Incidence, prevalence and risk factors for low back pain in adolescent athletes: a systematic review and meta-analysis

Julia Wall,[1,*] William P Meehan, III,[2] Katharina Trompeter,[3,4] Conor Gissane,[1]
David Mockler,[5] Nicol van Dyk ,[6,7] Fiona Wilson [1]

[1] Discipline of Physiotherapy, School of Medicine, Trinity College, Dublin, Ireland
[2] The Micheli Center for Sports Injury Prevention, Division of Sports Medicine, Boston Children's Hospital, Waltham, Massachusetts, USA
[3] Department of Applied Health Sciences, Division of Physiotherapy, Hochschule für Gesundheit Bochum, Bochum, Nordrhein-Westfalen, Germany
[4] Department of Sports Medicine and Sports Nutrition, Ruhr University Bochum, Bochum, Nordrhein-Westfalen, Germany
[5] John Stearne Medical Library, Trinity College Dublin, Dublin, Ireland
[6] High Performance Unit, Irish Rugby Football Union, Dublin, Ireland
[7] Section Sports Medicine, Faculty of Health Sciences, University of Pretoria, Pretoria, South Africa

*Correspondence to Julia Wall, Discipline of Physiotherapy, School of Medicine, Trinity College, Dublin, Ireland; wallju@tcd.ie

ABSTRACT

Objective To investigate the incidence, prevalence, risk factors and morphological presentations of low back pain (LBP) in adolescent athletes.

Design Systematic review with meta-analysis.

Data sources Medline, Embase, CINAHL via EBSCO, Web of Science, Scopus.

Eligibility criteria for selecting studies Studies evaluating the incidence and/or prevalence of LBP in adolescent athletes across all sports.

Results There were 80 studies included. The pooled incidence estimate of LBP in adolescent athletes was 11% (95% CI 8% to 13%, I^2=0%) for 2 years, 36.0% (95% CI 4% to 68%, I^2=99.3%) for 12 months and 14% (95% CI 7% to 22%, I^2=76%) for 6 months incidence estimates. The pooled prevalence estimate of LBP in adolescent athletes was 42% (95% CI 29% to 55%, I^2=96.6%) for last 12 months, 46% (95% CI 41.0% to 52%, I^2=56%) for last 3 months and 16% (95% CI 9% to 23%, I^2=98.3%) for point prevalence. Potential risk factors were sport participation, sport volume/intensity, concurrent lower extremity pain, overweight/high body mass index, older adolescent age, female sex and family history of LBP. The most common morphology reported was spondylolysis. Methodological quality was deemed high in 73% of cross-sectional studies and in 30% of cohort studies. Common reasons for downgrading at quality assessment were use of non-validated survey instruments and imprecision or absence of LBP definition.

Summary/conclusion LBP is common among adolescent athletes, although incidence and prevalence vary considerably due to differences in study methodology, definitions of LBP and data collection.

PROSPERO registration number CRD42020157206.

WHAT IS ALREADY KNOWN ON THIS TOPIC

- Low back pain (LBP) is prevalent in the general adolescent population and in adult athletes. It is a notable cause of disability and can stop athletes from participating in sport.

WHAT THIS STUDY ADDS

- LBP is common among adolescent athletes.
- Incidence and prevalence of LBP varied considerably due to differences in methodology, LBP definition and data collection.
- Spondylolysis was the most common reported morphological presentation.
- Potential risk factors for LBP in adolescent athletes presented in included studies were sport participation, sport volume/intensity, concurrent lower extremity pain, overweight/high body mass index, older adolescent age, female sex and family history of LBP.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- In clinical practice, clinicians should be aware of LBP as a common condition in adolescent athletes.
- Further research into methods of diagnosis and management of spondylolysis in adolescent athletes may be warranted.
- Future research in this population would benefit from a clear, specific definition of LBP for adolescent athletes.

INTRODUCTION

A leading cause of disability worldwide,[1] low back pain (LBP) is prevalent in adolescents, with some studies estimating twelve month prevalence to be 33%–57%[2 3] and lifetime prevalence to be 70%–80% by the age of 20.[4]

LBP can pose unique risks to adolescents participating in sport. Estimates suggest that 10%–15% of young athletes experience LBP, with some variation based on sport played.[5 6] Although LBP resolves quickly for some athletes, it can result in consequences including time off from playing sports or quitting sports entirely.[7] Since a previous history of LBP is a risk factor for the development of future episodes, the onset of LBP during adolescence also carries other risks, such as the potential for continued LBP later in life.[8 9] There has not been a published synthesis exploring prevalence of LBP in adolescent sport even though adolescent athletes report LBP regularly.[6]

In this systematic review, we aim to create a comprehensive synthesis across multiple sports to establish the incidence, prevalence, risk factors and morphologies associated with LBP in adolescent athletes.

METHODS

Protocol and registration

We used the Preferred Reporting Items for Systematic Reviews and Meta- Analyses[10] recommendations in the reporting of this systematic review. Prior to beginning the review, criteria were established and published in a protocol on PROSPERO (https://www.crd.york.ac.uk/prospero/), registration number: CRD42020157206. Differences between protocol and review can be found in online supplemental file 1.

Study eligibility criteria

We included prospective and retrospective studies that evaluated the incidence and/or prevalence of LBP in athletes aged 10–19 years. An athlete was defined as an individual participating in extracurricular sport. Population studies and studies that compared athletes to a non-sport population were included if they reported sport-related LBP. This review was limited to observational studies only, including case control, cross-sectional and cohort studies. We excluded studies that were published in a language other than English without an easily accessible translation, and conference papers with insufficient data (figure 1).

