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# Cardiorespiratory Fitness as a Modifiable Target in Scoliosis Surgery: A Narrative Review of Prehabilitation and Perioperative Exercise Interventions

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**ABSTRACT**

**Background.** Adolescent idiopathic scoliosis (AIS) is associated with clinically significant cardiorespiratory impairment, including reduced peak oxygen consumption, ventilatory inefficiency, and diminished exercise tolerance, even in mild-to-moderate curves. These deficits are compounded by lower habitual physical activity, creating a deconditioning cycle that compromises physiological reserve before surgical correction.

**Aim.** To evaluate current evidence on the relationship between physical activity, cardiorespiratory fitness, and surgical outcomes in AIS, with emphasis on the potential of prehabilitation to optimize perioperative cardiorespiratory function.

**Material and methods.** A narrative literature review was conducted using PubMed, covering studies published between 2003 and 2026. The search combined free-text terms and MeSH headings related to scoliosis, preoperative physical activity, and surgical outcomes. Included study types were randomized controlled trials, systematic reviews, and meta-analyses involving human subjects published in English.

**Results.** AIS patients demonstrate VO2max values reduced by 23% compared to healthy peers, with vigorous physical activity associated with a 24% reduction in AIS odds. Scoliosis-specific exercises reduce curve progression by 70-73%, while surgical prehabilitation reduces pulmonary morbidity by 60% and overall morbidity by 37%. The only AIS-specific prehabilitation RCT confirmed durable cardiopulmonary improvements persisting 12 months postoperatively. Postoperative rehabilitation further enhances respiratory muscle strength, thorax mobility, and quality of life while reducing hospital stay.

**Conclusions.** Evidence supports incorporating cardiorespiratory-targeted exercise in both preoperative and postoperative phases of scoliosis surgery. Large-scale multicenter RCTs with standardized protocols and cardiopulmonary endpoints are urgently needed in the AIS population.

**Keywords:** adolescent idiopathic scoliosis, prehabilitation, cardiorespiratory fitness, posterior spinal fusion, scoliosis-specific exercises, six-minute walk test

## 1. Introduction

Adolescent idiopathic scoliosis (AIS) is the most prevalent structural spinal deformity in the pediatric population, affecting approximately 2–3% [2,3,15]. Defined as a lateral curvature of the spine exceeding 10 degrees as measured by the Cobb angle method [1], AIS presents a spectrum of clinical severity ranging from mild cosmetic asymmetry to significant trunk deformity with functional consequences, including chronic back pain, psychosocial impairment, and reduced quality of life [2,4]. The management of AIS follows a graduated approach outlined by the 2016 SOSORT guidelines, encompassing observation, physiotherapeutic scoliosis-specific exercises, bracing, and — for curves exceeding 45–50 degrees — surgical correction by posterior spinal fusion [4]. Although only a subset of patients with progressive curves ultimately require operative treatment, scoliosis surgery remains a major procedure associated with substantial physiological stress and a postoperative recovery period that places significant demands on the patient's cardiopulmonary reserve [7,9].

A growing body of evidence indicates that AIS is associated with measurable impairment of cardiorespiratory fitness (CRF) that extends beyond the skeletal deformity itself. The thoracic distortion characteristic of scoliosis alters chest wall mechanics, reduces lung compliance, and compromises respiratory muscle function, resulting in restrictive pulmonary dysfunction even in patients with mild-to-moderate curves [2,4]. People with AIS are likely to do less vigorous physical and sporting activity [27]. The clinical relevance of this cycle is amplified in the perioperative context, where surgical recovery increases oxygen demand substantially, placing patients with reduced CRF at heightened risk for postoperative complications, particularly pulmonary morbidity [7,9].

