European Spine Journal (2024) 33:2088–2096
https://doi.org/10.1007/s00586-023-08083-8

ORIGINAL ARTICLE

Prevalence of spinal deformity development after surgical management of a congenital heart disease among children: a systematic review and meta-analysis

Renad N. Balubaid[1,4] · Raghd S. Aljedani[1,4] · Abdulaziz Moglan[1,4] · Yasser B. Hennawi[2,4] · Ahmed Hafez Mousa[3,4] · Majed Alosaimi[1,4,5,6]

Received: 4 October 2023 / Revised: 4 October 2023 / Accepted: 1 December 2023 / Published online: 11 March 2024

Abstract

Introduction Open heart surgery is the most common treatment for congenital heart disease. Thoracotomy, sternotomy, or a combination of both are the main approaches used in open heart surgeries. In cardiac surgery, there have been concerns that these surgeries increase the likelihood of spinal deformities. Therefore, this systematic review and meta-analysis provided updated evidence on the prevalence of spinal deformities following congenital heart surgery.

Method EMBASE, Medline, ScienceDirect, and Google Scholar were used to search for studies published until 2022. We include randomized clinical trials and observational studies that reported the prevalence of spinal deformities (scoliosis and kyphosis) after congenital heart surgery among participants without these deformities before surgery. Two independent reviewers independently screened literature identified from the databases. Two reviewers independently conducted screening of studies identified during the search, data extraction, and quality assessment of the included studies.

Results In total, 688 studies were screened; 13 retrospective and one prospective cohort studies were included, encompassing 2294 participants. The pooled prevalence of spinal deformities (scoliosis and kyphosis) after open heart surgery performed on skeletally immature patients was 23.1% (95% confidence interval [CI] = 23.1–35.3; $I^2 = 97.5\%$).

Conclusion This review suggests that the prevalence of spinal deformities was high among patients who underwent sternotomy or thoracotomy.

Keywords Prevalence · Spinal deformity · Scoliosis · Congenital heart disease

Introduction

A spinal deformity is a disposition in the angulation of a natural spinal curvature, causing it to deviate beyond the established normative range [1, 2]. Kyphosis and lordosis are spinal dispositions in the sagittal axis, while scoliosis is a three-dimensional rotational deformation of the spine characterized by an abnormal deviation of the lateral spinal curvature [3]. The most common form of spinal deformities is idiopathic scoliosis, with a prevalence ranging between 2 and 3%. Female gender, genetic predisposition, and developmental delays are associated with higher risks of idiopathic scoliosis [4].

A high prevalence of scoliosis has been reported after cardiac surgery for the treatment of congenital heart diseases (CHD), and surgical interventions involving the immature rib cage (sternotomy or thoracotomy) are considered to be complicated by significant musculoskeletal and cosmetic

✉ Majed Alosaimi
OsaimiMA@MNGHA.MED.SA

1 College of Medicine, King Saud Bin Abdulaziz University For Health Sciences, Jeddah, Saudi Arabia

2 Faculty of Medicine, Umm Al-Qura University, Makkah, Saudi Arabia

3 College of Medicine and Surgery, Batterjee Medical College, Jeddah, Saudi Arabia

4 King Abdullah International Medical Research Center, Jeddah, Saudi Arabia

5 Department of Orthopedic, King Abdulaziz Medical City, Jeddah, Saudi Arabia

6 King Khalid National Guard Hospital, King Abdulaziz Medical City, National Guard, Jeddah, Saudi Arabia

deformities that may not become apparent until the child is much older [4]. CHDs affect nearly 1% of all live births [5]. CHD is a broad and heterogeneous condition with diverse etiologies [6].

The vast majority of CHD cases are treated by open heart surgery [7], and the main approaches in open heart surgeries include thoracotomy, sternotomy, or a combination of both [8]. Despite the significant advances in cardiac surgery in recent decades leading to improvements in the prognosis of CHD, studies suggest that these surgeries may increase the likelihood of spinal deformities, especially scoliosis [9]. Meanwhile, there has also been a notable increase in the risk of developing secondary scoliosis in CHD patients, and various studies estimated the risk to range from 2 to 31% [6–8]. Other theories have been proposed to identify the possible mechanisms by which open heart surgery contributes to spinal defects. Some studies suggest that manipulating the thoracic cage in the early stages of life is likely a mechanical contributory mechanism [10, 11]. However, the precise mechanism remains uncertain.

Most studies on the prevalence and determinants of spinal deformities following heart surgery are chiefly limited by small sample sizes. Small sample sizes predispose the findings of these studies to random error, making it challenging to precisely estimate the prevalence of spinal deformity after heart surgery and limited statistical power to identify factors associated with spinal deformity following heart surgery. There is a need, therefore, to combine the findings of previous studies in a meta-analysis to provide precise estimates of the prevalence of and identify factors associated with spinal deformity after heart surgery. This systematic review and meta-analysis summarized evidence on the prevalence and associated factors with spinal deformities, particularly scoliosis and kyphosis, after open heart surgeries in pediatric patients with congenital heart diseases.

Methods

This systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [12] and was registered with PROSPERO (registration number: CRD42022379813).

