Is patellofemoral pain preventable? A systematic review and meta-analysis of randomised controlled trials

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► Additional material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/bjsports-2020-102973).

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Accepted 6 October 2020
Published Online First 28 October 2020

Check for updates

To cite: Culvenor AG, van Middelkoop M, Macri EM, *et al. Br J Sports Med* 2021;**55**:378–384.

ABSTRACT

Objective To evaluate the effectiveness of interventions to reduce the risk of incident patellofemoral pain.

Design Systematic review and meta-analysis, with strength of evidence evaluated separately for each intervention type.

Data sources MEDLINE, EMBASE, CINAHL, Web of Science and SPORTDiscus.

Eligibility criteria for selecting studies Randomised controlled trials evaluating the effectiveness of interventions to reduce patellofemoral pain risk compared with a control/non-exposed group.

Results Thirteen trials of mostly military recruits and young athletes analysed six different interventions. There was low certainty evidence from two trials (227 participants) that patellofemoral braces worn during physical activity (compared with no brace) effectively reduced the risk of patellofemoral pain (risk ratio (RR) 0.40, 95% CI 0.22 to 0.73; I^2=24.0%). There was low certainty evidence from one trial (320 participants) that running technique retraining to (run softer) reduced patellofemoral pain risk (RR 0.21, 95% CI 0.07 to 0.60). There was low certainty evidence from four trials (3364 participants) that multicomponent (strengthening/neuromuscular) exercise programmes did not significantly reduce the risk of patellofemoral pain (RR 0.49, 95% CI 0.18 to 1.36; I^2=64.9%), although broad CIs may reflect exercise dose variations among studies. There was very low certainty evidence from four trials (2314 participants) that foot orthoses (compared with flat inserts/no orthosis) did not significantly reduce the risk of patellofemoral pain (RR 0.63, 95% CI 0.35 to 1.13; I^2=0.0%). Static stretching and a running programme that progressed intensity (compared with volume) did not significantly influence patellofemoral pain risk (single studies).

Conclusion There is low-level evidence that patellofemoral braces and running technique retraining can reduce the risk of patellofemoral pain by 60%–79%.

INTRODUCTION

Patellofemoral pain is a common knee complaint affecting approximately 23% of the general population.[1] It accounts for 11%–17% of all knee pain presentations to general practice[2 3] and imposes a considerable burden on individuals and healthcare systems internationally.[4 5] Its characteristic pain behind or around the patella is typically aggravated by an increased frequency or duration of patellofemoral loaded activities (ie, squatting, running, climbing stairs and jumping).[4]

The prognosis for people with patellofemoral pain is often poor. Unfavourable outcomes (ie, persistent symptoms) are reported in more than 50% of patients with patellofemoral pain after 5–20 years.[6–8] Patellofemoral pain is associated with restricted physical activity[9] and lower quality of life,[10] and may lead to patellofemoral osteoarthritis[11–14] and further disability.[15 16] Therefore, effective strategies to reduce the prevalence and associated burden of patellofemoral pain are needed.

Primary prevention of patellofemoral pain might be the solution to decreasing its burden. Many prevention programmes have been designed to reduce the incidence of knee injuries; however, these predominantly focus on traumatic knee injuries, particularly anterior cruciate ligament (ACL) rupture.[17] While several systematic reviews showed that injury reduction programmes successfully reduce the risk of ACL injuries by 50%,[18] no systematic review has synthesised the evidence from randomised controlled trials (RCTs) evaluating strategies to prevent patellofemoral pain. The aim of this systematic review and meta-analysis was to evaluate the effectiveness of interventions to reduce the risk of incident patellofemoral pain.

METHODS

Search strategy and selection criteria

This systematic review conforms to the Preferred Reporting Items for Systematic reviews and Meta-Analysis guidelines and is registered with PROSPERO (CRD42018110667). We performed a systematic literature search in April 2020 with no restriction on publication year or language in MEDLINE, EMBASE, CINAHL, Web of Science and SPORTDiscus. The search combined Medical Subject Headings (MeSH) terms and keywords (title and abstract) related to patellofemoral/knee, pain/injury, prevention and clinical trial (online supplemental appendix 1). RCTs evaluating the efficacy of any intervention to reduce the risk of incident patellofemoral pain compared with a control/non-exposed group were included. Exclusion criteria were: (1) participants with pre-existing injury/pain at baseline, unless analyses adjusted for pre-existing injury/pain; (2) patellofemoral pain not diagnosed by physical assessment by research team or other medical professional (ie, self-report only) and (3) rates of patellofemoral pain only reported in combination with other injuries (eg, patellar tendinopathy, lower-limb overuse injuries more broadly). In

