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Physical Activity and Exercise-Based Interventions in Congenital Heart Disease: Implications for Quality of Life Across Age Groups

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Abstract

Background: Congenital heart disease (CHD) is one of the most common congenital conditions. Advances in treatment have improved survival, shifting focus toward long-term outcomes such as quality of life (QoL/HRQoL). Appropriately prescribed physical activity is generally safe, though its effects may vary by age and CHD subtype.

Aim: This scoping review aimed to map evidence on physical activity and exercise-based interventions and their association with QoL in children, adolescents, and adults with CHD.

Materials and Methods: The review followed PRISMA-ScR guidelines. English-language studies published between 2010 and 2025 were identified through PubMed and Google Scholar. Eligible studies included original research (e.g., randomized controlled trials, cohort, and cross-sectional studies) assessing physical activity or exercise interventions and reporting QoL/HRQoL and/or cardiorespiratory fitness outcomes.

Results: In children, early individualized programs are safe and may improve exercise tolerance and motor outcomes. In adolescents, digital and behavioral interventions targeting increases in moderate-to-vigorous physical activity (MVPA) show mixed results, with greater benefits in those with low baseline activity. Structured aerobic training improves cardiopulmonary exercise testing (CPET) outcomes but often does not increase daily activity. In adults, most studies report improved cardiopulmonary fitness (VO_2peak), while effects on biomarkers and QoL vary. Respiratory training may improve selected patient-reported outcomes but has less consistent effects on VO_2peak. Serious adverse events are rare.

Conclusions: Exercise in patients with CHD is safe and improves fitness; however, its effects on QoL/HRQoL are heterogeneous and depend on age, context, and CHD subtype. A key gap is the mismatch between improved fitness and daily activity, highlighting the need for long-term, multicomponent programs with objective monitoring and standardized HRQoL measures.

Key words: congenital heart disease (CHD), exercise training, physical activity, health-related quality of life (HRQoL), cardiopulmonary capacity, peak oxygen uptake (VO_2peak)27

1. Introduction

Congenital heart disease (CHD) is one of the most common congenital anomalies worldwide and represents a significant public health concern (1) . Owing to substantial advances in pediatric cardiology, cardiac surgery, interventional techniques, and perioperative care, survival rates among patients with CHD have improved dramatically over recent decades (2) . As a result, an increasing proportion of children born with CHD now survive into adulthood, leading to a rapidly expanding population of adults with congenital heart disease (2,3). Consequently, the focus of clinical care and research has shifted from survival alone toward long-term outcomes, including functional status, psychosocial well-being, and overall quality of life across the lifespan (4,5) . Quality of life is a multidimensional construct encompassing physical, psychological, and social domains of health (6). Patients with CHD—regardless of age—often experience reduced exercise capacity, chronic fatigue, anxiety related to physical exertion, and challenges in social participation (7,8). Historically, physical activity was frequently restricted in this population due to concerns about potential cardiovascular complications (9) . However, contemporary evidence and evolving clinical guidelines increasingly support appropriately prescribed physical exercise as a safe and beneficial component of comprehensive care. Exercise-based interventions may improve cardiorespiratory fitness, functional capacity, and psychological well-being, thereby positively influencing overall QoL (9,10) . Nevertheless, the impact of physical exercise on quality of life in individuals with CHD appears to vary across age groups and developmental stages. In children, considerations include growth, motor development, school participation, and family involvement (11). During adolescence, issues such as identity formation, autonomy, peer integration, and transition from pediatric to adult care become particularly relevant (12). In adults with CHD, additional challenges emerge, including employment, family planning, comorbidities, and long-term cardiovascular complications. Given the growing number of adult survivors, increasing attention is being directed toward understanding and optimizing long-term quality of life outcomes in this population (2,3,5) . The aim of this scoping review is to systematically map the existing literature on physical exercise and exercise-based interventions in relation to quality of life among patients with congenital heart disease across different age groups—children, adolescents, and adults. By identifying key concepts, types of interventions, outcome measures, and research gaps, this review seeks to provide a comprehensive overview of the current evidence and inform future research as well as age-specific clinical practice in the management of CHD.