Search strategy

A structured electronic search was performed from March 9th, 2022, until December 8th, 2022, in EMBASE, Medline, ScienceDirect, and Google Scholar with no restrictions on the publication date or language. Combinations of the following text words and MeSH terms were used: "congenital heart disease," "congenital heart defect," "congenital heart anomaly," “cardiac surgical procedures," "sternotomy," "thoracotomy," "spine malformation," "scoliosis," and "kyphosis" (see Appendix for search strategy). Additionally, a manual search of reference lists of the retrieved articles was carried out in order to cover more relevant studies.

Eligibility criteria

The systematic review included the following studies: (1) All study designs, including prospective and retrospective studies; (2) conducted on children with congenital heart diseases who underwent surgery (thoracotomy, sternotomy, or both) before reaching skeletal maturity, which is 18 years and younger; (3) had sufficient follow-up to detect spinal deformity following surgery; (4) did not include patients with deformity before the surgery. The exclusion criteria were: studies conducted on patients with syndromes that increased the risk of spinal deformity; (5) did not provide the required data to calculate the prevalence of spinal deformity.

Study selection and data abstraction

Two reviewers independently screened the titles and abstracts of articles identified from database searches based on the eligibility criteria, excluding articles that were clearly not eligible for this review. They then screened the full texts of articles considered to be eligible for inclusion based on the title and abstract stage. Disagreements between the two reviewers were resolved through consensus or arbitration by a third author. A predesigned form was used to abstract the data from the full texts of eligible articles.

Risk of bias assessment

The National Institutes of Health Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (NIH-QAT, National Institutes of Health, 2017) was used to assess the risk of bias among the included studies. The tool assesses the clarity of the research question or objectives, the suitability of the selected study population and sample size in addition to the adequacy of its description, the exposure measurements, the outcomes, the sufficiency of the study timeframe with the adequacy of follow-ups, and the adequacy of the statistical analyses. Two reviewers independently assessed the risk of bias in the included studies, rating each study as good, fair, or poor quality. The two review authors resolved disagreements through discussions.

Statistical analysis

Statistical analyses were performed using the *“Meta”* and *“Metafor”* packages of the R programming language (version 4.2.2, 2022, The R Foundation for Statistical Computing

Platform, Vienna, Austria). Study-specific proportions were pooled by inverse-variance weighted random-effects meta-analysis after their variances were stabilized using Freeman-Tukey double-arcsine transformation before calculating the pooled summary estimate. The exact binomial interval was used to calculate the confidence interval of the individual study estimates.

The I^2 statistic and p-value from Cochrane's Q χ^2 test were used to assess heterogeneity in the study-specific estimate across studies [13]. I^2 statistics below 30%, 30–49%, 50–70%, and over 70% were interpreted to indicate low, moderate, substantial, and considerable heterogeneity in study-specific effects. A p-value < 0.05 from Cochrane's Q test indicated statistically significant evidence of heterogeneity [13].

Subgroup and metaregression analysis were performed to investigate potential sources of heterogeneity for the main analysis by age at the time of surgery, percentage of females, duration of follow-up, and type of intervention. Subgroup analysis was performed if at least ten studies were included in the meta-analysis. Funnel plot asymmetry was used to assess evidence of small-study effect, and Egger's regression test was used to formally test for publication bias. The threshold of statistical significance for the subgroup analysis, metaregression, and Egger's test was set at 0.1.

Sensitivity analysis was performed using leave-one-out analysis. In addition, the pooled summary prevalence was re-estimated after excluding poor-quality studies.

For the analysis of the factors associated with spinal deformity, we first recalculated the unadjusted odds ratios (ORs) and their respective variances for each study. The log-ORs were then pooled into a fixed-effect meta-analytic model using the Mantel–Haenszel method if the $I^2 < 50\%$: the estimates were pooled using random-effects meta-analysis if the $I^2 \geq 50\%$ [13–15].

Results

Literature search and study characteristics

A total of 662 studies were identified, 91 full texts were assessed, and 13 out of them met our inclusion criteria (Fig. 1). Our included studies reporting data on 2294 patients were included in this study (Table 1). The included studies were published between 1975 and 2018, and most (77%) were published from 2010 and beyond. Most studies were retrospective cohort studies (92%), conducted in the USA (23%), and used a combination of sternotomy and thoracotomy (69.2%) for managing CHD (Table 1 and S1). The detailed characteristics of the included studies are shown in Table S1. The quality of most studies was fair (62%), 23.1% was good, and 15.4% was poor (Table 1 and S2).

Prevalence of deformity

Figure 2 shows the prevalence of total deformity among patients who underwent surgical intervention for congenital heart disease. Data was pooled from 13 studies, including 2294 participants and 577 cases. The pooled prevalence of total deformity was 23.1%, with considerable heterogeneity across studies (pooled prevalence = 23.1%; 95% confidence interval [CI] = 23.1–35.3; $I^2 = 97.5\%$; Fig. 2).

Figures S1–4 show the results of the subgroup analysis. Differences in follow-up times between studies were a significant source of heterogeneity in the prevalence of total deformity between studies (Fig. S1; Tables S1 and S12). There was no significant evidence of moderation of the pooled prevalence by age, sex, and type of intervention (Figs. S2–4). We found no evidence of publication bias among studies reporting on the pooled prevalence of total deformity (Fig. S5). On sensitivity analysis, we found no evidence of influential studies on leave-1-out analysis (Fig. S6), and the pooled prevalence did not change substantially after excluding poor-quality studies (Fig. S2), indicating that our finding was robust. After excluding poor quality studies, the pooled prevalence of total deformity was 20.9% (95% CI = 10.0–34.3; $I^2 = 97.8\%$; Fig. S7).

