The effects of hip- and ankle-focused exercise intervention on dynamic knee valgus: a systematic review

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Background. A range of non-contact injuries such as anterior cruciate ligament tear, patellar displacement and patellofemoral pain syndrome are caused by disordered knee joint loading from excessive dynamic knee valgus (DKV). Previous systematic reviews showed that DKV could be modified through the influence of hip strength and ankle range of motion. There was also a narrative review that investigated hip-focused neuromuscular exercise intervention on DKV. Therefore, the purpose of this systematic review was to examine the effects of exercise intervention which involved either top-down or bottom-up kinetic chains on minimizing DKV in male and female adults and adolescents, with and without existing knee pain . **Methodology.** Electronic searches were conducted in SAGE, Science Direct, SCOPUS, and Pubmed. The search strategy consisted of the medical subject headings and the free-text search keywords, synonyms and variations of 'exercise intervention,' 'knee alignment,' 'dynamic knee valgus', 'knee abduction' that were merged via the Boolean operator 'AND' and 'OR'. The search was conducted on full-text journals that documented the impact of the exercise intervention program involving either the bottom-up or top-down DKV mechanism on the knee kinematics. Furthermore, exercise intervention in this review should last at least one week which included two or three sessions per week. This review also considered both men and women of all ages with a healthy or symptomatic knee problem. The risk of bias of the included studies was assessed by Cochrane risk assessment tool. The protocol of this review was registered at PROSPERO (registration number: CRD42021219121). **Results.** Ten studies with a total of 289 participants (male= 122, female= 321; adults= 230, adolescents= 142; pre-adolescent= 51) met the inclusion criteria were included in this review. Seven studies showed the significant effects of the exercise intervention program (range from two weeks to ten weeks) on reducing DKV. The exercise training in these seven studies focused on muscle groups directly attached to the knee joint such as hamstrings and gastrocnemius.

The remaining three studies did not show significant improvement in DKV after the exercise intervention (range between eight weeks to twelve weeks) probably because they focused on trunk and back muscles instead of muscles crossing the knee joint.

Conclusion. Exercises targeting specific knee-joint muscles, either from top-down or bottom-up kinetic chain, are likely to reduce DKV formation. These results may assist athletes and coaches to develop effective exercise program that could minimize DKV and ultimately prevent lower limb injuries.

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Abstract

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Conclusion. Exercises targeting specific knee-joint muscles, either from top-down or bottom-up kinetic chain, are likely to reduce DKV formation. These results may assist athletes and coaches to develop effective exercise program that could minimize DKV and ultimately prevent lower limb injuries.

Keywords: biomechanics, kinetic chain, knee alignment, strength training

Introduction

58
59   Dynamic knee valgus (DKV) is defined as a body position in which the knee collapses
60 from excessive valgus, excessive internal-external rotation, or both conditions (Krosshaug et al.,
61 2007). DKV can be caused by hip abductor weakness that entails internal rotation of the hip,
62 excessive frontal knee alignment or tibial rotation angles and contralateral pelvic drop (Powers,
63 2010). Disordered knee joint loading from excessive DKV can trigger a spectrum of injuries
64 such as anterior cruciate ligament (ACL) tear, patellar displacement, and patellofemoral pain
65 (Myer et al., 2015).

66   Two types of kinetic chains play a major role in the mechanisms of DKV, namely top-
67 down (proximal origin) and bottom-up (distal origin) kinetic chains (Jamaludin et al., 2020). A
68 top-down kinetic chain occurs when the hip and trunk muscles alter the distal joints' kinematic
69 patterns (Snyder et al., 2009). On the contrary, a bottom-up kinetic chain involves the influence
70 of ankle musculature and foot structures on knee joint motions (Khamis & Yizhar, 2007).
71 Several studies have reported that the strength of hip adduction, knee flexion, and knee extension
72 were the key indicators of knee valgus (top-down kinetic chain) (Willson et al., 2011; Willson,
73 Ireland & Davis, 2006). Besides, recent studies also observed that excessive DKV could be
74 associated with foot-ankle strength as well as its range of motion (ROM) and kinematics
75 (bottom-up kinetic chain) (Kagaya, Fujii & Nishizono, 2015; Lima et al., 2018). Previous studies
76 aimed to find the sources of excessive DKV and knee joint loading to prevent lower extremity
77 injuries such as ACL strain (Nessler, Denney & Sampley, 2017). Several other studies also
78 presented evidence on how preventive training programs could minimize the occurrence of non-
79 contact lower extremity (Petersen et al., 2005), knee or ACL (Hewett et al., 1999), and ankle
80 injuries (Verhagen et al., 2004).

81   A systematic review by Lima et al. (2018) evaluated the association between ankle
82 dorsiflexion (bottom-up kinetic chain) and DKV in interventional and non-interventional studies.
83 By including the non-interventional studies, the review results might not be related to the impact
84 of exercises on reducing DKV. Meanwhile, a systematic review by Dix et al. (2018) investigated
85 the association between hip muscle strength (top-down kinetic chain) and DKV in asymptomatic
86 (i.e., free from any injury) females. Similarly, the review did not investigate the effects of
87 exercises that contribute to hip muscle strength in reducing DKV. A narrative review by Ford et
88 al. (2015) provided details on a hip-focused neuromuscular exercise intervention to improve
89 DKV. However, narrative review by Ford et al., (2015) excluded in-depth and systematic
90 literature search approach, hence it may miss out several relevant papers. The review with meta-
91 analysis conducted by Lopes et al., (2018) was focused on the effects of injury prevention
92 programs (IPPs) specifically on landing biomechanics as they relate to the ligament, quadriceps,
93 trunk, and leg dominance theories of ACL injury. To the best of our knowledge, no systematic
94 review has been conducted that focused on the effects of top-down (hip-focused) or bottom-up
95 (ankle-focused) kinetic chain of exercise intervention on DKV mechanisms. The review will
96 shed light on how the exercise training programs may improve the mechanisms behind knee

97   injury. Therefore, the present systematic review aims to determine the influence of hip- and
98   ankle-focused exercise intervention on improving DKV.