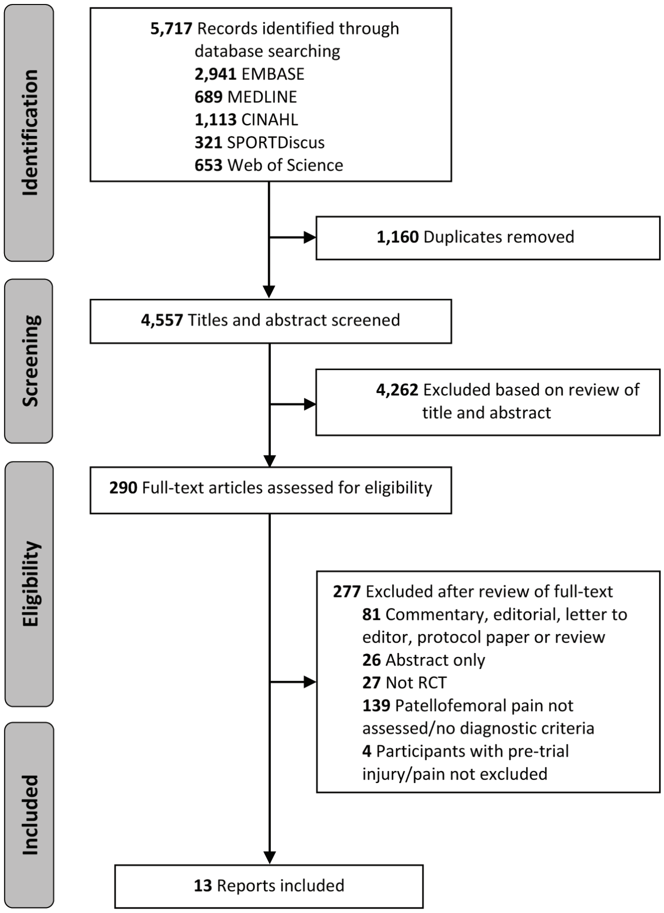

Figure 1 Flow diagram of study selection. RCTs, randomised controlled trial.

the latter case, we contacted authors to check if patellofemoral pain data were recorded separately.

Two authors (AGC and EMM) independently assessed all titles and abstracts for eligibility, and screened reference lists of all systematic reviews and relevant articles identified in the search. When eligibility could not be confirmed from title and abstract, full texts were reviewed and study investigators contacted as required. Disagreements between the two reviewers were discussed until consensus was reached as reported previously.[19] Only full-text published articles published in English were eligible.

Data extraction

The following information was independently extracted from the included studies by two investigators (AGC, EMM) using a customised data extraction spreadsheet: study setting (eg, military and athletes), trial design, intervention and control characteristics (eg, type, duration, dosage, supervised/non-supervised), number of participants allocated to intervention and control groups, participant baseline characteristics (eg, age, sex, body mass index (BMI)), intervention adherence, follow-up duration, patellofemoral pain diagnostic criteria, and number of participants developing patellofemoral pain in intervention and control groups.

Risk of bias assessment

Two reviewers (AGC, MvM) independently assessed risk of bias using the Cochrane Risk of Bias tool (version 1).[20] Both reviewers assessed whether each of the following domains was adequate (eg, low, unclear, or high risk of bias): selection bias (sequence generation and allocation concealment), performance bias (blinding to allocated intervention), detection bias (blinding during outcome assessment), attrition bias (handling of incomplete outcome data), reporting bias (selective outcome reporting), and other bias (eg, funding). Disagreements in initial risk of bias ratings were discussed until consensus was reached.

Data synthesis and analysis

We calculated the effect size of each study as risk ratios (RRs) (cumulative patellofemoral pain incidence in intervention group divided by cumulative patellofemoral pain incidence in control group) and 95% CI, and transformed these into natural log RRs (95% CI) allowing pooling of data from individual studies. We combined individual study results using random effects meta-analyses (Stata, V.14.0), stratified by intervention type (eg, strengthening, patellofemoral brace, foot orthosis). Heterogeneity was quantified using the I^2 statistic, describing the percentage of the variability in effect estimates that is due to heterogeneity rather than chance. The numbers needed to treat (NNT) were generated (1÷absolute risk reduction) as a meaningful indicator of prevention efficacy for practitioners and health/athletic staff across different settings.[21] We planned an a priori secondary analysis to separately assess the short-term (0–6 months) and long-term (>6 months) effect of interventions; however, this proved not feasible because only two studies (using different interventions) evaluated long-term effects. Where possible, subgroup results based on sex and study setting (military/adolescents/athletes) were reported separately based on a priori secondary analyses. For individual trials with no patellofemoral pain observed in one or both groups, a continuity correction of 0.5 was added to each cell.[22] Publication bias was assessed using funnel plots and Egger's test when there were ≥10 studies in a meta-analysis.[23]