2. Methods

This scoping review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) extension for scoping reviews (13). A systematic search of **PubMed** and **Google Scholar** was performed to identify English-language articles published between 2010 and 2025 using the following terms: “congenital heart disease” OR “congenital heart defect” OR “inherited cardiac disease” combined with “exercise” OR “physical activity” OR “rehabilitation” and “quality of life” OR “QoL” OR “HRQoL”. Original studies (randomized controlled trials (RCTs), cohort, and cross-sectional) involving patients with congenital heart disease that assessed physical activity or exercise interventions and reported outcomes related to quality of life or cardiorespiratory capacity were included. Studies focusing exclusively on acquired heart disease, review articles, case reports (<10 participants), editorials, and commentaries were excluded. The detailed study selection process is presented in the PRISMA flow diagram and corresponding **Figure** 1.

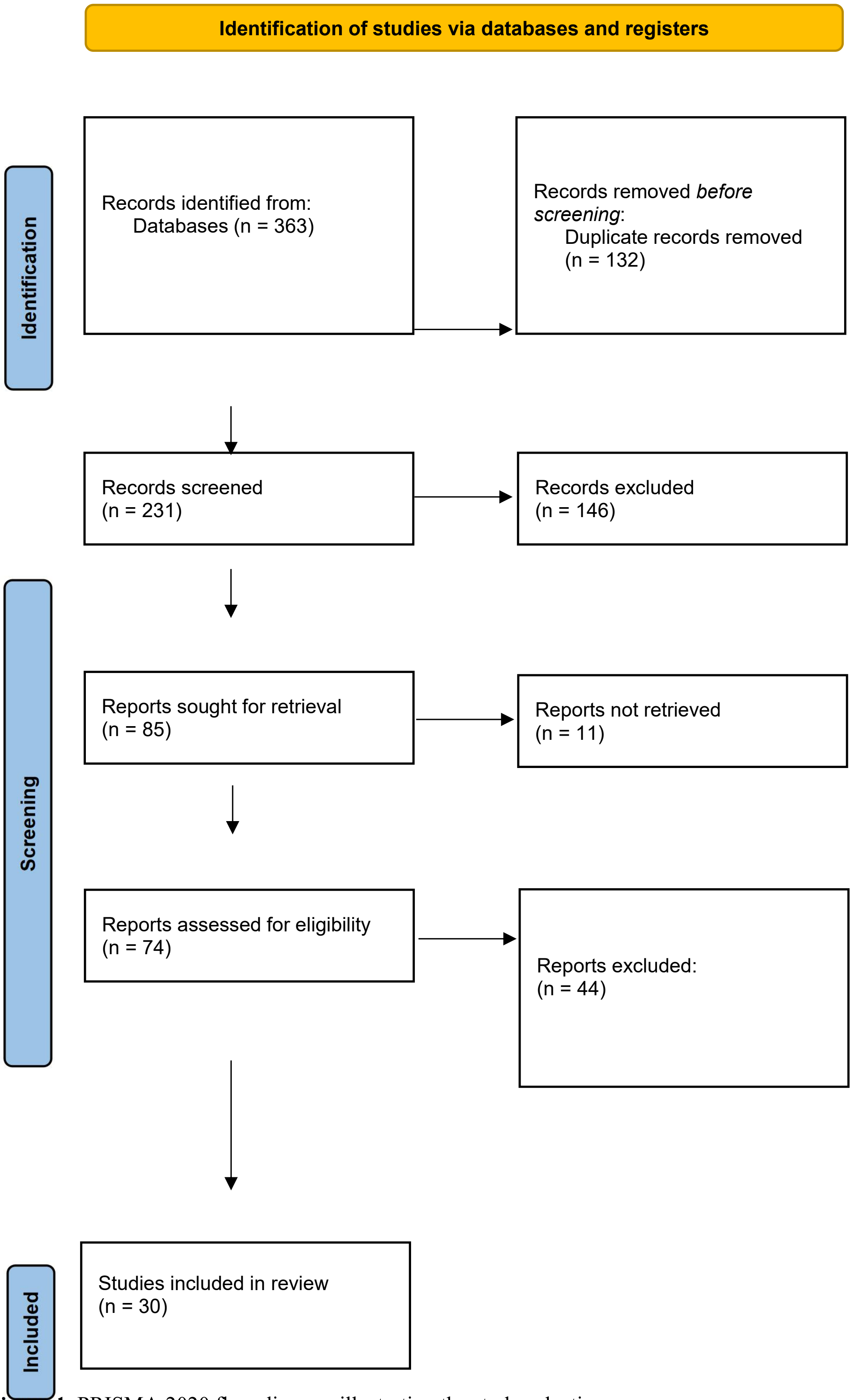

Figure 1. PRISMA 2020 flow diagram illustrating the study selection process.

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3. Results

3.1. Children

A growing number of evidence indicates that appropriately prescribed physical activity constitutes an important component of comprehensive care for children with congenital heart disease, providing benefits for both motor development and exercise tolerance. In a randomized study, Du et al. demonstrated that an individualized, supervised home-based exercise program implemented in children aged 0–5 years after cardiac catheterization led to significant improvements in global and specific motor development indices (GMQ, FMQ, TMQ) as early as the first month of intervention, with effects sustained over 6 months. The intervention was also associated with favorable changes in selected echocardiographic parameters depending on the defect type (including atrial and ventricular septal defect) (14). In turn, the largest randomized trial conducted to date in this age group, performed by Callaghan et al. in children aged 5–10 years, showed that a structured program based on a single educational session, an individualized exercise prescription, and motivational interviewing techniques significantly increased