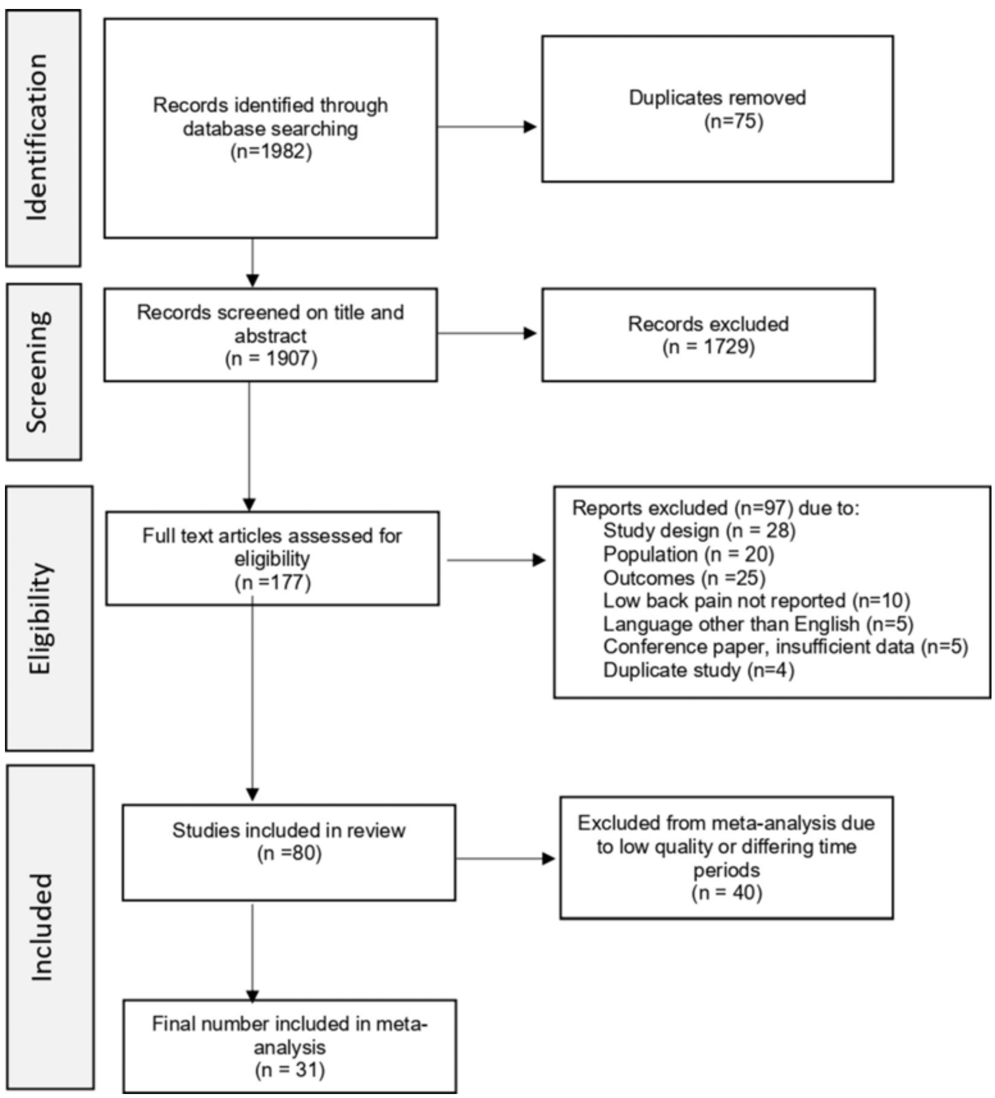

Figure 1. Flow chart of study selection for the analysis of incidence, prevalence, and risk factors for low back pain in adolescent athletes.

Sources and study selection

We searched five sources (Medline, Embase, CINAHL, Web of Science and Scopus) from inception to 30 September 2021, using a search strategy designed by a librarian experienced in the process (DM) (online supplemental file 2). The final search was conducted on 30 September 2021. Search results were exported to EndNote (Clarivate Analytics, Philadelphia, USA) citation management software where duplicates were removed. Studies were uploaded to Covidence Systematic Review Software (Veritas Health Innovation, Melbourne, Australia). Two researchers (FW and JW) screened the titles and abstracts of these studies using Covidence. Titles, keywords and abstracts were screened to determine whether they met inclusion criteria. Disagreements identified by Covidence were discussed until consensus was reached. There was no blinding to study author, institution or journal. The same two researchers conducted full-text screening of studies using Covidence software. Grey literature was included by searching the reference lists of included studies as well as American College of Sports Medicine conference abstracts 2016–2020, American Physical Therapy Association conference abstracts 2015–2020 and World Physiotherapy conference abstracts 2019 and archive.

Data extraction and management

One review author (JW) independently extracted data from included studies using a customised data extraction form, based on a recent systematic review of LBP in adult athletes.[11] Extracted data contained the following study details: design, aims, objectives, country, sport, sample size and setting. Characteristics of participants were extracted including age and type of participants. We also extracted main observations, outcome measures, definition of LBP (if included), reported incidence and/or prevalence, time period used and risk factors reported using ORs.

Data analysis

We synthesised data to calculate an overall weighted mean incidence and prevalence estimate of LBP in adolescent athletes for each different time period used. Data from studies on 6-month, 12-month and 2-year time periods for incidence were synthesised. For prevalence, data from high-quality studies 12-month period prevalence, 3-month period prevalence and point prevalence were synthesised. Weighted means were calculated for high-quality studies in each time period to consider the effect of sample size using a random effects model in Metafor in R Core Team (2020).[12] Forest and funnel plots were generated for all time periods. It was assumed that random effects followed a normal distribution. For the meta-analyses an expit link function was used with a random effects model [$y_i = (\mu + \mu_i)$ ε_{ij}] that allowed for random errors and true variation between studies. Where y_i is the dependent variable (prevalence), μ is the mean prevalence effect, μ_i is the study specific deviation with between study variation, ε_{ij} is the difference between observed and predicted

Meta-regression analyses using a mixed-effects model were conducted using Metafor in R.[12] Factors which could potentially contribute to heterogeneity in incidence and prevalence estimates were investigated, including methodological quality (high or low), number of participants (N), outcome expression (percentage of people with LBP or percentage of injuries to the low back out of all injuries), LBP definition (yes or no, included written and drawn definitions), sex (male or female), mean age, sport (specific sport or multiple), prospective or retrospective study design and method of data collection (questionnaire or other). The linearity assumptions were tested using QQ plots and residual plots.

Assessment of methodological quality

Two reviewers (KT and JW) assessed included studies using a quality appraisal tool developed by Leboeuf-Yde and Lauritsen[13] to assess quality in studies of LBP cohorts (online supplemental file 3). This tool was modified by Walker[14] to include an additional criterion. It was further modified by Trompeter *et al* [15] to consider studies scoring 65% and above as high quality. This tool (online supplemental file 4) assesses three main areas (12 items in total): whether the final sample was representative of the target population (three items), quality of the data (six items) and definition of back pain (three items). Each item is scored as criteria fulfilled (+), criteria not fulfilled (−) or not applicable (NA). The percentage of items with criteria fulfilled out of the total applicable items represents the methodological quality score.

RESULTS

Search strategy

After removing duplicates, the search yielded 1907 papers for screening. After screening and exclusions (figure 1), 80 studies were eligible for data extraction.

Characteristics of included studies

A total of 80 studies included 31 cohort studies and 49 cross-sectional studies (online supplemental file 11). Athlete-specific participant numbers ranged from 7[16] to 21 280.[17] There were 60 sports across 23 countries. Data were most often collected by use of a questionnaire. Common questionnaires included Nordic Musculoskeletal Questionnaire[18] or adaptations thereof, and the Oslo Sports Research Trauma Centre Questionnaire.[19]

Among the 31 cohort studies, 10 were included in the meta-analysis of studies reporting 2-year incidence (n=2), 12-month incidence (n=4) and 6-month incidence (n=4). Since there were so few high-quality cohort studies reporting the same time period, data from high-quality and low-quality cohort studies was included in the meta-analysis for incidence. Among the 49 cross-sectional studies, 22 (reported in 23 papers) were included in meta-analysis of high-quality studies reporting 12-month prevalence (n=8), 3-month prevalence (n=4) and point prevalence (n=15). Further details of reported incidence, prevalence, and risk factors can be found in online supplemental file 12.

Data from 74 studies (study reporting explanation in online supplemental file 5) was included in the analyses. For this review, ‘soccer’ refers to football, while other football codes are explicitly stated (ie, ‘American football’, ‘Australian Rules football’, and ‘Gaelic football’).

