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REVIEW

Exercise for improving age-related hyperkyphosis: a systematic review and meta-analysis with GRADE assessment

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Abstract

Summary We reviewed exercise trials in men and women ≥ 45 years with hyperkyphosis at the baseline and performed meta-analyses for kyphosis and health-related outcomes.

Purpose To determine the effects of exercise interventions on kyphosis angle, back extensor muscle strength or endurance, physical functioning, quality of life, pain, falls, and adverse events in adults 45 years or older with hyperkyphosis.

Methods Multiple databases were searched to May 2020. Randomized controlled trials (RCTs), non-RCT, and pre-post intervention studies that had at least one group with a mean kyphosis angle of at least 40° at the baseline were included.

Results Twenty-four studies were included. Exercise or physical therapy improved kyphosis outcomes (SMD − 0.31; 95% confidence intervals [CI] − 0.46, − 0.16; moderate certainty evidence), back extensor muscle strength (MD 10.51 N; 95% CI 6.65, 14.38; very low certainty evidence), and endurance (MD 9.76 s; 95% CI 6.40, 13.13; low certainty evidence). Meta-analyses showed improvements in health-related quality of life (HRQoL) (SMD 0.21; 95% CI 0.06, 0.37; moderate certainty of evidence), general pain (MD − 0.26; 95% CI − 0.39, − 0.13; low certainty of evidence), and performance on the timed up and go (TUG) test (MD − 0.28 s; 95% CI − 0.48, − 0.08; very low certainty of evidence). The effects on the rate of falls (incidence rate ratio [IRR] 1.15; 95% CI 0.64, 2.05; low certainty evidence) or minor adverse events (IRR 1.29; 95% CI 0.95, 1.74; low certainty evidence) are uncertain. No serious adverse events were reported in the included studies.

Conclusions Interventions targeting hyperkyphosis may improve kyphosis outcomes in adults with hyperkyphosis.

Keywords Posture · Aging · Osteoporosis · Rehabilitation

Introduction

The term hyperkyphosis defines a thoracic spine sagittal curvature of at least 40°, [1, 2] and it is usually associated with forward head posture, shoulder protraction, and flattening of lumbar lordosis. [3] Hyperkyphosis increases the risk of reduced physical functioning, vertebral fractures, and impaired pulmonary function [3–10]. Twenty to forty percent of older adults have hyperkyphosis, [11] which is associated with mortality independent of bone mineral density (BMD) and vertebral fractures. [2, 12].

The etiology of hyperkyphosis is multifaceted and several risk factors are associated with its onset. Height loss greater than 4 cm and multiple thoracic wedge fractures are predictive of hyperkyphosis, [5] while women with hyperkyphosis have higher rate of incident vertebral fractures. [6] Degenerative disc disease and poor spine mobility, resulting from calcifications and ossification of the anterior longitudinal ligament, may increase the Cobb

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angle. [13–17] Weakness of the spinal extensor muscles and shortening of pectoral and hip flexors muscles are associated with the presence of hyperkyphosis, even though it is not clear whether muscle shortening is cause or consequence of hyperkyphosis. [11, 18–20] Individually tailored exercise programs may improve kyphosis and back extensor muscle strength in individuals with hyperkyphosis. However, there is still uncertainty about the true effects of exercise on posture or degree of kyphosis. Two narrative reviews made a call for new studies, as the available evidence was conflicting and heterogeneous. [21, 22] A recent meta-analysis showed modest improvements in kyphosis after exercise programs among participants 18 years old and older; however, the review combined studies of age-related hyperkyphosis with hyperkyphosis in younger adults. [23] A previous systematic review conducted in studies of adults aged 45 years or over could not perform a meta-analysis due to the limited number of studies available, and the findings from the included studies were contradictory. [24] Moreover, previous systematic reviews focused exclusively on kyphosis outcomes, while several studies have shown that quality of life and physical functioning are reduced in presence of hyperkyphosis. [3, 5, 9, 10].

In light of new studies published in the past decade, we performed a systematic review to determine the effects of targeted exercise on kyphosis angle, back extensor muscle strength or endurance, physical functioning, quality of life, pain, falls, and adverse events in adults 45 years or older. The present review is part of a series of reviews that will inform the 2020 Clinical Practice Guidelines for Management of Osteoporosis and Fracture Prevention in Canada, including recommendations on risk assessment, medications, nutrition, and several types of exercise. The efficacy of each type of exercise (e.g., progressive resistance training, walking, balance, impact exercise, yoga, etc.) is being examined separately to inform recommendations specific to the type of exercise.

Methods

Protocol

The present systematic review was reported according to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA). [25] The protocol was informed by the Cochrane Handbook for Systematic Review of Interventions and registered via the International Prospective Register of Systematic Reviews (PROSPERO) at https://www.crd.york.ac.uk/prospero/ (number CRD42020180848, registered and last updated on August 28, 2020).

Search strategy and selection criteria

The literature search was conducted in the following databases: MEDLINE (Ovid), EMBASE (Ovid), Cochrane CENTRAL (clinical trial), Cochrane database of systematic reviews (meta-analyses), CINAHL (allied health journal content), Web of Science, and no restrictions by language were applied at this stage. Medical Subject Headings (MeSH terms) and keywords associated with kyphosis, posture, and exercise interventions were used to design the search strategy. The literature search was performed in May 2020. The full search strategy is reported in Appendix A. Selection criteria related to study design, population, intervention, comparator, outcome, and time are listed below. [26].

Study design

Based on our experience conducting a similar review in 2014, [24] we were not expecting to retrieve a large number of randomized controlled trials (RCTs) and quasi-RCTs. Therefore, in addition to RCTs and quasi-RCTs, we included pre-post design studies, cohort studies, and case–control studies to provide a comprehensive understanding of the research in this area. Only RCTs and quasi-RCTs were included in meta-analyses. Full texts published in English or Italian were screened, because members of the research team could speak those languages fluently.

Participants

We included studies on men and women aged 45 years or older with hyperkyphosis, defined as a thoracic spine curvature of 40° or more measured with any validated tools. [1, 2] To be consistent with our prior review, we decided to make our criteria less restrictive so that we might capture more studies and make inferences with higher certainty. Therefore, we expanded the inclusion criteria to studies that did not specify how hyperkyphosis was measured but described their participants as having a flexed posture at baseline, or that had at least one group with a mean kyphosis angle of at least 40° at the baseline. We considered sensitivity analyses in studies of individuals with low bone mass or vertebral fractures to determine if the effects varied by population.

