasingly
271 challenging by adding new stimuli.⁴⁸ However, we found that the PFP literature is mainly
272 comprised of basic, controlled versions of popular rehabilitation exercises in this field (eg.
273 standing or sidelying hip abduction, seated hip external rotation), where patients focus primarily
274 on single plane tasks or movements. By manipulating more key variables, such as speed, power
275 and neuromotor control, PFP rehabilitation can cumulate in more complex challenges; this is
276 more likely to improve the muscular deficits associated with PFP, lower limb alignment, reduce
277 patellofemoral joint loads and maintain tissue homeostasis.^{19,26,46} We would suggest that a key
278 challenge for PFP is progressing rehabilitation to the point where exercise can be optimized by
279 concomitantly providing the missing elements illustrated in the Venn diagram in Fig. 2: single
280 limb loading, eccentric hip strengthening, external loading directed around triplanar demand, and
281 particularly about the z-axis (Supplementary File 4).⁵⁵

282

283 Lastly, reporting of exercise programs being utilized to treat PFP needs improvement. CERT
284 scoring of the included studies revealed an average score of 8.0, indicating below average
285 reporting across a number of domains, including fidelity and individualization of exercise
286 programs. Future studies should prioritize reporting on these domains to improve homogeneity
287 and interpretation of studies, and most importantly, to increase the success of replicating exercise
288 programs in the clinic. Future studies may wish to employ technology for more accurate
289 translation of exercises utilizing pictures and video formats to increase the implementation
290 clinically. In order for research to reach clinical treatment strategies, it is relied upon that research
291 be reported with sufficient detail to replicate the intervention. We recommended that future trials
292 should publish details of the intervention in sufficient detail to enable clinicians to apply these in
293 clinical practice, possibly as supplementary files.²⁵

294

295 **6. Limitations**

296 The primary focus of this review was to determine the nature and content of hip focused
297 rehabilitation exercises used for PFP. Our key finding was that the majority of research in this
298 field is limited to more simplistic exercise training. This is indicative of many areas of
299 musculoskeletal rehabilitation; whereby simplistic frameworks are applied to complex injury
300 pathologies.⁵⁶ Whilst it is pragmatic that more clinically appropriate interventions would be
301 associated with greater magnitudes of effect, this must be verified in future randomized studies. It
302 is also possible that optimization of proximal exercises may create other limitations.

303 Implementation of a more complex task-specific approach may require increased supervision,
304 potentially making home exercises more difficult, consequently, affecting fidelity. Our results
305 indicate that there is currently insufficient study data to consider a meta-regression, whereby key
306 exercise variables (e.g. z axis) are included as moderator variables. Additionally, the authors
307 acknowledge that there are likely some subjective interpretations in the categorization of existing
308 exercise elements. Also of note are the deviations from the original PROSPERO registration.

309 There was a title change, two authors dropped out and one new author added, the meta-analysis
310 was not submitted with this manuscript, and the aim was slightly altered to where the exercises
311 that were extracted were compared to task specific movements related to the PFP injury etiology.

312

313 The authors of this review acknowledge the multidimensional nature of PFP etiology, and the
314 complex interactions between anatomical, biomechanical, neurophysiological and
315 biopsychosocial factors, and how these impairments intertwine with pain science.^{19,42,57-64} This
316 review only focuses on a small portion of the exercise therapy and methods that may potentially
317 optimize a hip focused rehabilitation for PFP.

318

319 Indeed, there is evidence that incorporating exercises involving more complex task repetition
320 with feedback is the most effective for correcting aberrant running patterns associated with PFP.⁶⁵
321 Although this review did not assess feedback specifically, future research may attempt to include
322 a complex task specific exercise approach as suggested with this review and include the
323 appropriate feedback mechanisms in future trials.

324

325 **7. Conclusion**

326 This review suggests that most of the rehabilitation exercises within the current evidence base
327 may be too simplistic to address key pathomechanics associated with PFP. The inclusion of
328 exercises targeting muscle deficits in hip muscle strength, power, and neuromotor control are
329 crucial exercise progressions. Including these missing elements could potentially optimize PFP
330 exercise therapy and potentially improve longer term outcomes with more complex and task
331 specific intervention strategies. Ultimately, any newly developed exercises designed to optimize
332 exercise therapy for PFP should be exposed to high quality prospective pragmatic and
333 explanatory trials to determine both intervention effectiveness and efficacy.

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336

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