Pain definitions

There were 23 studies with definitions of LBP that included a reference to an anatomical location, either written or with a reference image (reported in 30 papers) (online supplemental file 13). There was no agreement between studies on LBP definition used, but the definitions of pain and injury could be grouped into five main areas. A total of 18 studies used time loss from training/competition or impaired ability to participate as part of the definition.[20–38] There was a specific duration of pain in three studies.[22 39 40] Treatment from a doctor or physiotherapist was used to define an injury in five studies.[16 30 41–43] A specific pain frequency per week was used in two studies.[44 45] A threshold of pain severity was used in two studies.[46 47]

Methodological assessment

Of the included studies, 33 studies (reported in 42 papers)[21,25,30,33,39,40,43–45,48–83] scored above 65% on the quality appraisal tool, indicating high quality (online supplemental table 4). Only 16 studies (reported in 20 papers) described reasons for non-response or compared the sample and target population,[17,26,32,39,40,48,50,54,56–62,69,77,79,84,85] though this criterion was only applicable to 63 studies. Of the five studies that included interviews, one used a validated, reproducible or adequately described interview format.[62] Of the 13 studies that included a clinical examination, 4 used a validated, reproducible or adequately described examination method,[22,32,35,68] such as the use of a standardised pro forma for injury reporting. Only 38 studies had a precise anatomic location of back pain or reference to an easily attainable article that contained a precise location.[25,27,31,33,44,45,49–56,58–64,66,67,69,71,73–79,81–83,86–88]

Included sports

Soccer was included in 13 studies,[17,23,25,30,31,35,41,46,57–60,62,74,78,8]1 while 10 studies included prevalence estimates for gymnastics.[16,17,39,46,54,62,73,74,85,89] Skiing,[50,51,68,77,90,91] volleyball,[17,25,46,52,82,88] swimming,[17,46,52,62,73,74] basketball,[17,25,33,43,55,79] and martial arts[17,46,62,74,83,92] were investigated in six studies each. This review does not include a meta-analysis of incidence or prevalence rates categorised by sport. Sports cannot be compared closely in this review due to methodological heterogeneity, including differing recall periods, definitions and quality, however, some general patterns were noted in studies reporting on specific sports. Soccer[30,31,35,41,81] and martial arts[83,92] reported generally lower levels of LBP, whereas ballet[75,76] gymnastics[16,85,89] and rowing[37,64] reported generally higher levels of LBP.

Cohort study design

Of 31 studies with a cohort study design, only 9 were high quality (30%). Twenty-nine studies reported incidence of LBP. More than one study reported on three incidence time periods: 6 months (n=4), 12 months (n=4) and 2 years (n=2). Only 3 of these 10 studies were high quality. Since there were so few, both high-quality and low-quality studies were synthesised for meta-analyses.

Incidence estimates of LBP in adolescent athletes

The pooled incidence estimate of four studies reporting 6-month incidence was 14% (95% CI 7% to 22%, I^2=76%) (figure 2).[21,24,26,31] In the meta-regression analysis, methodological quality had a significant effect on the heterogeneity between studies (p=0.003) and accounted for 100% of observed heterogeneity (online supplemental file 6). Of note, there was only one high-quality study of cohort design reporting 6-month incidence (36%).[21]

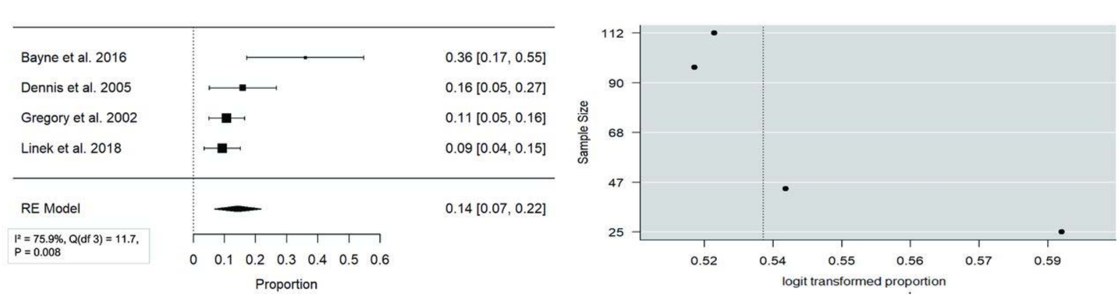

Figure 2. Forest (left) and funnel (right) plot of weighted pooled means of studies reporting 6-month incidence of LBP. LBP, low back pain.

The pooled incidence estimate of four studies reporting 12-month incidence was 36% (95% CI 4% to 68%, I^2=99.3%) (figure 3).[28 29 60 92] In the meta-regression analysis, LBP definition and methodological quality had a significant effect on heterogeneity (p<0.0001 for both) and accounted for 99.98% of the high heterogeneity between studies online supplemental file 6. Of note, there was only one high quality study of cohort design reporting 12-month incidence (10.4%).[60]

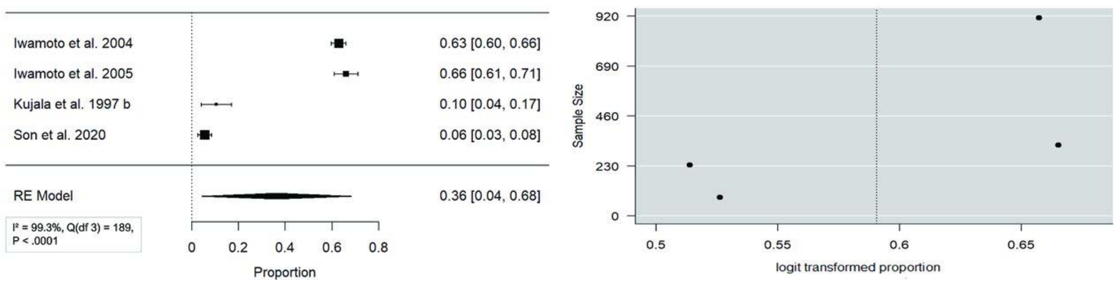

Figure 3. Forest (left) and funnel (right) plot of weighted pooled means of studies reporting 12-month incidence of LBP. LBP, low back pain.

The pooled incidence estimate of two studies reporting 2-year incidence was 11% (95% CI 8.0% to 13%, I^2=0%) (figure 4). Because of the low heterogeneity and low number of studies, meta-regression could not be conducted. Of note, there was only one high-quality study of cohort design reporting 2-year incidence (10%).[46]

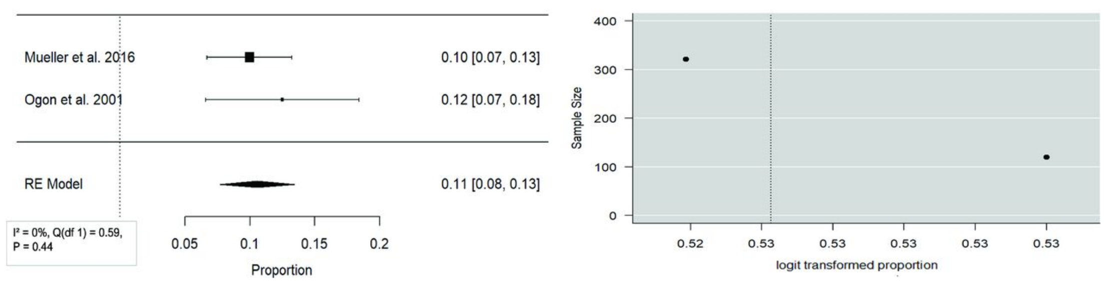

Figure 4. Forest (left) and funnel (right) plot of weighted pooled means of studies reporting 2-year incidence of LBP. LBP, low back pain.

Risk factors for LBP in cohort studies

One study of cohort design reported sport volume or intensity as a risk factor for pain or injury. In this study, injured cricket bowlers participated in sport more frequently than non-injured, though this did not separate by type of injury.[24]

Cross-sectional study design

Of 49 studies with a cross-sectional design, 36 were high quality (73%). Of these, 22 were included in meta-analyses of high-quality studies reporting 12-month prevalence (n=8), 3-month prevalence (n=4) and point prevalence (n=15).

Lifetime prevalence

Lifetime prevalence in adolescent athletes was reported in 19 studies.[17 25 39 40 48 49 52–54 56 63 64 67 69 71 74 75 77] Cumulative lifetime prevalence in these studies ranged from 9.6%[40] to 91.9%.[56] Lifetime prevalence could not be pooled due to differing ages included in the review (mean age 10–19 years of age).