The concept of prehabilitation — preoperative interventions designed to optimize physiological reserve before surgical stress — has gained substantial traction across multiple surgical disciplines as a strategy to improve postoperative outcomes [7]. Multimodal prehabilitation programs incorporating exercise training, nutritional optimization, and psychological support have demonstrated reductions in postoperative morbidity, shortened hospital stays, and accelerated functional recovery in abdominal, thoracic, and orthopedic surgery populations [8,9,25]. The six-minute walk test and peak oxygen consumption have emerged as clinically practical measures for quantifying preoperative fitness and predicting surgical outcomes [8,15,20]. Within spine surgery, preliminary evidence suggests that preoperative exercise conditioning can reduce postoperative pain, improve trunk muscle strength, and enhance early functional recovery [20]. However, the vast majority of spine prehabilitation research has been conducted in adult populations with degenerative conditions, and the applicability of these

findings to the typically younger, physiologically distinct AIS population remains uncertain [19,25].

Parallel to the development of surgical prehabilitation, scoliosis-specific exercise programs have demonstrated efficacy in modifying both disease progression and functional capacity in AIS. Physiotherapeutic scoliosis-specific exercises, particularly Schroth-based protocols, have been shown to reduce curve deterioration and improve patient-reported outcomes [6,11]. More recently, high-intensity interval training and digitally supported home-based programs have emerged as promising approaches to improving physical activity levels and body composition in AIS patients [26]. These exercise interventions are of particular relevance to cardiorespiratory fitness optimization, as they target the modifiable component of the deconditioning cycle that characterizes AIS and may serve as a foundation for perioperative conditioning strategies [5,26,27].

Despite the accumulating evidence linking cardiorespiratory fitness to surgical outcomes and the growing interest in perioperative exercise interventions, no comprehensive narrative review has synthesized the available literature specifically examining the role of preoperative physical activity and cardiorespiratory fitness as determinants of postoperative outcomes in scoliosis surgery. The aim of the present review is to evaluate the current evidence on the relationship between physical activity, cardiorespiratory fitness, and surgical outcomes in AIS, with particular emphasis on the potential of prehabilitation to optimize perioperative cardiorespiratory function. This review examines three interconnected domains: (1) the epidemiology of AIS and the cardiorespiratory impairment inherent to the condition; (2) the evidence for physical activity interventions and prehabilitation targeting cardiorespiratory fitness in surgical populations; and (3) the direct evidence for perioperative exercise interventions in scoliosis surgery and their cardiorespiratory outcomes.

## 2. Methodology

A narrative literature review was conducted using the PubMed database, covering studies published between 2003 and 2026. The aim of this review was to provide an overview of the role of preoperative physical activity and cardiorespiratory fitness in influencing postoperative outcomes in scoliosis surgery.

The search strategy combined free-text terms and Medical Subject Headings (MeSH) related to scoliosis, preoperative physical activity, and surgical outcomes. The primary search included the following terms:

((scoliosis OR “adolescent idiopathic scoliosis” OR AIS OR “spinal deformity” OR “spinal curvature”) AND (“spinal fusion” OR “spinal surgery” OR “spine surgery” OR “scoliosis surgery” OR “posterior spinal fusion” OR “deformity correction”) AND (“prehabilitation” OR “preoperative exercise” OR “preoperative physical activity” OR “exercise therapy” OR “physical activity” OR “physical therapy” OR “cardiorespiratory fitness” OR “aerobic exercise”) AND (“postoperative outcomes” OR “treatment outcome” OR recovery OR “length of stay” OR pain OR “quality of life” OR “return to activity” OR “pulmonary complications” OR “six-minute walk test”)).

Due to limited data specific to scoliosis, an additional broader search including general spine surgery and prehabilitation terms was performed. A MeSH-based search was also applied to identify studies on physical activity, functional status, and clinical outcomes. The following filters were applied: English language, article types including randomized controlled trials, systematic reviews, and meta-analyses, and studies involving human subjects. No time restrictions were imposed within the selected time frame.

Articles were included if they were relevant to scoliosis, preoperative physical activity, or postoperative outcomes and if full texts were available. Studies not meeting these criteria, including non-human studies and publications without accessible full text, were excluded.

