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Effectiveness and Cost Burden of School Screening for Adolescent Idiopathic Scoliosis: A Systematic Review and Meta-Analysis

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Study Design: Systematic review and meta analysis of school based AIS screening programmes

Objective: To determine the prevalence, diagnostic performance, clinical impact, and cost burden of routine school screening for adolescent idiopathic scoliosis

Summary of Background Data: The rationale for routine screening is that curves detected before skeletal maturity respond to bracing, reduce progression, and avert costly fusion, yet controversy persists regarding false positives, radiation exposure, and programme affordability across health care systems

Methods: Databases searched were PubMed, Embase, Scopus, Web of Science, and Cochrane Central from inception to February 2025. Inclusion criteria were asymptomatic pupils aged ten to sixteen screened at school and reporting prevalence, test accuracy, treatment, or cost. Data were pooled with random effects models, heterogeneity was assessed by I squared, and currency was expressed as United States dollars

Results: Thirty four studies covering two point eight million pupils met inclusion. Prevalence was 0.66 percent for curves over ten degrees, 0.33 percent over twenty, and 0.02 percent over forty. Screening tests gave sensitivity 74 to 100 percent and specificity 80 to 99 percent, negative predictive value approached 100 percent, positive predictive value four to eighty percent. Screen detected adolescents showed mean Cobb 28 degrees versus 40 in usual care, with 73 percent lower fusion odds. Numbers needed to screen to start bracing ranged 448 to 2,234. Costs were 0.47 to 55 dollars per pupil, and most economic models predicted net savings despite heterogeneity

Conclusions: School-based screening reliably detects AIS at milder stages, is associated with lower surgical rates, and can be economically defensible under well-designed, multi-step protocols. Nevertheless, wide variations in prevalence, screening methods, and cost frameworks

highlight the need for standardised programmes and contemporary economic evaluations to optimise benefit while minimising unnecessary referrals and radiation exposure.

Key Points

1. School screening programs for adolescent idiopathic scoliosis (AIS) show high diagnostic accuracy, with reported sensitivities ranging from 74 to 100 per cent and specificities from 80 to 99 per cent, giving near perfect negative predictive values.

2. Across 34 studies that included more than 2.8 million students, the pooled prevalence of curves greater than 10 degrees was 0.66 per cent, curves greater than 20 degrees 0.33 per cent, and severe curves greater than 40 degrees 0.02 per cent.

3. Children identified through screening presented with milder curves (about 28 degrees compared with 40 degrees in usual care) and had markedly lower odds of requiring surgery (odds ratio about 0.27).

4. Numbers needed to screen to initiate any treatment ranged from 448 to 2 234 students, and per pupil screening costs varied from US $0.47 to 55, yet several economic analyses reported net savings once avoided surgery and productivity losses were included.

5. Despite substantial heterogeneity among studies, evidence supports well designed, multi step school screening as a reliable method for early AIS detection that can be economically defensible, although standardised protocols and contemporary cost evaluations are still required.

Introduction

Adolescent Idiopathic Scoliosis (AIS) is a curvature of the spine greater than 10° in the coronal plane with associated vertebral rotation occurring in patients aged 10–18 years. While many curvatures remain asymptomatic, some may progress, especially during adolescent growth spurts, and may lead to long-term morbidity. Severe spinal deformities (e.g. curves >40–50°) are associated with an increased risk of chronic back pain, respiratory impairment, cosmetic concerns, and reduced quality of life if left untreated [1]. The rationale for early detection of AIS is that identifying scoliosis at an early stage, whilst patients are still skeletally immature, could enable timely interventions to limit progression. In principle, such early intervention (typically bracing for moderate curves) might prevent some patients from eventually requiring surgery or experiencing disability in adulthood.

School-based screening programmes have been explored as a strategy for early AIS detection in adolescent populations. These programmes typically utilise simple, noninvasive tests such as the Adam's forward bend test (FBT), scoliometer measurement, and Moiré topography to assess trunk rotation and back asymmetry [2–4]. When combined, these methods can achieve a diagnostic sensitivity of approximately 93.8% and specificity of 99.2%[1]. Students who screen positively are then referred for confirmatory radiographic evaluation and definitive diagnosis.

Despite the ease and accessibility of effective screening tests, universal implementation of school scoliosis screening remains controversial [5]. Proponents maintain that early detection of scoliosis enables more timely intervention that may limit progression and reduce the likelihood of requiring more invasive procedures in the future. However, critics highlight a dearth of conclusive evidence linking early screening to improved long-term outcomes. Additionally, concerns about false positive referrals, which may lead to undue anxiety, unnecessary follow-up evaluations, exposure to diagnostic X-rays, and significant manpower and financial costs, raise questions about cost burden and overall affordability of routine screening programmes [6].

Given the ongoing disagreement in the literature, there is a need to objectively evaluate the overall effectiveness of school-based AIS screening. This systematic review and meta-analysis assesses detection and diagnostic accuracy, downstream clinical outcomes, and the cost burden of screening, defined as direct costs within the screening pathway. The objective is to provide an updated comprehensive synthesis of the available evidence to determine whether the benefits of early scoliosis detection outweigh the potential harms and costs, thereby informing future clinical and policy decisions on AIS screening.