The overall quality of the body of evidence for the estimates of patellofemoral pain prevention was evaluated using the Grading of Recommendation, Assessment, Development and Evaluation (GRADE) considerations.[24] Details of the GRADE assessment are in online supplemental appendix 4, which is based on five domains: risk of bias, consistency of effect, indirectness, imprecision and publication bias.[24]

RESULTS

Study characteristics

Thirteen RCTs involving a total of eight thousand two hundred and ten individuals (mostly military recruits and young athletes) were included in this review (figure 1 and table 1).[25–37] The mean age of participants in the individual trials ranged from 13 to 39 years. The most common interventions evaluated were multicomponent exercise (n=4), foot orthoses (n=4) and patellofemoral braces (n=2), with single trials evaluating the effect of: (1) stretching; (2) two approaches to increase exercise dose in a running programme and (3) a running technique retraining programme. The details of the interventions and control treatments are described in table 2. The clinical diagnosis of patellofemoral pain was most commonly performed by medical doctors (table 2), with the specific diagnostic criteria summarised in online supplemental appendix 2. The follow-up duration during which the incidence of patellofemoral pain was evaluated varied between 6 weeks and 12 months (table 2).

Risk of bias

Risk of bias was low in only 1 (8%) of the 13 included trials (online supplemental appendix 3).[29] The main issues identified were

Table 1 Study characteristics

Study	Location	Population	Study design	Participants included (IG/CG)	Women (%)	Age, years Mean (SD)	BMI, kg/m^2 Mean (SD)
Multicomponent exercise							
Bonato *et al*[25]	Italy	Elite basketballers	Cluster RCT	86/74	100%	20 (2)	20.8
Brushøj *et al*[26]	Denmark	Military recruits	Cluster RCT	487/490	NR	21 (range 19–26)	23.0
Coppack *et al*[27]	UK	Military recruits	Cluster RCT	759/743	27%	20 (3)	22.6 (2.4)
Richmond *et al*[28]	Canada	Junior high school students	Cluster RCT	353/372	57%	13 (range 11–15)	19.4 (2.9)
Foot orthoses							
Bonanno *et al*[29]	Australia	Military recruits	Parallel group RCT	153/153	21%	22 (5)	25.3 (3.5)
Franklyn-Miller *et al*[30]	UK	Military recruits	Parallel group RCT	200/200	35%	25	24.3
Mattila *et al*[31]	Finland	Military recruits	RCT 1:2 ratio	73/147	0%	19 (range 18–29)	24.5
Schwellnus *et al*[34]	South Africa	Military recruits	RCT 1:5 ratio	237/1151	0%	19 (1)	21.9*
Knee braces							
BenGal *et al*[32]	Israel	Young athletes	Parallel group RCT	27/33	28%	Range 18–25	NR
Van Tiggelen *et al*[33]	Belgium	Military recruits	RCT 1:2 ratio	54/113	19%	19 (1)	21.9 (2.4)
Stretching							
Pope *et al*[35]	Australia	Military recruits	Cluster RCT	735/803	0%	Range 17–35	NR
Running programme that progressed intensity							
Ramskov *et al*[36]	Denmark	Recreational runners	Parallel group RCT	221/226	61%	39 (10)	24.9 (2.9)
Running technique retraining							
Chan *et al*[37]	Hong Kong	Novice runners (<2 years of running experience)	Parallel group RCT	166/154	51%	34 (10)	22.1

*Calculated from a random sample (n=129).
BMI, body mass index; CG, control group; IG, intervention group; NR, not reported; RCT, randomised controlled trial; ;SD, standard deviation.

performance bias, with clear blinding of participants and study personnel achieved in only two (15%) studies,[28 29] and detection bias, with only seven (54%) studies assessing patellofemoral pain incidence blind to group allocation.[26–29 31 32 36]

Synthesis of results

Meta-analysis of two trials (227 participants) showed evidence that patellofemoral braces worn during physical activity for 6–8 weeks (compared with no brace) was associated with lower risk of patellofemoral pain (RR 0.40, 95% CI 0.22 to 0.73; I^2=24.0%)[32 33] (figure 2). However, the level of evidence was rated as low due to high risk of bias and few events recorded (contributing to imprecision) (online supplemental appendix 4).