Research focusing on patients with adolescent idiopathic scoliosis or other spinal deformities undergoing or awaiting surgical correction. Interventions explicitly involving physical activity, exercise-based prehabilitation, scoliosis-specific exercise programs, or perioperative rehabilitation. Outcomes assessing cardiorespiratory fitness, pulmonary function, six-minute walk distance, peak oxygen consumption, postoperative complications, pain, disability, quality of life, length of hospital stay, or return to physical activity.

Exclusion criteria comprised narrative reviews, editorials, commentaries, and letters to the editor; case reports or case series with fewer than 10 participants; conference abstracts without full-text availability; studies on animal models or in vitro research; non-English publications; and studies with insufficient data to evaluate the relationship between physical activity and surgical outcomes. Full texts of potentially eligible articles were then appraised for methodological quality, sample characteristics, intervention design, and reported outcomes. Disagreements among reviewers were resolved through consensus discussion.

Selected studies were analyzed qualitatively with respect to study design, sample size and population characteristics, type and duration of intervention, comparator conditions, and reported outcomes with statistical significance. Additionally, key PubMed-indexed articles on

the epidemiology and clinical characteristics of adolescent idiopathic scoliosis were included to provide foundational context, including seminal publications predating the primary search timeframe [1,2,24]. One supplementary source published in Quality in Sport was identified through manual reference searching and included to reflect current narrative reviews on conservative AIS management.

## 3 Results and Discussion

### 3.1. Epidemiology, Clinical Characteristics, and Cardiorespiratory Impairment in Adolescent Idiopathic Scoliosis

Adolescent idiopathic scoliosis (AIS) is defined as a lateral spinal curvature exceeding 10 degrees measured by the Cobb angle method, first standardized by Cobb in 1948 [1]. AIS represents the most common form of spinal deformity in the pediatric population, affecting approximately 1–3% of adolescents worldwide [2,3]. The etiology remains multifactorial and not fully understood; however, genetic predisposition, neuromuscular imbalance, and growth-related factors are considered key contributors [2,4]. Among affected individuals, only 0.2–0.5% develop curvatures exceeding 20 degrees that require active intervention, and the condition predominantly affects females, with a female-to-male ratio reaching 7.2:1 for curves requiring treatment [2,3]. Clinical presentation ranges from mild cosmetic asymmetry to significant trunk deformity, with potential consequences including reduced pulmonary function, chronic back pain, and impaired quality of life [2,4,30]. The 2016 SOSORT guidelines recommend a staged approach depending on curve magnitude and skeletal maturity: observation for curves below 15 degrees, physiotherapeutic scoliosis-specific exercises (PSSE) for curves between 10 and 30 degrees, bracing for curves between 20 and 45 degrees during growth, and surgical correction — typically posterior spinal fusion — for curves exceeding 45–50 degrees [4]. Despite advances in surgical techniques, 0.1–0.3% of the at-risk population ultimately require operative treatment, which carries risks including neurological complications, pseudarthrosis, implant failure, and prolonged rehabilitation periods [2,4].

Beyond the skeletal deformity itself, the thoracic distortion characteristic of AIS produces well-documented alterations in chest wall mechanics, including rib cage asymmetry, reduced chest wall compliance, and impaired respiratory muscle function [2,4]. These structural changes result in restrictive pulmonary dysfunction and measurably reduced cardiorespiratory fitness (CRF), even in patients with mild-to-moderate curves. CPET studies have demonstrated that adolescents with AIS exhibit a 23% decrease in body weight-normalized $VO_2max$ (38.6 vs. 49.0 mL/kg/min, $p < 0.001$) compared to age-matched healthy controls, along with significant