Methods

Study Design

This meta-analysis was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. A comprehensive systematic review of English-language literature was performed across the following databases: Web of Science, The Cochrane Library, Scopus, Embase, and PubMed/MEDLINE, up to February 2025. Studies that met predefined inclusion criteria were selected for data synthesis. The primary outcome was to estimate the pooled prevalence of adolescent idiopathic scoliosis (AIS) among school-aged children and adolescents between 10 and 18 years of age. Secondary outcomes included evaluation of clinical parameters (such as curve severity, progression, and requirement for surgical intervention) in screened individuals, and the direct cost of the screening programmes. To further characterise the effectiveness of screening programmes, the authors extracted diagnostic accuracy measures including sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) from eligible studies.

Search Strategy

The search strategy for each database was custom-developed using key phrases, free-text terms, and controlled vocabulary, such as MeSH terms, to comprehensively capture studies related to school-based screening for AIS. The strategy included terms such as “adolescent idiopathic scoliosis,” “AIS,” “school screening,” “school-based screening,” “early screening,” and “screening programme,” in conjunction with outcome descriptors like “effectiveness,” “outcomes,” “detection rate,” and “diagnostic accuracy.” Reference lists of all included studies were manually searched to identify additional relevant articles. No trial registries or grey literature were utilised.

Inclusion and Exclusion Criteria

Studies were included if they focused on asymptomatic children and adolescents (10–18 years) attending school and evaluated any school-based screening programme for AIS. Eligible studies reported at least one primary outcome on detection rates or diagnostic accuracy, provided secondary outcomes such as curve progression or severity, referral rates, quality of life, harms (e.g., psychological impacts, radiation exposure), or direct cost data related to the screening pathway. Randomised controlled trials, controlled clinical trials, cohort studies, case–control studies, and large cross-sectional studies that offered quantitative data on screening effectiveness were accepted. Studies were excluded if they involved participants outside the 10–18 age range, symptomatic individuals, non school-based screening settings, or if they did not report quantitative outcome data. Case reports, narrative reviews, editorials, and letters were also excluded. A summary of the inclusion and exclusion criteria is provided in **Table 1**.

Study Selection Process

All records identified from the database searches were imported into Covidence, where duplicates were automatically removed prior to screening. Two reviewers independently examined the titles and abstracts of the retrieved studies to assess their eligibility based on the

inclusion criteria described above. Following this initial screening phase, full-text articles of all potentially relevant studies were obtained and reviewed independently by the same two reviewers. Disagreements regarding study eligibility were resolved through discussion, with persisting conflicts mediated by a third reviewer. In cases where a study did not meet the inclusion criteria for the entire cohort but contained data pertaining to a relevant subgroup that could be distinctly extracted, such data were included in the review.

Statistical Methods:

Statistical analyses were conducted using the JAMOVI statistical software. Pooled effect sizes were calculated to estimate overall prevalence rates and their corresponding 95% confidence intervals (CIs). A random-effects model was applied to account for expected heterogeneity among included studies. Heterogeneity was assessed using the I^2 statistic, with thresholds of 25%, 50%, and 75% interpreted as low, moderate, and high heterogeneity, respectively. Forest plots were constructed to illustrate individual study estimates and pooled effects. All statistical tests were two-tailed, with significance set at $p<0.05$.

Results

Literature Screening

A total of 773 records were initially identified through five databases: Web of Science (n=284), Cochrane (n=238), Scopus (n=117), Embase (n=69), and PubMed/MEDLINE (n=65). Following the removal of 136 duplicate records and two additional records deemed ineligible, 635 unique records remained for title and abstract screening. Of these, 584 were excluded for failing to meet the predefined inclusion criteria, leaving 51 full-text reports to be assessed for eligibility. Ultimately, 16 of these full-text articles were excluded for reasons such as inappropriate outcomes, study design, or setting. Consequently, 34 studies met all inclusion criteria and were included in the final analysis[6–38]. (**Figure 1**)

Included Studies:

This meta-analysis included 34 studies with 2839204 participants from diverse geographic regions, offering a detailed assessment of scoliosis prevalence stratified by curve magnitude thresholds (>10°, >20°, and >40°). Sample sizes ranged from 428 [11] to over 1.2 million individuals [31]. Our review included studies from China [10,23,26], Japan [12,31], Greece [32,34,37], Italy [11,13,19], Turkey [22,25], North America [9,15,18,36], South America [24,29], Malaysia [6,35], Indonesia [39], and Singapore [21].

The majority of included studies were observational, with 26 school-based cross-sectional surveys providing point-prevalence estimates at the time of screening. The remaining 8 were retrospective cohort studies using medical records or insurance databases that enabled estimation

of incidence over time. No randomised or interventional trials met the inclusion criteria. A summary of the included studies is presented in Table 2.

