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Prevalence of idiopathic scoliosis in athletes: a systematic review and meta-analysis

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ABSTRACT

Objective This study aimed to determine the prevalence of idiopathic scoliosis (IS) in child, adolescent and adult athletes of all sports activity levels.
Design Systematic review with meta-analysis.
Data sources Electronic databases (PubMed, Scopus, ProQuest, Sage journals, ScienceDirect, Google Scholar and Springer) were systematically searched up from inception to 28 September 2021.
Eligibility criteria for selecting studies Observational investigations were included to evaluate the prevalence of IS in athletes (engaged in any type of individual and team sports). Congenital scoliosis, neuromuscular scoliosis, Scheuermann's kyphosis and de novo scoliosis were not included. The risk of bias was assessed using the tool developed by Hoy *et al.*
Results Twenty-two studies were included (N=57 470, range 15–46544, participants), thirteen studies were of high-quality. The estimated prevalence of IS in athletes was 27% (95% CI 20% to 35%, I^2=98%), with a 95% prediction interval (1% to 69%). The prevalence of IS was significantly higher in female athletes (35%, 95% CI 27% to 34%, I^2=98%). Ballet dancers showed a high IS prevalence (35%, 95% CI 24% to 47%, I^2=98%). Recreational athletes showed a higher IS prevalence (33%, 95% CI 24% to 43%, I^2=98%) than at competitive-level athletes (0.05%, 95% CI 0.03% to 0.08%, I^2=98%), followed by elite (20%, 95% CI 13% to 27%, I^2=98%).
Conclusions The prevalence of IS in athletes was similar or higher to that as seen in other studies of the general population. IS prevalence may have a U-shaped relationship relative to level of competition. Further studies are required to determine which sports have the highest IS prevalence.

WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ Although precise idiopathic scoliosis (IS) prediction is impossible, there is a need to prevent the curve progression.
- ⇒ The prevalence of IS is higher among females.
- ⇒ IS can cause postural changes, standing instability and gait variations, as well as pain, poor quality of life and negative self-image.
- ⇒ The prevalence of IS in athletes can be associated with sports injuries.

WHAT THIS STUDY ADDS

- ⇒ The prevalence of IS in athletes was similar or higher to that as seen in other studies of the general population.
- ⇒ The prevalence of IS among ballet dancers (0.35) is significantly high.
- ⇒ This review showed a U-shaped curve of IS prevalence in athletic sports levels. Recreational and elite athletes exhibited a higher prevalence of IS.
- ⇒ Current literature does not provide enough information about all sports to determine which sport causes the highest prevalence of IS.
- ⇒ For more strong conclusions, we need high-quality epidemiological studies on male athletes as well as child athletes.

INTRODUCTION

Idiopathic scoliosis (IS) is a three-dimensional change in the spine.[1] The prevalence of SI, which depends on the size of the curve, has been reported to range between 0.47% and 5.2%.[2] Spinal health is a common concern in all kinds of sports. Several studies have reported the prevalence of scoliosis among the athletes engaged in ballet and dance,[1 3–5] gymnastics,[6] volleyball[7] and swimming.[8 9] The prevalence of IS is higher in women with a curvature equal to or greater than 10°.[10]

Because the causes of IS are unknown, it is impossible to definitely prevent this disease. However, there is agreement on the need to prevent the progress of the curve.[11] The curve pattern is probably related to increased pain (thoracolumbar curves have the least pain and double curves have the most pain).[12] Self-image is frequently affected and diminished.[12] IS causes posture changes and standing instability. It is also associated with gait changes in larger curves, which can cause pain and poor quality of life.[13] Therapeutic exercises,[14] bracing and surgery are all treatment options for this disease.[12] Therapeutic exercises, acupuncture, manual therapy alone or in combination with rehabilitation exercises and traction are some of the interventions discussed in the literature for this postural disorder.[10] A review of the literature shows that exercise can reduce the Cobb angle and improve the strength, balance and mobility of adolescents with IS.[14]

Competitive sports such as javelin throwing, gymnastics and weightlifting impose great pressure on the spine.[15] Spinal injuries account for approximately 15% of all sports injuries.[16] It is unclear whether the prevalence of IS among athletes from different sports is lower or higher than that of non-athletes.