Twelve-month prevalence

Twelve-month prevalence was reported by 12 studies (reported in 13 papers) and ranged from 14.6%[25] to 64%.[16 22 25 39 67 71 74 75 78 88 89] The pooled 12-month prevalence estimate of eight high quality studies was 42%, 95% CI 29% to 55%, I^2=96.6% (online supplemental file 7).[25 39 57 67 68 71 75 78]

Meta-regression was conducting using the factors LBP definition, number of participants, sport, sex and data collection method. None of these factors were statistically significant. The factors included in the meta-regression analysis did not account for any heterogeneity, and the test for residual heterogeneity was significant (p<0.0001) (online supplemental file 6).

Three-month prevalence

Overall 3-month prevalence was reported in four studies and ranged from 43.7%[65] to 51.3%.[73] The pooled 3-month prevalence estimate of four high-quality studies was 46%, 95% CI 41.0% to 52%, I^2=56%, (see online supplemental file 8).[50 65 73 75] Meta- regression was conducted using LBP definition. Variation in LBP definition had a statistically significant effect on heterogeneity (p=0.01) and accounted for 100% of the moderate heterogeneity among these studies.

Point prevalence

Point prevalence was reported by 18 studies (reported in 22 papers).[25 40 44 45 47 55 63 64 67 69 71 72 74 75 77 79–83 93 94] Overall point prevalence ranged from 3.2%[81] to 86%.[16] The pooled point prevalence estimate of 15 high-quality studies (reported in 13 papers) was 16%, 95% CI 9% to 23%, I^2=98.3% (see online supplemental file 9).

Meta-regression was performed using the factors LBP definition, number of participants, sport, sex and outcome. Sport (p<0.0001) and number of participants (p=0.02) had a statistically significant effect on heterogeneity. The amount of heterogeneity accounted for was 45.9%, leaving an unaccounted-for heterogeneity level of 27.0%.

Other recall periods

Other recall periods were used to report prevalence in five studies, including 2-week,[95] 1-month,[62 76] 6-month prevalence[61 86] and 11-month prevalence.[30]

Interpretation of funnel plots

There were outlying studies throughout the funnel plots. There was no clear explanation for many of these outliers. Variation in report incidence and prevalence is likely to reflect inconsistencies in methodological design, in particular, variance in definitions, sample size and method of recruitment. Please see online supplemental file 10 for further possible interpretations.

Risk factors for LBP in cross-sectional studies

In eight studies that compared athletes to a non-sport group, sport participation was identified as a risk factor for developing LBP.[16 17 71 73 74 77 87 94] Some studies identified risk associated with certain sports, such as basketball,[25] jogging,[73] handball[73] and gymnastics.[16 73]

A further 9 studies (reported in 10 papers) reported sport volume or intensity as a risk factor for developing LBP.[39 45 52 58 64 71 74 78 95] In one study, the level of sports exposure, measured by hours of sport participation per week, was only associated with LBP in younger athletes.[95] In the youngest girls (mean age 12.9±0.5 years), 6–10 hours per week of sport participation increased risk of LBP (unadjusted OR 5.3, 95% CI 1.2 to 24.3). In the second youngest group of boys (mean age 13.8±0.4 years), 10+ hours of sport participation increased risk of LBP (unadjusted OR 6.6, 95% CI 1.2 to 35). Finally, another study reported that both female and male athletes participating in sport more than 6 hours per week experienced higher rates of LBP than female and male athletes participating in less than 6 hours of sport per week.[74]

There were three high-quality cross-sectional studies that reported that concurrent lower extremity pain was associated with LBP.[79 82 83] These studies adjusted for sex, age, body mass index (BMI), team levels, number of days for training per week, number of hours in practice per day on weekdays and weekends, frequency of participation in games and practice intensity. The adjusted ORs were 6.56 (95% CI 1.57 to 27.3) for judo, 21.66 (95% CI 6.96 to 67.41) for kendo, 11.07 (95% CI 5.64 to 21.71) for volleyball and 4.25 (95%CI 2.55 to 7.07) and 3.79 (95% CI 2.26 to 6.36) for knee and ankle pain, respectively, in basketball.

Three studies reported being overweight/having a higher BMI as an associated factor.[54 63 96] In one study, the odds of developing LBP when classified as overweight was 1.4 times higher (OR 1.4, 95% CI 1.1 to 1.7 (analyses adjusted by sex)).[63] In another study, those who did not report LBP had lower BMI and body weight compared with those that did report LBP.[54] In the third study, overweight participants were more likely to have higher risk of lifetime or severe LBP compared with those with normal weight (OR 1.4, 95% CI 1.1 to 1.7 and 1.7, 95% CI 1.2 to 2.5 (analyses adjusted by sex)).[63]

Older adolescent age was reported by three studies (reported in four papers) as an associated factor.[47 52 66 67] In one study, the prevalence of LBP in children >13 years old more than doubled when compared with those aged 8–12 years.[52] Similarly, another study found that the prevalence of LBP increased from 2%–4% in those aged 11–13 years to 12%–20% in those aged 14–17 years.[47]

A group of seven studies reported female sex as a potential associated factor.[49 52 61 63 74 85 94] In three studies which reported on athletic girls specifically, there was a significantly higher prevalence of LBP in female athletes than in male athletes[61 85] with one study noting this especially in older grades.[94] Another study found that female sex was associated with only severe LBP,[49] and female sex was associated with double the risk of lifetime LBP in a fifth and sixth grade primary students (OR 2.5, 95% CI 1.7 to 2.5 (analyses adjusted by sex)),[63] although these did not separate athletes from non-athletes.

Three studies (reported in four papers) reported a family history of LBP or musculoskeletal pain as an associated factor of LBP in adolescent athletes.[52 66 67 85] Those with parents who were treated for LBP had twice as much chance of LBP in one study (adjusted OR 1.73, adjusted for age, sex and ‘other independent variables’, as reported by the study).[52]

Similarly, a second study reported a doubled risk of LBP when there was a family history of musculoskeletal disorders (OR 2.0, 95% CI 1.2 to 3.3 (adjusted by team level).[67]

Diagnoses and morphologies associated with LBP in adolescent athletes

Thirteen studies reported specific diagnoses relating to LBP. Spondylolysis and spondylolisthesis were most often reported, and were included in 9 of the 13 studies.[16 24 28 29 35 36 43 77 96] This was followed by Schmorl's nodes,[28 29 68 77 90] disc degeneration,[36 58 68 97] strains,[16 24 35] spina bifida occulta,28 29 90 end plate changes[58 90] and scoliosis.[77 90]

The most common method of imaging used to confirm diagnoses among the thirteen studies was MRI.[24 36 58 68 77 96 97] Lumbar radiographs/films were also used in four studies.[28 29 90 97]

DISCUSSION

The incidence and prevalence of LBP in adolescent athletes varied considerably due to differences in study methodology, definitions of LBP and data collection.

Comparison to general adolescent population

The reported incidence and prevalence estimates of LBP in adolescent athletes range widely. The LBP incidence and prevalence estimates for adolescent athletes are consistent with LBP estimates in the general adolescent population. Research indicates that annual incidence can range from 12% to 33%.[98] Similarly, studies show that point prevalence of LBP in adolescents can range from 3.2% to 39%.[2 98] The pooled 12-month incidence estimate falls within this range.

Physical activity can be both a risk factor and preventive factor for LBP, depending on the level of physical activity.[99] It is unclear from this review whether the 'U-shaped'[99] relationship between physical activity and LBP found in adults is also present in adolescents. The decrease in risk of LBP that accompanies physical activity participation in adults was not observed in adolescent athletes, contradicting the protective findings of physical activity on LBP in adults. While this does not consider a more nuanced view of the level of physical activity adolescent athletes participate in, several studies in this review did explore level of sport workload or exposure as a risk factor for LBP.[16 17 25 53 71 73 74 77 87 94] Those with a higher level of sport exposure were at higher risk of LBP.