Evidence from a single study (320 participants) evaluating the effect of a running retraining programme demonstrated a statistically significant patellofemoral pain risk reduction 12 months following eight sessions of instantaneous visual feedback to reduce the vertical impact peak of the ground reaction force (ie, run softer) (RR 0.21, 95% CI 0.07 to 0.60).[37] However, the level of evidence was also rated as low due to high risk of bias and few events recorded (online supplemental appendix 4).

Meta-analysis of four trials (3364 participants) evaluating the effect of multicomponent exercise programmes of 15–30 min duration, 2–7 times per week for 12–34 weeks (compared with stretching/light aerobic warm-up) indicated a 51% risk reduction; however, it did not reach statistical significance (RR 0.49, 95% CI 0.18 to 1.36; I^2=64.9%)[25–28] (figure 2). The level of evidence for multicomponent exercise programmes was rated as low due to high risk of bias and inconsistency (online supplemental appendix 4).

Similarly, meta-analysis of four trials (2314 participants) evaluating the effect of foot orthoses/insoles worn for 7–26 weeks showed evidence favouring a reduction in patellofemoral pain incidence for customised orthoses and shock absorbing insoles versus flat insoles/no orthoses, but this effect was not statistically significant (RR 0.63, 95% CI 0.35 to 1.13; I^2=0.0%)[29–31 34] (figure 2). The level of evidence for foot orthoses was rated as very low due to a high risk of bias, inconsistencies in the type of orthoses evaluated and few events recorded (online supplemental appendix 4).

Single studies evaluating the effect of a passive stretching intervention compared with no stretching (1538 participants, very low level of evidence),[35] nor a running programme that progressed intensity (compared with volume) (447 participants, low level of evidence)[36] had a statistically significant influence on patellofemoral pain risk (figure 2).

The NNT for specific interventions was: patellofemoral bracing=4, running technique modification=11, multicomponent exercise=60, foot orthoses=14 and stretching=76. On the other hand, an increase in running intensity programme had a number needed to harm of 207, indicating 207 individuals treated with an intensity-based running programme would result in one person experiencing a harmful effect (ie, develop patellofemoral pain) in comparison to individuals treated with a volume-based programme.

Subgroup analysis and publication bias

Subgroup analysis of study level characteristics, where possible (ie, male vs female, military vs athletes), were generally consistent with the overall effect of each intervention. Sex-specific effects could only be determined from four studies that included exclusively male or female participants. Of these, two evaluated the male-specific effect of foot orthoses (RR 0.74, 95% CI 0.33 to 1.66; I^2=0%),[31 34] which was similar to the effect of foot orthosis interventions with all studies combined. All studies evaluating foot orthoses were in military populations; while the two studies of multicomponent exercise interventions in military recruits had a similar pooled effect (RR 0.54, 95% CI 0.14 to