Figures 3, 4, 5 display the prevalence of scoliosis, hypokyphosis, and hyperkyphosis, respectively. The pooled prevalence of scoliosis using data from 10 studies, including 1351 patients, was 19.5% (95% CI = 10.2–30.7; $I^2 = 95.1\%$; Fig. 3). Data used for the meta-analysis of the prevalence of hypokyphosis was provided by three studies (Fig. 4), while four studies provided data for the meta-analysis of the prevalence of hyperkyphosis (Fig. 5). The prevalence of hypokyphosis and hyperkyphosis were 17.3% (95% CI = 3.1–39.2; $I^2 = 94.2\%$; Fig. 4) and 4.7% (95% CI = 0.2–13.4; $I^2 = 89.0\%$; Fig. 5).

Risk factors of total deformity

We investigated the association between age, gender, and type of heart disease with total deformity (Figs. 6, 7, 8). Two, eight, and five studies provided data on the association of age, gender, and type of congenital heart disease with total spinal deformities, respectively. We found no evidence of an association between age (pooled odds ratio [OR] = 0.52; 95% CI = 0.00–313.78; $I^2 = 97\%$; Fig. 6), gender (OR = 0.90; 95% CI = 0.71–1.15; $I^2 = 49\%$; Fig. 7), and type of congenital heart disease (OR = 1.25; 95% CI = 0.84–1.86; $I^2 = 46\%$; Fig. 8).

Discussion

This systematic review and meta-analysis aimed to investigate the prevalence of spinal deformities following surgical management of CHD in pediatric patients with no prior

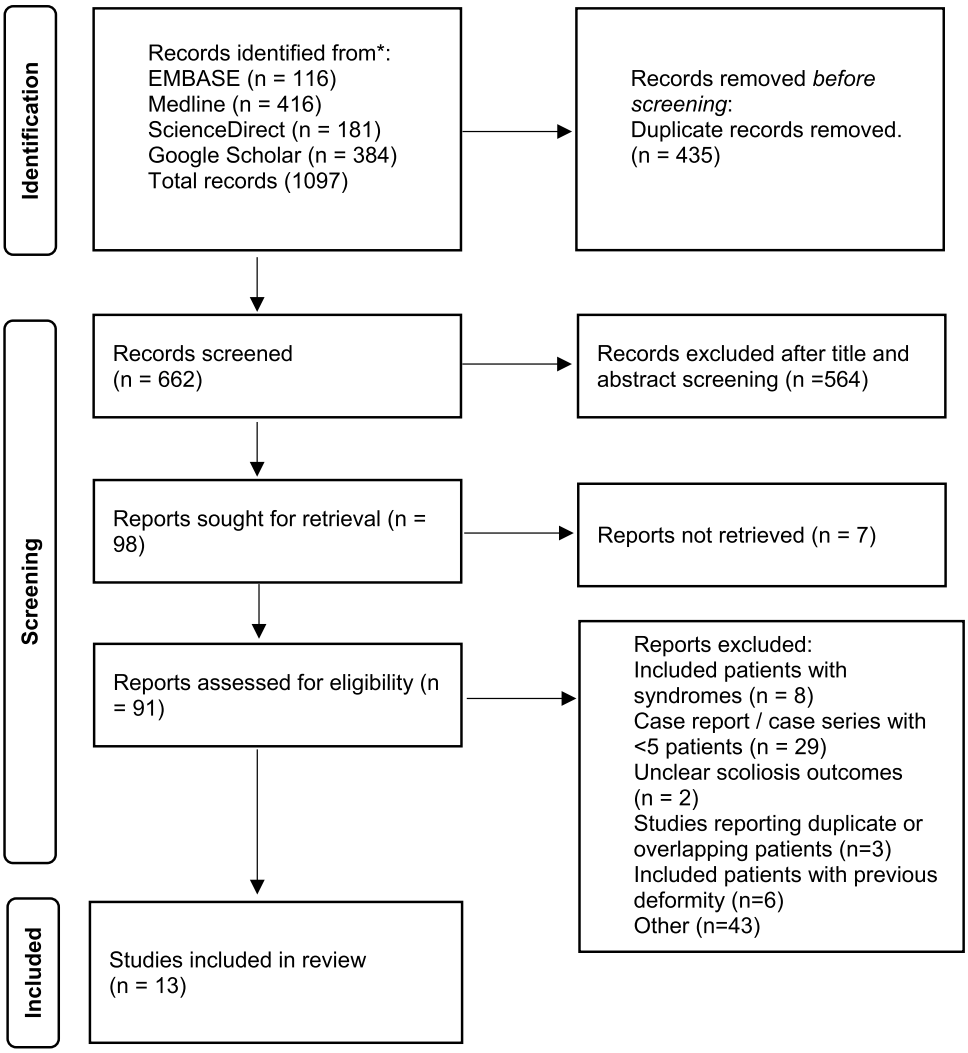

Fig. 1 The PRISMA flow diagram of the study inclusion and exclusion process

spinal deformity or congenital conditions that increase their risk of spinal deformity following surgery. The pooled prevalence of spinal deformity after surgical management of CHD was found to be 23.1%, indicating about one in four children undergoing surgical management for CHD are at risk of spinal deformities, which is higher than the risk in the general population and patients with other underlying conditions.