peak exercise capacity, as measured by exercise test duration and maximal workload, while maintaining intervention safety (15) . Although Callaghan et al. did not observe a statistically significant increase in daily physical activity assessed by accelerometry, the authors emphasized that baseline activity levels were already satisfactory in most children, except for a subgroup with cyanotic heart defects after palliative treatment, who exhibited significantly lower exercise tolerance and shorter durations of moderate-to-vigorous physical activity (15) . Together, these studies indicate that early, individualized exercise interventions—implemented in the home setting or supported by specialist counseling—are safe and effective, and may help prevent both motor developmental delays in younger children and progressive exercise intolerance in older patients with CHD, underscoring the pivotal role of parental education and engagement in the rehabilitation process.

3.2. Adolescents

Adolescence and early adulthood are periods during which many patients with congenital heart disease establish lifestyle patterns that influence later exercise tolerance and everyday physical activity. At the same time, several studies indicate that, already at the outset of this life stage, a substantial proportion of adolescents with CHD do not achieve the level of activity recommended for the healthy population (≥60 min/day of MVPA), and sedentary behaviours are common (16–18).

3.2.1. Daily physical activity and sedentary behaviour (baseline levels and variability)

In the CHD-PAL study in adolescents aged 15–18 years (N=60), mean moderate-to-vigorous physical activity was 19.8 min/day, alongside a very high accelerometer-measured sedentary time (568.7 min/day) (16). In the PReVaiL RCT (13–16 years; N=158), mean ActiGraph-measured MVPA over the 1-year follow-up was similar in both arms and amounted to approximately 40–41 min/day, highlighting substantial heterogeneity in baseline activity levels across different CHD cohorts (19). Likewise, in an RCT including a motivational component in adolescents aged 12–20 years, only 14 participants met the criterion of >60 min/day of MVPA at baseline, illustrating that marked physical inactivity is already evident in a subset of patients during school and secondary school age (18)