99

Methods

101   This review was conducted in compliance with the recommendations of the Preferred
102   Reporting Items for Systematic Reviews (PRISMA) (Liberati et al., 2009). Universiti Sains
103   Malaysia granted ethical approval to carry out the study within its facilities (Ethical Application
104   Ref: USM/JEPeM/18070316). The protocol of this review was registered at PROSPERO
105   (registration number: CRD42021219121).

106   Search Strategy

107   Two researchers (FNAS and NIJ) individually screened through four medical databases,
108   namely SCOPUS, SAGE, Pubmed, and Science Direct from database inception until November
109   2020. The search technique consisted of medical subject headings (MeSH) and free text search
110   keywords, synonyms, and variations to retrieve all relevant articles. Three phrases were merged
111   for searching databases using the Boolean operator 'AND' and 'OR': i.e. 'exercise intervention,'
112   'training', 'knee alignment,' 'dynamic knee valgus', 'knee abduction'. The reference lists of all
113   the included manuscripts and authors' files were also reviewed to identify other relevant studies.

114   Study Selection

115   The titles and abstracts of the retrieved studies were downloaded into Mendeley (version
116   1.19.4, Mendeley, London, United Kingdom). Two independent reviewers scanned all abstracts
117   for eligibility and removed any duplicates. Full texts were obtained for abstracts that fulfilled the
118   inclusion criteria. In the event of any ambiguous details, the corresponding authors of the studies
119   were contacted via e-mail. Any disagreement between the two investigators would be resolved
120   by discussing with the third investigator (SS) so that a consensus could be reached. A schematic
121   diagram of the study selection is shown in Figure 1.

122   <<< insert Figure 1 here >>>

123   Inclusion and Exclusion Criteria

124   To be eligible for inclusion, the studies must describe the impact of the exercise
125   intervention program that involved either the bottom-up or the top-down DKV mechanism on the
126   knee kinematics. The duration of the intervention must be at least one week with two or three
127   sessions per week. Men and women of all ages with healthy or symptomatic knee conditions
128   were included. There was no limitation on the date of publication. Only human interventional
129   studies presented in English full-text journals that discussed DKV or knee alignment were
130   included in this review. Other research designs such as meta-analyses, systematic reviews, case

131   reports and series, cross-sectional studies, concept papers, editorials, opinions, and *in vitro*
132   research were excluded. Seminar, poster presentations, reviews, case studies, editorials, letters,
133   and abstract-only texts were also excluded.

134   Data Extraction

135   For every included study, two researchers extracted the information. The data were
136   synthesized and tabulated based on the first authors' surname, date of publication, sample size,
137   participants' age and fitness level, exercise intervention and its duration, group allocations,
138   methods of outcome assessment, functional tasks, and outcomes (Table 1).

139   <<< insert Table 1 here >>>

140

141   Quality Assessment

142   The methodological quality of the included studies was evaluated based on the Cochrane
143   risk bias assessment tool. The tool assessed random sequence generation, allocation
144   concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete
145   outcome data, selective reporting, and other biases in the studies. Items were scored as "yes",
146   "no", or "unclear". The details of the analysis of the risk of bias are described in Figure 2.

147   <<< insert Figure 2 here >>>

148

149   **Results**

150   Characteristics of Included Studies

151   A total of 590 articles were identified in the database search, but only two were included
152   in the final review (Bell et al., 2013; Barendrecht et al., 2011). Additionally, thirteen other
153   potential papers were identified when manually checking the reference lists of the included
154   articles. Only eight fulfilled the inclusion criteria (Sheerin, Hume & Whattman, 2012; Baldon et
155   al., 2014; Czasche et al., 2017; Araújo et al., 2017, McCurdy et al., 2012; Jeong et al., 2021;
156   Thompson-Kolesar et al., 2017 & Saad et al., 2018). Therefore, a total of ten studies were included
157   in the final review.

158   In general, the results of included studies are differed based on the types of exercise
159   prescribed in the training program and the participants involved. Most studies focused on
160   strengthening the hamstring and quadriceps muscles. Only Bell et al., (2013) targeted the
161   improvement of the hip and ankle muscles' strength and flexibility. The duration and frequency of
162   exercise training program ranged from three to 12 weeks, with two to three sessions per week. The
163   participants in the included studies were volunteers (Bell et al., 2013), university students (Araújo

164 et al., 2017), handball players (Barendrecht et al., 2011), , young athletes (Sheerin, Hume &
165 Whattman, 2012), recreational athletes (Czasche et al., 2017; Jeong et al., 2021), preadolescent
166 and adolescent soccer athletes (Thompson-Kolesar et al., 2017), females with previous athletic
167 experience (McCurdy et al., 2012) and patients with patellofemoral pain syndrome, PFPS (Baldon
168 et al., 2014; Saad et al., 2018). Six studies involved only women (Baldon et al., 2014; Saad et al.,
169 2018; Araújo et al., 2017; Czasche et al., 2017; McCurdy et al., 2012; Thompson-Kolesar et al.,
170 2017), one study included only men (Jeong et al., 2021) and the remaining studies included both
171 genders.