Intervention

We included any exercise interventions or physical therapy that involved at least one active component performed independently by the participants, to distinguish active exercise from passive mobilization aided by a physical therapist. We hypothesized that exercise programs targeting back extensor muscles would be the most common and wanted to explore the efficacy of these programs separately. Accordingly, a sensitivity analysis was performed including studies with at least one exercise component targeting muscular strength or endurance of thoracic or lumbar spine extensor muscles, cervical retractors, muscles involved in shoulder external rotation or scapular retraction, or other muscles involved in stability or movement of the thoracic or lumbar spine (e.g., prone trunk lift to neutral, thoracic rotations/extension from lateral decubitus position, shoulder flexion and thoracic spine extension with back at the wall, etc.).

Comparator

We included in the meta-analysis studies that had at least one comparator group that received no intervention or a non-exercise or a non-physical therapy intervention (e.g., educational intervention). Studies with an active or attention control group that participated in a different type of physical activity were considered for inclusion in the meta-analysis if the attention control was not hypothesized to have an effect on kyphosis outcomes. Studies comparing two interventions or within-group comparisons from non-RCTs were included in narrative syntheses only.

Outcomes

Primary outcomes

We included studies that had the Cobb angle of kyphosis [27] as an outcome, or any other indirect measures of kyphosis (e.g., flexicurve index [28] or angle, [29] manual inclinometers, [30] goniometers, [31] kyphometer, [32] Spinal Mouse®, [33] etc.). When more than one measure of kyphosis was reported, we based the decision for inclusion in the main analysis on the level of evidence reported by Barrett et al. [34] Therefore, we prioritized the outcomes as follows: Cobb angle (with patient in standing position), kyphometer, spinal mouse, flexicurve, manual inclinometer, digital inclinometer. The direct measures of kyphosis not included in the main analysis have been reported in sensitivity analyses. Measurements of forward head posture (e.g., occiput-wall distance, [35] blocks method, [2] etc.) were included as surrogate outcomes of kyphosis. However, since all the studies included in the meta-analysis reported at least one direct measure of kyphosis, we did not pool surrogate outcomes. Studies that used apps for smartphones and tablets to assess spine curvature were also included, as well as studies that measured back extensor strength or endurance.

Secondary outcomes

We included the following secondary outcomes: (1) number of people who experienced one or more falls, total number falls and fall-related injuries; (2) hip fractures, either self-reported or X-ray-verified fracture of the proximal femur that occurred at the femoral neck or trochanter in a low trauma event, such as a fall from a standing height or less; and (3) fragility fractures, either self-reported or X-ray-verified fracture of the spine, wrist, humerus, and pelvis that occurred following a low trauma event; (4) physical functioning and disability, measured using a validated tool to assess ability to perform activities of daily living, or performance-based measures of physical functioning (e.g., gait speed, 5 times sit-to-stand, timed up and go [TUG]); (5) health-related quality of life (HRQoL), determined using any validated measure such as a generic quality of life questionnaire or osteoporosis-specific quality of life questionnaire; (6) pain outcomes determined using a pain intensity scale (e.g., visual analog scale) or a pain subscale from a generic functional status questionnaire (e.g., SF-36, Nottingham Health Profile); (7) serious adverse events, defined as any untoward medical occurrence that, at any dose, results in death, a threat to life, inpatient hospitalization, or prolongation of existing hospitalization, or in persistent or significant disability/incapacity [36]; (8) non-serious adverse events, which include any reaction related to the intervention such as musculoskeletal injuries (e.g., sprain, strains, joint pain, overuse injury); (9) mortality, due to any cause such as aging, disease, or injury-related circumstances that result in death. Selection of secondary outcomes was based on a survey circulated among over 1000 members of the Canadian Osteoporosis Patient Network [37] and over 100 exercise professionals. [38].

Timeframe

Studies were included if the intervention lasted at least 4 weeks, deemed the minimum time to observe an effect on the outcomes of interest, in keeping with previous systematic reviews in people with low bone mass or vertebral fractures. [39, 40].

Study selection process

The screening process was performed using Covidence (https://www.covidence.org/home; Covidence, Melbourne, Australia). Two authors (MP and NT) independently reviewed titles and abstracts and the full texts of the records deemed eligible after the first level of screening. Conflicts between reviewers were resolved by discussion or, when an agreement could not be reached, by a third author (LG). We extracted the following information from each study:

descriptive information about the study (title, authors, publication date and status, country, study design); population and participants characteristics (Cochrane PROGRESS Plus); [41] number of recruited participants, dropout rates and reasons, adherence rates and adverse events; intervention (frequency, intensity, type, duration and setting of the delivered intervention, qualification of the person delivering the intervention, if the programs were supervised/unsupervised or in group/alone and information about progression); type of comparator (if any); outcomes described above. In case of missing information, the corresponding authors of the individual studies were contacted.

Data synthesis and statistical analysis

Data were extracted using Covidence (https://www.covidence.org/home; Covidence, Melbourne, Australia) and then imported to RevMan 5.3 (Cochrane Community, London, UK; https://community.cochrane.org/help/tools-and-software/revman-5) for statistical analysis. We used descriptive statistics to describe studies, such as mean and standard deviation (SD), count and percent or median and inter-quartile range (Q_1–Q_3). Mean between-group post-intervention differences and confidence intervals or standard deviations were reported for every study, where applicable. We performed a fixed-effect meta-analysis and calculated a mean difference (MD) with a 95% confidence interval (CI) for continuous outcomes. When a variety of methods to measure kyphosis or other outcomes were used across the studies, we calculated a standardized mean difference (SMD) with a 95% CI. Incidence rate ratio (IRR) with a 95% confidence interval (CI) was calculated for dichotomous and count outcomes. Heterogeneity between trials was assessed by using the I^2 statistic. We performed sensitivity analyses to determine if effects were similar if limited to studies of people with low bone mass or vertebral fractures at baseline. Sensitivity analyses were also performed to determine whether including only exercise programs with at least one active component targeting back extensor strength or endurance led to similar findings. We did not assess publication bias, as the power of the test is too low to detect a real asymmetry via visual inspection of funnel plots when less than ten RCTs are pooled. [42] Findings from non-pooled studies are reported in Appendix B (Table B.1).

Risk of bias and assessment of the certainty of evidence

Two reviewers (MP and NT) independently assessed risk of bias of RCTs and quasi-RCTs using the Cochrane Risk of Bias Assessment Tool [43]. Discordance was resolved by consensus or by a third author (LG). Reviewers were not involved in data extraction or risk of bias assessment of studies on which they were an author. The Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach was used to assess the certainty of the evidence. [44].