Table 2 Intervention and outcome characteristics of included studies

Study	Intervention characteristics					Patellofemoral pain characteristics	
	Intervention details	Control details	Frequency and duration	Physical exposure	Compliance	Diagnosis by*	Follow-up period
Multicomponent exercise							
Bonato *et al*[25]	Warm-up to practice/games: running, active lower-limb stretches and strength, plyometrics, balance, agility (focus on quality of movement)	Warm-up: light aerobic exercises, basketball drills, stretching	30 min, 4 times/week for 8 months	1 basketball season (26 matches, 120 training sessions)	IG: 78% completed ≥75% of sessions CG:NR	Medical doctors	8 months
Brushøj *et al*[26]	Progressive strengthening (squats, lunges, hip abduction/external rotation, forefoot lift), coordination, quadriceps stretches	Trunk/upper limb strength, pectorals stretch	15 min, 3 times/week for 12 weeks (3 sets of 5–25 reps)	Military training for 12 weeks	IG/CG: average 75% training sessions completed	Medical doctor	12 weeks
Coppack *et al*[27]	Warm-up to training (close chain quadriceps and gluteal strengthening) and warm-down (stretching of quadriceps, ITB, hamstrings and calf)	Jogging, general stretches, sit-ups, push-ups	15 min, 7 times/week for 14 weeks	Military training for 14 weeks	IG/CG: average 91% training sessions completed	Physical therapist	14 weeks
Richmond *et al*[28]	Warm-up to PE lessons: progressive neuromuscular training aerobic session (10 min) and core/lower-limb strength/balance training (5 min)	Warm-up: low-intensity jogging and stretching	15 min, 2–3 times/week for 12 weeks	Sports participation (2–3 times/week) for 12 weeks	IG: 84% of sessions CG: 95% of sessions	Physical therapists	12 weeks
Foot orthoses							
Bonanno *et al*[29]	'Formthotics' prefabricated foot orthoses (full length 140 kg/m^3 single-density, closed-cell polyethylene foam) moulded to feet (Foot Science International)	3 mm flat insoles (full length 140 kg/m^3 single-density, closed-cell polyethylene foam)	Worn in athletic and military shoes for all training	Military training for 11 weeks	IG: worn 10.5±3.6 hours/day CG: worn 10.2±5.2 hours/day	Blinded assessor	11 weeks
Franklyn-Miller *et al*[30]	Customised orthoses (modular injection moulded) different densities and arch profiles available to account for dynamic foot type	Non-exposed group	Worn for all physical training	Military training for 7 weeks	IG: NR CG: NA	Sports physician	7 weeks
Mattila *et al*[31]	'Thermo+Camel' orthotic insoles (three-quarter length firm-density polyethylene) moulded to feet in ankle boots	Non-exposed group	Worn for 70%–80% of training (ie, when ankle boots used)	Military training (19 hours/week for 6 months)	IG: Insole use: 80% CG: NA	Military physician	6 months
Schwellnus *et al*[34]	Flat insoles (neoprene impregnated with nitrogen bubbles covered with stretch nylon)	Non-exposed group	Worn for all physical training	Military training 3–5 times/week for 9 weeks	IG: 85% wore insoles every day† CG: NA	Medical doctor	9 weeks
Patellofemoral braces							
BenGal *et al*[32]	Genutrain silicon ring knee brace worn during physical activity	Non-exposed group	Worn for all physical training	Intensive physical training (6 hours/day) for 8 weeks	IG: NR CG: NA	Medical doctors	8 weeks
Van Tiggelen *et al*[33]	On-track (Donjoy Orthopaedics) dynamic patellofemoral braces (bilateral) (knee patches with Velcro and a neoprene sleeve)	Non-exposed group	Worn for all physical training	Military training for 6 weeks	IG: NR CG: NA	Military physician	6 weeks
Stretching							
Pope *et al*[35]	Bilateral stretches before all physical training sessions (gastrocnemius, soleus, hamstring, quadriceps, hip adductor, hip flexor)	Warm-up activities with no stretching	1×20 s each muscle, 3–4 times/week	Military training (4–5 hours/week for 11 weeks)	IG: NR CG: 94% (6% crossed over to stretches)	Medical officer	11 weeks
Running programme that progressed intensity							
Ramskov *et al*[36]	Running intensity schedule (increase time spent at ≥88% VO_2 max after each 4-week block)‡	Running volume schedule (increase volume by 23% after each 4-week block)	Running 3 times/week for 24 weeks	Running 3 times/week for 24 weeks	IG/CG: 85% completed≥80% of all running sessions scheduled	Physical therapist	24 weeks
Running technique retraining							
Chan *et al*[37]	Running retraining on a treadmill with visual biofeedback (instantaneous ground reaction force signal) aiming to reduce the vertical impact peak using the verbal cue 'run softer'	Treadmill running (same dose as intervention) with no feedback	Running 15–30 min, 4 times/week for 2 weeks	Normal recreational running (mean 19 km/week) for 12 months	IG/CG: 100% of all running retraining sessions completed	Medical professional§ (physician, physical therapist, orthopaedic surgeon)	12 months

*See online supplemental appendix 2 for details regarding criteria used to define the presence of patellofemoral pain.
†Assessed only in subgroup of 143 participants.
‡The running programme that progressed intensity was considered the intervention group because this programme (compared with the increase in running volume programme) was hypothesised by the authors of the original trial to reduce the risk of patellofemoral pain.
§Patellofemoral pain diagnosed by medical professional not involved in the study—participants reported their diagnosis to researchers who authenticated the injury incidence.
CG, control group; IG, intervention group; ITB, iliotibial band; NA, not applicable; NR, not reported; PE, physical education.

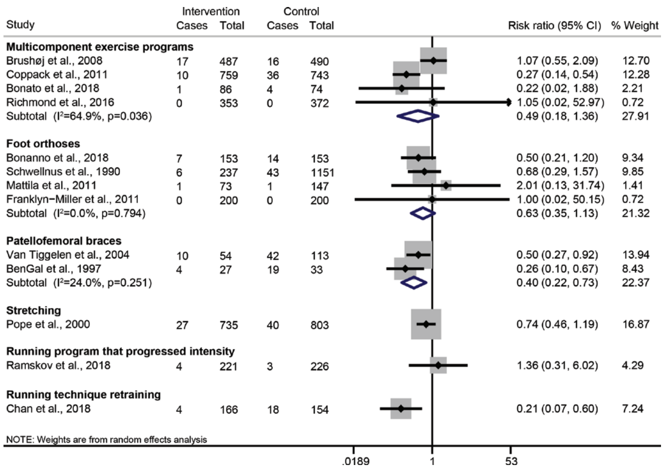

Figure 2 Forest plot displaying effects of interventions on reducing risk of incident patellofemoral pain.