decreases in minute ventilation, tidal volume, and breathing reserve, early onset of the anaerobic threshold, and elevated ventilatory equivalents ($VE/VO_2$ ratio 35.2 vs. 29.6, $p < 0.001$), indicating ventilatory inefficiency during maximal exercise, although ventilatory capacity shows a modest correlation with curve severity ($r = -0.374$, $p < 0.05$) . Recent evidence from CPET studies suggests that cardiorespiratory fitness parameters in adolescents with mild-to-moderate scoliosis do not depend on the Cobb angle value, although ventilatory capacity shows a modest inverse correlation with curve severity [28,29]. The cardiorespiratory deficit is compounded by consistently lower levels of habitual physical activity observed in AIS patients. Glavaš et al. conducted a cross-sectional study of 18,216 pupils and found that adolescents with presumed AIS were significantly less physically active than their peers ($p < 0.001$), with a higher prevalence of AIS among inactive or recreationally active schoolchildren compared to those engaged in organized sports ($p = 0.001$) [5]. In the most comprehensive meta-analysis to date, Newman et al. analyzed 16 studies involving 9,627 participants and reported that vigorous physical activity was associated with a 24% reduction in the odds of AIS diagnosis (OR 0.76, 95% CI 0.65–0.89; high certainty evidence) [27]. These findings suggest a bidirectional relationship: the thoracic deformity impairs cardiorespiratory function, which in turn discourages physical activity, further perpetuating deconditioning and diminishing the physiological reserve necessary for surgical recovery. This vicious cycle makes physical activity interventions particularly relevant in AIS management, both as a therapeutic strategy to preserve cardiopulmonary function and as a preoperative conditioning tool for patients progressing toward surgical correction.

### 3.2. Physical Activity Interventions, Scoliosis-Specific Exercise, and Prehabilitation Targeting Cardiorespiratory Fitness

Scoliosis-specific exercise programs have demonstrated the capacity to modify both spinal deformity progression and functional fitness, providing a therapeutic strategy to break the deconditioning cycle described above. Schreiber et al., in a SOSORT 2017 Award-winning randomized controlled trial, showed that Schroth PSSE added to standard care produced a 70–73% relative risk reduction in curve deterioration, with a number needed to treat (NNT) of approximately 4 patients [6]. In a subsequent analysis, patients receiving the Schroth intervention perceived significant patients perceived clinically significant improvement in overall back status regardless of Cobb angle changes, suggesting benefits extending beyond radiographic parameters to encompass enhanced physical confidence and activity tolerance [11]. Lau et al. tested the E-Fit program, a home-based modified high-intensity interval training

(HIIT) intervention for AIS girls (n = 40), and demonstrated improvements in physical activity participation (Modified Baecke Questionnaire total score, p = 0.016), lean body mass (p = 0.046), and self-image at 12-month follow-up [26]. These findings collectively support the premise that structured exercise programs targeting the AIS population can simultaneously address spinal deformity management and cardiorespiratory fitness preservation.

The concept of prehabilitation — preoperative interventions designed to enhance physiological reserve before surgical stress — has gained substantial support across multiple surgical disciplines [7]. Carli and Scheede-Bergdahl proposed a multimodal framework incorporating exercise training, nutritional optimization, and psychological support, grounded in the principle that patients with higher baseline CRF demonstrate superior postoperative recovery trajectories [7]. The six-minute walk test (6MWT) and its distance measure (6MWD) have emerged as clinically practical surrogate markers of submaximal aerobic capacity that correlate well with $VO_2$peak and can be used to monitor CRF changes in perioperative settings [15,20]. In the foundational surgical prehabilitation literature, Hughes et al. conducted a meta-analysis of 15 RCTs (n = 907) involving major abdominal surgery patients and demonstrated a 60% reduction in pulmonary morbidity (OR 0.40, 95% CI 0.23–0.68, p = 0.0007) and a 37% reduction in overall morbidity (OR 0.63, 95% CI 0.46–0.87, p = 0.005) in the prehabilitation group [9]. The magnitude of the pulmonary morbidity reduction is particularly noteworthy in the context of scoliosis surgery, where baseline restrictive pulmonary dysfunction predisposes patients to postoperative respiratory complications. Minnella et al. further demonstrated in a randomized clinical trial of esophagogastric cancer surgery that prehabilitated patients improved their 6MWD by a mean of 36.9 m preoperatively compared to a 22.8 m decline in controls ($p < 0.001$), and this advantage persisted postoperatively with a mean change of +15.4 m versus −81.8 m in controls ($p < 0.001$) [8]. Katiyar et al. reviewed 70 studies and concluded that optimization of modifiable preoperative risk factors — including physical deconditioning — can reduce perioperative complications in adult spinal deformity surgery [12]. Liu and Yang synthesized data from 27 studies (n = 2,449) and found that prehabilitation significantly reduced postoperative back pain (SMD = −0.40, p = 0.027) and improved trunk muscle strength (SMD = 0.15, p = 0.014), although no significant effects were observed for disability or quality of life [18]. Takenaka et al. demonstrated in a pilot RCT of lumbar spinal stenosis surgery that prehabilitated patients achieved significantly greater 6MWD at three months (446.8 ± 48.9 m vs. 384.3 ± 58.3 m, p = 0.01, Hedges' g = 1.11) and lower disability scores (ODI 10.2 vs. 19.0, p = 0.04) [20]. Punnoose et al., in a JAMA meta-analysis of 48 RCTs encompassing 3,570 orthopedic surgery patients, reported high-certainty evidence for prehabilitation reducing