Results

Characteristics of included studies

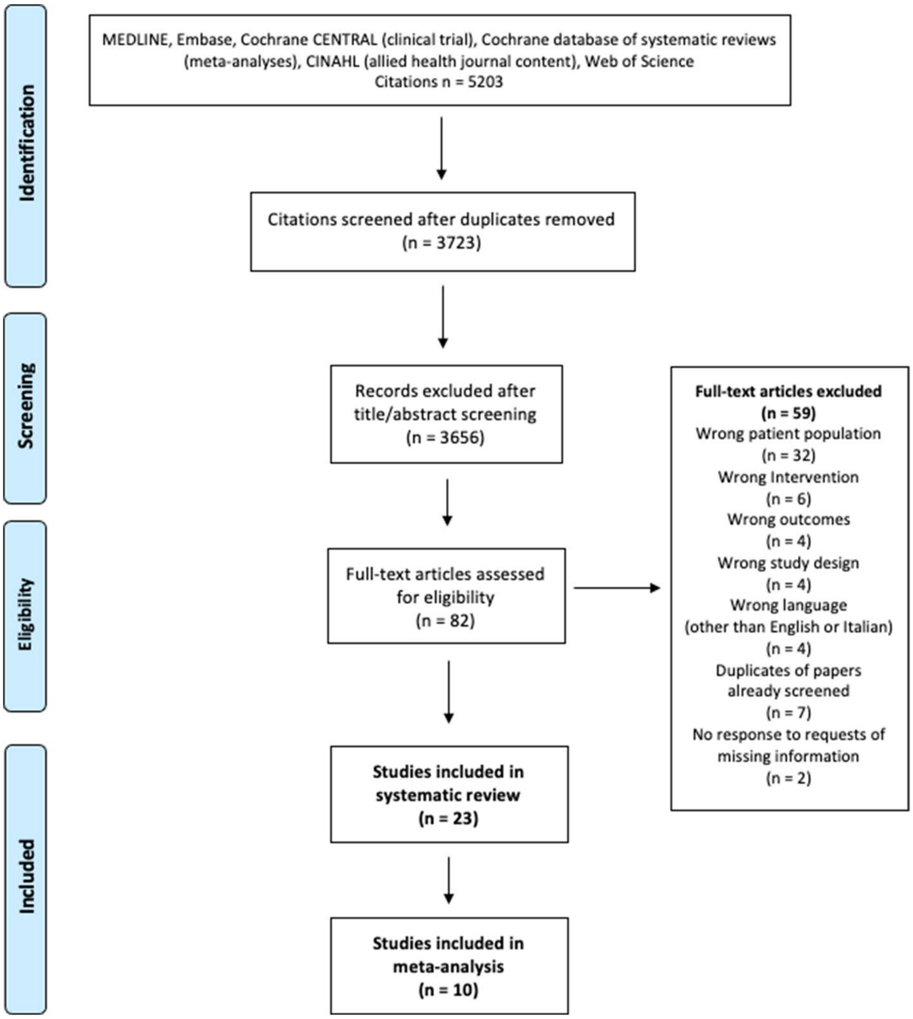
We identified 3723 unique records (Fig. 1). After title and abstract screening, we assessed 56 full-text reports, and 23 studies, with 1399 participants (6% men) were included (the reasons for exclusion are reported in the Appendix A). Eleven studies included only participants with hyperkyphosis at the baseline, [29, 51, 53–59, 61, 65] but only two [55, 57] were RCTs with a non-active control group and could be pooled in the meta-analyses. Five studies included participants with both hyperkyphosis and low bone mass or vertebral fractures at baseline. [45–49] The median duration of the interventions was 2.5 months (Q_1–Q_3 = 2, 5.55), and the median frequency was 3 days per week (Q_1–Q_3 = 2, 5). One study evaluated the effects of yoga, [29] and one other study combined physical therapy and taping. [50] Three studies included only a back extensor muscle strengthening intervention, [48, 51, 52] while other studies combined back extensor muscle strengthening with postural exercises, [47, 49, 53–57, 59–61] balance training, [45, 53, 60, 62–64] mobility exercises, [63, 65] physical therapy, [46] impact exercises, [66] taping, [63] walking, [45] or Nordic Walking. [64] Nine studies had group interventions, [29, 47, 51, 55, 57, 61, 64–66] and seven others had individual interventions, [45, 49, 50, 53, 56, 58, 63] while four studies included both group and individual components [46, 48, 54, 62] and three studies did not report this information. [52, 59, 60] Four RCTs [45, 46, 49, 50] reported adherence as percentage of participants who completed all or most sessions, and it ranged from 38 to 100% (median 75.5%), while six RCTs [29, 48, 55, 57, 62, 63] reported the percentage of sessions completed and it ranged from 70.3 to 100% (median 84.5%). Thirteen studies received funding from non-profit organizations [29, 45, 46, 53–57, 59, 60, 62, 65, 66] and two studies received private funding, [47, 50] while eight studies did not report funding information. [48, 49, 51, 52, 58, 61, 63, 64] The characteristics of included studies are reported in the Appendix B (Table B.1). The GRADE summary of findings is reported in Fig. 2.