Prevalence of Students with Curves

Pooled prevalence estimates from random-effects models showed that 0.66% (95% CI: 0.638–0.701%) of students had curves >10° (k = 31), 0.33% (95% CI: 0.296–0.372%) had curves >20° (k = 30), and 0.0166% (95% CI: 0.0115–0.0217%) had curves >40° (k = 32). All estimates were statistically significant ($P < 0.01$) and demonstrated consistency across studies, despite underlying heterogeneity. (Figures 2–4)

Diagnostic Performance:

Across the reviewed screening protocols, sensitivity lay between 73.7 and 100 %, with most reports above 90 %, and specificity ranged from 79.8 to 99.7 %. PPV showed the greatest spread, 4.6 % in very low-prevalence cohorts up to about 86 % when prevalence or referral thresholds were higher. NPV remained high, 44.6 to 100 % and typically above 80 %.

Clinical Outcomes:

Fifteen studies mentioned clinical outcomes, however heterogeneity in populations, screening protocols, radiographic thresholds, follow-up periods, and measured clinical outcomes was high. Across these studies, screen-detected children presented with milder curves (20–28° compared to 35–40° in usual-care cohorts), and only 8% exhibited curves >40° (compared to 22% in usual-care cohorts). Disease progression for small curves was common (36% of curves <10° and 48 % of curves 10–20° increased by ≥5° by last follow-up) Progression to severe curves or surgery was uncommon (≤1 % of those screened). The odds of surgery were lower when detection occurred through screening vs usual means (OR ~0.27), and absolute treatment rates were low (0.04–11.7 % for bracing and 0–0.64 % for surgery). The estimated number needed to screen to initiate any treatment ranged from 448 to 2,234.

Cost Burden

Nine studies reported data on costs; however, substantial variation in study design, currency, time period, and lack of inflation adjustment precluded quantitative pooling. Findings are therefore presented as a narrative summary with values converted to US dollars ($) for ease of interpretation.

Reported costs of the initial screening encounter varied widely across settings, ranging: from $0.47 per pupil in Turkey to $54.63 in a territory-wide Hong Kong programme that bundled initial screening, confirmatory imaging and onward care [16,27]. Intermediate estimates for screening calculated $4.45 per child in Oakland County USA, and per-session costs of $4.72–7.87 when screening was performed by a physician, compared to $1.90 when the same screening

was delivered by a nurse [15]. In Singapore, screening, follow-up, and treatment of a single birth cohort of 45,000 students over three years cost SGD 1.06 million (approximately $0.78 million) (33).

Once downstream investigation and treatment were added, the cost to confirm one case of scoliosis ranged from $236.81 (clinical examination plus radiographs) to nearly $2,000 when Moiré topography preceded radiography, and the cost to identify a curve ≥ 20° lay between $4,476 and $7,260 [10]. Treating a confirmed scoliotic patient cost on average $10,985 in Hong Kong [16], where the majority of confirmed cases were treated with braces only. Whereas treating a Turkish adolescent was put at $1,302 [27]. Nonetheless, several analyses suggested net savings after avoided surgery and family costs were counted: $230,102 in total saved over three years in Singapore, and $13,132 per 10,000 pupils in Oakland USA, scaling to around $4.5 million saved annually for all U.S. seventh-graders (12-13 years old) [15,33].

Heterogeneity Assessment

Heterogeneity was assessed using the I^2 statistic. High heterogeneity was observed for all three pooled prevalence estimates ($I^2 > 75\%$), indicating substantial variability among studies. Despite this, the p-values and 95% confidence intervals remained consistent and supported the reliability of the pooled estimates.

Discussion

The findings from this review indicate that school-based screening for adolescent idiopathic scoliosis (AIS) is an effective tool for early detection of spinal curvatures when using tests such as the Adam's forward bend test, Moire topography, and scoliometer measurements. The pooled data from diverse populations support its potential to enable timely interventions and reduce the need for later invasive treatments. However, the low prevalence and variable predictive values across studies raise important issues regarding cost burden and resource allocation, suggesting that while beneficial, screening protocols still require refinement to balance early detection with minimising unnecessary costs to healthcare systems.

The primary outcome of this study was to estimate the detection rate of AIS from school screening. Across the studies included in this review, the prevalence of scoliosis among adolescents shows notable variability. The pooled data indicate that approximately 0.66% of screened students exhibit curves greater than 10°, 0.33% have curves exceeding 20°, and approximately 0.017% present with curvatures over 40°. While these pooled estimates demonstrate statistical significance, the considerable heterogeneity across studies highlights differences in screening protocols, demographic characteristics, and geographical factors. Some individual studies reported prevalence rates below 0.5%, whereas others identified notably higher rates in specific subgroups. These variations emphasise the need to consider local

screening practices and population profiles when interpreting and applying prevalence data for AIS. (**Figure 4-6**)

Based on estimated prevalence rates, the burden of AIS varies considerably between regions. Using population data, it can be predicted that in the United Kingdom, approximately 48,000 students have spinal curvatures greater than 10°, with around 24,000 exceeding 20° and 800 curves exceeding 40°. In comparison, the European Union faces a higher approximate patient population, with nearly 540,000 students exhibiting curves greater than 10°, 270,000 with curves over 20°, and around 9,000 experiencing curves greater than 40°. This difference in prevalence emphasises the need for tailored screening and intervention strategies that take into account regional, demographic, and healthcare system differences.