3.2.2. Digital and behavioural interventions targeting MVPA—effectiveness dependent on baseline activity

In CHD-PAL, a hybrid model was implemented, consisting of an exercise prescription, an activity monitor (Fitbit), and eight video consultations over 20 weeks. In the overall sample, the intervention had no effect on changes in MVPA, sedentary behaviour, or cardiorespiratory fitness; however, among participants with very low baseline MVPA (<21 min/day), a greater increase in MVPA was observed in the intervention arm (difference +16 min/day; d≈0.90) (16). This finding suggests that the greatest gains may occur in the least active adolescents, whereas those who are already moderately active may have less room for improvement (16)

In PReVaiL, the eHealth intervention (web-based platform + mobile application + individually tailored SMS prompts) was added to health education and counselling. After one year, no significant between-group differences were found in MVPA or in key fitness outcomes (19). The intervention design—including tailoring mechanisms and self-monitoring components—had been described previously in the eHealth protocol publication (20) ; however, the RCT findings did not confirm sustained effectiveness of this strategy in increasing physical activity over the longer term (19)

In another mHealth RCT (COOL; 15–24 years; N=143), an app (COOL Passport) and a version supplemented with "Health Promotion Cloud" features and gamification platforms were compared with standard care. After 12 months, neither active arm demonstrated superiority with respect to disease-related knowledge or physical activity intensity (21). Similarly, a pilot intervention based on telephone sessions of modified motivational interviewing (3 months; N=36) was acceptable, but no significant between-group differences were observed in changes in MVPA or in behaviour-change mechanisms (stage of change, self-efficacy) (22)

3.2.3. Structured training—effects on exercise capacity (VO_2peak/VO_2max) and exercise-test parameters

In a cohort aged 10–25 years with repaired tetralogy of Fallot (ToF) or Fontan circulation (N=93; 56 training vs 37 control), a 12-week aerobic programme improved exercise capacity assessed by CPET; however, the effect was driven mainly by patients with ToF, whereas no comparable improvement in VO_2peak was observed in those with Fontan circulation (17). Importantly, despite improved fitness indices, the proportion of time spent in MVPA in daily activity monitoring did not change significantly, indicating a gap between "capacity" and real-life behaviour (17).

In an RCT in adolescents aged 12–20 years, the implementation of motivational techniques together with a structured exercise programme was associated with both increased MVPA and improved exercise-test parameters (longer test duration and higher predicted VO_2max (maximal oxygen uptake)), without adverse events (18). By contrast, in a web-based "motor intervention" study (10–18 years; N=70; 24 weeks, 3×/week for 20 min), no significant improvements were found in health-related physical fitness, z-score or HRQoL, suggesting that a remote format and the applied "dose" of training may not translate into measurable gains in functional fitness (23)

3.2.4. Peripheral and respiratory mechanisms—skeletal muscle and ventilation as intervention targets

In adolescents aged 12–15 years with CHD, a 12-week aerobic cycling programme improved lower-limb muscle strength and endurance (maximal voluntary contraction, time to exhaustion), and near-infrared spectroscopy measures indicated favourable changes in muscle oxygenation kinetics and faster post-exercise recovery (24). In patients with ToF (mean age 14.7±4.8 years; N=60), home-based respiratory training using a volume-oriented inspiratory device was associated with a more favourable change in VO_2peak (increase in the training group vs decrease in controls) and improvements in dynamic lung volumes (forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1)) compared with controls during the first 6 months of follow-up (25)

3.2..5 Safety and cardiac remodelling—imaging data and biomarkers

Given concerns regarding potentially unfavourable structural cardiac changes, RCT data on remodelling are particularly relevant. In an RCT including patients aged 10–25 years with ToF or Fontan circulation, 12 weeks of aerobic training was not associated with clinically meaningful adverse remodelling: systolic parameters, cardiac dimensions, and neurohormonal markers did not deteriorate. No adverse events were reported during training sessions; however, one episode of collapse occurred in a patient with Fontan circulation outside the training setting, and the cause could not be established despite further investigations (26) . A similar conclusion emerges from a pilot RCT in patients with ToF (10–25 years; 12 weeks, 3×/week for 1 h), in which no unfavourable changes were observed in regional ventricular function assessed using imaging modalities (27)