We found that the duration of follow-up explained some of the heterogeneity in the prevalence across studies. Studies with longer duration of follow-up had a higher prevalence of total spinal deformities compared to those with shorter durations of follow-up. Studies with longer durations of follow-up are more likely to detect new cases and, therefore, have a higher prevalence.

The incidence of idiopathic scoliosis in the general population has been reported in various epidemiological studies worldwide. More recent studies report a lower incidence of scoliosis compared to earlier studies. In 2021, the prevalence of scoliosis was reported to range between 0.2 and 0.8% among children in a nationwide study conducted in South Korea by Sung et al. [16]. the prevalence among children 10–18 years in the US was reported to be 0.52% in 2022 by Thomas et al. [17]; the prevalence reached up to 2.3% in a Turkish study conducted in 2020 by Yilmaz et al. [18]. By contrast, an earlier review published in 2012 by Konieczny et al. [19]—including seven studies published between 1976 and 2010 that collected data through school screening from six countries—reported a prevalence of up to 5.2%. The lowest reported rates were 0.47% and 0.59%, but those studies only included children younger than 15 years—higher rates are usually detected in older children, which might have underestimated the prevalence.

Multiple studies suggest even higher rates among children who underwent sternotomy or thoracotomy on an immature rib cage. Mishra et al. [20]. conducted a systematic review of 14 institution-based retrospective cohort studies published between 1969 and 2019, including 1338 children born with esophageal atresia and treated early in life via thoracotomy. They reported a prevalence of scoliosis of 20% among all

Table 1 Summary characteristics of studies included in the meta-analysis

Characteristics	N = 13 studies
Age at surgery in months, median (IQR)	36 (14–63)
Year of publication	
Range	1975–2018
Before 2000	3 (23.1%)
2000 and beyond	10 (76.9%)
Study design	
Retrospective	12 (92.3%)
Prospective	1 (7.7%)
Country	
USA	3 (23.1%)
Germany	2 (15.4%)
Turkey	2 (15.4%)
Others	6 (46.2%)
Intervention	
Thoracotomy	2 (15.4%)
Sternotomy	1 (7.7%)
Both	9 (69.2%)
Not reported	1 (7.7%)
Study quality	
Good	3 (23.1%)
Fair	8 (61.5%)
Poor	2 (15.4%)

IQR Interquartile range

included children and a prevalence of 13% after excluding patients with congenital musculoskeletal anomalies. Both reported percentages exceeded the rates reported in any of the general population, indicating that these patients have a higher risk of scoliosis following thoracotomy compared to the general population.

Gender, age at the time of surgery, follow-up period, and the type of heart disease have been suggested to be associated with spinal deformity following heart surgery, but none showed a significant association in the present meta-analysis. In contrast, Mery et al. [21] reported gender and developmental delay were associated with spinal deformity. By combining cases from previous studies, this meta-analysis had a greater statistical power to investigate associations than individual studies, indicating that findings from this meta-analysis may be more reliable. Nevertheless, our result on the association between age at surgery and risk of spinal deformity may be unreliable as only two studies were included in this specific meta-analysis. Therefore, further studies are warranted to explore the association between age at surgery and the risk of spinal deformity after open heart surgery for CHD.

Cyanotic CHD has been hypothesized to cause asymmetrical bone growth owing to decreased bony perfusion, but the findings from previous studies have been controversial. Studies have shown no association between the type of CHD and the development of spinal deformity after open heart surgery [10, 22]. While other studies have reported that patients with cyanotic CHD are more likely to develop spinal deformity after surgery compared to patients with non-cyanotic CHD [9]. This meta-analysis found no association between cyanotic CHD and the risk of spinal deformity following open heart surgery.

The severity and types of spinal deformities varied across the studies included in our analysis. Scoliosis was the most commonly reported spinal deformity, followed by kyphosis and lordosis. The heterogeneity in the reported types and severity of spinal deformities indicates the complex nature of these conditions and underscores the importance of individualized assessment and management approaches.

Health implications of the findings

The observed prevalence of deformities of the spine sheds light on the critical need to raise awareness among providers of healthcare and long-term strategies focused on follow-up plans for CHD patients. The implications of spinal deformity development in children after surgical management of CHD are far-reaching [23]. And can negatively impact the overall quality of life, functional abilities, and psychological well-being of affected individuals [24]. Moreover, spinal deformities may lead to additional healthcare needs, such as the requirement for orthopedic interventions or physical therapy, further burdening the healthcare system [25]. Moreover, the management of spinal deformities is associated with a substantial economic burden on the patient's family, which can plunge the patient's family into poverty. Understanding the prevalence of spinal deformities in patients undergoing open heart surgery for CHD is crucial to guide resource allocation for better management of this complication. Moreover, there is a need for large-scale (multinational) prospective cohort studies with long durations of follow-up to understand the risk factors of spinal deformities in patients with CHD after open heart surgery.