2.07; I^2=87.1%)[26 27] to the overall findings for multicomponent exercise interventions. Assessment for publication bias in analyses of each intervention was not possible because of the limited number of studies in each meta-analysis.

DISCUSSION

This systematic review and meta-analysis of 13 RCTs involving 8210 participants demonstrated that a number of strategies may be effective in preventing patellofemoral pain, but the level of evidence was low to very low. Low certainty evidence suggests that patellofemoral braces worn during physical activity and a 2-week running retraining programme may reduce the risk of patellofemoral pain. Low to very low certainty evidence also suggests that multicomponent exercise programmes, foot orthoses, running intensity programmes and static stretching may not significantly reduce the risk of patellofemoral pain.

This systematic review extends previous systematic reviews evaluating interventions to prevent traumatic knee injuries, particularly the ACL,[18 38] and any lower-limb overuse injuries.[39] The evidence base for preventing patellofemoral pain was limited to a relatively small number of studies focussing on military recruits and young athletes and was only statistically significant for patellofemoral braces worn during physical activity and a running modification programme to run softer (ie, attenuate landing stiffness) in novice runners. Pooled data from the low number of studies need to be interpreted with some caution, given the considerable influence that one study can have on the pooled results and the low level to very low level of evidence for the interventions.

Effect of patellofemoral braces on reducing the risk of patellofemoral pain

The two braces worn during physical activity that significantly reduced patellofemoral pain risk included a silicon patellar support ring and a neoprene sleeve designed to optimise the position of the patella. While the mechanisms through which these braces elicited a risk reduction were not reported, patellofemoral bracing can change patellar mechanics,[40] proprioceptive feedback[41] and muscular recruitment patterns,[42] which are associated with patellofemoral pathology.[43 44] As it was not possible to blind participants or assessors (due to skin shaving/brace marks) to group allocation, the influence of other contextual factors also points to a potential placebo effect. The pooled observation of a 60% reduced risk of patellofemoral pain resulted in an NNT of 4. Although indicating that only four individuals need to wear a brace over 6–8 weeks of high-intensity exercise to prevent one case of patellofemoral pain, the NNT is likely to be larger in the general athletic population where a lower base patellofemoral pain prevalence rate (approximately 23%) typically exists,[1] compared with the 37%[33] and 58%[32] in the military and intensive exercise (6 hours daily) groups not exposed to bracing, respectively. The low certain evidence, together with the cost, potential inconvenience and associated non-adherence of prophylactic knee brace use in populations outside the military and intensive training settings, indicates that widespread implementation of bracing as an intervention to prevent patellofemoral pain should not be recommended.

Effect of running modifications on reducing the risk of patellofemoral pain

Two different running modification interventions in recreational runners (one for retraining technique and one for modifying running intensity) were included in this review; however, their disparate approaches prevented data pooling. A 2-week (eight session) running retraining programme, consisting of instructions to reduce the amplitude of the vertical impact peak of the ground reaction force (visualised instantaneously on a screen), was successful in reducing patellofemoral pain risk by 79% over a 12-month observation period. Although the vertical loading rate on foot strike was reduced at the end of the 2-week training period, it is unclear if this adaptation was maintained over the 12-month follow-up period. It is important to note that, despite achieving a reduction in patellofemoral pain risk, the incidence of other overuse injuries increased with the new running technique (eg, Achilles tendinitis, shin splints) highlighting a potential risk of changing running technique too quickly.[45] The substantial risk reduction reported and the low certainty evidence from this single study should encourage future trials to further evaluate the impact of running retraining on reducing patellofemoral pain (and other injury) risk. In contrast to running technique adaptations, adapting a running programme to progressively increase running intensity did not reduce the risk of patellofemoral pain compared with a programme of progressive increases in running volume. Indeed, the intensity programme was associated with a 36% higher risk of patellofemoral pain. This effect was statistically non-significant, with a wide CI contributing to the low-level of evidence.