172   Regarding the study procedures, Czasche et al. (2017), Jeong et al., (2021) & McCurdy et
173 al., (2012) did not mention any screening procedure used to evaluate excessive DKV. Moreover,
174 Baldon et al., (2014) and Saad et al., (2018) did not specify any screening procedure to evaluate
175 excessive DKV because they implied the presence of knee valgus based on the diagnosis of PFP
176 injury. However, other five studies, namely Barendrecht et al., (2011); Bell et al., (2013); Araújo
177 et al., (2017); Sheerin, Hume & Whattman, (2012); Thompson-Kolesar et al., (2017), screened the
178 participants for excessive DKV through various types of test. Barendrecht et al., (2011) measured
179 knee valgus from the drop-jump test by evaluating the knee minimum distance values (i.e., less
180 than 49.96% showed the presence of knee valgus) using 2-D analysis. Meanwhile, Bell et al.,
181 (2013) visually confirm the presence of knee valgus during double-legged squat (DLS) whereas,
182 Araújo et al., (2017) screened DKV during 18-cm step-down task. Sheerin, Hume & Whattman
183 (2012) screened DKV based on the pre-running test's knee abduction angle while, Thompson-
184 Kolesar et al., (2017) evaluated baseline knee valgus angle and moments for double, single-legged
185 landing, preplanned and unanticipated cutting tasks.

186   The effectiveness of an exercise intervention program in improving DKV was evaluated
187 using a variety of tasks such as step-up and step-down (Saad et al., 2018; Araújo et al., 2017),
188 DLS (Bell et al., 2013), single-leg squat (Baldon et al., 2014), double, single-legged landing,
189 preplanned and unanticipated cutting (Thompson-Kolesar et al., 2017), side step cutting (Jjeong et
190 al., 2021), drop jump (Barendrecht et al., 2011), unilateral and bilateral landings (Czasche et al.,
191 2017), unilateral and bilateral drop jumps (McCurdy et al., 2012), and running analysis (Sheerin,
192 Hume & Whattman, 2012). Our results showed that seven studies reported significant difference
193 in DKV following the exercise intervention program (Saad et al., 2018; Bell et al., 2013; Baldon et
194 al., 2014; Jeong et al., 2021; Thompson-Kolesar et al., 2017; Barendrecht et al., 2011; Sheerin,
195 Hume & Whattman, 2012)). On the other hand, Czasche et al., (2017), Araújo et al., (2017) and
196 McCurdy et al., (2012) did not detect any significant improvement on DKV after the exercise
197 intervention program.

Discussion

199   Previous systematic reviews revealed the association of increased ankle dorsiflexion
200 ROM (i.e., bottom-up kinetic chain) and hip strength (i.e., top-down kinetic chain) in reducing
201 DKV (Lima et al., 2018; Dix et al., 2018). Additionally, a narrative review found that

202   neuromuscular exercises targeting hip musculature strength may alter DKV (Ford et al., 2015).
203   However, to date, there is no systematic review investigating the impact of exercise intervention
204   based on top-down and bottom-up kinetic chains on DKV. We found that several exercise
205   programs have successfully minimized excessive DKV in several tasks, for example, step-up and
206   step-down (Saad et al., 2018), DLS (Bell et al., 2013), single leg squat (Baldon et al., 2014),
207   double-legged landing (Thompson-Kolesar et al., 2017), drop jump (Barendrecht et al., 2011),
208   side step cutting (Jeong et al., 2021) and running gait (Sheerin, Hume & Whattman, 2012).
209   However, some studies showed no changes on DKV particularly during unilateral and bilateral
210   landings (Czasche et al., 2017), unilateral and bilateral drop jumps (McCurdy et al., 2012) and
211   step-down task (Araújo et al., 2017) following exercise intervention programs.
212   Sheerin, Hume & Whattman, (2012) observed that eight weeks of lower limb functional
213   exercise program minimally altered the knee frontal plane motions during running. The study
214   randomly assigned 19 youth athletes from a long-term athletic development program to either the
215   control group that received only upper limb strengthening exercises or the experimental group
216   that received both upper limb strengthening and lower limb functional exercises that focused on
217   minimizing knee valgus angle. The experimental group performed functional weight bearing
218   exercises aimed at reducing knee valgus angle and open and closed kinetic chain exercises to
219   promote hip muscle activation. Thus, the exercises training involved a top-down kinetic chain
220   that emphasized hip muscle to reduce knee valgus. The study was among the first to describe the
221   effects of a lower limb functional exercise intervention on the running mechanics in the cohort of
222   youth athletes. The minimal changes of knee valgus angle could be due to the studied population
223   (i.e., youth athletes) who are accustomed to regular high-intensity training. Additionally, the
224   study provided important insight on injury prevention as injury rates were often higher among
225   youth athletes (Mail et al., 2019).
226   Barendrecht et al. (2011) showed that neuromuscular training resulted in greater contact
227   time, knee valgus and knee flexion angles during a drop jump test. They divided 80 adolescent
228   handball players into two groups that received either neuromuscular training (NMT) (n=49) or
229   regular training (RT) (n=31). The exercises in the NMT group included a combination of top-
230   down and bottom-up kinetic chain exercises that were focused on enhancing hamstrings
231   muscular strength and ankle motion control to alter knee mechanics. Meanwhile, the RT group
232   received only regular handball training. Following that, the participants were also grouped based
233   on their knee minimum distance values measured during landing or take-off in a drop jump test
234   (Noyes et al., 2005). By using a cut-off point of 49.96%, those with knee minimum distance
235   below the cut-off point value were assigned to the below-average valgus aligned (BAVA) group
236   as compared to those in the above-average valgus aligned (AAVA) group (Barendrecht et al.,
237   2011). The integrated NMT group displayed better knee kinematics and single-leg stability than
238   RT, particularly among adolescent handball players with AAVA. Thus, it is recommended to
239   incorporate the NMT program to improve knee valgus angle particularly among adolescent
240   handball players between 13-16 years old who were predisposed to a high risk of ACL injury