Limitations

The limitations of the present study should be acknowledged. First, the included studies exhibited heterogeneity in terms of patient characteristics and follow-up duration, reducing the precision of the pooled prevalence. Second, even though we found no evidence of publication bias, this cannot be entirely ruled out, as studies with negative or non-significant findings may be underrepresented in the literature. Third, a number of the included studies lacked long-term follow-up, making it challenging to determine the true incidence and progression of spinal deformities

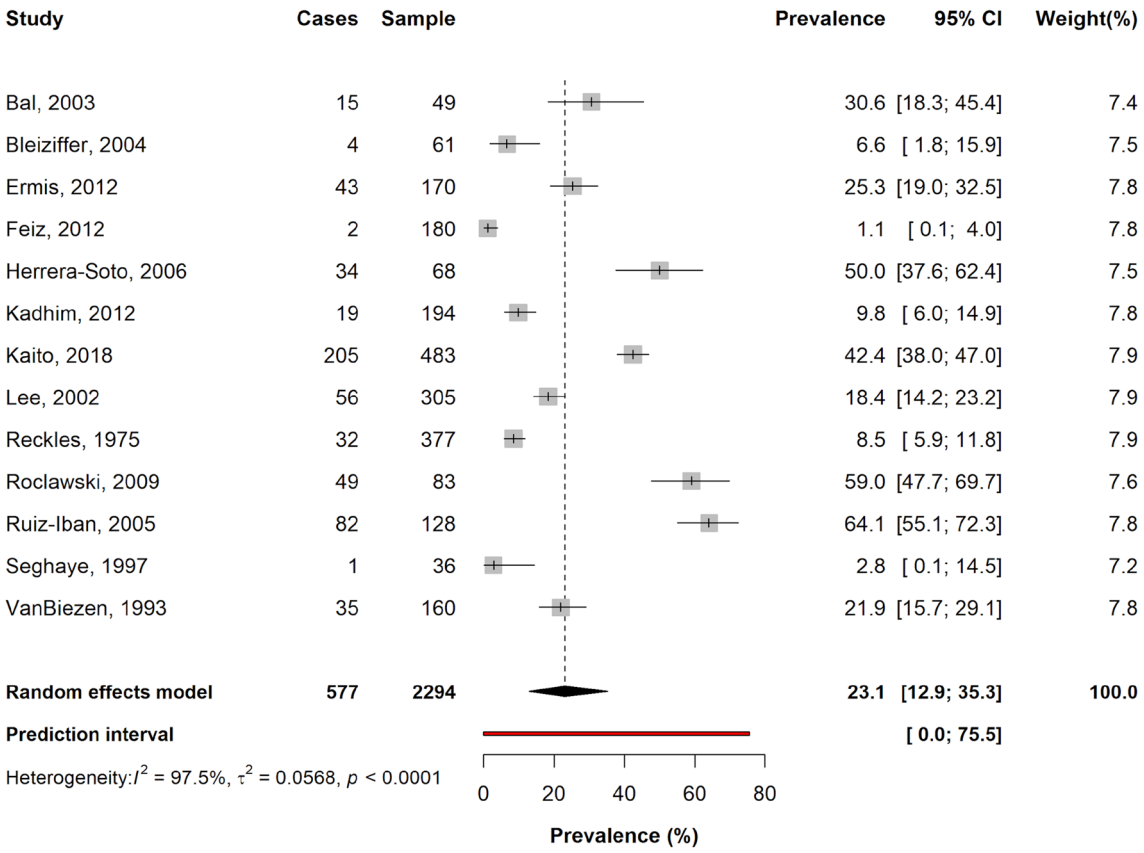

Fig. 2 Pooled prevalence of total spinal deformity after spinal surgery among patients with congenital heart disease