Understanding the prevalence of IS in various sports is important for several reasons. Researchers can assess a disease load by knowing the number of people in a population who suffer from a disease or a specific disorder.[17] Normal posture may play an important role in sports performance,[18] and the loss of normal spinal alignment caused by IS may be related to adjustments in muscular moments that can alter joint alignment.[19] As a result, the prevalence of IS in athletes may have an impact on their athletic performance. Since the common prevalence of IS among athletes has been attributed to sports injuries,[3 20 21] knowing its exact prevalence in athletes can aid in the use of preventative strategies.

If the prevalence of IS varies from sport to sport, this information can lead to earlier diagnosis of IS in those sports. This can help to lower the risk of progression and the need for surgical intervention and also improve the health status and performance of athletes. This study aims to determine the prevalence of IS among athletes of different sports.

METHODS

Protocol and registration

This systematic review was conducted according to the recommendations in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 statement.[22] The study protocol was registered in the PROSPERO database with this ID: CRD42021270390.

Study eligibility criteria

This study reviewed observational investigations (cross-sectional, case–control and cohort) along with those on the following diagnostic methods for IS: surface topography imaging and spinal deformity assessment, radiography-based imaging and evaluation of IS, MRI-based evaluation of IS, CT, Adam's forward bend test, scoliometer measurements, individual Moiré topography,[23] the Watson-MacDonncha Posture Analysis (WMPA) and spinal mouse. The studies that investigated the prevalence of IS in child, adolescent and adult athletes (any type of sports; individual and team sports) were also reviewed.

Participants were selected from among the athletes aged 8–60 years. Sports activity was classified into three levels: a recreational athlete is someone who engages in a sports team for fun and does not train or compete on a national or international level,[24] a competitive athlete is someone who plays in a competitive sports team, trains and/or competes in local competition, and an elite athlete is someone who plays on a competitive sports team and competes on a national or international level.[24 25] The case studies and case series with a sample size of less than 6, letters and opinion pieces and studies on congenital scoliosis, neuromuscular scoliosis, Scheuermann's kyphosis and de novo scoliosis were excluded from this review. Unpublished studies were not sought. It is noteworthy that papers in all languages were included in this review.

Sources and study selection

Electronic databases (PubMed, Scopus, ProQuest, Sage journals, ScienceDirect, Google Scholar and Springer) were searched for eligible studies from inception to 28 September 2021. Reference lists of included studies were searched to identify further appropriate studies. keywords were searched for subject headings (MeSH headings). The complete search strategy is presented in online supplemental appendix 1. To identify relevant outcome, we included the term: 'Scoliosis'. To identify relevant sports, we included the terms: 'Sports' or 'Sport' or 'Athletics' or 'Athletic' or 'Athletic performance' or 'Physical fitness' or 'Youth Sports' or ' Racquet Sports' or 'Water sports' or ' Team sports'. To identify relevant populations, we included the terms: 'Athlete' or 'Athletes' or 'Professional athlete' or 'Professional athletes' or 'Elite athletes' or 'Elite athlete' or 'College athletes' or 'College athlete'. Also, to identify relevant populations, we included the terms: 'Physical Activities' or 'Physical Activity' or 'Physical Exercise' or 'Physical Exercises'.

No language or time limitations were applied. These search filters were used to extract related studies on ProQuest; audio and video content, magazines, trade journals, reports, newspapers and other sources were excluded.

The results were screened by title, abstract and full text to identify relevant studies. If abstracts or articles needed to be translated into another language, a translator was asked to do so. (MO) screened the literature for inclusion and (MI) double-checked the decision. Disagreements were settled through discussion. If the disagreement had persisted, the third reviewer's (SE) decision would have been final.

Data extraction and management

For each study, the following information was extracted: first author, year of publication, country, language, sports fields, levels of sports activity, sample size, gender and age of participants, number of athletes, number of controls, diagnosis method, Cobb angle limit considered as scoliosis, IS prevalence in athletes and IS prevalence in the control group. The data were extracted collaboratively by two reviewers (LM and FS). Discussion was used to settle disagreements. Reviewers communicated for unreported data or extra details in the case of missing data. There was no blinding of study authors, institutions or journals during data extraction. Data were recorded in a data extraction form.