Effects of interventions on primary outcomes

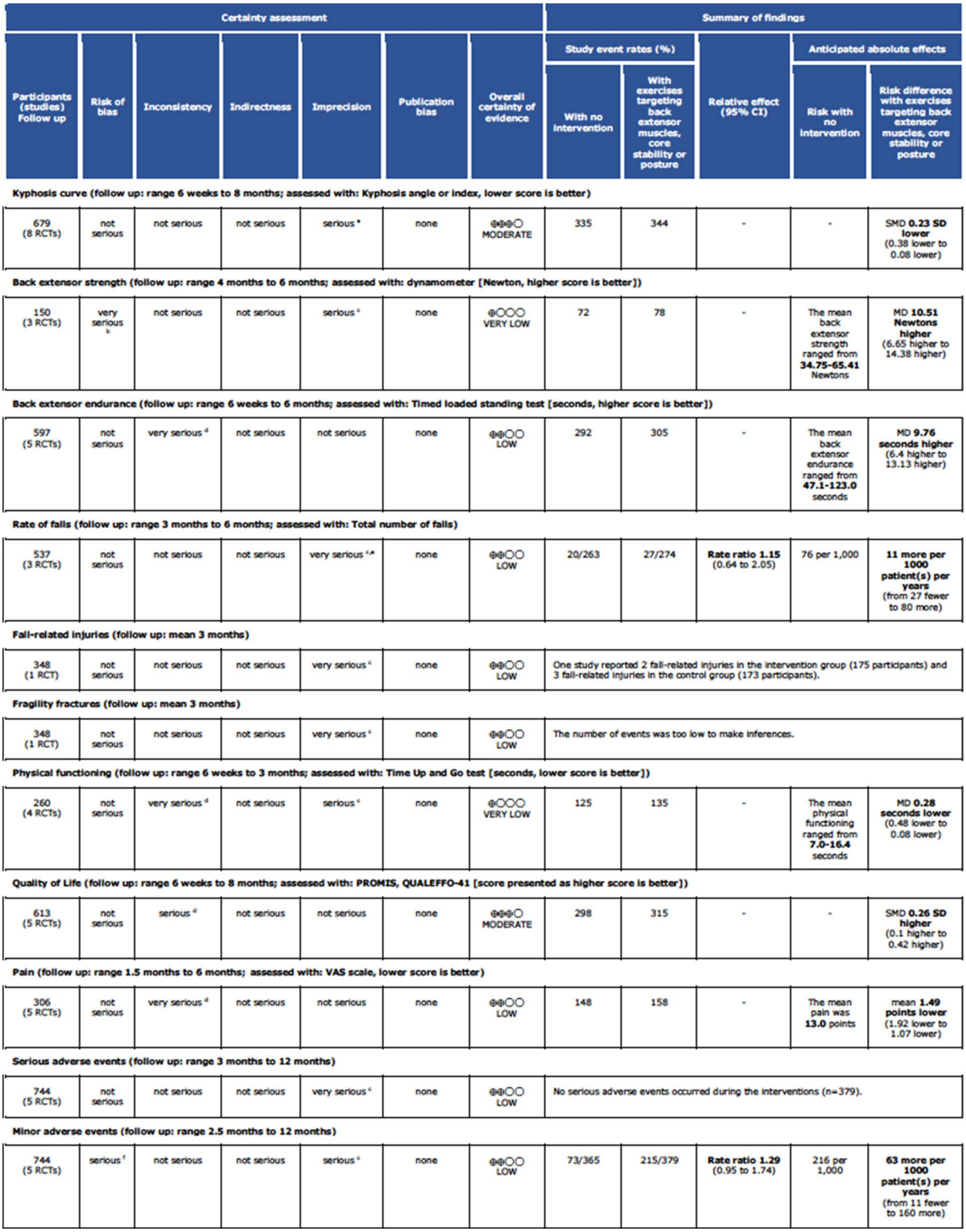
Kyphosis outcomes

Kyphosis index or angle was reduced after exercise or physical therapy interventions (SMD −0.31; 95%

Fig. 1 PRISMA flow chart



CI – 0.46, – 0.16; 727 participants; 9 studies; $I^2 = 77\%$; moderate certainty evidence; Fig. 3). Only two studies[55, 57] recruited exclusively participants with hyperkyphosis at the baseline (Table B.1, Appendix B). A sensitivity analysis limited to studies targeting back extensor muscle strength showed similar findings with less heterogeneity (SMD – 0.23; 95% CI – 0.38, – 0.08; 679 participants; 8 studies; $I^2 = 39\%$; high certainty evidence; Figure C.1, Appendix C). A sensitivity analysis limited to only studies with people with both hyperkyphosis and low bone mass or vertebral fractures did not show a statistically significant effect (SMD – 0.07; 95% CI – 0.26, 0.11; 459 participants; 5 studies; $I^2 = 0\%$; moderate certainty evidence; Figure C.2, Appendix C)). Two RCTs reported on kyphosis outcomes but could not be included in the meta-analysis. Bergström et al. [47] did not observe statistically significant between-group differences after a 6-month progressive resistance training and walking program, but the authors did not report the data regarding kyphosis outcomes. Greendale et al. [29] included only participants with hyperkyphosis at the baseline, and reported a statistically significant between-group difference in kyphosis index measured with flexicurve (median – 3.64%; Q_1–$Q_3 = -8.98\%, 1.34\%$; $p = 0.004$) but not in the degree of kyphosis assessed with kyphometer (median – 5.17%; Q_1–$Q_3 = -8.38\%, 0.93\%$; $p = 0.44$) after 6 months of yoga classes. Seven RCTs measured kyphosis but were not included in pooled analyses because they compared the effects of two different interventions (Appendix B). Other sensitivity analyses (e.g., including alternative kyphosis outcome measures or home exercise programs instead of supervised ones) related to kyphosis outcomes did not show different findings (Figures C.3, C.4, C.5, Appendix C). Seven studies measured kyphosis with an inclinometer, [46, 48, 49, 51, 61, 63, 66] six studies utilized a kyphometer, [29, 47, 54–57] five studies utilized a flexible ruler (flexicurve), [29, 45, 52, 61, 66] three studies measured the Cobb angle with the subject in the standing position, [55, 57, 59] three studies used photometric or stereophotogrammetric techniques, [60, 64, 65] three studies measured the tragus-to-wall distance, [51, 54, 61] two studies measured the occiput-to-wall distance, [56, 65] one study measured the Cobb angle with DXA with the subject in the lateral



Certainty assessment							Summary of findings				
							Study event rates (%)			Anticipated absolute effects	
Participants (studies) Follow up	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Overall certainty of evidence	With no intervention	With exercises targeting back extensor muscles, core stability or posture	Relative effect (95% CI)	Risk with no intervention	Risk difference with exercises targeting back extensor muscles, core stability or posture
Kyphosis curve (follow up: range 6 weeks to 8 months; assessed with: Kyphosis angle or index, lower score is better)											
679 (8 RCTs)	not serious	not serious	not serious	serious [a]	none	⊕⊕⊕○ MODERATE	335	344	-	-	SMD **0.23 SD lower** (0.38 lower to 0.08 lower)
Back extensor strength (follow up: range 4 months to 6 months; assessed with: dynamometer [Newton, higher score is better])											
150 (3 RCTs)	very serious [b]	not serious	not serious	serious [c]	none	⊕○○○ VERY LOW	72	78	-	The mean back extensor strength ranged from **34.75-65.41** Newtons	MD **10.51 Newtons higher** (6.65 higher to 14.38 higher)
Back extensor endurance (follow up: range 6 weeks to 6 months; assessed with: Timed loaded standing test [seconds, higher score is better])											
597 (5 RCTs)	not serious	very serious [d]	not serious	not serious	none	⊕⊕○○ LOW	292	305	-	The mean back extensor endurance ranged from **47.1-123.0** seconds	MD **9.76 seconds higher** (6.4 higher to 13.13 higher)
Rate of falls (follow up: range 3 months to 6 months; assessed with: Total number of falls)											
537 (3 RCTs)	not serious	not serious	not serious	very serious [c,e]	none	⊕⊕○○ LOW	20/263	27/274	**Rate ratio 1.15** (0.64 to 2.05)	76 per 1,000	**11 more per 1000 patient(s) per years** (from 27 fewer to 80 more)
Fall-related injuries (follow up: mean 3 months)											
348 (1 RCT)	not serious	not serious	not serious	very serious [c]	none	⊕⊕○○ LOW	One study reported 2 fall-related injuries in the intervention group (175 participants) and 3 fall-related injuries in the control group (173 participants).				
Fragility fractures (follow up: mean 3 months)											
348 (1 RCT)	not serious	not serious	not serious	very serious [c]	none	⊕⊕○○ LOW	The number of events was too low to make inferences.				
Physical functioning (follow up: range 6 weeks to 3 months; assessed with: Time Up and Go test [seconds, lower score is better])											
260 (4 RCTs)	not serious	very serious [d]	not serious	serious [c]	none	⊕○○○ VERY LOW	125	135	-	The mean physical functioning ranged from **7.0-16.4** seconds	MD **0.28 seconds lower** (0.48 lower to 0.08 lower)
Quality of Life (follow up: range 6 weeks to 8 months; assessed with: PROMIS, QUALEFFO-41 [score presented as higher score is better])											
613 (5 RCTs)	not serious	serious [d]	not serious	not serious	none	⊕⊕⊕○ MODERATE	298	315	-	-	SMD **0.26 SD higher** (0.1 higher to 0.42 higher)
Pain (follow up: range 1.5 months to 6 months; assessed with: VAS scale, lower score is better)											
306 (5 RCTs)	not serious	very serious [d]	not serious	not serious	none	⊕⊕○○ LOW	148	158	-	The mean pain was **13.0** points	mean **1.49 points lower** (1.92 lower to 1.07 lower)
Serious adverse events (follow up: range 3 months to 12 months)											
744 (5 RCTs)	not serious	not serious	not serious	very serious [c]	none	⊕⊕○○ LOW	No serious adverse events occurred during the interventions (n=379).				
Minor adverse events (follow up: range 2.5 months to 12 months)											
744 (5 RCTs)	serious [f]	not serious	not serious	serious [c]	none	⊕⊕○○ LOW	73/365	215/379	**Rate ratio 1.29** (0.95 to 1.74)	216 per 1,000	**63 more per 1000 patient(s) per years** (from 11 fewer to 160 more)