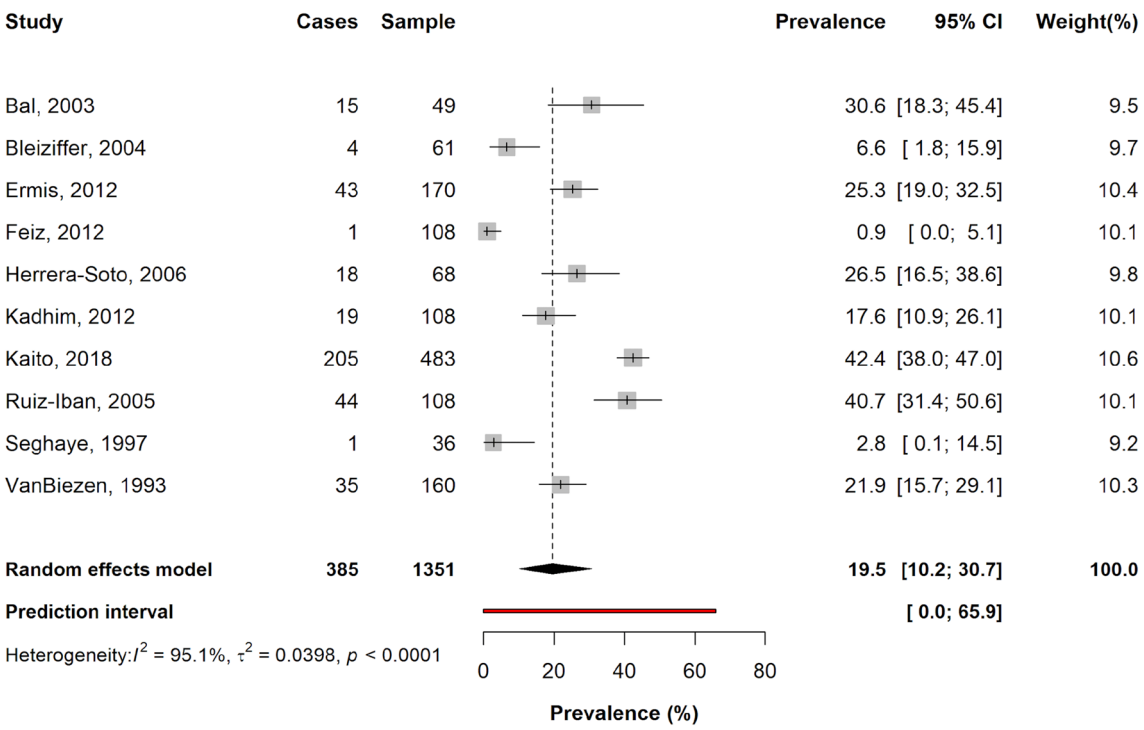

Fig. 3 Pooled prevalence of scoliosis after spinal surgery among patients with congenital heart disease

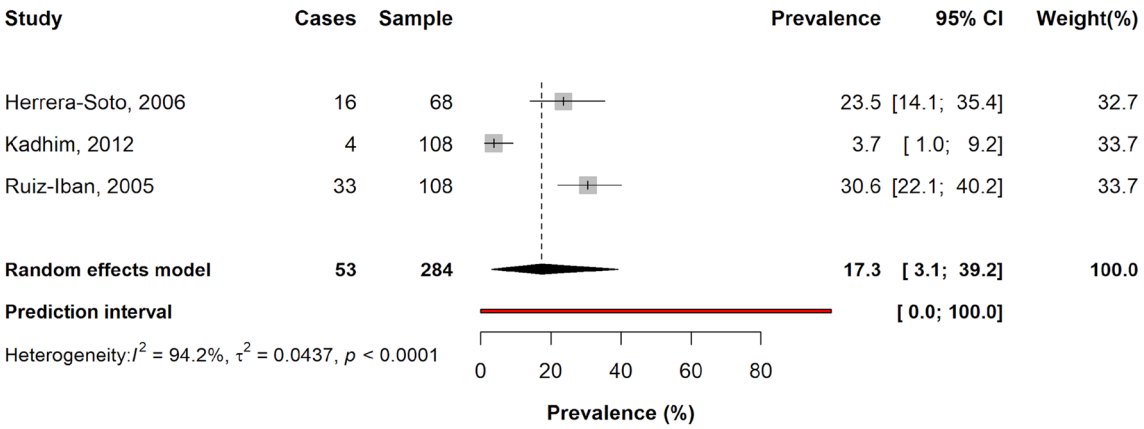

Fig. 4 Pooled prevalence of hypokyphosis after spinal surgery among patients with congenital heart disease

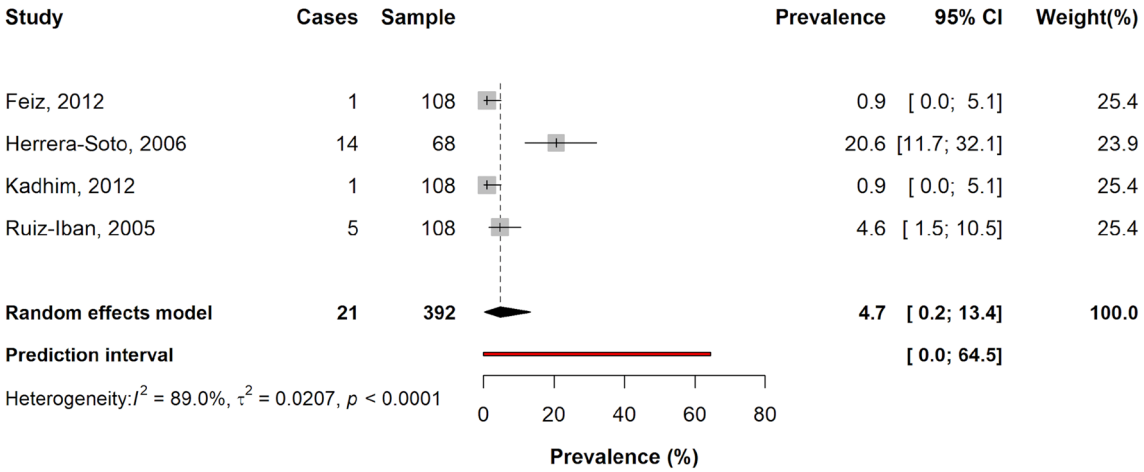

Fig. 5 Pooled prevalence of hyperkyphosis after spinal surgery among patients with congenital heart disease