Multiple studies indicate that school-based scoliosis screening results in tangible clinical benefits. One study reported that among children with mild curves (initial Cobb angle <10°), roughly one-third experience progression by about 8° at 10-year follow-up, while nearly half of those with moderate curves (10°–20°) show progression averaging 10° at 10-year follow-up. Findings from several papers emphasise that these differences in progression are driven primarily by age rather than by the initial curve magnitude, younger children progress more rapidly whereas older adolescents show slower or negligible progression over comparable follow up periods. Another study reported that screen-detected patients present with lower mean Cobb angles (approximately 28°) compared to those identified through other pathways (around 40°), with a significantly lower likelihood of needing surgery (odds ratio ~0.27). Recent improvements in screening protocols have resulted in earlier detection and a decrease in the average curve magnitude over time [18], further supporting the value of early intervention despite a high number-needed-to-treat.

Few studies reported formal cost-effectiveness analyses. Those that did indicated meaningful economic benefit, with per-pupil screening costs ranging from roughly $0.50 in Turkey to $55 in Hong Kong. This variability likely reflects heterogeneity in screening protocols, which deploy nurses, medical students, physicians, or mixed teams of these professionals. Cost-per-case metrics were equally variable: with confirming a diagnosis of scoliosis costing between $237 and $2,000, identifying a curve ≥ 20° costing between $4,500 and $7,300, and treating a case from $1,300 to $11,000 depending on local care pathways, with most patients being treated with bracing. Several studies reported net savings after avoided surgery, parental loss of earnings and reduced specialist referrals were factored in.

The limited literature on direct costs suggests that well-designed multi-step school-screening programmes may be economically defensible in certain settings. Nevertheless, the heterogeneity of methods, outdated prices and jurisdiction-specific pathways hinder generalisation. Moving forward, standardised economic evaluations, explicitly stating currency, price-year and inflation adjustments, are needed before definitive policy recommendations can be made.

Regarding diagnostic performance, screening tests typically show high sensitivity and specificity. Reported sensitivities range from 73.7% to 100%, meaning that most true cases of scoliosis are correctly identified. Specificities vary between 79.76% and 99%, which indicates low false-positive rates. However, the PPV ranged from as little as 4–5% up to around 80% in some instances; this could be due to the different definitions of PPV the various studies had, with some studies reporting PPV as the percentage of those diagnosed amongst those who were positively screened, and some studies reporting PPV as the percentage of those receiving treatment amongst those who were positively screened. Conversely, the NPV is consistently excellent, providing strong reassurance that a negative screening result accurately reflects the absence of significant curvature.

Building on these findings, our next step will be a review that catalogues all established scoliosis screening techniques and examines the newest detection innovations, reflecting the diversity of methodologies currently used around the world.

Limitations

A key limitation of this review is the significant heterogeneity among the included studies. Variations in screening protocols, diagnostic criteria, and follow-up procedures contributed to wide-ranging sensitivity, specificity, PPV, and NPV values, complicating direct comparisons across studies. Moreover, the study designs and goals varied considerably across the papers, further exacerbating the heterogeneity. Not all studies reported the outcomes the authors aimed to evaluate, such as detailed clinical endpoints and long-term progression data, potentially introducing selection bias. Furthermore, this review included studies of different types, such as snapshot and longitudinal studies, which may yield different effect sizes. In addition, due to the nature of systematic reviews, some suitable studies may not have been identified owing to the search strategy. Inconsistencies in study designs and population characteristics further limit the generalisability of the pooled estimates, underscoring the need for more standardised, comprehensive research to better assess the effectiveness and economic impact of school-based scoliosis screening programmes. Finally, when it came to the direct costs, each analysis used a different price-year, meaning that a simple inflation adjustment would materially alter their conclusions, and all were conducted over ten years ago in single jurisdictions with unique funding models and practice patterns. Implementation details (for example, one- versus two-step imaging protocols) further complicate transferability.

Conclusion

This meta-analysis demonstrates that school-based screening for adolescent idiopathic scoliosis (AIS) effectively identifies spinal curvatures at early stages, with high sensitivity and specificity, enabling timely interventions that may reduce progression to severe deformity and surgical need. While the pooled prevalence of clinically significant curves is low, direct cost findings suggest that screening programmes can lower long term healthcare burdens. However, substantial

heterogeneity in screening protocols and regional variability in prevalence underscore the need for standardised methods and localised cost-benefit evaluations. Policymakers should balance early detection benefits against risks of overtesting, prioritising tailored approaches to optimise resource allocation and minimise unnecessary referrals.

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Adolescent Idiopathic Scoliosis: Results of School-based Screening in Surabaya, Indonesia. *Malays Orthop J* 2017;11:17–22.