3.2.6. Quality of life and psychosocial functioning—effects dependent on age and family context

In the 10–25-year ToF/Fontan cohort (N=93), aerobic training did not improve self-reported sports enjoyment or "active" leisure-time spending, but it was associated with reduced passive leisure activities (television/computer use) compared with controls; additionally, disease-related knowledge moderated changes in sports enjoyment (28)

Regarding HRQoL, in the ToF/Fontan RCT (N=93), favourable changes after training were observed mainly in the younger subgroup (10–15 years), whereas no significant improvement in HRQoL was noted among participants aged 16–25 years (29). Family context also appeared to modify the effect: in an RCT focused on younger adolescents (10–15 years; N=56), parental mental health moderated HRQoL changes after training, and higher levels of parental anxiety/insomnia or depressive symptoms were associated with a less favourable pattern of change in adolescents' social functioning (30)

In the domain of emotional and behavioural problems, a multicentre RCT (10–17 years; questionnaire-based analysis n=71) found no significant between-group differences in the main measures of emotional–behavioural difficulties; however, within the training arm, a reduction in anxiety related to sports was observed in within-group analyses (31)

3.2.7. Sleep and fatigue—physical activity as a potential factor supporting sleep quality in Fontan patients

In patients with Fontan circulation (n=30) compared with controls (n=25), sleep duration and sleep efficiency were similar, but sleep-onset latency was longer. Importantly, greater daily MVPA correlated with more favourable sleep parameters in Fontan patients (longer sleep, higher efficiency, fewer awakenings), although sleep variables did not improve after a 12-week endurance training programme; at 1-year follow-up, deterioration of selected sleep parameters was observed in patients (32)

Based on the available evidence, adolescents and young adults with CHD often exhibit low daily activity levels and substantial sedentary time, with marked heterogeneity across cohorts. Digital and behavioural interventions rarely lead to sustained increases in MVPA, whereas structured exercise programmes more often improve exercise capacity and appear largely safe; however, translation of these effects into everyday behaviour and HRQoL may be limited and seems to depend on age, underlying diagnosis, and family context.

3.3. Adults

3.3.1. Effects of Physical Exercise in Adults with Congenital Heart Disease

We analyzed studies investigating exercise-based interventions, increased levels of physical activity, inspiratory muscle training and their effects on adult patients with congenital heart disease. The majority of the included studies demonstrated a beneficial impact on exercise capacity, indicating that adults with congenital heart disease retain the ability to adapt positively to physical training. In most trials, exercise interventions were associated with significant improvements in aerobic capacity, most consistently reflected by an increase in peak oxygen uptake (33–38). Although the magnitude of change varied between studies and training modalities, the overall direction of effect was favorable, supporting the role of structured exercise and regular physical activity as effective strategies to enhance functional capacity in this patient population (detailed results are presented in Table X). However, not all interventions led to improvements in aerobic capacity. Continuous training in the study by Novaković et al. did not significantly increase VO_2peak. Similarly, interventions targeting inspiratory muscle strength or breathing exercises showed limited effects on aerobic performance (38). In patients with Fontan circulation, Fritz et al. and Wu et al. reported no significant improvements in VO_2peak, pulmonary function, cardiac output, or quality of life following inspiratory muscle training (39,40), although Wu et al. observed an increase in peak work rate and non-significant trends toward improved ventilatory efficiency (40). In contrast, Ganzoni et al. demonstrated significant improvements in inspiratory muscle strength and quality of life after choir singing sessions and breathing exercises, without changes in VO_2peak; however, this study included not only patients with congenital heart disease but also individuals with acquired cardiomyopathies (e.g., ischaemic or dilated cardiomyopathy) (41). Overall, inspiratory muscle training appears to improve selected respiratory or patient-reported outcomes but does not consistently enhance global exercise capacity. Exercise tolerance and performance improved in several studies, as reflected by longer exercise test duration (33,35–37,42) and higher achievable workloads (33,36,38,40). These findings indicate that exercise training can effectively enhance functional capacity and physical performance in adults with congenital heart disease. However, evidence regarding the long-term sustainability of these benefits remains limited. While short-term interventions frequently improved exercise capacity, extended follow-up in one study did not demonstrate persistent effects on exercise performance, cardiopulmonary parameters, biomarkers, or habitual physical activity (34,43). Notably, individuals who engaged in regular sports participation prior to study inclusion exhibited superior long-term outcomes, including higher exercise capacity, more favorable biomarker profiles, and improved event-free survival. This highlights the importance of long-term, habitual physical activity, rather than short-duration training programs alone (34,43).