It is also possible that the rate of LBP reported in adolescent athletes is too heavily attributed to sport. The general adolescent population does not engage in sufficient physical activity[100] and still reports a high prevalence of LBP.[2 4 101] Since it is unclear at this point whether the prevalence of LBP increases based solely on sport engagement, the benefits of sports likely outweigh the risk of LBP for adolescent athletes. It may be more important to examine the causes and duration of LBP in adolescent athletes, as these may differ from the overall adolescent population.

Common morphologies associated with LBP in adolescent athletes

Like previous research in this area, spondylolysis is the morphology that appears in the highest number of studies in this review. It is well supported that spondylolysis is most common in adolescent athletes.[102–104] It appears that the rate of spondylolysis that is reported in adolescent athletes is greater than that of the general adolescent population. The rate of spondylolysis reported in radiographs of those aged 12–18 has been documented as between 5.2% and 6%.[105] Some studies suggest that the majority of spondylolysis is asymptomatic,[102 103 106] and in adults, imaging reveals incidental asymptomatic findings of spinal changes that are not necessarily associated with pain.[107–110] It is possible that some of the spondylolysis findings in adolescents are also not associated with the LBP that the athlete is experiencing and are a normal response to high levels of loading and stress on a developing spine in this population. MRI was the most commonly used method of confirming diagnosis in this review, although it is not the most sensitive tool to assess spondylolysis.[111] MRI was chosen over CT scan in several included studies due to the risk of increased radiation exposure in adolescents.[24 36] From a clinical standpoint, it may be important to assess the methods used to confirm diagnoses in adolescents and consider that a focus on imaging may lead to overdiagnosis. Currently, a diagnosis of spondylolysis can lead to specific treatment methods that impact significantly on an adolescent's life, such as lumbar bracing,[103] rest from sport,[112] pharmacologic pain management[106] and surgery.[103 106] Optimal diagnosis (including a better understanding between the relationship of imaging findings and clinical presentation), treatment and management methods for spondylolysis in this population should be better refined.

Comparison to adult athletes

A recent systematic review of LBP in adult athletes found a high prevalence of LBP, with a history of LBP associated with risk of new onset.[11] The onset of LBP early in life puts adolescent athletes at higher risk for continuing LBP later in life.[8 9] Thus, the use of appropriate load monitoring and education to reduce risk of a primary episode of LBP in adolescence might mitigate future risk of LBP-related disability in adulthood. In addition, LBP was more common in adults with high training volumes. [11] This review has a similar finding, suggesting that an emphasis on adequate load management beginning as early as adolescence may decrease the risk of LBP in athletes of all ages.

As with adult literature, [11] there is little agreement on the definition of LBP in studies among adolescent athletes. In the meta-regression analyses, methodological quality and LBP definition accounted for most of the heterogeneity in studies of cohort design. Similarly, LBP definition accounted for all heterogeneity in cross-sectional studies reporting 3-month prevalence. The results of the meta-regression suggest that the lack of standardised method of assessing LBP in adolescent athletes may affect the overall prevalence reported. A definition of LBP more specific to adolescent athletes may improve assessment of LBP in this group.

Adolescent-specific factors in comparison to adult athletes

Several factors that may increase risk of LBP are unique to adolescent athletes when compared with adult athletes, including the effect of lower extremity pain and female sex on risk of developing LBP. Several studies identified female sex as a potential risk factor for LBP in adolescent athletes. Female adolescent athletes drop-out of sport twice as often as their male counterparts by the age of 14.[113] There are many factors contributing to this, including physical and psychological barriers[114] to sport participation. It is possible that increased rate of pain or injury may be a contributing factor, but this requires further exploration. Further research into causes of a higher the prevalence of LBP among female adolescent athletes may be essential to mitigating risk and retaining female athlete participation in adolescence.

There are three high-quality studies that suggest that concurrent lower extremity pain may be associated with LBP (OR 8.3, 95% CI 4.8, 14.4, I^2=45%).[79 82 83] Pain reporting can be influenced by factors such as female sex,[115] social factors[115 116] and past experiences with pain.[117] It is possible that the adolescents reporting concomitant lower extremity pain and LBP are more likely to report pain in general, although further exploration of factors influencing pain reporting in adolescent athletes is required. The role of parent/guardian involvement is a unique challenge of LBP prevalence assessment in adolescent sport. Several studies in this review allowed parents to answer the questionnaire on behalf of their children. Research has shown that parents' perception of their child's pain differs from the child's, with the adult often underestimating the pain of their child.[7 118] This could lead to an inaccurate representation of the prevalence of LBP in adolescent athletes and should also be reflected in considerations of injury prevention and load monitoring education. Adolescent athletes are best able to report their own pain, with appropriate adult consultation and consent.

In the meta-regression analyses of cross-sectional studies reporting lifetime and 12-month prevalence, none of the factors explored contributed to heterogeneity between the studies. This suggests that there may be other factors impacting heterogeneity among studies on adolescent athlete LBP that may not have been explicitly explored in the reported studies

Confidence in estimated values

There was considerable variability across studies in terms of methodology, definitions and data collection mode. This suggests a lack of standardisation in studies evaluating incidence and prevalence of LBP in adolescent athletes. A standardised definition of LBP for adolescent athlete research may enhance accuracy of the reported findings. Caution in interpreting results is warranted due to the overall low quality of available evidence and high heterogeneity among included studies. The search strategy was designed to capture studies exploring LBP incidence or prevalence in adolescent athletes, and did not specifically address risk factors, so some relevant studies may have been left out of this section.

Clinical implications

The results of this review suggest that clinicians should be aware of LBP as a common condition in adolescent athletes. Spondylolysis is the most reported morphology, suggesting that further research into methods of diagnosis and treatment in this population is warranted.

Limitations

Less than half of included studies were high quality. The majority of studies in this review were of cross-sectional design (49 studies), which does not represent the highest level of the aetiology hierarchy.[119] Only 9 of the 31 cohort studies were considered high quality. There was not sufficient information to describe how the study population reflects the broader population size.

The pooled estimates of incidence are limited by the lack of high-quality cohort studies reporting on incidence in the same time period—there was a low number of studies in these meta-analyses. This also limited the use of meta-regression in some meta-analyses.

Confounding in OR estimates was unmeasured, as some studies used crude ORs or did not specify covariates included in OR adjustment. There are important limitations to consider in reporting ORs from cross-sectional studies, including reverse causality.

This review only included studies published in English or with an English translation available. The term 'back pain' was considered LBP unless otherwise specified, since back pain and LBP are often used interchangeably. Low back injury was also considered LBP until otherwise specified. The determination was made at the stage of full-text screening that the study included an investigation of LBP. The quality appraisal tool used is specific to LBP but not specific to athletes or adolescents. The term ‘point prevalence’ in this review included current pain or pain in the past 7 days.

CONCLUSIONS

LBP is as common among adolescent athletes, though incidence and prevalence varied widely. Risk factors for LBP reported by included studies were sport participation, sport volume or intensity, concurrent lower limb pain, being overweight/having a higher BMI, older adolescent age, female sex and family history of LBP or musculoskeletal pain. Spondylolysis was the most reported morphology associated with LBP in adolescent athletes.

Ethics statements

Patient consent for publication

Not applicable.