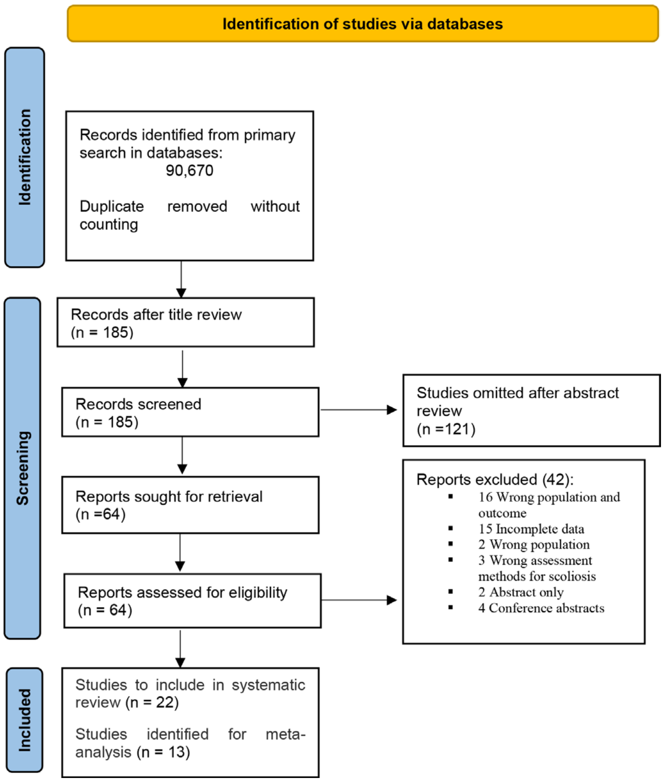

Figure 1 Flow diagram for study selection process.

Assessment of methodological quality

Two authors (LM and FS) independently assessed the quality of studies using the JBI critical appraisal tool, which was developed by Munn *et al*.[26] Intraclass correlation coefficient (ICC) was calculated to ensure inter-rater reliability (ICC=0.85, 95% CI=0.55 to 0.95). This tool included 10 criteria for evaluating the methodological quality of studies reporting prevalence data. Answers to the questions can be yes, no, unclear or not applicable. Because the appraisal tool does not provide a specific definition of acceptable quality, the acceptable quality scores were defined to be five or higher. Disagreements were settled through consensus discussions. The same authors (LM and FS) independently assessed the risk of bias in prevalence studies using the tool developed by Hoy *et al*.[27] The tool consists of 10 items that evaluate both internal and external validity. To ensure inter-rater reliability, the ICC was calculated (ICC=0.87, 95% CI=0.65 to 0.95). Disagreements were settled through consensus discussion.

Data synthesis

Under a random-effects model, the weighted summary proportion was estimated using the arcsine transformation and the inverse variance approach. Due to significant heterogeneity, the random-effects model was used. Publication bias was assessed graphically using funnel plots, and Peters' test was used to assess publication bias and the small study effect statistically. The inverse SE was used in the y-axis of the funnel plots because conventional funnel plots are not recommended for meta-analyses of proportion studies.[28]

Heterogeneity was assessed using I^2 statistics, which shows the percentage of the total variation in all studies resulting from heterogeneity between studies.[29] Subgroup analysis was performed in the subsequent classes: gender, age, sports fields and levels of sports activity. The leave-one-out meta-analysis was used for sensitivity analysis. To quantify the range of existing heterogeneity, we calculated predictive intervals. The CI measures the precision of an estimated effect, whereas the prediction interval accounts for the true effect of a future study.[30] A $p \leq 0.05$ was considered statistically significant for all statistical tests. The meta-analysis was carried out using the package 'meta' in R V.4.0.5.

RESULTS

The preliminary search identified 90 670 records for further investigation (duplicates were manually deleted during the initial search and were not recorded). Figure 1 shows a flow diagram for study selection as well as details for excluding studies. The full texts of 64 articles were evaluated for eligibility; 42 were excluded (online supplemental appendix 2) and data from 22 studies were extracted.