241 (Griffin et al., 2006). In fact, the overall rate of injury among this group of players was
242 comparable to those in the senior handball team (Olsen et al., 2006).
243   Thompson-Kolesar et al., (2017) investigated the effects of FIFA Medical and Research
244 Center (F-MARC) 111 injury prevention warm-up program on differences in biomechanical risk
245 factors for ACL injury between pre-adolescent and adolescent female soccer playersEach age
246 group was divided into two groups; intervention (received F-MARC 11+ injury prevention
247 warm-up program in 15 sessions 7-8 weeks (2 sessions per week)) and control (did not received
248 any program). The F-MARC 11+ involved exercises for core strength, neuromuscular control
249 and balance, eccentric training of the hamstrings, plyometric and agility. The program involved a
250 combination of top-down and bottom-up kinetic chain to alter the mechanisms of knee valgus
251 formation as the exercises in the program focused on hip and ankle muscles. Then, the
252 biomechanical changes were evaluated during four functional tasks; double-legged landing,
253 single-legged landing, pre-planned and unanticipated cutting. The authors noted that the
254 preadolescent athletes improved more in knee valgus angle and moment during the double-
255 legged jump than adolescent athletes, implying that they can gain more from participation in the
256 F-MARC 11+ program.
257   Bell et al., (2013) recruited a total of 32 volunteers with knee valgus before assigning
258 them randomly to either the control or intervention group. Knee valgus was identified visually
259 through the usage of corrected heel lift during a DLS. Bell, Padua & Clark, (2008) mentioned
260 that corrected heel lift during DLS might restrict certain ankle motion, especially ankle
261 dorsiflexion associated with the bottom-up mechanism of DKV. If the midpoint of the patella
262 moved medially to the great toe in three to five squats, the participants were identified as having
263 knee valgus. The intervention program was comprised of hip- and ankle-focused muscle
264 strengthening and ankle flexibility exercises for two to three weeks. Therefore, the intervention
265 program used a combination of top-down and bottom-up kinetic chain to reduce knee valgus. As
266 for the control group, they did not receive any exercise program throughout the intervention
267 period. The intervention group showed a 64% reduction of knee valgus during squat compared to
268 their baseline and the control group. The ankle strength and flexibility (i.e., bottom-up kinetic
269 chain) may alter the individual's poor movement patterns by limiting medial knee displacement
270 (MKD) and increasing the ankle dorsiflexion ROM during DLS (Bell et al., 2013). This is due to
271 the ankle being placed in a more plantarflexed position, which reduced the knee abduction. The
272 study by Bell et al., (2013) was among the first to demonstrate changes in the knee valgus angle
273 during DLS following bottom-up DKV kinetic chain (i.e., ankle-focused) exercise intervention in
274 individuals with identified knee valgus. However, it is crucial to highlight that the physical
275 activity level of the participants in this study was not assessed or controlled, which may have
276 influenced the results. Moreover, fitness level and gender of participants may influence the
277 outcomes of intervention. For instance, in a study by Mohd Azhar et al., (2019), no association
278 of foot positions on lower limb kinematics during single leg squat (i.e., bottom-up kinetic chain)
279 among highly trained male youth athletes, although Ishida et al., found significant association of
280 similar variables among sedentary females.

281   Baldon et al., (2014) found that functional stabilization training (FST) consisted of hip
282 muscle strengthening, lower limb and trunk movement control exercises (i.e., a combination of
283 top-down and bottom-up kinetic chain exercises), modified the knee kinematics in the frontal
284 plane during single leg squat (SLS). In this study, a total of 31 female recreational athletes with
285 PFPS were assigned randomly to either standard training (ST) or FST group. The ST group
286 received stretching, traditional weight-bearing and non-weight-bearing exercises that stressed on
287 strengthening the quadriceps (i.e., top-down kinetic chain only). Although no DKV screening
288 test was conducted by Baldon et al. (2014), PFPS was regularly associated with excessive DKV
289 (Hewett et al., 2005). The study highlighted the contribution of FST towards improving the
290 lower limb control on the frontal plane motion following 8-weeks of intervention. Nevertheless,
291 this study's findings were only limited to females with PFPS (Baldon et al., 2014).
292   Jeong et al., (2021) reported that the intervention group showed reduced knee valgus
293 during side-step cutting task following ten weeks of core strength training. This study involved
294 48 male participants who were assigned randomly to either the intervention or control group. The
295 intervention group performed core muscles' exercises (i.e., top-down kinetic chain) for ten
296 weeks with three sessions per week while the control group continued their daily routine. The
297 results corroborate the findings of Willson et al., (2006), who discovered that participants with
298 greater isometric core strength had reduced knee valgus angles during SLS. Jeong et al., (2021)
299 concluded that that core strengthening, which involves top-down kinetic chain exercises, may
300 assist male athletes in avoiding knee valgus alignment during side-step cutting.
301   Saad et al., (2018) reported that eight weeks of hip and quadriceps exercises (i.e., top-
302 down kinetic chain) significantly reduced knee valgus angle during step tasks. A total of 40
303 female recreational athletes with PFPS were randomly assigned to hip-focused exercises,
304 quadriceps-focused exercises, stretching exercises, and control (i.e., no intervention) groups.
305 DKV was evaluated using a 3-D analysis of tibiofemoral flexion at 45° during step tasks. The
306 step-up task was associated with a higher DKV incidence rate because it is a challenging motion
307 for individuals with PFPS (Saad et al., 2011). From the pre-test results, the valgus movement
308 pattern appeared for 87.18% during step-up and 82.05% during step-down. However, these
309 values decreased at the end of the intervention program to 66.67% in the hip-focused group and
310 48.72% in the quadriceps-focused group. Thus, the quadriceps-focused group showed a greater
311 improvement than the hip-focused group in minimizing knee valgus.
312   Three other included studies found no significant changes in DKV following exercise
313 intervention programs. Czasche et al. (2017) reported a change in the medial/lateral loading of
314 the knee following eight weeks of lower limb strength training (i.e., top-down kinetic chain)
315 despite a small non-statistically significant difference in the kinematics and GRF during drop
316 landing. The study involved 16 untrained and healthy young students assigned to either control
317 or intervention group. The intervention group received a leg strengthening exercise program for
318 eight weeks while the control group continued their daily routines. The lack of changes in DKV
319 could be due to the period of neural adaptation for strength training among untrained individuals.
320 Previous research suggests that the motion of the knee valgus may be altered in highly untrained