postoperative back pain and moderate-certainty evidence for improved physical function at six months [25]. However, the evidence is not uniformly positive. Janssen et al. found very low-to-low certainty evidence of no additional effect of predominantly cognitive behavioral therapy-based prehabilitation on outcomes in lumbar spine surgery, though exercise-based interventions showed more promising short-term results [19]. Marchand et al. reported that while six weeks of progressive prehabilitation improved preoperative pain and disability in patients awaiting lumbar spinal stenosis surgery, postoperative outcomes did not differ significantly between groups, suggesting that the immediate benefits of surgery may have overshadowed preoperative conditioning effects in this population [21]. Oliveira et al. concluded that prehabilitation appears promising for enhancing short-term recovery following lumbar surgery but acknowledged that long-term effectiveness remains uncertain due to limited evidence quality [17]. Licina et al. identified moderate-level evidence supporting prehabilitation as a key component of enhanced recovery after spinal surgery (ERSS) protocols, positioning preoperative fitness optimization within a broader multimodal perioperative care framework [16]. These conflicting results likely reflect methodological heterogeneity rather than a true lack of efficacy, as studies vary considerably in intervention type, duration, intensity, outcome measures, and patient populations studied [17,19].

### 3.3. Direct Evidence for Perioperative Exercise Interventions in Scoliosis Surgery: Cardiorespiratory Outcomes

While the broader prehabilitation literature provides a strong physiological rationale, the direct evidence base for exercise interventions targeting scoliosis surgery patients and their cardiorespiratory outcomes is limited but compelling. The most pivotal evidence comes from the research program of dos Santos Alves and colleagues, who conducted two landmark randomized controlled trials specifically examining preoperative rehabilitation in AIS patients. In 2014, dos Santos Alves et al. demonstrated that a four-month preoperative aerobic exercise protocol produced significant improvements across all SF-36 quality of life domains in AIS patients awaiting surgery, including domains directly related to physical functioning and vitality [23]. Notably, the authors emphasized that patients with AIS have inherently lower potential for physical activity due to lung dysfunction and diminished muscle strength, conditions that can be reversed through targeted cardiorespiratory and musculoskeletal conditioning [23]. Building on these findings, dos Santos Alves et al. conducted a randomized clinical trial (n = 50) in 2015 specifically evaluating the impact of preoperative rehabilitation on cardiopulmonary function using the 6MWT. The four-month intervention resulted in

significant progressive improvements in heart rate, respiratory rate, peripheral oxygen saturation, distance walked, and perceived exertion (Borg scale) at all postoperative time points (3, 6, and 12 months), demonstrating that preoperatively gained cardiorespiratory fitness has durable benefits extending well beyond the immediate postoperative period [15].