Fig. 2 GRADE summary of findings table. CI: Confidence interval; SMD: Standardized mean difference; MD: Mean difference. Explanations. A. Confidence intervals close to the no difference line. B. Outcome assessors were not blinded in one study, and two studies had incomplete and selective outcome reporting. C. Low number of studies and/or participants. D. Serious unexplained heterogeneity. E. Confidence intervals overlap with the no difference line. F. Many studies did not report adverse events

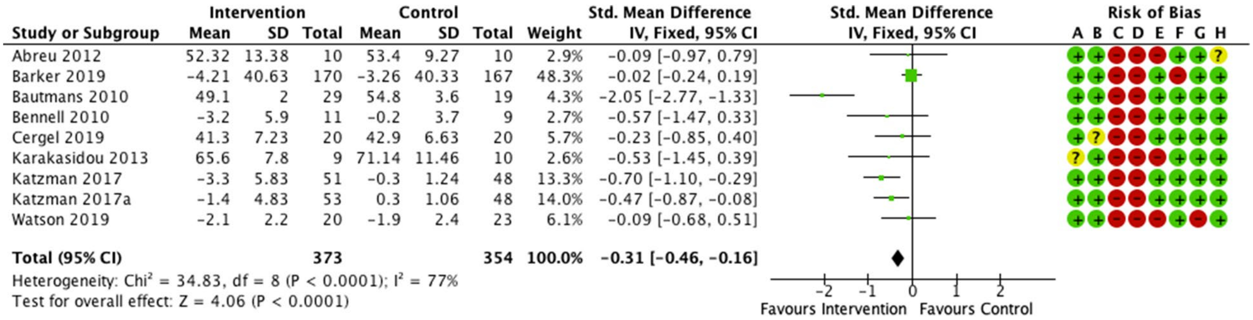
decubitus, [66] one study utilized the Spinal Mouse®, [50] one study used the Rancho Bernardo Blocks method, [29] and one other study used the Posture Pro 8 software [58].

Back extensor muscle strength

Exercise had a positive effect on back extensor muscle strength (MD 10.51 N; 95% CI 6.65, 14.38; 3 RCTs; 150 participants; $I^2=0\%$; very low certainty evidence; Fig. 4). The three RCTs reporting back extensor muscle strength as an outcome were performed in people with hyperkyphosis and low bone mass or vertebral fractures, and included interventions targeting back extensor muscle strength. Two pre-post trials showed improvements in back extensor strength after a 1-month and a 3-month back extensor strengthening program, respectively.[53, 54].

Back extensor muscle endurance

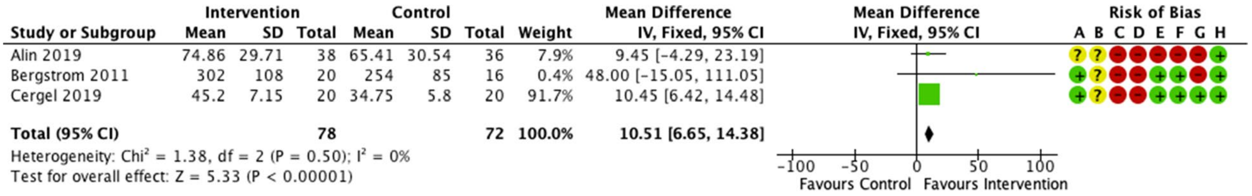
Exercise improved back extensor muscle endurance assessed with the timed loaded standing test (MD 9.76 s; 95% CI 6.40, 13.13; 5 studies; 597 participants; $I^2=95\%$; low certainty evidence; Fig. 5). Sensitivity analysis including only studies performed among people with both hyperkyphosis and low bone mass or vertebral fractures showed a significant mean difference in back extensor endurance in favor of exercise (MD 29.81 s; 95% CI 22.61, 37.01; 397



	Intervention			Control				Std. Mean Difference	Risk of Bias							
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Fixed, 95% CI**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Abreu 2012	52.32	13.38	10	53.4	9.27	10	2.9%	−0.09 [−0.97, 0.79]	+	+	−	−	−	+	+	?
Barker 2019	−4.21	40.63	170	−3.26	40.33	167	48.3%	−0.02 [−0.24, 0.19]	+	+	−	−	+	−	+	+
Bautmans 2010	49.1	2	29	54.8	3.6	19	4.3%	−2.05 [−2.77, −1.33]	+	+	−	−	+	+	+	+
Bennell 2010	−3.2	5.9	11	−0.2	3.7	9	2.7%	−0.57 [−1.47, 0.33]	+	+	−	−	+	+	+	+
Cergel 2019	41.3	7.23	20	42.9	6.63	20	5.7%	−0.23 [−0.85, 0.40]	+	?	−	−	+	+	+	+
Karakasidou 2013	65.6	7.8	9	71.14	11.46	10	2.6%	−0.53 [−1.45, 0.39]	?	+	−	−	−	+	+	+
Katzman 2017	−3.3	5.83	51	−0.3	1.24	48	13.3%	−0.70 [−1.10, −0.29]	+	+	−	−	+	+	+	+
Katzman 2017a	−1.4	4.83	53	0.3	1.06	48	14.0%	−0.47 [−0.87, −0.08]	+	+	−	−	+	+	+	+
Watson 2019	−2.1	2.2	20	−1.9	2.4	23	6.1%	−0.09 [−0.68, 0.51]	+	+	−	−	−	+	−	+
Total (95% CI)			**373**			**354**	**100.0%**	**−0.31 [−0.46, −0.16]**								