321   subjects who make significant gains in strength. For instance, Mascal, Landel & Powers, (2003)
322   observed reduced knee valgus motion during step-down task in two untrained patients with
323   PFPS. The patient's strength increased by 50–110 % in specified muscle groups after resistance
324   training, indicating major muscle weakness prior to training (Mascal, Landel & Powers, 2003).
325   Thus, for untrained participants, longer duration of lower limb strengthening program may be
326   needed for observable DKV kinematical changes.
327   McCurdy et al. (2012) found no significant difference in knee valgus angle during
328   bilateral (60 cm) and unilateral (30 cm) drop jumps between groups after eight weeks of
329   resistance training. Twenty-nine young adult females with previous athletic experience were
330   randomly assigned into either control or resistance training group. For two sessions a week, the
331   experimental group engaged in progressive load of resistance training. Although multi joints
332   weight-bearing training with free weights is assumed to be more sport-specific than resistance
333   band training, it appears that neither form of training affect knee valgus angles during landing
334   tasks (McCurdy et al., 2012). Even though they observed that 1RM squat increased by 19%,
335   athletes with previous resistance training experience will need more gains to dramatically change
336   frontal plane kinematics during a drop jump task. Hence, the authors propose that long-term
337   resistance training with a focus on increasing frontal plane intensity might be needed to change
338   frontal plane kinematics.
339   Araújo et al. (2017) reported no significant differences in transverse plane knee
340   kinematics during step-down task among women with DKV. The five exercises in the
341   experimental group comprised hip and trunk (i.e., top-down kinetic chain) muscle strengthening
342   exercises for three sessions per week. The load of the exercises was increased gradually over the
343   eight-week intervention. Meanwhile, the control group did not receive any training program. The
344   step-down task was used to evaluate the presence of DKV among the participants, which was
345   confirmed when the tibial tuberosity shifted over the second toe on a vertical imaginary line.
346   Despite the high training volume, the intervention was not adequate to alter any frontal and
347   transverse kinematic variables. This may be caused by the lack of specificity of the prescribed
348   exercises to the tested motions. Thus, they suggested a longer period of interventions and
349   specific exercises to strengthen certain muscles such as hamstring and gastrocnemius, to produce
350   more significant changes on the knee kinematics. They also addressed the need for additional
351   functional training, such as real-time feedback training during the step-down task to help the
352   participants inspect the changes in hip function. Despite a review from Dix et al., (2018) that
353   showed the relationship between hip muscle strength and DKV, Araújo et al., (2017) did not
354   report any significant improvement in DKV following eight-weeks of intervention. To the best of
355   our knowledge, this study represented one of the negative findings about top-down kinetic chain
356   exercises on DKV.
357   About half of the included studies showed high risk of bias in terms of randomization,
358   allocation concealment, blinding of participants, study personnel and outcome assessors, which
359   could have influenced their results. Also, the review was limited to the biomechanical knee
360   outcomes thus, future studies should consider other factors such as hip and ankle biomechanics.

361

Conclusion

363   In this review, we investigated the effects of exercise interventions, based on either top-
364 down or bottom-up kinetic chains, on minimizing DKV during specific tasks. As DKV is one of
365 the main factors that could increase the risk of lower limb injury, findings from this review
366 highlighted the importance of prescribing exercise training program to improve DKV.
367 Four studies (Barendrecht et al., 2011; Bell et al., 2013; Baldon et al., 2014; Thompson-Kolesar
368 et al., 2017) found significant changes in knee valgus following a training program that
369 combined both top-down and bottom-up kinetic chain exercises. Three studies (Sheerin, Hume,
370 and Whattman, 2012; Saad et al., 2018; Jeong et al., 2021) discovered that top-down kinetic
371 chain exercise intervention programs were also effective in reducing knee valgus. However,
372 McCurdy et al., (2012), Czasche et al., (2017) and Araújo et al., (2017) did not detect any
373 significant effects of the exercise intervention in minimizing DKV. Therefore, we concluded that
374 a combination hip- and ankle- focused exercises and hip-focused (top-down kinetic chain)
375 exercises only are more favorable than exercise program consisted of ankle-focused (bottom-up
376 kinetic chain) exercises only. Apart from focusing on the load and volume of prescribed
377 exercises, the specificity of exercises should also be emphasized. These findings might help the
378 athletes and coaches to design appropriate exercise programs in reducing DKV.

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382

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Figure 1

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analyses) flow chart of the included studies.