Figure 1. PRISMA Outflow Chart.

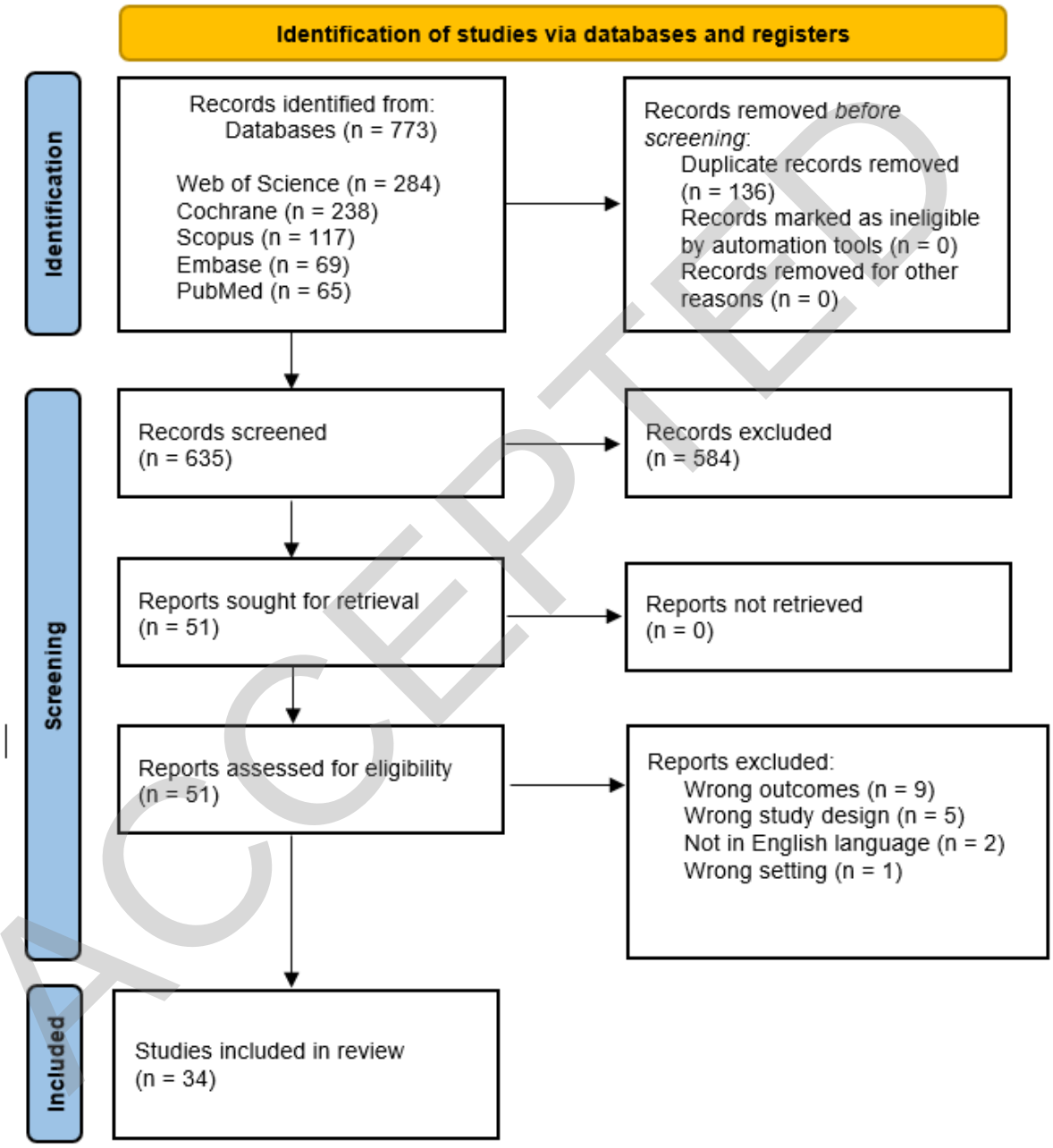

Figure 2. Forest plot for the Prevalence of Students with Curves >10 Degrees.