Heterogeneity: Chi² = 34.83, df = 8 (P < 0.0001); I² = 77%
Test for overall effect: Z = 4.06 (P < 0.0001)

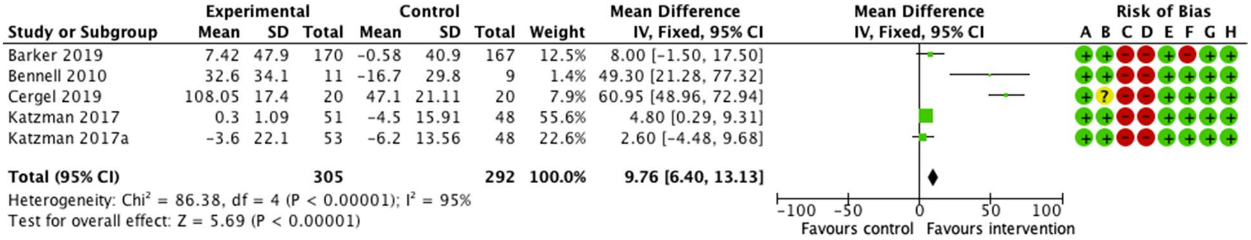
Fig. 3 Forest plot of the effects of exercise or physical therapy interventions on kyphosis angle or index. Risk of bias. **A** Random sequence generation; **B** allocation concealment; **C** blinding of participants; **D** blinding of intervention specialists; **E** blinding of outcome assessors; **F** incomplete outcome data; **G** selective outcome reporting; **H** other sources of bias



	Intervention			Control				Mean Difference	Risk of Bias							
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Fixed, 95% CI**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Alin 2019	74.86	29.71	38	65.41	30.54	36	7.9%	9.45 [−4.29, 23.19]	?	?	−	−	−	−	−	+
Bergstrom 2011	302	108	20	254	85	16	0.4%	48.00 [−15.05, 111.05]	+	?	−	−	+	+	−	+
Cergel 2019	45.2	7.15	20	34.75	5.8	20	91.7%	10.45 [6.42, 14.48]	+	?	−	−	+	+	+	+
Total (95% CI)			**78**			**72**	**100.0%**	**10.51 [6.65, 14.38]**								

Heterogeneity: Chi² = 1.38, df = 2 (P = 0.50); I² = 0%
Test for overall effect: Z = 5.33 (P < 0.00001)

Fig. 4 Forest plot of the effects of back extensor strengthening programs on back extensor strength. Risk of bias. **A** random sequence generation; **B** allocation concealment; **C** blinding of participants; **D** blinding of intervention specialists; **E** blinding of outcome assessors; **F** incomplete outcome data; **G** selective outcome reporting; **H** other sources of bias



	Experimental			Control				Mean Difference	Risk of Bias							
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Fixed, 95% CI**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Barker 2019	7.42	47.9	170	−0.58	40.9	167	12.5%	8.00 [−1.50, 17.50]	+	+	−	−	+	−	+	+
Bennell 2010	32.6	34.1	11	−16.7	29.8	9	1.4%	49.30 [21.28, 77.32]	+	+	−	−	+	+	+	+
Cergel 2019	108.05	17.4	20	47.1	21.11	20	7.9%	60.95 [48.96, 72.94]	+	?	−	−	+	+	+	+
Katzman 2017	0.3	1.09	51	−4.5	15.91	48	55.6%	4.80 [0.29, 9.31]	+	+	−	−	+	+	+	+
Katzman 2017a	−3.6	22.1	53	−6.2	13.56	48	22.6%	2.60 [−4.48, 9.68]	+	+	−	−	+	+	+	+
Total (95% CI)			**305**			**292**	**100.0%**	**9.76 [6.40, 13.13]**								

Heterogeneity: Chi² = 86.38, df = 4 (P < 0.00001); I² = 95%
Test for overall effect: Z = 5.69 (P < 0.00001)

Fig. 5 Forest plot of the effects of back extensor strengthening programs on back extensor endurance assessed with timed loaded standing test. Risk of bias. **A** Random sequence generation; **B** allocation concealment; **C** blinding of participants; **D** blinding of intervention specialists; **E** blinding of outcome assessors; **F** incomplete outcome data; **G** selective outcome reporting; **H** other sources of bias participants; 3 studies; $I^2 = 96\%$; low certainty evidence; C.7, Appendix C).

Effects of interventions on secondary outcomes

Falls and fractures

No studies reported on hip fractures as an outcome. Barker et al. [45] reported 6 fragility fractures in the exercise group (216 participants) and 8 fragility fractures in the control group, but they do not state that any were attributable to the intervention. Three studies reported falls as an outcome, and they all were performed among people with both hyperkyphosis and low bone mass or vertebral fractures, and targeted back extensor muscle strength. Effects of exercise on the rate of falls were not statistically significant (IRR 1.15; 95% CI 0.64, 2.05; 537 participants; 3 studies; $I^2 = 0\%$; low certainty evidence; C.8, Appendix C).

Physical functioning, quality of life, and pain

Four studies reported TUG test as an outcome, and they all targeted back extensor muscle strength. Exercise interventions resulted in a small, statistically significant improvement in the TUG test (MD – 0.28 s; 95% CI – 0.48, – 0.08; 260 participants; 4 studies; $I^2 = 94\%$; very low certainty evidence; C.9, Appendix C). We chose to pool data for the TUG test as it was the test most frequently performed. Other physical functioning assessments were performed across studies, but the number of studies for each outcome was very small and the results varied across studies (Table D1, Appendix D). There was an improvement in HRQoL with exercise alone or combined with physical therapy (SMD 0.21; 95% CI 0.06, 0.37; 661 participants; 6 studies; $I^2 = 78\%$; moderate certainty evidence; C.10, Appendix C). A sensitivity analysis of studies that targeted back extensor muscle strength showed similar findings (SMD 0.26; 95% CI 0.10, 0.42; 613 participants; 5 studies; $I^2 = 78\%$; moderate certainty evidence; C.11, Appendix C). Findings from a sensitivity analysis including only studies in people with both hyperkyphosis and low bone mass or vertebral fractures were consistent (SMD 0.28; 95% CI 0.08, 0.48; 413 participants; 3 studies; $I^2 = 87\%$; moderate certainty evidence; C.12, Appendix C). There was a statistically significant reduction in general pain with exercise alone or combined with physical therapy (MD – 1.44 points; 95% CI – 0.39, – 0.13; 352 participants; 6 studies; $I^2 = 91\%$; low certainty evidence; C.13, Appendix C). A sensitivity analysis including studies in people with both hyperkyphosis and low bone mass or vertebral fractures showed similar effects on pain (MD – 1.49 points; 95% CI – 1.92, – 1.07; 306 participants; 5 studies; $I^2 = 95\%$; low certainty evidence; C.14, Appendix C). The interventions of the studies included in this sensitivity analysis targeted back extensor muscle strength.