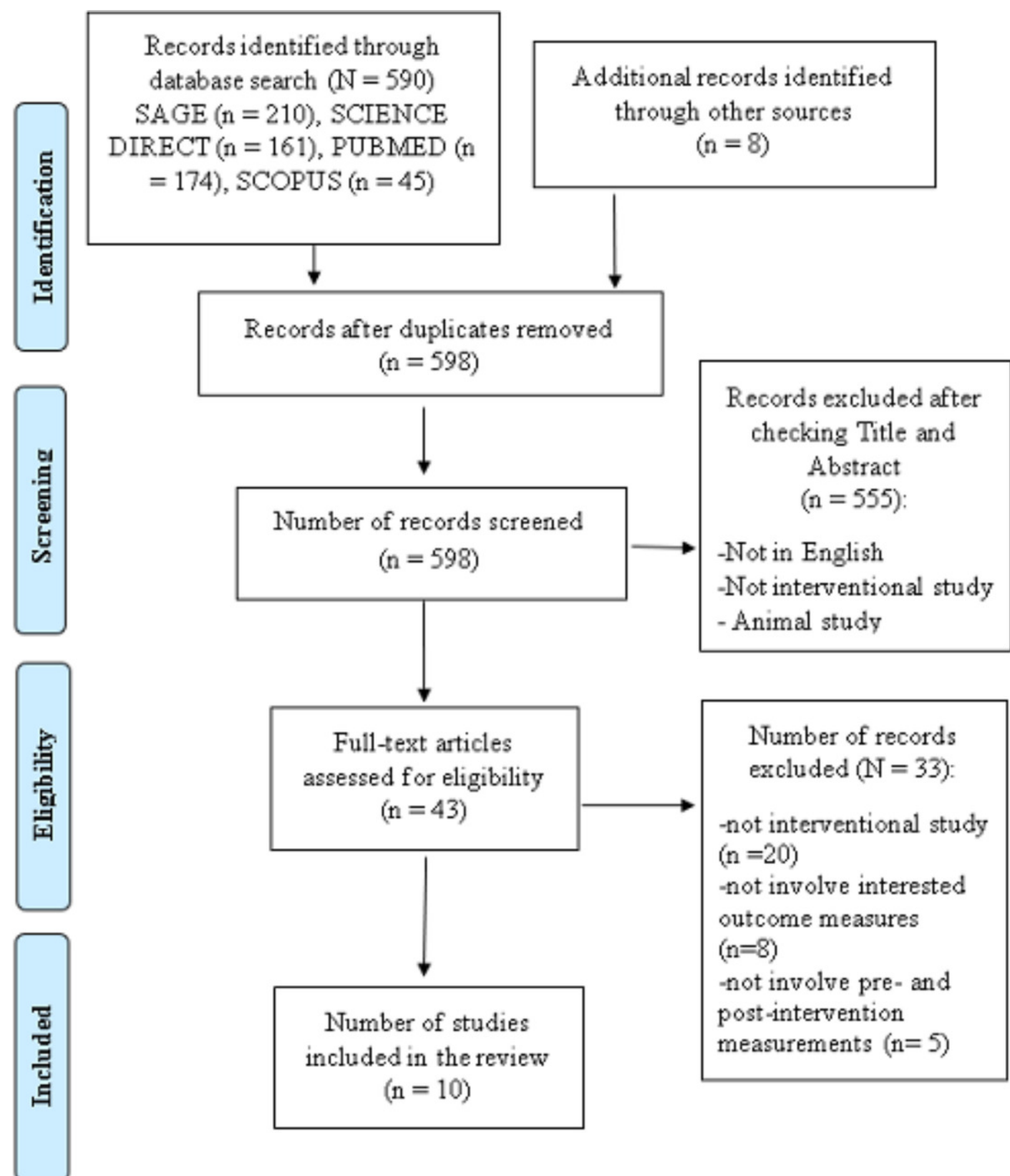
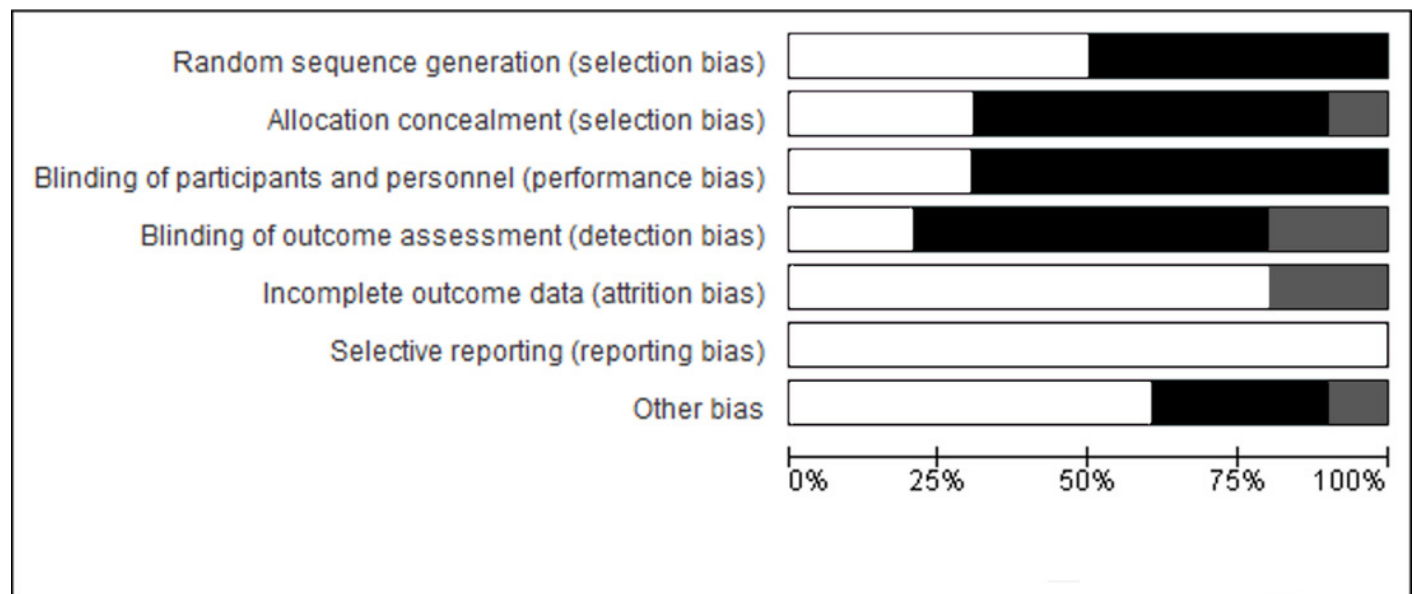



Figure 2

Risk of bias of the included studies.