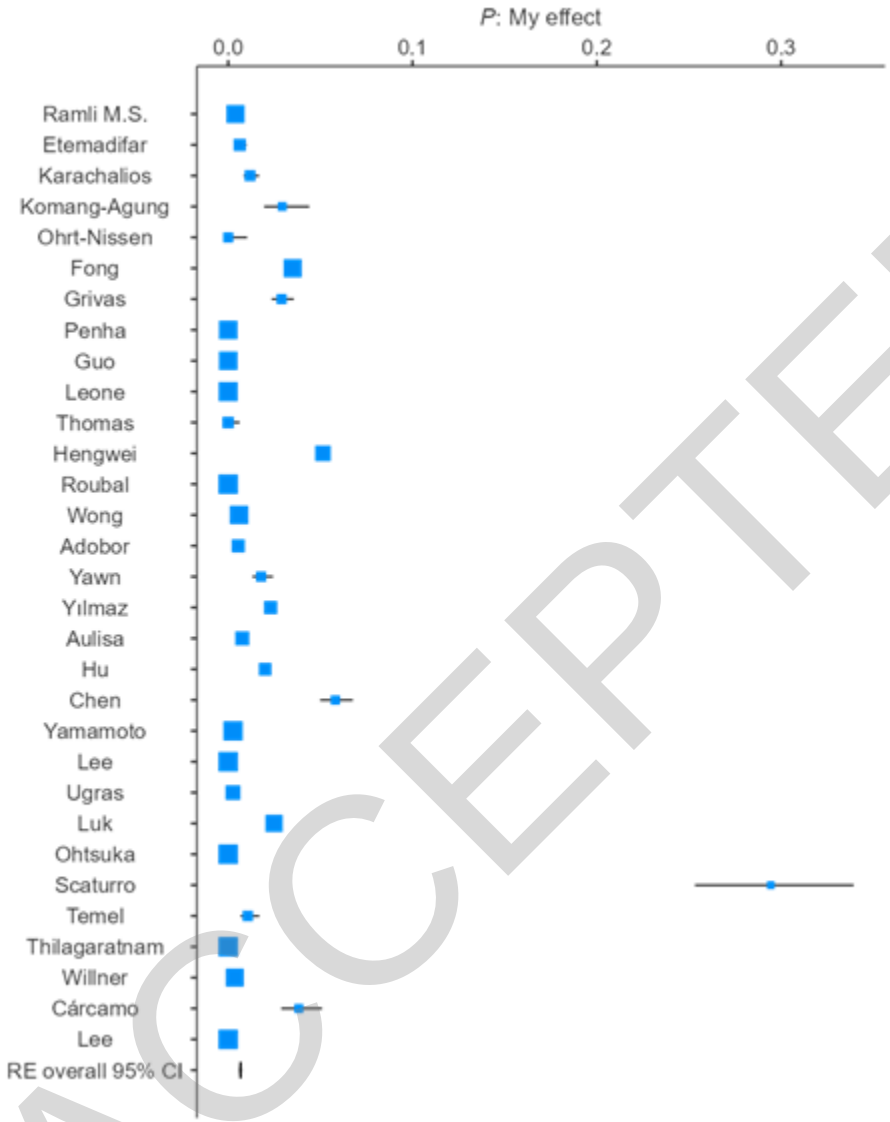

Figure 3. Forest plot for the Prevalence of Students with Curves >20 Degrees.

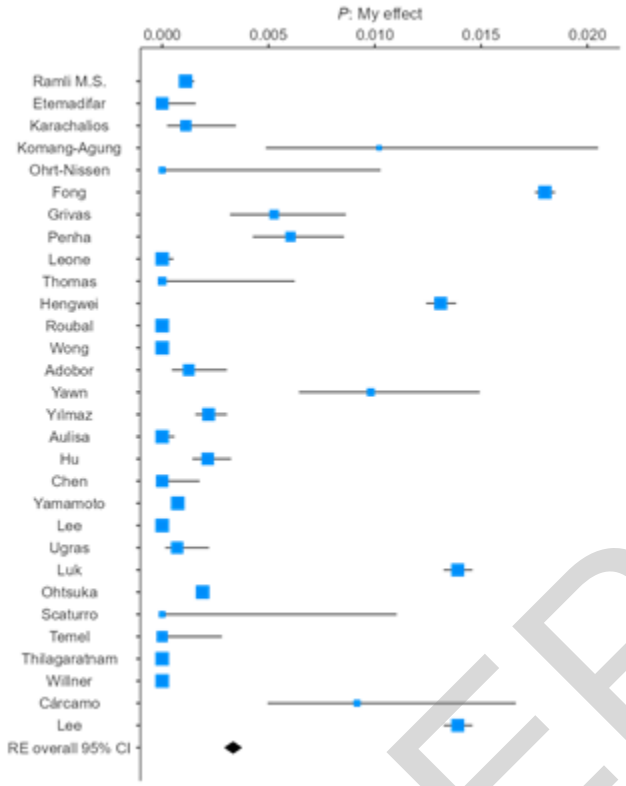

Figure 4. >10 degree Cobb angle back image (left) and forward bending image (right).