Adverse events

Only six studies reported on adverse events. Five studies [45, 46, 55, 57, 62] stated that there were no serious adverse events associated with the intervention. The effect on the rate of minor adverse events was not statistically significant (IRR 1.29; 95% CI 0.95, 1.74; 707 participants; 5 studies; $I^2 = 41\%$; low certainty evidence; C.16, Appendix C), and adverse events were attributable to interventions only in two studies. Bennell et al. [46] reported six minor adverse events that were related to intervention among 11 participants (shoulder pain: $n = 2$; flare-up of a wrist injury: $n = 1$; sore knee: $n = 1$; sore waist with particular exercises: $n = 1$; irritation with the tape: $n = 1$) and all were resolved with intervention modifications. Bautmans et al. [50] stated that some patients reported discomfort during the execution of overhead exercises, while others experienced mild skin irritations due to the tape and pain during the mobilizations (not pooled). Kaijser Alin et al. [62] reported twelve minor adverse events in intervention group (38 participants) and 25 in the control group (37 participants), without specifying whether they were due to the intervention, and muscle or joint complaints occurred at a similar rate in both the groups (4 intervention, 3 control). Katzman et al. [55] reported 30 minor adverse events in the intervention group (51 participants) and twelve in the control group (48 participants), but none was directly attributed to intervention. Katzman et al. [57] reported 56 minor adverse events (including 4 falls) in 53 participants in the intervention group, and 31 minor adverse events (of which 7 were falls and 22 musculoskeletal pain) during the 3-month waitlist period (48 participants). Katzman et al. [57] stated that the majority of the musculoskeletal complaints were pre-existing and none of the events was directly attributable to the intervention. Barker et al. [45] reported two deaths and 26 adverse events (including 5 falls and 6 fragility fractures) in the exercise group (216 participants) compared to 22 adverse events (including 4 falls and 8 fragility fractures) in 196 participants of the control group, but they did not state that any were attributable to the intervention. Watson et al. [66] did not report any fractures after the intervention.

Risk of bias in individual studies

Among the 23 included studies, 19 were RCTs or quasi-RCTs. The risk of bias graph is reported in Fig. 6. The risk of bias summary for individual studies is reported in the Appendix E (Figure E.1). Sensitivity analyses including

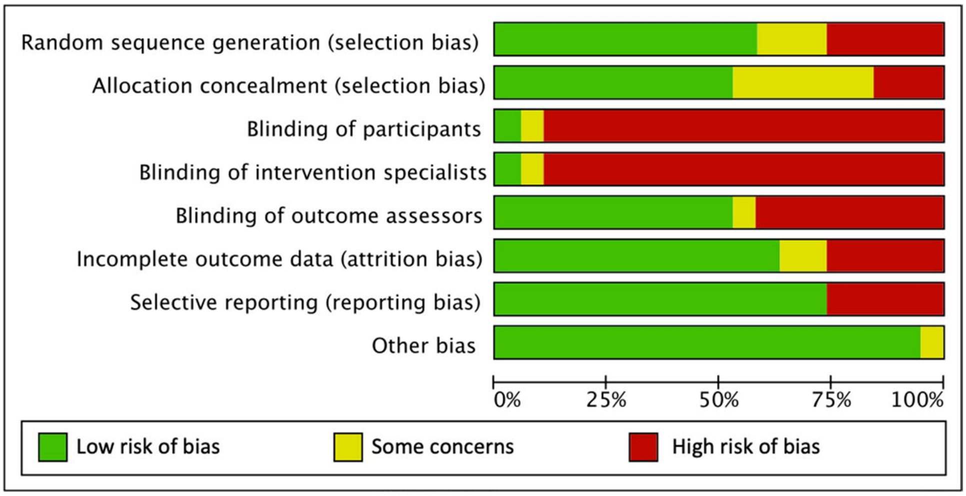


Fig. 6 Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies

only RCTs considered at low risk of bias did not alter the findings.

Discussion

There is moderate-to-high certainty evidence that multicomponent interventions, often targeting back extensor muscle strength, cause a small improvement in hyperkyphosis. Furthermore, small improvements in physical functioning and HRQoL, along with a reduction in general pain, have been observed. However, the effects of back extensor exercise programs on kyphosis outcomes among people with low bone mass or vertebral fractures were less certain. The findings support the inclusion of recommendations in favor of exercise programs that target hyperkyphosis and back extensor muscles in adults with hyperkyphosis.

Our review included a larger number of studies and for some outcomes, moderate-to-high certainty evidence, when compared to the previous systematic review from Bansal et al. [24], where the limited number of studies did not permit a meta-analysis, the evidence was conflicting and the included studies of low quality. One other systematic review [23] reported larger standardized mean differences for effects on measures of thoracic kyphosis (SMD 1.4; 95% CI $-2.15, -0.66$); however, they also included studies performed in younger adults whose hyperkyphosis may have a different etiology and, compared to older adults, they are less likely affected by factors that may interfere with the training process and reduce the margins for improvements in kyphosis, such as vertebral fractures, ossification of ligaments, or degenerative disc disease. Furthermore, González-Gálvez and colleagues [23] utilized a random-effect model in their meta-analyses, while we adopted a fixed model, as it is recommended to estimate the same underlying intervention effect in a specific population and, consequently, trials with larger sample sizes were given more weight. [42] Moreover, in keeping with the findings of our meta-analyses, a few prospective and pre-post studies [54, 56, 60] (of which two included only people with hyperkyphosis[54, 56]) showed beneficial effects of multicomponent interventions that included back extensor exercises in reducing the kyphosis. Even though a minimal clinically important difference (MCID) in the degree of kyphosis has not been determined yet, our findings support recommending exercise, and perhaps a focus on back extensor muscle exercises, for improving age-related hyperkyphosis.