3.3.2. Vascular, Hemodynamic, and Autonomic Effects

Improvements in vascular function were reported only in one study involving a group undergoing high-intensity interval training (HIIT), with favorable changes in endothelial function and arterial stiffness (38). Continuous training showed more limited or borderline effects in this domain (38). Reductions in resting blood pressure (34) and resting heart rate, as well as increases in heart rate reserve (37), were observed in some studies, indicating favorable effects of exercise on cardiovascular regulation. However, most trials did not demonstrate significant changes in other vascular parameters. Consistently, Wu et al. found no significant changes in resting or peak heart rate, cardiac output, O_2 pulse, or pulmonary function parameters, suggesting that the impact of exercise on Hemodynamic function may be limited or dependent on the intensity and type of training. Autonomic and metabolic responses to exercise were training modality–dependent (40). Continuous training appeared to preferentially improve cardiac autonomic regulation and mental aspects of quality of life, whereas HIIT was associated with broader cardiovascular and metabolic adaptations (38). Westhoff-Bleck et al. additionally demonstrated significant metabolic adaptations, including a reduction in lactate concentration at the aerobic threshold and preserved diastolic function reflected by a smaller increase in isovolumetric relaxation time compared to controls (33)

3.3.3. Biomarkers

Changes in circulating biomarkers were inconsistent. Serum NT-proBNP decreased significantly only following HIIT (38), while remaining unchanged in most other interventions (33–35,37,39), including during long-term follow-up (43). Similarly, Catecholamines (37), D-dimer, total cholesterol, LDL cholesterol, triglycerides and cardiac structural parameters (33,38) remained unchanged. These findings suggest that biomarker modulation may require higher-intensity or prolonged exercise exposure.

3.3.4. Physical Activity and Psychosocial Outcomes

Increases in physical activity levels, assessed using both objective and subjective measures, were reported in Dua et al., accompanied by higher levels of moderate-to-vigorous physical activity and energy expenditure (42). However, only a limited number of studies demonstrated improvements in quality of life, which were observed in Dua et al (42). In other study, improvements were confined to the mental health domain following continuous training (38). Ganzoni et al. reported a significant improvement in quality of life following weekly singing lessons combined with daily breathing exercises (41). However, most studies did not report an improvement in quality of life (33–36,39,40,43). Psychological outcomes, including anxiety, depression, and exercise self-efficacy, remained unchanged (36)

3.3.5. Safety

All exercise interventions were **safe and well tolerated**. No deaths or major exercise-related adverse events were reported (33–42). Only **isolated and minor adverse events** were observed, including transient dizziness during exercise sessions (37), suspected but unconfirmed arrhythmia leading to study withdrawal (36), and brief arrhythmias detected during cardiopulmonary exercise testing (35); all were managed conservatively without clinical consequences. In addition, Ávila et al., in a cohort of patients with repaired tetralogy of Fallot, reported stable arrhythmic burden during training, with no increase in premature ventricular or atrial contractions and a reduction in episodes of non-sustained ventricular tachycardia over the intervention period (37). During long-term follow-up in Van der

Boom et al., clinical events occurred but were not attributable to the exercise intervention, whereas habitual sports participation at baseline was associated with a lower incidence of adverse events (43).