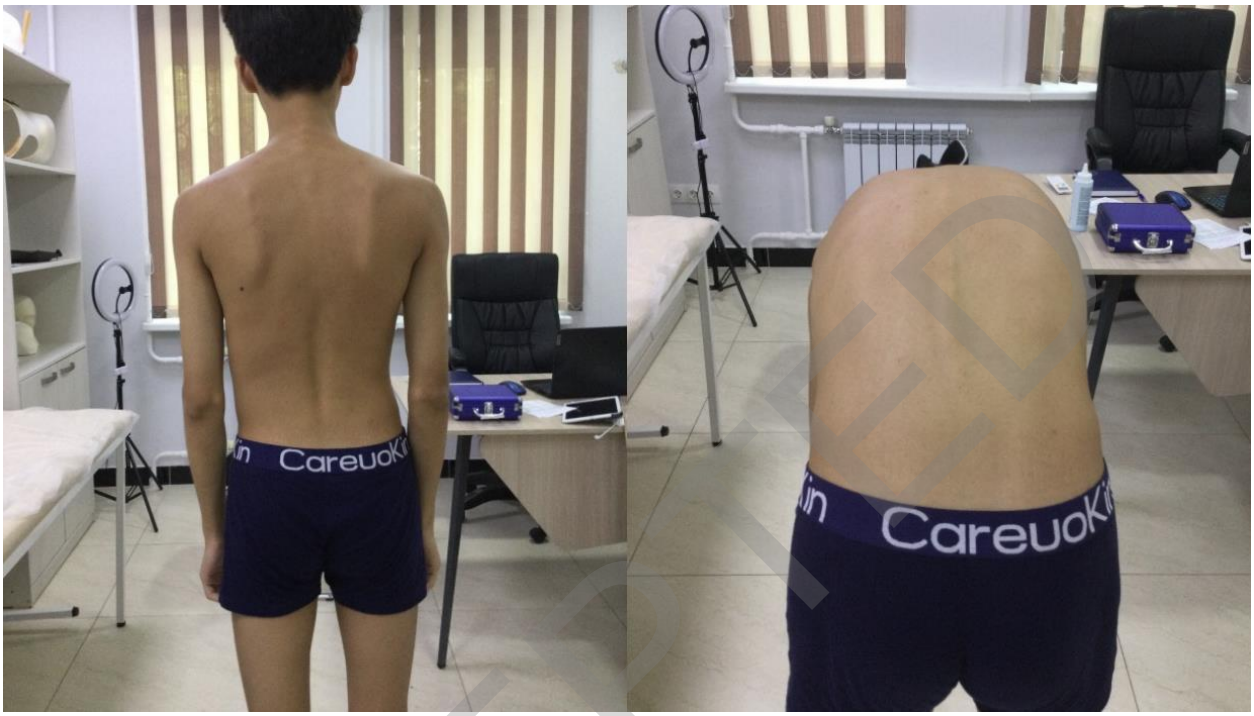

Figure 5. >20 degree Cobb angle back image (left) and forward bending image (right).

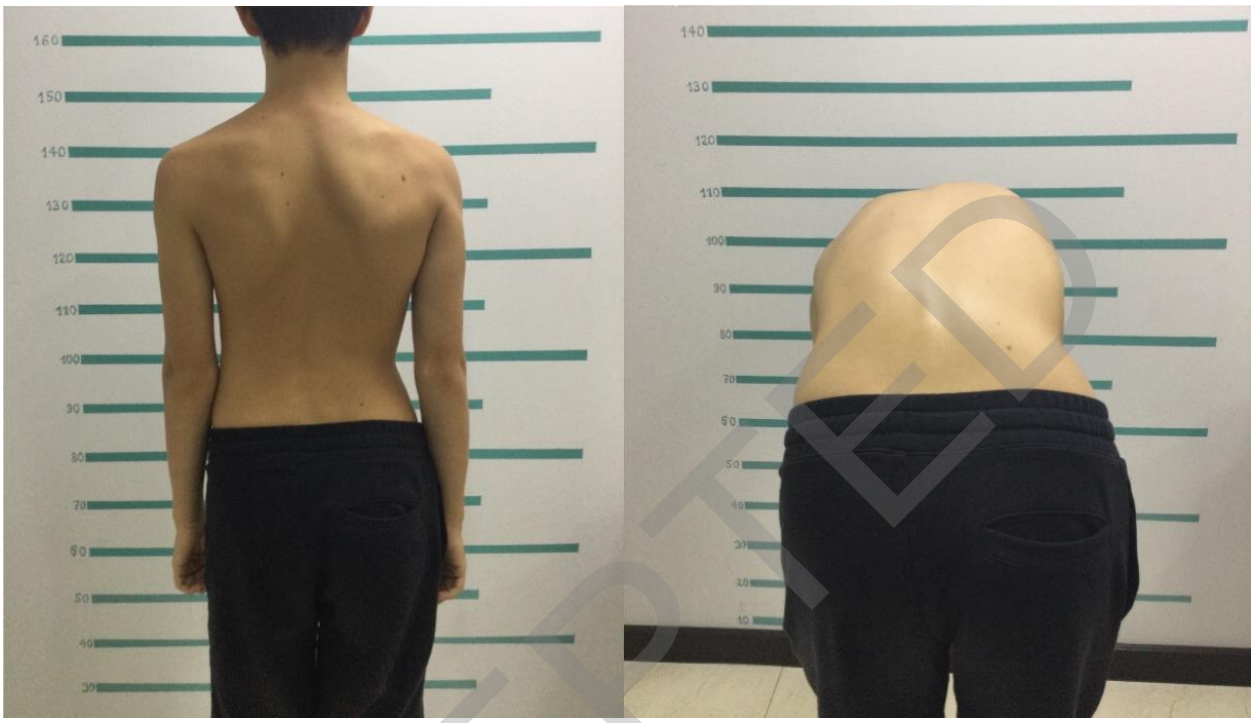

Figure 6. >40 degree Cobb angle back image (left) and forward bending image (right).