Effect of multicomponent exercise programs on reducing the risk of patellofemoral pain

Pooled data from this systematic review indicates that multicomponent exercise programmes can reduce the risk of patellofemoral pain by 51% but this finding did not reach statistical significance. This effect size is consistent with the 50% risk reduction for ACL injuries experienced after performing similar training programmes;[18] however, it is important to note that the magnitude of patellofemoral pain risk reduction was not consistent across studies (I^2=65%). The variability in the direction and size of the effect between the original trials resulted in the pooled effect being imprecise (ie, wide CI). We were unable to rule out a possible harmful effect (ie, increased risk of patellofemoral pain) of the multicomponent exercise programmes. The imprecise findings contributed to an overall low certainty of evidence.

A potential explanation for the differing effect sizes in the original exercise trials may lie in differences in exercise prescription. Most exercise interventions in the four included studies included an aerobic warm-up, lower-limb muscle stretching, strengthening and neuromuscular control exercises. As most of the control groups in the four studies also included aerobic warm-ups, general stretching and upper body/trunk strengthening, the major difference in the intervention and control programmes were the inclusion of lower-limb strengthening. While all exercise interventions were prescribed at least 2–3 times per week for ≥3 months, in the studies that did not find a preventative effect,[26 28] the duration of strengthening exercises was only 5–10 min per session, consisting of only one quadriceps strengthening exercise, and prescription (eg, 3 sets × 20 reps or no dosage direction provided) not adhering to established muscle strengthening guidelines.[46] The two studies with the largest effect size reported more than double the minutes of exercise per week and included 2–3 quadriceps strengthening exercises,[25 27] supporting previous findings that weekly volume/intensity is important in preventing overuse injuries.[47] These findings are also consistent with ACL injury prevention programmes, where studies reporting the largest preventive effects met strengthening and/or plyometric guidelines.[38] Optimal quadriceps strength is also likely to be important in preventing longer-term burden of patellofemoral structural changes and associated symptoms.[48–50] It is unlikely that the static stretching component of the multifaceted exercise programmes contributed substantially to the observed patellofemoral pain risk reduction as the single study included in this review evaluating static muscle stretching (3–4 times per week vs no stretching, in a military population) observed no significantly reduced risk of patellofemoral pain.[35] Although the level of evidence for this finding from static stretching was very low, it is consistent with a previous systematic review concluding that static stretches do not effectively reduce soft tissue running-related injuries.[39] Future studies should deliver sufficient doses of strength training to achieve and maximise preventative effects. These programmes may also be optimised by targeting them towards individuals with muscle weakness, particularly the uninjured limb of individuals with a traumatic knee injury,[51] given that quadriceps weakness is a risk factor for patellofemoral pain.[11]

Effect of foot orthoses on reducing the risk of patellofemoral pain

Foot orthoses may prevent patellofemoral pain in some individuals, with the pooled point estimate from our meta-analysis of four trials indicating a 37% reduced risk. However, this effect was not statistically significant and was associated with a very low quality of evidence. Our results extend data from a recent systematic review evaluating the effect of foot orthoses to prevent any injury indicating a non-significant 31% reduction in risk of general soft tissue injuries (patellofemoral pain was not specifically evaluated).[52] All foot orthoses trials included in the current review were conducted in military settings, with three of the four studies using prefabricated orthoses (two were heat moulded to participant's feet,[29 31] one was customised to the arch profile[30]) and one study used shock absorbing flat insoles.[34] Sensitivity analysis excluding the flat insole intervention resulted in a similar effect size (RR 0.58, 95% CI 0.26 to 1.32). Only one study used a flat insole as the control intervention to successfully blind participants to group allocation, which was also the study with the largest preventative effect size.[29] While the NNT for foot orthoses was 14, indicating 14 individuals needing to use foot orthosis to prevent one case of patellofemoral pain, it is important to note that prefabricated foot orthoses and shock absorbing insoles can have adverse events (although mostly minor blisters and arch irritation) in up to 20% of individuals.[29] Foot orthoses are generally inexpensive and easily accessible and have the potential to prevent other musculoskeletal conditions, such as lower-limb stress fractures.[52] Future studies might assist in elucidating individuals most likely to benefit from foot orthosis prescription, such as those with certain biomechanical loading characteristics,[11] to prevent patellofemoral pain and other overuse conditions.