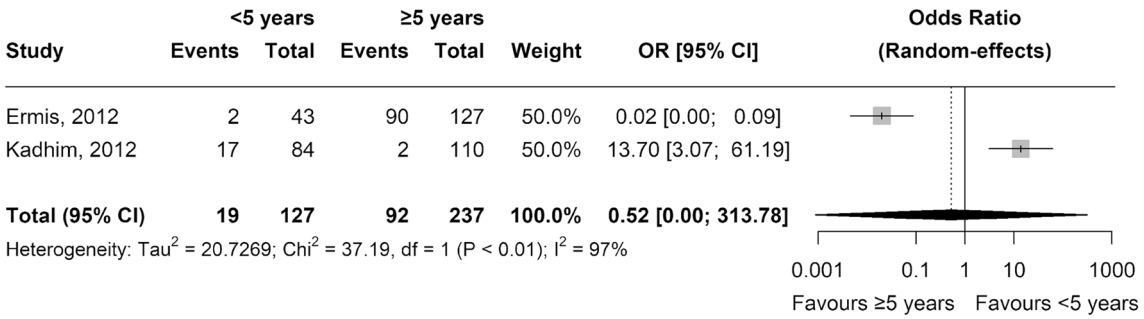

Fig. 6 Association between age and total spinal deformities

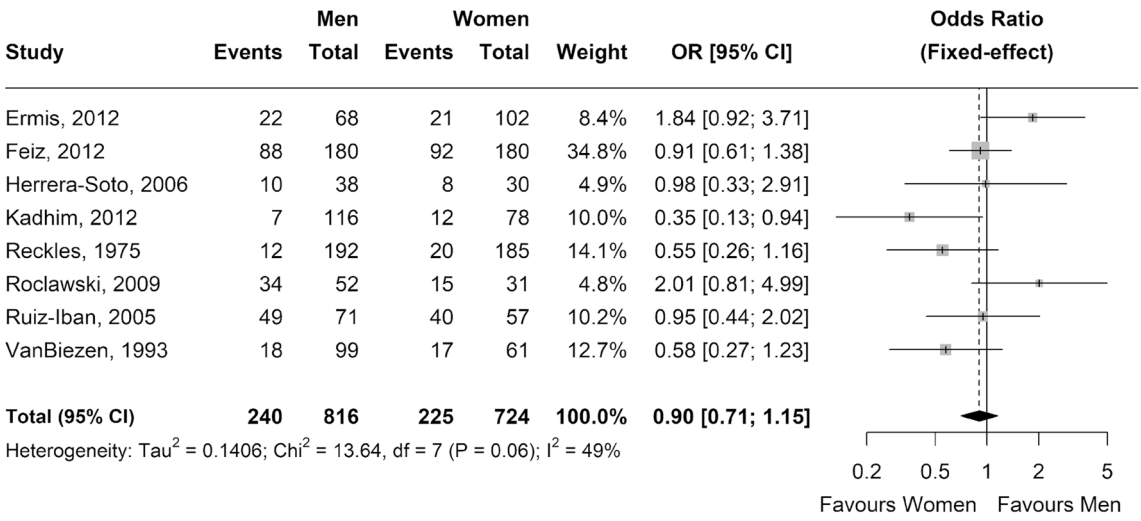

Fig. 7 Association between sex and total spinal deformities

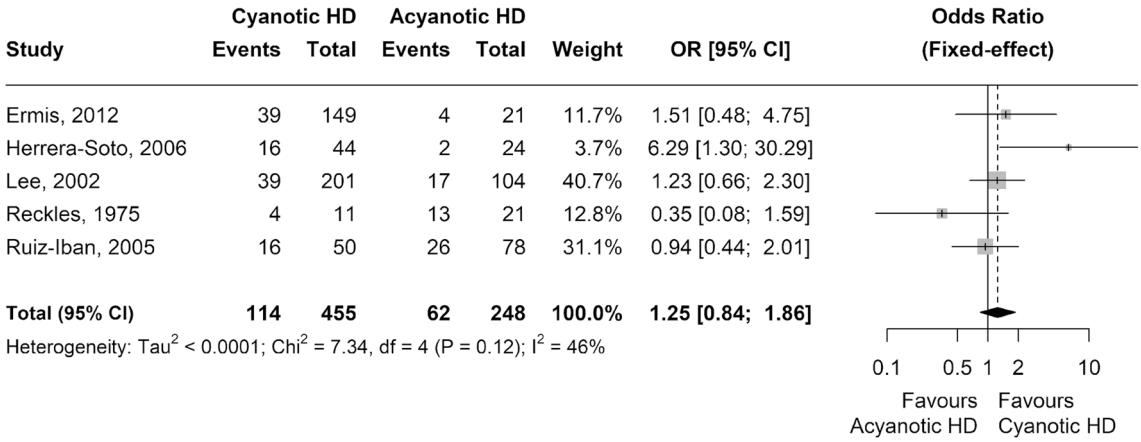

Fig. 8 Association between type of congenital heart disease and total spinal deformities

beyond the immediate postoperative period. Fourth, this meta-analysis was underpowered in investigating some factors associated with spinal deformities, such as age.

Conclusions

This systematic review and meta-analysis showed that about one in four children with CHD developed spinal deformity following surgical management of CHD. Healthcare providers should be aware of this potential complication and implement appropriate monitoring and management strategies. Future research should focus more on understanding the underlying mechanisms, risk factors, and long-term outcomes associated with spinal deformities in this population to optimize patient care and improve overall outcomes.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00586-023-08083-8.

Declarations

Conflict of interest In compliance with the ICMJE uniform disclosure form, all authors declare the following: Payment/services info: All authors have declared that no financial support was received from any organization for the submitted work. Financial relationships: All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. Other relationships: All authors have

declared that there are no other relationships or activities that could appear to have influenced the submitted work.