Table 1 Summary of Inclusion and Exclusion Criteria.

Inclusion Criteria	**Exclusion Criteria**
Asymptomatic children and adolescents aged 10–18 years attending school.	Studies including populations outside the specified age range or those involving only symptomatic individuals.
School-based screening programs for AIS utilising clinical techniques such as the forward bend test, scoliometer measurement, Moiré topography, or comparable methods.	Studies evaluating screening programs conducted in settings other than schools or not focusing on AIS.
Studies reporting quantitative data on detection rates, diagnostic accuracy (sensitivity and specificity), and/or clinical outcomes including curve progression (Cobb angle), surgical referral rates, quality of life, reported harms, or cost-effectiveness.	Studies without quantitative data on screening outcomes.
Randomised controlled trials, controlled clinical trials, cohort studies, case–control studies, and large cross-sectional studies containing relevant quantitative data.	Case reports, narrative reviews, protocols, editorials, and letters.

Table 2. Summary of Included Studies.

Author (s)	Year of Publication	Country	Sample Size	Number of Curves >10	Number of Curves >20	Number of Curves >40
Ramli M.S.	**2018**	**Malaysia**	**34638**	**137.00**	**38.00**	**6.00**
Etemadifar, M	**2020**	**Iran**	**3018**	**19.00**	**0.00**	**0.00**
Karachalios	**1999**	**Greece**	**2700**	**32.00**	**3.00**	**0.00**
Deepak, A.S.	**2017**	**Malaysia**	**8966**	**87.00**	**20.00**	**4.00**
Komang-Agung I.S.	**2017**	**Indonesia**	**784**	**23.00**	**8.00**	**3.00**
Ohrt-Nissen S	**2016**	**Denmark**	**460**	**0.00**	**0.00**	**0.00**

Fong, D.Y.T	**2015**	**Hong Kong**	**306144**	**10,715.00**	**5,511.00**	**612.00**
Grivas, T.B	**2002**	**Greece**	**3039**	**88.00**	**16.00**	**0.00**
Penha, P.J.	**2018**	**Brazil**	**5302**	**0.00**	**32.00**	**0.00**
Leone, A.	**2010**	**Italy**	**8995**	**0.00**	**0.00**	**0.00**
Thomas, J.J	**2018**	**USA**	**761**	**0.00**	**0.00**	**0.00**
Hengwei,F.	**2016**	**China**	**99695**	**5,124.00**	**1,306.00**	**0.00**
Roubal, P.J.	**1999**	**USA**	**175365**	**0.00**	**0.00**	**0.00**
Grivas, T.B.	**2002**	**Greece**	**215899**	**88.00**	**16.00**	**0.00**
Wong	**2005**	**Singapore**	**72699**	**429.00**		**0.00**

Adobor R.D.	**2011**	**Norway**	**4000**	**22.00**	**5.00**	**0.00**
Yawn, B.P.	**1999**	**USA**	**2242**	**40.00**	**22.00**	**9.00**
Yılmaz, H.	**2020**	**Turkey**	**16045**	**369.00**	**35.00**	**3.00**
Aulisa, A.G.	**2019**	**Italy**	**8238**	**63.00**	**0.00**	**0.00**
Hu, M.	**2022**	**China**	**10731**	**215.00**	**23.00**	**0.00**
Chen, C.;	**2020**	**China**	**2702**	**157.00**	**0.00**	**0.00**
Yamamoto, S.	**2015**	**Japan**	**195149**	**519.00**	**143.00**	**0.00**
Lee, C.F.	**2010**	**Hong Kong**	**115190**	**0.00**	**0.00**	**0.00**
Ugras, A.A.;	**2010**	**Turkey**	**4259**	**11.00**	**3.00**	**0.00**

Luk, K.D.K.	**2010**	**Hong Kong**	**115190**	**2,868.00**	**1,601.00**	**265.00**
Ohtsuka, Y.	**1988**	**Japan**	**1246798**	**0.00**	**2,369.00**	**0.00**
Scaturro, D;	**2021**	**Italy**	**428**	**126.00**	**0.00**	**0.00**
Temel,	**2015**	**Turkey**	**1693**	**18.00**	**0.00**	**0.00**
Thilagaratnam, S.	**2007**	**Singapore**	**45845**	**0.00**	**0.00**	**0.00**
Glavas, J	**2023**	**Croatia**	**18216**	**344.00**	**0.00**	**0.00**
Willner, S.	**1982**	**Sweden**	**30031**	**108.00**	**0.00**	**0.00**
Cárcamo	**2023**	**Chile**	**1200**	**46.00**	**11.00**	**0.00**
Yawn, B.P	**2000**	**USA**	**2242**	**40.00**	**22.00**	**9.00**

Lee, C.F.;	**2010**	**Hong Kong**	**115178**	**0.00**	**1,601.00**	**0.00**