Strengths and limitations

To eliminate a potential source of detection bias, we only included studies with a confirmed diagnosis of new-onset patellofemoral pain following physical assessment rather than relying on a self-report diagnosis. Most included studies reported excellent adherence to the interventions and no/little loss to follow-up reflecting the included populations of military recruits, elite athletes and school students being closely monitored. It is unclear if the findings of this review of primarily military recruits and young adult athletes are generalisable to other populations, such as active adolescents, who have a high prevalence of patellofemoral pain.[1] Our findings must be considered in the context of limitations in the primary studies which resulted in an overall low to very low quality of evidence, mostly due to the high risk of bias and relatively low number of patellofemoral pain cases. The relatively low number of studies and patellofemoral pain cases (potentially reflecting the time-loss diagnostic criteria used in some studies) indicate that additional studies may have a considerable influence on the pooled results. The low number of studies for each intervention also limited our a priori secondary analyses evaluating sex-specific and setting-specific effects. Where it was possible, the subgroup effects were aligned with the overall pooled estimates. No study evaluated the effect of education. Given that health professional delivered education can produce similar outcomes as exercise therapy for patellofemoral pain management,[53] the potential effect of education to prevent patellofemoral pain could be explored. Another limitation was the heterogeneity in the different interventions including the duration of delivery (range: 2 weeks to 8 months) and follow-up period to monitor patellofemoral pain incidence (range: 6 weeks to 12 months). Finally, we were unable to assess publication bias because of all intervention types including four studies or less.

Practical implications

According to the current systematic review, patellofemoral braces and running retraining (to run softer) might be used to effectively reduce incident patellofemoral pain in active young adults. In the absence of data from large general athletic and military populations, the cost and convenience of providing patellofemoral braces and instrumented (treadmill) running retraining to such groups needs to be considered in the context of the low-quality evidence from this systematic review prior to implementation. Multicomponent neuromuscular warm-up and strengthening programmes that are strongly advocated to reduce the risk of ACL injuries may also reduce the risk of patellofemoral pain.[54] While the current level of evidence for these programmes being effective at preventing patellofemoral pain is low, they are unlikely to do harm and may help to prevent other injuries. Although only one of the included multicomponent exercise interventions was designed specifically to prevent patellofemoral pain,[27] half as many people need to perform these exercises to prevent one case of patellofemoral pain (n=60) compared with the number required to prevent one ACL injury (n=120).[55] The results from this systematic review may also help to reduce the risk of patellofemoral problems after ACL injury.[56] Our results further emphasise the importance of widespread implementation of appropriately dosed strengthening and neuromuscular training injury prevention programmes. In contrast, foot orthoses, static stretching and running modification (increase in intensity vs increase in volume) should not be advocated to reduce the risk of patellofemoral pain without further high-quality evidence.

CONCLUSIONS

This systematic review found low-level evidence that the risk of patellofemoral pain can be reduced by up to 60%–79% with the use of patellofemoral braces worn during physical activity or running retraining to run softer (to attenuate landing stiffness). Although multicomponent exercise programmes and foot orthoses appear to be associated with a favourable effect on patellofemoral pain risk, further studies are required to establish their preventative effect.

What is already known

- Patellofemoral pain is common in young athletes and military recruits and is associated with a considerable personal and healthcare burden.
- Evidence-based interventions to treat patellofemoral pain include hip-based and knee-based exercise-therapy and foot orthoses, yet approximately half of all patients have an unfavourable outcome over the following 12 months.
- Injury prevention programmes can effectively reduce the risk of traumatic knee injuries such as anterior cruciate ligament tears.

What are the new findings

- In young athletes and military recruits, there is low-quality evidence that patellofemoral braces worn during physical activity reduce the risk of patellofemoral pain by 60% (risk ratio (RR) 0.40, 95% CI 0.22 to 0.73).
- In novice runners, low-quality evidence suggests a running retraining programme to run softer (ie, attenuate landing stiffness) reduced the risk of patellofemoral pain by 79% (RR 0.21, 95% CI 0.07 to 0.60).
- Although the pooled estimate indicates that multicomponent exercise-based injury prevention programmes may reduce the risk of patellofemoral pain by 51% (RR 0.49, 95% CI 0.18 to 1.36), this effect was not statistically significant and had low certainty of evidence.
- Foot orthoses may reduce the risk of patellofemoral pain (pooled estimate suggests a 37% reduced risk (RR 0.63, 95% CI 0.35 to 1.13)); however; this effect was not statistically significant and was associated with a very-low certainty of evidence.

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Contributors All authors contributed to the conception, data analysis and interpretation, and writing and/or drafting of the manuscript. All authors approve the final version.

Funding AGC is a recipient of a National Health and Medical Research Council of Australia Early Career Fellowship (Neil Hamilton Fairley Clinical Fellowship, APP1121173). EMM received funding support from a Canadian Institutes of Health Research Banting Postdoctoral Fellowship.

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

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