REFERENCES

1 Koes BW, van Tulder MW, Thomas S. Diagnosis and treatment of low back pain. *BMJ* 2006; 332:1430–4.
2 Calvo- Muñoz I, Gómez- Conesa A, Sánchez-Meca J. Prevalence of low back pain in children and adolescents: a meta-analysis*. BMC Pediatr* 2013; 13:14.
3 Silva MROGCM, Badaró AFV, Dall’Agnol MM. Low back pain in adolescent and associated factors: a cross sectional study with schoolchildren. *Braz J Phys Ther* 2014; 18:402–9.
4 Jones GT, Macfarlane GJ. Epidemiology of low back pain in children and adolescents 2005; 90:312–6.
5 d’Hemecourt PA, Gerbino PG, Micheli LJ. Back injuries in the young athlete. *Clin Sports Med* 2000; 19:663–79.
6 Purcell L, Micheli L. Low back pain in young athletes. *Sports Health* 2009; 1:212–22.
7 Haraldstad K, Sørum R, Eide H, et al. Pain in children and adolescents: prevalence, impact on daily life, and parents’ perception, a school survey*. Scand J Caring Sci* 2011; 25:27–36.
8 Hestbaek L, Leboeuf-Yde C, Kyvik KO, et al. The course of low back pain from adolescence to adulthood: eight-year follow-up of 9600 twins. *Spine* 2006; 31:468–72.
9 Hestbaek L, Leboeuf-Yde C, Manniche C. Low back pain: what is the long-term course? A review of studies of general patient populations. *Eur Spine J* 2003; 12:149–65.
10 Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement*. BMJ* 2009;339: b2535.
11 Wilson F, Ardern CL, Hartvigsen J, et al. Prevalence and risk factors for back pain in sports: a systematic review with meta- analysis. *Br J Sports Med* 2021; 55:607–607.
12 Viechtbauer W. Conducting meta-analyses in R with the metafor package. *Journal of Statistical Software* 2010; 36:1–48.
13 Leboeuf-Yde C, Lauritsen JM. The prevalence of low back pain in the literature. A structured review of 26 Nordic studies from 1954 to 1993. *Spine* 1995; 20:2112–8.
14 Walker BF. The prevalence of low back pain: a systematic review of the literature from 1966 to 1998*. J Spinal Disord* 2000; 13:205–17.
15 Trompeter K, Fett D, Platen P. Prevalence of back pain in sports: a systematic review of the literature. *Sports Med* 2017; 47:1183–207.
16 Hutchinson MR. Low back pain in elite rhythmic gymnasts*. Med Sci Sports Exerc* 1999; 31:1686.
17 Sato T, Ito T, Hirano T, et al. Low back pain in childhood and adolescence: assessment of sports activities*. Eur Spine J* 2011; 20:94–9.

18 Kuorinka I, Jonsson B, Kilbom A, et al. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Appl Ergon* 1987; 18:233–7.
19 Clarsen B, Myklebust G, Bahr R. Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo sports trauma research centre (OSTRC) overuse injury questionnaire. *Br J Sports Med* 2013; 47:495.
20 Aoki H, Kohno T, Fujiya H, et al. Incidence of injury among adolescent soccer players: a comparative study of artificial and natural grass turfs. *Clin J Sport Med* 2010; 20:1–7.
21 Bayne H, Elliott B, Campbell A, et al. Lumbar load in adolescent fast bowlers: a prospective injury study. *J Sci Med Sport* 2016; 19:117–22.
22 Cejudo A, Ginés-Díaz A, Rodríguez-Ferrán O, et al. Trunk lateral flexor endurance and body fat: predictive risk factors for low back pain in child Equestrian athletes. *Children* 2020;7. doi:10.3390/children7100172. [Epub ahead of print: 09 10 2020].
23 Cezarino LG, Grüninger BLdaS, Scattone Silva R. Injury profile in a Brazilian first-division youth soccer team: a prospective study. *J Athl Train* 2020; 55:295–302.
24 Dennis RJ, Finch CF, Farhart PJ. Is bowling workload a risk factor for injury to Australian junior cricket fast bowlers? *Br J Sports Med* 2005; 39:843.
25 Farahbakhsh F, Akbari-Fakhrabadi M, Shariat A, et al. Neck pain and low back pain in relation to functional disability in different sport activities. *J Exerc Rehabil* 2018; 14:509–15.
26 Gregory PL, Batt ME, Wallace WA. Comparing injuries of spin bowling with fast bowling in young cricketers. *Clin J Sport Med* 2002; 12:107–12.
27 Hjelm N, Werner S, Renstrom P. Injury profile in junior tennis players: a prospective two year study. *Knee Surg Sports Traumatol Arthrosc* 2010; 18:845–50.
28 Iwamoto J, Abe H, Tsukimura Y, et al. Relationship between radiographic abnormalities of lumbar spine and incidence of low back pain in high school and College football players: a prospective study. *Am J Sports Med* 2004; 32:781–6.
29 Iwamoto J, Abe H, Tsukimura Y, et al. Relationship between radiographic abnormalities of lumbar spine and incidence of low back pain in high school rugby players: a prospective study. *Scand J Med Sci Sports* 2005; 15:163–8.
30 Lee I, Jeong HS, Lee SY. Injury profiles in Korean youth soccer. *Int J Environ Res Public Health* 2020; 17:5125.
31 Linek P, Noormohammadpour P, Mansournia MA, et al. Morphological changes of the lateral abdominal muscles in adolescent soccer players with low back pain: a prospective cohort study. *J Sport Health Sci* 2020; 9:614-619.
32 Palmer-Green DS, Stokes KA, Fuller CW, et al. Training activities and injuries in English youth Academy and schools rugby Union. *Am J Sports Med* 2015; 43:475–81.
33 Rossi MK, Pasanen K, Heinonen A, et al. Incidence and risk factors for back pain in young floorball and basketball players: a prospective study. *Scand J Med Sci Sports* 2018; 28:2407–15.
34 O' Connor S, McCaffrey N, Whyte EF, et al. Epidemiology of injury in male adolescent Gaelic games. *J Sci Med Sport* 2016; 19:384–8.
35 Shah T, Cloke DJ, Rushton S, et al. Lower back symptoms in adolescent soccer players: predictors of functional recovery. *Orthop J Sports Med* 2014; 2:2325967114529703.
36 Shimozaki K, Nakase J, Yoshioka K, et al. Incidence rates and characteristics of abnormal lumbar findings and low back pain in child and adolescent weightlifter: a prospective three-year cohort study. *PLoS One* 2018;13: e0206125.
37 Smoljanovic T, Bojanic I, Hannafin JA, et al. Traumatic and overuse injuries among international elite junior rowers. *Am J Sports Med* 2009; 37:1193–9.
38 Sommerfield LM, Harrison CB, Whatman CS, et al. A prospective study of sport injuries in youth females. *Phys Ther Sport* 2020; 44:24–32.
39 McMeeken J, Tully E, Stillman B, et al. The experience of back pain in young *Australians. Man Ther* 2001; 6:213–20.
40 Kaldau NC, Kerr S, McCaig S, et al. Training and injuries among world elite junior badminton players - Identifying the problems. *Asia Pac J Sports Med Arthrosc Rehabil Techno*l 2021; 26:21–6.
41 Fouasson-Chailloux A, Mesland O, Menu P. Soccer injuries documented by F-MARC