Postoperative evidence further supports the critical role of cardiorespiratory fitness in recovery from scoliosis surgery. Ozger et al. conducted a single-blind randomized trial (n = 28) evaluating virtual reality-based rehabilitation (VRBR) following posterior spinal fusion for AIS. The VRBR group demonstrated statistically significant between-group improvements in maximal inspiratory pressure (MIP, $p = 0.029$), spinal mobility ($p = 0.048$), and physical activity levels ($p < 0.01$), with within-group improvements also observed in maximal expiratory pressure (MEP) [14]. These respiratory muscle strength improvements are of particular clinical relevance, as MIP is a direct measure of diaphragmatic and inspiratory muscle function and correlates with postoperative pulmonary complication risk. The improvement in MIP following targeted postoperative rehabilitation indicates that the respiratory muscle weakness inherent to AIS is modifiable through structured exercise interventions, even in the postoperative period. Meng et al. complemented these findings in a 2026 RCT comparing Schroth exercises combined with core stabilization training versus core training alone in post-AIS surgery patients. The combined Schroth-core group demonstrated significantly greater improvements in pelvic symmetry ($p = 0.032$), trunk extensor endurance, and SRS-22 self-image scores ($p < 0.01$) [13]. The improvement in trunk muscle endurance is functionally linked to enhanced respiratory mechanics, as trunk extensors contribute to spinal stabilization and thoracic cage dynamics that underpin efficient ventilation. Bazancir et al. provided additional evidence in a single-blind RCT comparing five days of intensive postoperative rehabilitation versus early mobilization alone in 40 adolescent patients following scoliosis surgery. The intensive rehabilitation group showed significantly greater improvements in thorax mobility, pain scores, balance, walking distance (assessed by the 2-minute walk test), and quality of life (SRS-22) at one week postoperatively, along with a significantly shorter length of hospital stay [22]. The improvements in thorax mobility and walking distance are especially relevant as surrogate markers of cardiorespiratory function recovery, suggesting that intensive early mobilization protocols can accelerate the restoration of ventilatory mechanics that are acutely compromised following posterior spinal fusion.

The synthesis of evidence across these three domains — baseline cardiorespiratory impairment in AIS, general surgical prehabilitation targeting CRF, and scoliosis-specific perioperative exercise interventions — supports a coherent mechanistic pathway. AIS patients enter the

surgical pathway with a measurable cardiorespiratory deficit: reduced $VO_2$peak, ventilatory inefficiency, and diminished exercise tolerance [28,29], compounded by consistently lower levels of habitual physical activity [2,5,27]. Preoperative exercise conditioning can partially reverse this deficit, as demonstrated by improved 6MWT performance, respiratory parameters, and quality of life in the only AIS-specific prehabilitation trials available [15,23]. The magnitude of CRF improvement achieved through prehabilitation translates into clinically relevant postoperative benefits, including reduced pulmonary morbidity (OR 0.40) [9] and sustained functional recovery [8,20]. Postoperatively, scoliosis-specific rehabilitation further enhances respiratory muscle strength, physical activity, and functional outcomes [13,14,22]. However, significant limitations persist in the current evidence base. The paucity of large-scale RCTs specifically addressing prehabilitation in scoliosis surgery represents a critical gap; most spine surgery evidence derives from adult degenerative populations that differ fundamentally from the typically younger AIS cohort [19,25]. Furthermore, the economic feasibility of implementing structured prehabilitation programs within existing scoliosis care pathways remains unexplored, and identifying which patient subgroups — based on baseline functional capacity or disease severity — derive the greatest benefit from preoperative conditioning represents an important area for future investigation. Future research should prioritize multicenter trials implementing standardized preoperative exercise protocols with CPET-based cardiorespiratory endpoints ($VO_2$peak, 6MWD, MIP) as primary outcome measures, enabling precise quantification of the dose-response relationship between preoperative CRF optimization and postoperative surgical outcomes in scoliosis patients.

## 4. Conclusion

Adolescent idiopathic scoliosis is accompanied by a clinically significant reduction in cardiorespiratory fitness that extends beyond the structural spinal deformity itself. Patients with AIS demonstrate reduced peak oxygen consumption, diminished ventilatory efficiency, decreased tidal volume, and earlier onset of the anaerobic threshold during exercise, even when spinal curves are classified as mild to moderate. These cardiorespiratory limitations are compounded by consistently lower levels of habitual physical activity observed in affected adolescents compared to their healthy peers, creating a self-perpetuating cycle of deconditioning that progressively diminishes physiological reserve. Given that surgical recovery after posterior spinal fusion substantially increases metabolic and oxygen demand, this baseline cardiorespiratory deficit places AIS patients at a significant disadvantage in the

perioperative period and underscores the clinical importance of addressing fitness optimization as an integral component of comprehensive scoliosis management.