Study characteristics

This analysis included 22 studies with a total sample size of 59 161 (the total number of athletes was equal to 7453). Seven studies were conducted in Asia, eight in Europe, four in North America and three in Australia.

X-ray was the most commonly used data collection tool. Only three of the eight studies that used Adam's test used a scoliometer to evaluate trunk rotation. Thirty different sports were studied. On the risk of bias scoring criteria,[27] 16 studies received 0–3 points (low risk), 6 received 4–6 points (moderate risk) and no study received 7–9 points (high risk). The characteristics of the studies that were included are presented in online supplemental appendix 3, table 1–3.

Methodological assessment

The quality assessment score of the 22 studies is shown in online supplemental appendix 3, table 1 and 2. The mean quality score of the reviews was 6.9±0.2; 95% CI 6.3 to 7.5 (maximum possible quality score was 10). Studies frequently failed to meet the criteria for being recruited in an appropriate manner (88.8%), have an adequate sample size (77.7%), report on appropriate statistical analysis (88.8%), identify and account for confounding factors (88.8%), or use objective criteria for identifying subpopulations (66.6%). In 15 studies, a score equal to or greater than 6 was obtained. Two studies met the criteria but were excluded from the data pooling; one reported the presence of lower limb dissymmetry in athletes (5 mm or more),[31] and the other did not report the number and prevalence of scoliosis in athletes.[32] As a result, 13 studies were included in the data pooling, with a total sample

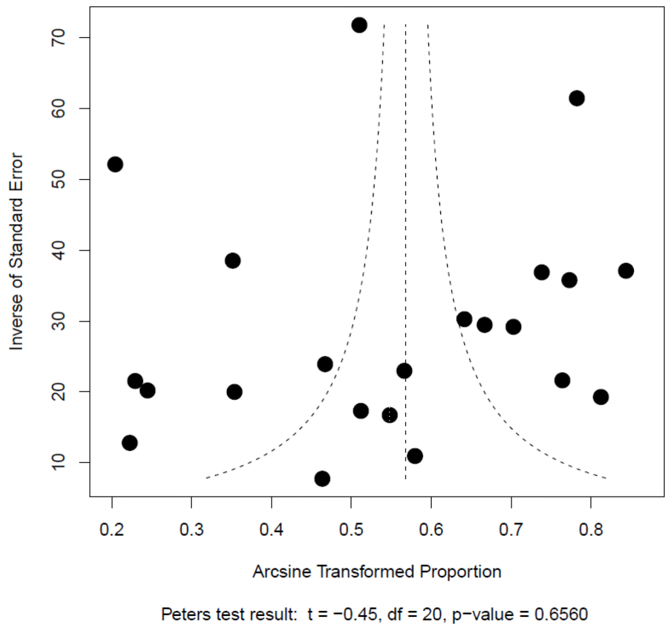

Figure 3 Funnel plot and Peters' test result.

size of 57 470 (range 15–46544) and 5979 athletes (range 15–1288) (online supplemental appendix 3, table 2).

Ballet dance, classical ballet, dance, modern dance and jazz were all classified under ballet dance and also gymnastics, rhythmic gymnastics and artistic gymnastics under gymnastics during data analysis. Del Castillo Campos *et al*[33] reported two types of IS prevalence, one for basketball and one for other sports. As a result, we analysed them in the following manner: campos 1: various sports; campos 2: basketball. Watanabe *et al*[34] reported nine distinct prevalence rates for various sports. We analysed them in the following manner: (1) swimming, (2) rhythmic gymnastics, (3) classical ballet, (4) dancing, (5) artistic gymnastics, (6) tennis, (7) basketball, (8) badminton and (9) volleyball.