The black fill indicates high risk of bias. The grey fill indicates unclear risk of bias. The white

fill indicates low risk of bias.

Summary of the included studies

1   Table 1: Characteristics of included studies

Study	Participant's characteristics	Program duration, sessions per week	Groups		Task	Outcome Measures
Sheerin, Hume & Whattman, 2012	n=19 (11 male, 8 female), 9 to 14 years old (11.54 ±1.34 years) Healthy youth athletes, competitive sports. Presence of DKV was determined based on knee abduction angle from pre-intervention	-8 weeks -3 times per week	Control group (n=10): Open and closed kinetic chain upper limb strengthening exercises:- -low pulley row and over- head pull-down with a resistance band, -bicep curls -lying chest press -front and side shoulder raises -overhead press with small hand-weights -triceps dips from a bench.	Experimental group (n=9) Similar training as control with additional functional weight bearing exercises:- -side lying hip abduction -double leg squats -crab walking - standing hip abduction -single leg squat -jump squats -jumps squats with rotation 90º and 180º -Broad jump (forward deep hold, single leg) -double leg landing	Treadmill-based assessment of running gait with 3D analysis (while wearing shoes)	Differences in pre- to post-intervention changes between control and experimental groups: -trivial for the right knee (-0.3°) - large detrimental increase in left knee valgus angle (1.9°)
Baldon et al., 2014	n=31 females 18-30 years old (ST= 22.7±3.2, FST=	8-weeks -3 times per week Duration: ST=	ST (n=16) -Quadriceps and lateral retinaculum, hamstrings, soleus, gastrocnemius, and iliotibial band stretches exercise -straight leg raise in supine	FST (n=15) Transversus abdominis and multifidus muscle training exercise -lateral and ventral bridge -trunk extension on the Swiss	Single Leg Squat test with depth squat at least 60° of knee flexion	-significant reduction of knee abduction moment after 8-weeks of intervention in FST only.

	21.3±2.6) Diagnosed with Patellofemoral Pain (PFP), recreational athletes (athletic activity for at least 3 times per week) DKV status was based on diagnosed of PFP.	75-90 minutes per week FST= 90-120 minutes per week	seated knee extension (90º-45 º of knee flexion) -leg press (0º-45º of knee flexion) -wall squat (0º-60 º of knee flexion) -step-ups and step-downs from a 20-cm step -single leg standing on the unstable platform.	ball -Isometric hip abduction/ lateral rotation in standing - hip abduction/ lateral rotation/ extension in side-lying - hip extension/ lateral rotation in prone - hip abduction/ lateral rotation with slight knee and hip flexion in side-lying - pelvic drop in standing - hip lateral rotation in closed kinetic chain - single-leg deadlift - single leg squat - forward lunge - prone knee flexion - seated knee extension (90º-45º of knee flexion) -single-leg standing on unstable platform.		
			The strengthening exercises performed by both groups were based on a 1-RM, pain not higher than 3/10 of 10-cm VAS scale. Loads were progressed across 8-weeks of intervention when patients perform without excessive knee pain, fatigue and muscle pain 48 hours after training session.			
Barendrecht et al., 2011	N=80 Age (years): -AAVA (NMT = (15.6±1.5) & RT = (15.6±1.5))	-10-weeks -2 sessions per week	NMT AAVA (n=27) BAVA (n=22) -usual handball training and standard warm-up.	RT AAVA (n=22) BAVA (n=9) -performed standard warm- up and the usual handball training	Test: Drop jump test (2D) from 30-cm height with double leg landing. The highest jump of 2 trials was measured.	Linear Regression analysis showed that in the NMT groups (AAVA and BAVA groups), initial minimum normalized knee

	-BAVA (NMT = (14.9±1.3) & RT = (15.2±1.3)), Handball player (2 female and 2 male team) The status of DKV divided into two groups (AAVA and BAVA) based on drop-jump test.		-balance and coordination exercises on a wobble board and a mat -strength and plyometric exercises	only.		distance predicted 59% of the variance in pre- to post-test for knee flexion angle.
Bell et al., 2013	N= 32 Volunteers Age, (years)= (Control group=20.4 ± 2.9, intervention group = 20.9 ± 2.6), DKV were screened in double-leg squats test.	-3 weeks -2 or 3 sessions per week	Control Group (n=16) -No exercise intervention -only perform functional test at pre- and post-intervention.	Intervention Group (n=16) -Single limb Balance with Squat (1-3 set x 10-15 rep) -Single limb balance with squat on unstable surface (2-3 set x 10 rep) -Star Excursion Balance (2 to 3 set x 10 rep) -Star Excursion Balance on unstable surface (2 to 3 set x 10 rep) -Hop to balance (3 set x 10 rep)	Test: Double-legged squat at 90° of knee flexion	Only the intervention group showed a significant improvement on the knee valgus by 5° (64% reduction) during half squat.