The available evidence supports the efficacy of structured physical activity interventions in modifying both the disease trajectory and the cardiorespiratory status of AIS patients. Scoliosis-specific exercise programs, including Schroth-based physiotherapeutic exercises and high-intensity interval training protocols, have demonstrated the capacity to reduce curve progression, improve physical activity participation, and enhance cardiorespiratory parameters. The broader surgical prehabilitation literature provides compelling evidence that preoperative exercise-based conditioning meaningfully improves cardiorespiratory fitness — as measured by the six-minute walk distance and peak oxygen consumption — and that these improvements translate into reduced postoperative morbidity, most notably a substantial reduction in pulmonary complications. Within spine surgery, prehabilitation has been associated with improved postoperative pain outcomes, enhanced trunk muscle strength, and better early functional recovery, although the evidence remains heterogeneous in terms of intervention protocols, outcome measures, and populations studied.

The limited but pivotal randomized controlled trials conducted specifically in adolescents with AIS have confirmed that a structured preoperative aerobic exercise protocol significantly improves cardiopulmonary parameters, quality of life, and six-minute walk test performance, with benefits persisting up to twelve months after surgery. Postoperative rehabilitation approaches specifically designed for scoliosis patients — including virtual reality-based programs, Schroth exercises combined with core stabilization, and intensive early mobilization protocols — have demonstrated additional benefits in restoring respiratory muscle strength, thorax mobility, walking capacity, and overall quality of life, while reducing the length of hospital stay. These findings support a paradigm in which perioperative care for scoliosis patients should incorporate disease-specific, cardiorespiratory-targeted exercise interventions in both the preoperative and postoperative phases, consistent with the principles of enhanced recovery after spinal surgery protocols.

Despite the promising findings summarized in this review, the current evidence base is limited by several critical gaps. The vast majority of spine surgery prehabilitation research has been conducted in adult populations with degenerative lumbar conditions, and direct extrapolation to the typically younger and physiologically distinct adolescent idiopathic scoliosis population requires caution. Only one randomized controlled trial has directly measured cardiopulmonary function as a primary outcome following preoperative conditioning in scoliosis surgery patients. Large-scale, multicenter randomized controlled trials specifically evaluating standardized

prehabilitation protocols in scoliosis surgery candidates are urgently needed. Future studies should employ cardiopulmonary exercise testing with peak oxygen consumption, six-minute walk distance, and respiratory muscle strength as primary outcome measures, enabling precise quantification of the relationship between preoperative cardiorespiratory optimization and postoperative surgical outcomes. Additionally, research should address the optimal timing, duration, intensity, and modality of perioperative exercise programs for this population, as well as the long-term sustainability of prehabilitation programs and the role of baseline functional status in predicting prehabilitation response. Only through such rigorous investigation can the full potential of cardiorespiratory-targeted prehabilitation be realized in the management of scoliosis surgery patients.

## 5. Disclosure

**Supplementary Materials:** Not applicable.

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**AI.**

AI was utilized for two specific purposes in this research. Text analysis of clinical reasoning narratives to identify linguistic patterns associated with specific logical fallacies. Assistance in refining the academic English language of the manuscript, ensuring clarity, consistency, and adherence to scientific writing standards. AI were used for additional linguistic refinement of the research manuscript, ensuring proper English grammar, style, and clarity in the presentation of results. It is important to emphasize that all AI tools were used strictly as assistive instruments under human supervision. The final interpretation of results, classification of errors, and conclusions were determined by human experts in clinical medicine and formal logic. The AI tools served primarily to enhance efficiency in data processing, pattern recognition, and linguistic refinement, rather than replacing human judgment in the analytical process.

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