Definition of IS

For identifying IS in athletes, the majority of studies used radiography and Cobb limits of 10°. In one study, Cobb limits of 15° for IS were considered.[34] In seven studies, Cobb limits for IS were considered 10°[6–8 31 35–37]; in two studies, Cobb limits for IS were considered 5°[33 38] and in one study, the Cobb limit was not reported.[5] Adam's test was used without a scoliometer in five studies[1 4 18 39 40]; one study used Adam's test with a scoliometer and a 5° limit of trunk rotation[21] and two studies used Adam's test with a scoliometer and a 7° limit of trunk rotation.[32 41] WMPA was used in one study,[42] and Spinal Mouse was used in another.[43] Photography was used in one study.[44]

Prevalence of IS in athletes

The IS prevalence data in various sports are available in online supplemental appendix 3, table 3. The pooled prevalence of IS in athletes (13 studies, see figure 2) was 27% (95% CI 20% to 35%, I^2=98%).[1 5–8 21 33–37 39 41] In this review, the predictive interval ranged from 0.01% to 0.69%, and it is appropriate for a future study based on previous knowledge.

Publication bias and sensitivity analyses

The funnel plot revealed asymmetry, indicating possible publication bias and high heterogeneity (figure 3). Peters' test revealed no evidence of small study bias (Peters' test, p=0.65). Sensitivity analyses were performed in all meta-analyses by sequentially removing studies. The overall effect sizes (ESs) from the leave-one-out meta-analysis

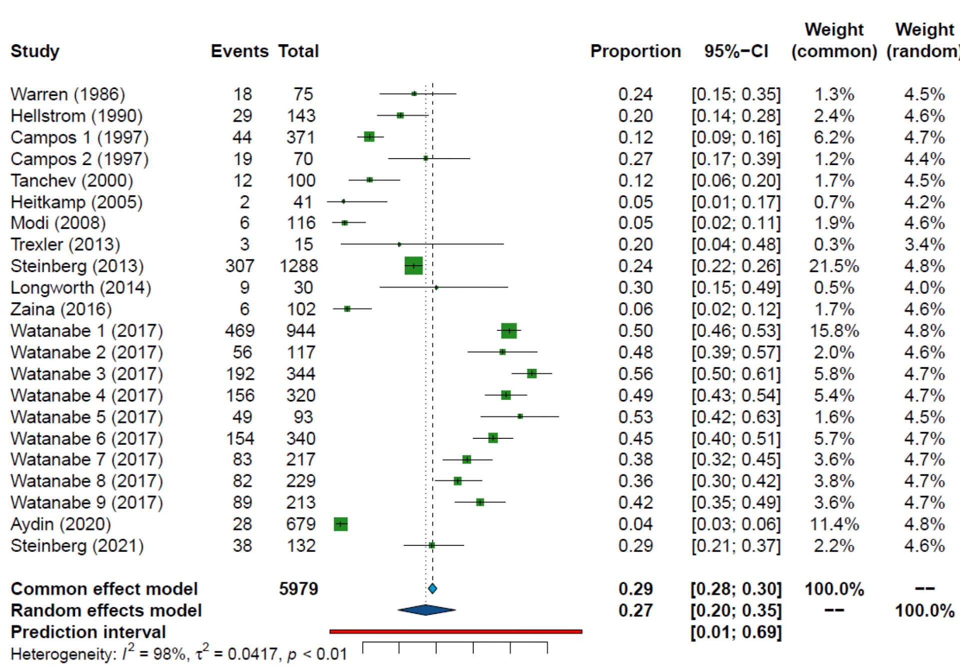

Figure 2 Forest plot of IS prevalence in athletes.

Table 1 Subgroup analysis of gender, age, sports fields, levels of sports activity

	Overall ES	95% CI (intergroup)	Prediction interval	I^2 (intergroup)	Test of group differences		No of studies	ES (95% CI)
Gender	0.27	(0.20 to 0.35)	(0.01 to 0.69)	98%	P<0.01	Female	16	0.35 (0.27 to 0.43)
						Both genders	6	0.11 (0.05 to 0.19)
Age	0.27	(0.20 to 0.35)		98%	P=0.33	Adult	2	0.23 (0.15 to 0.33)
			(0.01 to 0.69)			Adolescent	17	0.30 (0.21 to 0.40)
						Child and adolescent	2	0.14 (0.01 to 0.37)
Sports fields	0.27	(0.20 to 0.35)		98%	P=0.05	Ballet dance	6	0.35 (0.24 to 0.47)
						Swimming	2	0.22 (0.00 to 0.76)
						Tennis	2	0.22 (0.00 to 0.69)
			(0.01 to 0.69)			Gymnastic	5	0.25 (0.09 to 0.47)
						Basketball	2	0.34 (0.23 to 0.45)
						Volleyball	2	0.20 (0.00 to 0.64)
						Different sports	2	0.16 (0.08 to 0.24)
levels of sports activity	0.27	(0.21 to 0.36)		98%	P<0.01	Recreational	15	0.33 (0.24 to 0.43)
			(0.01 to 0.69)			Competitive	3	0.05 (0.03 to 0.08)
						Elite	4	0.20 (0.13 to 0.27)