References

1. González-Gálvez N, Gea-García GM, Marcos-Pardo PJ (2019) Effects of exercise programs on kyphosis and lordosis angle: a systematic review and meta-analysis. PLoS ONE 14(4):1–18
2. Diebo BG, Varghese JJ, Lafage R, Schwab FJ, Lafage V (2015) Sagittal alignment of the spine: What do you need to know? Clin Neurol Neurosurg 139:295–301. https://doi.org/10.1016/j.clineuro.2015.10.024
3. Shakil H, Iqbal ZA, Al-Ghadir AH (2014) Scoliosis: Review of types of curves, etiological theories and conservative treatment. J Back Musculoskelet Rehabil 27(2):111–115
4. Herrera-Soto JA, Vander Have KL, Barry-Lane P, Myers JL (2007) Retrospective study on the development of spinal deformities following sternotomy for congenital heart disease. Spine (Phila Pa 1976) 32(18):1998–2004
5. Rudolph CD, Rudolph AM, Lister GE, First LR (2011) GAA (Eds. Rudolph's Pediatrics, 22e Eds [Internet]. 22e. McGraw Hill. Available from: https://accesspediatrics.mhmedical.com/content.aspx?bookid=455&sectionid=40310237
6. Feiz HH, Afrasiabi A, Parvizi R, Safarpour A, Fouladi RF (2012) Scoliosis after thoracotomy/sternotomy in children with congenital heart disease. Indian J Orthop 46(1):77–80
7. Yu YF (1992) Re-open heart surgery in congenital heart disease An analysis of 23 cases. Zhonghua Wai Ke Za Zhi 30(12):749–750
8. Mavroudis CBC (2003) Pediatric cardiac surgery, 3rd edn. Mosby-Elsevier, Philadelphia
9. Herrera-Soto JA, Vander Have KL, Barry-Lane P, Woo A (2006) Spinal deformity after combined thoracotomy and sternotomy for congenital heart disease. J Pediatr Orthop 26(2):211–215
10. Van Biezen FC, Bakx PAGM, De Villeneuve VH, Hop WCJ (1993) Scoliosis in children after thoracotomy for aortic coarctation. J Bone Jt Surg Ser A 75(4):514–518
11. Ruiz-Iban MA, Burgos J, Aguado HJ, Diaz-Heredia J, Roger I, Muriel A et al (2005) Scoliosis after median sternotomy in children with congenital heart disease. Spine (Phila Pa 1976) 30(8):214–218
12. Moher D, Liberati A, Tetzlaff J, Altman DG (2009) Academia and clinic annals of internal medicine preferred reporting items for systematic reviews and meta-analyses. Ann Intern Med 151(4):264–269
13. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, et al (2019) Cochrane handbook for systematic reviews of interventions. Cochrane Handb Syst Rev Interv 1–694.
14. Egger M, Higgins JPT, Smith GD (2022) Systematic reviews in health research: an introduction. Syst Rev Heal Res Meta-Analysis Context1–16.
15. Robins J, Greenland S, Breslow NE (1986) A general estimator for the variance of the mantel haenszel odds ratio. Am J Epidemiol 124(5):719–723
16. Sung S, Chae HW, Lee HS, Kim S, Kwon JW, Lee SB et al (2021) Incidence and surgery rate of idiopathic scoliosis: a nationwide database study. Int J Environ Res Public Health 18(15):8152
17. Thomas JJ, Stans AA, Milbrandt TA, Kremers HM, Shaughnessy WJ, Larson AN (2021) Trends in incidence of adolescent idiopathic scoliosis: a modern US population-based study. J Pediatr Orthop 41(6):327–332
18. Yılmaz H, Zateri C, Kusvuran Ozkan A, Kayalar G, Berk H (2020) Prevalence of adolescent idiopathic scoliosis in Turkey: an epidemiological study. Spine J 20(6):947–955. https://doi.org/10.1016/j.spinee.2020.01.008
19. Konieczny MR, Senyurt H, Krauspe R (2013) Epidemiology of adolescent idiopathic scoliosis. J Child Orthop 7(1):3–9
20. Mishra PR, Tinawi GK, Stringer MD (2020) Scoliosis after thoracotomy repair of esophageal atresia: a systematic review. Pediatr Surg Int 36(7):755–761. https://doi.org/10.1007/s00383-020-04683-3
21. Mery CM, Guzmán-Pruneda FA, De León LE, Zhang W, Kuo FH, Carpenter KL et al (2018) Risk factors for development and progression of scoliosis after pediatric cardiothoracic operations. Ann Thorac Surg 105(6):1835–1841
22. Niebauer JJ, Wright WD (1956) Congenital heart disease and scoliosis. J Bone Joint Surg Am 38-A(5):1131–1136
23. Taggart NW, Shaughnessy WJ, Stans AA, McIntosh AL, Driscoll DJ (2010) Outcomes of spinal fusion in children with congenital heart disease. J Pediatr Orthop 30(7):670–675
24. Han J, Xu Q, Yang Y, Yao Z, Zhang C (2015) Evaluation of quality of life and risk factors affecting quality of life in adolescent idiopathic scoliosis. Intractable Rare Dis Res 4(1):12–16
25. Smith JS, Shaffrey CI, Baldus CR, Kelly MP, Yanik EL, Lurie JD et al (2021) Orthopedic disease burden in adult patients with symptomatic lumbar scoliosis: results from a prospective multicenter study. J Neurosurg Spine 35(6):743–751