guidelines in 13- and 14-year old national elite players: a 5- year cohort study. *Science & Sports* 2020;35:145–53.
42 Gamboa JM, Roberts LA, Maring J, et al. Injury patterns in elite preprofessional ballet dancers and the utility of screening programs to identify risk characteristics. *J Orthop Sports Phys Ther* 2008; 38:126–36.
43 Hickey GJ, Fricker PA, McDonald WA. Injuries of young elite female basketball players over a six- year period. *Clin J Sport Med* 1997; 7:252–6.
44 Abe T, Kamada M, Kitayuguchi J, et al. Is being a regular player with fewer teammates associated with musculoskeletal pain in youth team sports? A cross-sectional study. *BMC Musculoskelet Disord* 2017; 18:105.
45 Kamada M, Abe T, Kitayuguchi J, et al. Dose-Response relationship between sports activity and musculoskeletal pain in adolescents. *Pain* 2016; 157:1339–45.
46 Mueller S, Mueller J, Stoll J, et al. Incidence of back pain in adolescent athletes: a prospective study. *BMC Sports Sci Med Rehabil* 2016; 8:38.
47 Müller J, Müller S, Stoll J, et al. Back pain prevalence in adolescent athletes. *Scand J Med Sci Sports* 2017; 27:448–54.
48 Zaina F, Donzelli S, Lusini M, et al. Tennis is not dangerous for the spine during growth: results of a cross- sectional study. *Eur Spine J* 2016; 25:2938–44.
49 Harreby M, Nygaard B, Jessen T, et al. Risk factors for low back pain in a cohort of 1389 Danish school children: an epidemiologic study. *Eur Spine J* 1999; 8:444–50.
50 Alricsson M, Werner S. Self-Reported health, physical activity and prevalence of complaints in elite cross-country skiers and matched controls. *J Sports Med Phys Fitness* 2005; 45:547–52.
51 Alricsson M, Werner S. Young elite cross-country skiers and low back pain-A 5- year study. *Phys Ther Sport* 2006; 7:181–4.
52 Balagué F, Nordin M, Skovron ML, et al. Non-Specific low- back pain among school-children: a field survey with analysis of some associated factors. *J Spinal Disord* 1994; 7:374–9.
53 Brown EW, Kimball RG. Medical history associated with adolescent powerlifting. *Pediatrics* 1983;72:636–44.
54 Cupisti A, D'Alessandro C, Evangelisti I, et al. Low back pain in competitive rhythmic gymnasts. *J Sports Med Phys Fitness* 2004; 44:49–53.
55 Hagiwara Y, Yabe Y, Sekiguchi T, et al. Upper extremity pain is associated with lower back pain among young Basketball players: a cross- sectional study. Tohoku *J Exp Med* 2020; 250:79–85.
56 Hoskins W, Pollard H, Daff C, et al. Low back pain in junior Australian rules football: a cross-sectional survey of elite juniors, non-elite juniors and non-football playing controls. *BMC Musculoskelet Disord* 2010; 11:241.
57 Kujala UM, Salminen JJ, Taimela S, et al. Subject characteristics and low back pain in young athletes and nonathletes. *Med Sci Sports Exerc* 1992; 24:627–32.
58 Kujala UM, Taimela S, Erkintalo M, et al. Low-Back pain in adolescent athletes. *Med Sci Sports Exerc* 1996; 28:165–70.

59 Kujala UM, Taimela S, Oksanen A, et al. Lumbar mobility and low back pain during adolescence. A longitudinal three- year follow- up study in athletes and controls. *Am J Sports Med* 1997; 25:363–8.
60 Kujala UM, Taimela S, Salminen JJ, et al. Baseline anthropometry, flexibility and strength characteristics and future low-back pain in adolescent athletes and nonathletes. *Scand J Med Sci Sports* 1994; 4:200–5.
61 Legault Élise P, Descarreaux M, Cantin V. Musculoskeletal symptoms in an adolescent athlete population: a comparative study. *BMC Musculoskelet Disord* 2015; 16:210.
62 Mogensen AM, Gausel AM, Wedderkopp N, et al. Is active participation in specific sport activities linked with back pain? *Scand J Med Sci Sports* 2007; 17:680–6.
63 Muntaner- Mas A, Palou P, Ortega FB, et al. Sports participation and low back pain in schoolchildren. *J Back Musculoskelet Rehabil* 2018; 31:811–9.

64 Ng L, Perich D, Burnett A, et al. Self-Reported prevalence, pain intensity and risk factors of low back pain in adolescent rowers. *J Sci Med Sport* 2014; 17:266–70.
65 Noll M, de Avelar IS, Lehnen GC, et al. Back pain prevalence and its associated factors in Brazilian athletes from public high schools: a cross-sectional study*. PLoS One* 2016;11: e0150542.
66 Pasanen K, Rossi M, Heinonen A. Low back pain in young team sport players: a retrospective study. *British Journal of Sports Medicine* 2014; 48:651.
67 Pasanen K, Rossi M, Parkkari J, et al. Low back pain in young Basketball and Floorball players. *Clin J Sport Med* 2016; 26:376–80.
68 Peterhans L, Fröhlich S, Stern C, et al. High rates of Overuse- Related structural abnormalities in the lumbar spine of youth competitive alpine skiers: a cross-sectional MRI study in 108 athletes. *Orthop J Sports Med* 2020; 8:2325967120922554.
69 Rossi M, Pasanen K, Kokko S, et al. Low back and neck and shoulder pain in members and non-members of adolescents' sports clubs: the Finnish health promoting sports Club (FHPSC) study. *BMC Musculoskelet Disord* 2016; 17:263.
70 Sato T, Ito T, Hirano T, et al. Low back pain in childhood and adolescence: a cross-sectional study in Niigata City. *Eur Spine J* 2008; 17:1441–7.
71 Schmidt CP, Zwingenberger S, Walther A, et al. Prevalence of low back pain in adolescent athletes - an epidemiological investigation. *Int J Sports Med* 2014; 35:684–9.
72 Sekiguchi T, Hagiwara Y, Momma H, et al. Youth baseball players with elbow and shoulder pain have both low back and knee pain: a cross-sectional study. *Knee Surg Sports Traumatol Arthrosc* 2018; 26:1927–35.
73 Skoffer B, Foldspang A. Physical activity and low-back pain in schoolchildren. *Eur Spine J* 2008; 17:373–9.
74 Sundell C- G, Bergström E, Larsén K. Low back pain and associated disability in Swedish adolescents. *Scand J Med Sci Sports* 2019; 29:393–9.
75 Swain CTV, Bradshaw EJ, Whyte DG, et al. Life history and point prevalence of low back pain in pre-professional and professional dancers. *Phys Ther Sport* 2017; 25:34–8.
76 Swain CTV, Bradshaw EJ, Whyte DG, et al. The prevalence and impact of low back pain in pre-professional and professional dancers: a prospective study. *Phys Ther Sport* 2018; 30:8–13.
77 Thoreson O, Kovac P, Swärd A, et al. Back pain and MRI changes in the thoraco-lumbar spine of young elite Mogul skiers. *Scand J Med Sci Sports* 2017; 27:983–9.
78 van Hilst J, Hilgersom NFJ, Kuilman MC, et al. Low back pain in young elite field hockey players, football players and speed skaters: prevalence and risk factors. *J Back Musculoskelet Rehabil* 2015; 28:67–73.
79 Yabe Y, Hagiwara Y, Sekiguchi T, et al. High prevalence of low back pain among young basketball players with lower extremity pain: a cross-sectional study. *BMC Sports Sci Med Rehabil* 2020; 12:40.
80 Yabe Y, Hagiwara Y, Sekiguchi T, et al. Knee pain is associated with lower back pain in young baseball players: a cross-sectional study. *Knee Surg Sports Traumatol Arthrosc* 2019; 27:985–90.
81 Sogi Y, Hagiwara Y, Yabe Y, et al. Association between trunk pain and lower extremity pain among youth soccer players: a cross-sectional study. *BMC Sports Sci Med Rehabil* 2018; 10:13.
82 Yabe Y, Hagiwara Y, Sekiguchi T, et al. Association between lower back pain and lower extremity pain among young volleyball players: a cross-sectional study. *Phys Ther Sport* 2020; 43:65–9.
83 Yabe Y, Hagiwara Y, Sekiguchi T, et al. Low back pain in school-aged martial arts athletes in Japan: a comparison among Judo, Kendo, and karate. *Tohoku J Exp Med* 2020; 251:295–301.
84 Farahbakhsh F, Rostami M, Noormohammadpour P, et al. Prevalence of low back pain among athletes: a systematic review. *J Back Musculoskelet Rehabil* 2018; 31:901–16.
85 Vanti C MG. Low back pain in adolescent gymnasts. prevalence and risk factors. *Scienza Riabilitativa* 2010;12:45–50.