ES, effect size.

were all close to the overall ES, and the sensitivity analysis did not affect the significance or direction of the ESs, with point estimates ranging from 0.26 to 0.29. This means that there are no studies that have a significant impact on the results of our meta-analysis (online supplemental appendix 4).

SUBGROUP ANALYSIS

We were able to estimate the ES for each subgroup using subgroup analysis (table 1). Online supplemental appendix 5 contains the forest plots for all subgroup analyses.

Subgroup analysis for the prevalence of IS in athletes and gender

We discovered that female athletes had a significantly larger ES when we compared prevalence rates across subgroups (table 1 and online supplemental appendix 5). We compared female-only studies to studies that included both male and female subjects. We were unable to locate a high-quality article in which the subject was solely male.

Subgroup analysis for the prevalence of IS in athletes and age

Although adolescent athletes have a prevalence rate of 0.30 (table 1), there was no significant difference in IS prevalence when we compared athletes of different ages.

Subgroup analysis for the prevalence of IS in athletes and sports fields

The prevalence of IS was highest in ballet dance, according to pooled results (0.35). When different sports were evaluated together, the prevalence of IS was lower than in other sports fields (0.16). Figure 4 shows the forest plot of subgroup analysis for sports fields.

Subgroup analysis for the prevalence of IS in athletes and levels of sports activity

Our findings revealed a significant difference between athletes of various levels. The highest and the lowest prevalence of IS was observed at the recreational level (0.33) and the competitive level (0.05), respectively.

Sensitivity and subgroup analyses

We used sensitivity and subgroup analysis based on gender, age, sports fields and levels of sports activity to explore potential sources of heterogeneity but heterogeneity remained high.

Discussion

This study aimed to investigate the prevalence of IS in athletes of different sports using a meta-analysis study. The overall ES of IS in athletes was 27%, based on data pooling from 13 high-quality studies in this review. The predictive interval in this study ranged from 1% to 69% and includes the possibility that new research would detect an IS prevalence in this range.

The study findings showed that the prevalence of IS was significantly higher in female athletes. We were unable to identify a high-quality article in which the subject was solely male. As a result, this estimate should be interpreted cautiously. The female to male ratio ranges from 1.5:1 to 3:1 and can reach 7.2:1 in 40° curves.[2] The high prevalence of adolescent IS has been reported among