Czasche et al., 2017	N= 16, Age (years)= Control group= (22.9±2.4) & Intervention group= (22.0±3.2) Untrained female and only took part in recreational physical activity at most 4 times per week. DKV was not screened.	-8 weeks -180 minutes sessions per week	Control group (n=8) -continue their routine recreational activities		Intervention group (n=8) Performed strength training exercise:- -split squat / bulgarian -lunge -step-up -single leg bridge -squats -single leg good morning -single leg hip thrust -stiff leg deadlift *Load were progressively increased across 8 weeks based on individual responses to training (strength, experience and motivation) -sets, reps, rest and perceived exertion were fixed.		Test: bilateral landings (BL) and unilateral landings (UL) both from 30 cm platform.	Kinematics in both BL and UL in intervention group showed no significant differences from pre- to post-test.
Saad et al., 2018	N=40, Age (years)= (Quadriceps (n=23.2±2.53), HIP (n=22.5±1.08), Stretching (21.3±1.16) and Control (23.2±1.03)) Women with	-8 weeks -2 sessions per week	QG (n=10) - quadriceps strengthening exercises.	HG (n=10) - hip strengthening exercises	SG (n=10) -Physical therapists monitored and stabilized the patients while performing stretching exercises for all muscles involved in knee and hip stabilization.	CG (n=10) -Did not receive any kind of treatment	Test: Step-up and down -Dynamic valgus were measured in frontal plane at 45° tibiofemoral flexion during step-down task.	At pre-test, participants showed valgus movement (87.18% during step-up, and 82.05% during step-down) These values declined at the end of intervention around 66.67% and 48.72% respectively in HG

						and QG only.
	PFP, Participate in aerobic or athletic activity at least 3 times per week at least 30 min.

DKV status was based on diagnosed of PFP. | | | | | |
| Araujo et al., 2017 | N= 34

Age (years): (Experimental group=22.41 ± 3.81; Control group = 21.71 ± 2.08)

Female University students.

DKV status: present in both groups.

Screened DKV during assessment of | -8-week -three session per week | Control Group (n=17)

-continued their usual routines activities. | Experimental Group (n=17)

-Strengthening exercises: -Hip lateral rotators -Gluteus medium Latissimus dorsi Abdominal oblique and quadratus lumborum -Lateral rotation and extension of the hip and trunk in closed kinematic chain.

1st to 2nd weeks – minimal load 3rd to 4th weeks – 70-80% of 1RM 5th to 8th weeks – 90 -100% of 1RM

Three sets of eight repetitions with a one-minute interval between sets. | Test: step-down from 18cm step | Knee kinematics in transverse plane during step-down task was not statistically significant after intervention in both groups. |

	step-down task.				*If the participant performed three sets of nine repetitions on two consecutive sessions, she would perform the exercise with the load increased by 10% or 5%, in the consecutive session.		
Thompson-Kolesar et al., 2017	N= 94 Age (years): Preadolescent (intervention: 11.8±0.8; control: 11.2±0.6) Adolescent (intervention: 15.9±0.9; control: 15.7±1.1). Female soccer athlete. DKV status: Preadolescent displayed greater knee valgus than adolescent athlete. Screened DKV	15 sessions -2 sessions per week -7-8 weeks	Control group: (Preadolescent (n= 23) & adolescent athlete (n=21)) Continued their daily routine.	Intervention group: (Preadolescent (n=28) & adolescent athlete (n=22)) Each session lasted about 25 minutes and served as a replacement for each team's standard warm-up prior to daily practice. Exercises for core strength, neuromuscular control, balance, eccentric hamstring training, plyometric, and agility were included.	Test: -Single, double-legged jump from 30 m box. -Preplanned and unanticipated cutting. *running sidestepping cut off the dominant limb at 45º from the line approach.	A significant group effect in the pre- to post change for initial touch knee valgus angle (P=.004) and peak knee valgus moment (P=.011) during the double-legged jump test throughout the intervention group. Changes in initial contact and peak knee valgus angles were not significantly different for all activities in both age groups.

	from the baseline for all tasks.					
Jeong et al., 2021	N= 48, Age (years)= Control group= (23.1 ±1.2) & Intervention group= (22.4±2.6) Male with recreationally active. DKV was not screened in prior.	10 weeks -2/3 sessions per week	Control group (n= 16) Continued their usual routine.	Intervention group (n=32) Warm-up, 1.3-km jogging Core training 1. Leg raise 2. Crunch 3. Superman 4. Plank hip twist 5. Prone-plank 6. Side-plank (both sides) 7. Supine bridge Stretches 1. Quadriceps 2. Hamstring 3. Calf stretches 4. Latissimus dorsi 5. Hip muscles 6. Pectorals/biceps	Side step cutting: -Run 3 m at a speed of 3.5 to 4.0 m/s before contacting their dominant foot on the force plate and then switching to the opposite limb. The line was marked on the floor to cut at 45° angle in the direction of progression.	After training, the knee valgus angles at initial contact significantly decreased by 46%, compared with the corresponding values in pre training (P =.038) No significant differences were observed in the knee valgus for control group.
McCurdy et al., 2012	N= 29, Age (years)= (21.04 ±1.83) Female with previous high school athletic experience. DKV was not screened.	8 weeks -2 sessions per week	Control group (n=16) -Did not provide any training. -continued their routine as usual.	Experimental group (n=13) Bilateral squat Lunge Step up Romanian deadlift Unilateral squat -A linear periodized program was applied by increasing 5% each week while the volume decreased. -Progression was adopted by including bilateral squat and	Drop jump task: -Jump from 60 cm for bilateral jumps -Jump from 30 cm box for unilateral jumps	No significant main effects for training groups (control vs. resistance trained) or trials (pretest vs. posttest). No significant difference between pre- and post-test knee flexion values in the control group for

				Romanian deadlift in the first weeks and 8-week period while unilateral exercises were added in the mid-training period. -The intensity:- Bilateral squat- 50%-85% of 1RM Other exercises- 6-15RM		the unilateral jump, but there was a significant decrease from pretest (82.4 ± 3.9) to posttest (69.6 ± 5.2) values for the bilateral jump.

3   Abbreviation: Dynamic knee valgus- DKV; Functional Stabilization Training- FST; Standard Training- ST; Patellofemoral pain –
4   PFP; Above-Average Valgus Aligned –AAVA; Below Average Valgus Aligned – BAVA; Neuromuscular training- NMT; Regular
5   training- RT, Control Group- CG; Quadriceps Strengthening Group- QG; HIP Strengthening Group- HG; Stretching Group- SG;
6   Exercise Program Group- EP; Repetition maximum- RM.