86 Auvinen JP, Tammelin TH, Taimela SP, et al. Musculoskeletal pains in relation to different sport and exercise activities in youth. *Med Sci Sports Exerc* 2008; 40:1890–900.
87 Balagué F, Dutoit G, Waldburger M. Low back pain in schoolchildren. An epidemiological study. *Scand J Rehabil Med* 1988; 20:175–9.
88 Mizoguchi Y, Akasaka K, Otsudo T, et al. Factors associated with low back pain in elite high school volleyball players. *J Phys Ther Sci* 2019; 31:675–81.
89 Sweeney EA, Daoud AK, Potter MN, et al. Association between flexibility and low back pain in female adolescent gymnasts. *Clin J Sport Med* 2019; 29:379–83.
90 Ogon M, Riedl-Huter C, Sterzinger W, et al. Radiologic abnormalities and low back pain in elite skiers. Clin Orthop Relat Res 2001; 390:151–62.
91 Schoeb T, Peterhans L, Fröhlich S, et al. Health problems in youth competitive alpine skiing: a 12-month observation of 155 athletes around the growth spurt. *Scand J Med Sci Sports* 2020; 30:1758–68.
92 Son B, Cho YJ, Jeong HS, et al. Injuries in Korean elite Taekwondo athletes: a prospective study. *Int J Environ Res Public Health* 2020;17:5143.
93 HA D, Takemura M, Nagai S. Prevalence of Low Back Pain of South Korean Baseball Players in Childhood and Adolescence: 1496 Board #171 June 1 8: 00 AM - 9: 30 AM. *Medicine & Science in Sports & Exercise* 2017;49:418–9.
94 Kikuchi R, Hirano T, Watanabe K, et al. Gender differences in the prevalence of low back pain associated with sports activities in children and adolescents: a six-year annual survey of a birth cohort in Niigata City, Japan. *BMC Musculoskelet Disord* 2019; 20:327.
95 Grimmer K, Williams M. Gender-age environmental associates of adolescent low back pain. *Appl Ergon* 2000; 31:343–60.
96 Kountouris A, Portus M, Cook J. Quadratus lumborum asymmetry and lumbar spine injury in cricket fast bowlers. *J Sci Med Sport* 2012; 15:393–7.
97 Burnett AF, Khangure MS, Elliott BC, et al. Thoracolumbar disc degeneration in young fast bowlers in cricket: a follow-up study. *Clin Biomech* 1996; 11:305–10.
98 Kamper SJ, Yamato TP, Williams CM. The prevalence, risk factors, prognosis and treatment for back pain in children and adolescents: an overview of systematic reviews. *Best Pract Res Clin Rheumatol* 2016; 30:1021–36.
99 Heneweer H, Vanhees L, Picavet HSJ. Physical activity and low back pain: a U-shaped relation? *Pain* 2009; 143:21–5.
100 Guthold R, Stevens GA, Riley LM, et al. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants. *Lancet Child Adolesc Health* 2020; 4:23–35.
101 Jeffries LJ, Milanese SF, Grimmer-Somers KA. Epidemiology of adolescent spinal pain: a systematic overview of the research literature. *Spine* 2007; 32:2630–7.
102 McDonald BT HA, Lucas JA. *Spondylolysis*. Treasure Island, FL: StatsPearls Publishing, 2020.
103 Standaert CJ, Herring SA. Spondylolysis: a critical review. *Br J Sports Med* 2000; 34:415–22.
104 Micheli LJ, Wood R. Back pain in young athletes. significant differences from adults in causes and patterns. *Arch Pediatr Adolesc Med* 1995; 149:15–18.
105 Fredrickson BE, Baker D, McHolick WJ, et al. The natural history of spondylolysis and spondylolisthesis. *J Bone Joint Surg Am* 1984; 66:699–707.
106 Syrmou E, Tsitsopoulos PP, Marinopoulos D, et al. Spondylolysis: a review and reappraisal. *Hippokratia* 2010; 14:17–21.
107 Brinjikji W, Luetmer PH, Comstock B, et al. Systematic literature review of imaging features of spinal degeneration in asymptomatic populations. *AJNR Am J Neuroradiol* 2015; 36:811–6.
108 Boden SD, Davis DO, Dina TS, et al. Abnormal magnetic-resonance scans of the lumbar spine in asymptomatic subjects. A prospective investigation. *J Bone Joint Surg Am* 1990; 72:403–8.
109 Kalichman L, Kim DH, Li L, et al. Computed tomography-evaluated features of spinal degeneration: prevalence, intercorrelation, and association with self-reported low back pain.

Spine J 2010; 10:200–8.
110 Wiesel SW, Tsourmas N, Feffer HL, et al. A study of computer-assisted tomography. I. the incidence of positive cat scans in an asymptomatic group of patients. *Spine* 1984; 9:549–51.
111 Tofte JN, CarlLee TL, Holte AJ, et al. Imaging pediatric Spondylolysis: a systematic review. *Spine* 2017; 42:777–82.
112 Patel DR, Kinsella E. Evaluation and management of lower back pain in young athletes. *Transl Pediatr* 2017; 6:225–35.
113 Sabo DaV P. *Go out and play: youth sports in America*. East Meadow, NY: Women's Sports Foundation, 2008.
114 Adolescent girls get active. Dublin, ireland: sport Ireland 2021.
115 Bartley EJ, Fillingim RB. Sex differences in pain: a brief review of clinical and experimental findings. *Br J Anaesth* 2013; 111:52–8.
116 Tracy LM. Psychosocial factors and their influence on the experience of pain. *Pain Rep* 2017; 2: e602-e: e602.
117 Rollman GB, Abdel-Shaheed J, Gillespie JM, et al. Does past pain influence current pain: biological and psychosocial models of sex differences. *Eur J Pain* 2004; 8:427–33.
118 Kamper SJ, Dissing KB, Hestbaek L. Whose pain is it anyway? comparability of pain reports from children and their parents*. Chiropr Man Therap* 2016; 24:24:24.
119 McNair P, Lewis G. Levels of evidence in medicine. *Int J Sports Phys Ther* 2012;7:474–81.

Footnotes

- Twitter @NicolvanDyk, @fionawilsonf
- Contributors JW, FW and WPM were responsible for review conception and design. JW and FW screened and assessed for study eligibility. JW, FW, NvD and WPM assisted with writing and editing. CG analysed data. DM designed the search strategy. KT and JW reviewed studies for methodological quality. All review authors reviewed and approved the final manuscript.
- Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.
- Competing interests WPM receives royalties from ABC-Clio publishing for the sale of the books, Kids, Sports, and Concussion: A guide for coaches and parents, and Concussions; from Springer International for the book Head and Neck Injuries in Young Athlete; and from Wolters Kluwer for working as an author for UpToDate. WPM's research is funded, in part, by philanthropic support from the National Hockey League Alumni Association through the Corey C. Griffin Pro-Am Tournament and a grant from a grant from the National Football League.
- Provenance and peer review Not commissioned; externally peer reviewed.
-