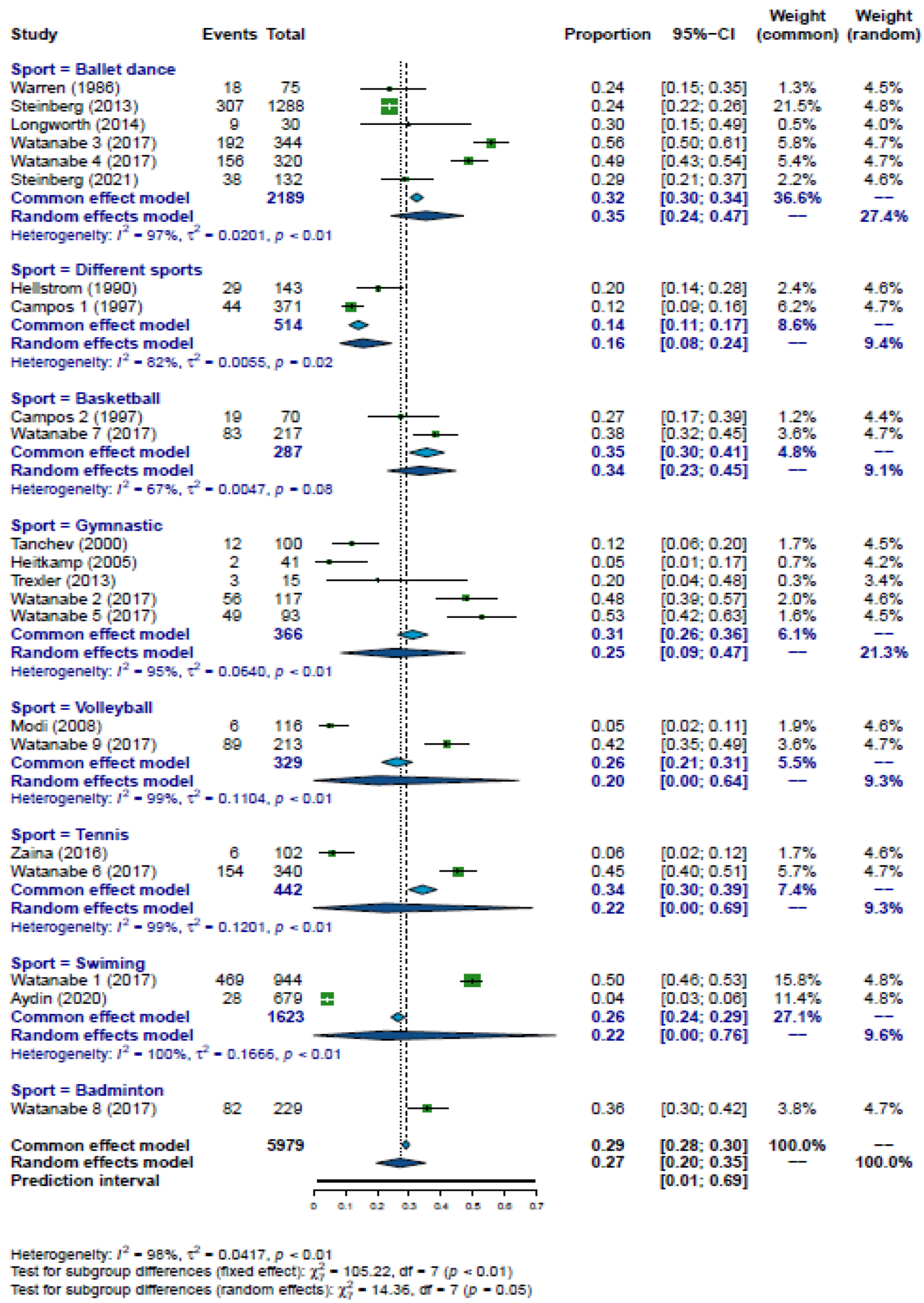

Figure 4 Forest plot of subgroup analysis for sports fields.

female adolescents.[2] Swimming, according to Zaina *et al*,[32] has a different effect on the spine depending on the gender of the swimmers. Swimming has a greater effect on the spine of female adolescents (OR=2.50) than male adolescents (OR=1.21). Their findings could explain the high prevalence of IS in females. Adolescent athletes have received the most attention from researchers. There was no special high-quality study for children, and only a few studies included adult athletes. It has been reported that there is a link between age and the prevalence of IS.[45] The prevalence of IS is higher in patients over the age of 15 (after puberty).[2] The study findings indicated that the prevalence of IS was higher in adolescents than in other age groups. McMaster *et al*[46] investigated the relationship between age and the prevalence of adolescent IS in swimmers and discovered that scoliosis is more common in those who begin swimming lessons as children.

Scoliosis develops due to a variety of causes, but once the scoliotic curve appears, it progresses according to its internal laws and 'scoliosis emancipates from its aetiology'.[6] The study findings showed that the highest prevalence of IS was observed among ballet dancers (0.35). Some authors suggested that the high prevalence of IS in ballet dance is due to body type selection by trainers and dancers themselves.[1 21] However, some studies have shown that vigorously mobilising sports can hasten the progression of scoliosis.[6] It has been suggested that ballet dancers may be predisposed to scoliosis due to their longer growth period. Ballet dancers who restrict their weight and exercise excessively are thought to be predisposed to bone development delays and abnormal pubertal growth associated with late menarche and secondary amenorrhoea.[5 21] Generalised joint hypermobility (GJH) is very common in ballet dancers[1 21] and has been implicated in scoliosis. It has been reported that collagen structure changes in GJH dancers may affect spinal stability and the development of scoliosis.[47] The majority of young dancers with scoliosis and GJH experience delayed puberty.[1 21] As a result, all repetitive and high-intensity activities may have an impact on the bone growth plates and contribute to the progression of IS.[1]

The prevalence of IS in athletic sports levels was found to be U-shaped in this review. Proprioceptive deficits were reported in AIS patients in a recent review and meta-analysis article by Lau *et al*.[48] A relationship between vestibular system abnormalities and IS has also been reported.[49] These data suggest that patients with IS experience changes in system complexity.