Among the included studies, the ones that demonstrated improvements in back extensor strength or endurance included specific exercises to target back extensor muscles, such as shoulder flexion and thoracic spine extension with back at the wall. However, the evidence is of low or very low certainty because of the risk of bias or high heterogeneity. Given that persons with hyperkyphosis have specific spinal strength and endurance impairments that are associated with adverse health outcomes, this study highlights the importance of targeted exercise in this population to reduce risk. Two pre-post trials in people with hyperkyphosis showed similar improvements after a 1-month and a 3-month back extensor strengthening program, respectively. [53, 54] Trunk extensor strength is associated with better performance on the Six-Minute Walk Test, the Sitting and Rising Test, and the Berg Balance Scale,[67] and the ability to limit trunk motion after trips and slips appears to discriminate between older adults who fall and those who do not. [68] We report very low certainty evidence that multicomponent or back extensor strengthening interventions can improve performance on the TUG test in people with age-related hyperkyphosis. Our results are in line with previous systematic reviews which showed improvements in the performance on the TUG test after progressive resistance training, with or without back extensor exercises, in people with low bone mass or osteoporotic vertebral fractures. [39, 69] A MCID for the TUG test has not been established in individuals with osteoporosis. Frank-Wilson et al. [70] noticed a difference of 1.2 s in the TUG test between people who experienced at least one fall and those who did not. However, community-dwelling older adults often have fast times for the TUG test at the baseline, so there might be ceiling effects or limited margin for improvement. A lower gait speed is associated with an increased risk of experiencing multiple falls in older adults [71]; therefore, improvements in functional performance may help prevent falls. We did not detect any effects of back extensor strengthening programs on the rate of falls, but the studies were not designed or powered to examine falls as an outcome. Other interventions incorporating balance and functional training successfully reduced the rate of falls and risk of being a person who falls among older adults. [72].

Exercise may improve HRQoL and general pain, and the reduction in general pain exceeded the MCID for chronic musculoskeletal pain. [73] We have observed similar small improvements in HRQoL and general pain in people with low bone mass after progressive resistance training interventions. [39] People with hyperkyphosis commonly present upper- and mid-back pain, [5] and usually report a poor quality of life. Indeed, the physical limitations resulting from hyperkyphosis affect the performance of several daily activities and increase the fear of falling, resulting in social limitations and low satisfaction with life. [1, 10, 74] However, none of the included studies was designed to measure quality of life or pain as a primary outcome. Considering the impact of poor quality of life and pain, adequately powered trials should investigate alternative interventions and strategies to improve quality of life among people with hyperkyphosis.

Back extensor strengthening or physical therapy interventions in older adults with hyperkyphosis appear to be safe, as no serious adverse events occurred. Some minor adverse events happened, but only Bennell et al. [46] reported that the events were attributable to the intervention. Similarly, systematic reviews of exercise interventions in older adults reported that some minor adverse events may occur, mostly joint or musculoskeletal pain. [75–77] Bautmans et al. [50] reported some mild skin irritations due to the tape and pain during the mobilizations or overhead exercises, but some patients stated that, at the end of the program, they experienced less pain, were able to walk longer, and were more flexible.

Implementation of the findings of our review may be informed by our pre-planned sensitivity analyses. The substantial heterogeneity resulting from the main analysis ($I^2 = 77\%$) can be explained in part by variability in interventions. Heterogeneity was lower ($I^2 = 39\%$) when we limited the analyses to studies that included back extensor muscle exercises (alone or combined with other exercises/interventions), as part of an a priori sensitivity analyses driven by our hypothesis that improving back extensor muscle strength or endurance is important for reducing hyperkyphosis. Back extensor strengthening combined with other exercises targeting posture (e.g., spine extension, core stability, etc.) was the most common exercises used in the studies we analyzed, frequently executed with elastic bands or body weight, both in standing and supine/lateral decubitus positions. Based on the existing evidence, it is not possible to recommend an ideal intensity or volume. The frequency of the training ranged from 2 to 7 days a week (median 3) and the duration ranged from 1.5 to 8 months (median 2.8). Exercise programs targeting specific impairments often require some instruction or supervision, and disability and lack of transportation are barriers to participation in in-person community exercise classes or services. [78, 79] Katzman et al. [56] pilot tested a remotely delivered exercise intervention in people with hyperkyphosis, showing good acceptability and improvements in kyphosis and physical activity outcomes, suggesting that using technology to deliver exercise interventions in older adults with hyperkyphosis may be an area for further investigation.

We acknowledge some limitations of our work. Due the limited number of studies, we could not perform sensitivity analyses of studies that recruited only participants with hyperkyphosis. Many studies included individuals with no hyperkyphosis at baseline, and this may result in a ceiling effect, in that it would be difficult to improve kyphosis in people with no hyperkyphosis at baseline. Exercise tolerance may also be different in people with hyperkyphosis compared to those without. Therefore, future studies of interventions to address hyperkyphosis should target only individuals with hyperkyphosis at baseline. Only 6% of the participants were men; therefore, caution is recommended before generalizing the results. More than a half of the studies did not blind outcome assessors, and most of the studies present concerns about generation and allocation of the random sequence. Moreover, most of the studies did not report on adverse events, raising some concerns for selective reporting bias. Therefore, even though only a few minor adverse events were noted, future investigations should comprehensively assess the safety of exercise and other interventions in this population. We identified studies that were eligible but were missing information; we contacted the authors, but some did not respond. Consequently, some data are missing and we had to exclude two studies. [80, 81] We screened only full texts in English or Italian; therefore, some eligible references might have been excluded. Finally, the submission of the manuscript was delayed and thus it is possible that new papers have emerged since our search.

Conclusion

Interventions targeting hyperkyphosis, often including back extensor muscle strengthening, may improve kyphosis and back extensor strength in older adults with hyperkyphosis. Furthermore, they may result in small improvements in physical functioning and HRQoL, along with a reduction in general pain. However, many studies included also individuals without hyperkyphosis at the baseline. Therefore, to have a more accurate estimation of the magnitude of the effects, future trials to improve hyperkyphosis should recruit only individuals with hyperkyphosis at baseline. Given that only a few minor adverse events were reported, exercise interventions to correct age-related hyperkyphosis can be implemented in clinical practice.

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Author contribution MP: conceptualization; data curation; formal analysis; investigation; resources; supervision; validation; visualization; writing — original draft; writing — review and editing.

NT: data curation; investigation; validation; writing — original draft; writing — review and editing.

SB: conceptualization; writing — review and editing.

WK: conceptualization; supervision; validation; project administration; writing — review and editing.

LG: conceptualization; data curation; funding acquisition, project administration; resources; supervision; validation; writing — review and editing.

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Data availability The data being reported are accurate and are coming from the official source.

Code availability Not applicable.

Declarations

Ethics approval Not required.

Conflicts of interest None.

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