Complexity is defined as the number of system components and their interactions.[50]

Low levels of complexity are associated with poor performance and unhealthy systems.[51] In elite athletes, low complexity combined with intense training load and years of training may contribute to the high prevalence of IS. According to the literature, long-term exercise can gradually lead to specific postural adaptations in athletes, and these postural adaptations are related to the specific movements and postures of the sports.[52 53]

Athletes need movement variability to effectively adapt to changes in sports activities. If the same movements are performed repeatedly, the same tissues are more likely to be severely overloaded. Movement variability may adjust loads from repetition to repetition, reduce injury risk and allow for variations in coordination patterns.[54] Variability has a chaotic structure that is essential for functional movement and health. Perversion from a chaotic structure in biological systems can result in either too robotic and rigid or unstable and noisy systems. These states are less tolerant of perturbations and are associated with pathological conditions or a lack of skill.[55] Injuries could result from either decreased or increased variability.[56–59]

It can be hypothesised that recreational and elite athletes who have lost chaotic structures of movement variability of their spines are more vulnerable to deviation from the normal alignment of the spine or make progress in their abnormal alignment of the spine because elite athletes have more hours of training and recreational athletes are in primary phases of learning to discover possible solutions for a specific task. It can be hence suggested that an athlete who has lost chaotic structure of movement variability (for any reason) is less likely to develop scoliosis if he or she exercises at the competitive level, and thus, the prevalence of scoliosis is lower at this level.

Clinical implications

It is possible that using a preventive strategy in athletes can help reduce the prevalence of IS. These data can be used by researchers, coaches and physiotherapists to develop prevention strategies for high-prevalence IS. To reduce the prevalence of IS among these athletes, it is critical to develop specific exercises to meet their spinal needs. Coaches and physicians should collaborate to create screening programmes that will effectively identify athletes with scoliosis.

Future research

The paucity of high-quality epidemiological studies on male athletes and child athletes indicates that more research is needed before strong conclusions can be drawn. We gathered data from seven different sports, so researchers should look into other sports fields. Prospective studies in all sports should be used to determine the prevalence of IS in athletes, while longitudinal studies will reveal long-term results.

Limitations of this review

The grey literature was not included in this review study. At no point were reviewers blind to the authors' identities. As previously stated, Cobb limits for included studies varied, and one study[36] assessed only the lower half of the thoracic and lumbar spines and half of the sacrum with radiography. These factors could have influenced the outcome. We did not receive all of the authors' requested information. Some studies' missing results may result in a reduction in statistical power. Unfortunately, the prevalence of scoliosis in all sports has not been studied. As a result, current evidence is insufficient to determine which sports have the highest prevalence.

Conclusion

It should be cautiously concluded that there is a cause-and-effect relationship between the prevalence of IS and sports activity, and more studies are needed to explain these findings. Researchers have been attempting for years to identify the sports that cause the highest prevalence of IS. The review's findings and research synthesis can help patients and parents make informed decisions about which sports to participate in, as well as professionals who work with athletes to conduct prevention and treatment programmes. Although IS has been commonly reported among athletes, not all sports have been studied in this regard. Therefore, more studies are needed to fill this research gap.

Contributors LM conceived the presented idea. LM and FS developed this theory. Search process, quality assessment and bias assessment were performed by LM, FS and HM. Analytical calculations performed by LM. All authors discussed the results and contributed to the final manuscript.

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Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data sharing statement Statistical codes and dataset are available from the corresponding author at foadseidi@ut.ac.ir. Also, these files are available in the online supplemental files 6 (appendix 6) and 7 (data file).

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