In adults with congenital heart disease, exercise training safely improves exercise capacity and selected cardiovascular parameters. Interventions focusing on ventilatory or inspiratory muscle training may improve specific outcomes such as inspiratory muscle strength or quality of life without significantly affecting VO_2peak (40,41). Effects on biomarkers and quality of life are variable, and durable long-term benefits appear to be more strongly linked to sustained, regular physical activity rather than short-term interventions alone. These findings support the integration of individualized exercise programs into long-term care strategies for adults with CHD.

4. Discussion

Overall, the evidence base supports a clear shift from historically restrictive counselling toward proactive, individualized promotion of physical activity and exercise training in congenital heart disease, with growing consensus that appropriately prescribed programs are safe and can yield clinically meaningful improvements in cardiorespiratory capacity across ages and diagnostic complexity (9,44,45). Across trials and meta-analyses, the most consistent physiological signal is an increase in exercise capacity—frequently reflected by improvements in peak oxygen uptake—especially when training is supervised and delivered at sufficient dose and intensity (46–48). Importantly, safety data are reassuring: aggregated evidence suggests adverse events are uncommon and serious exercise-related events are rare under structured protocols, reinforcing that supervised training can be offered even to patients with complex anatomy when appropriately tailored (45). At the same time, a clinically relevant gap repeatedly emerges between improvements in “capacity” (what patients can do in controlled testing, such as CPET outcomes) and everyday “participation” (what they actually do in daily life, such as habitual moderate-to-vigorous physical activity), with several pediatric/young adult studies demonstrating fitness gains without parallel increases in objectively measured daily activity (17). This disconnect likely reflects the multifactorial drivers of inactivity in

CHD—fear of symptoms, low exercise self-efficacy, misconceptions about risk, parental overprotection, and transition-related barriers—which can prevent patients from converting better fitness into sustained lifestyle behavior. Accordingly, effects on health-related quality of life remain heterogeneous: some interventions report improvements in selected domains, but pooled analyses and individual trials frequently show small or inconsistent HRQoL changes despite measurable physiological gains, suggesting that exercise alone may be insufficient to modify broader psychosocial and functional outcomes (45,47,48). Encouragingly, recent evidence indicates that multicomponent, hybrid rehabilitation models—combining supervised and home-based activity with education and multidisciplinary support—may be more effective at influencing HRQoL and real-world activity than training-only approaches, as demonstrated by the QUALIREHAB trial in adolescents and young adults with CHD (49). This integrated perspective is further strengthened by evidence that HRQoL in CHD is shaped not only by physiology but also by family context; parents of children with CHD often experience reduced HRQoL and psychosocial burden, which may indirectly influence children's activity opportunities and confidence, underscoring the rationale for family-informed behavioral strategies alongside lesion-specific exercise prescription (50,51). Future research should therefore prioritize longer follow-up, harmonized outcome sets (including objective activity monitoring and standardized HRQoL instruments), stratification by phenotype and developmental stage, and pragmatic interventions that intentionally bridge the "capacity-to-participation" gap through behavioral change techniques and systems of support—an approach aligned with ongoing innovation in remotely supervised and technology-enabled programs for complex CHD. populations (52)

5. Conclusions

This scoping review indicates that appropriately prescribed physical activity and exercise-based interventions in people with congenital heart disease are generally safe and are most consistently associated with improvements in cardiorespiratory fitness (often reflected by higher VO_2peak and better CPET performance) across pediatric and adult populations. However, effects on QoL/HRQoL are heterogeneous and frequently modest, with outcomes varying by age, lesion complexity/phenotype (e.g., more consistent fitness gains in repaired tetralogy of Fallot than in Fontan physiology), baseline activity levels, and psychosocial context. A recurring finding is the "capacity–participation gap": measurable gains in exercise tolerance do not reliably translate into higher habitual daily activity in real-world settings. This suggests that exercise prescriptions alone may be insufficient to change behavior and broader well-being outcomes, particularly during adolescence and the transition to adult care, when barriers such as risk perceptions, self-efficacy, family dynamics, and lifestyle factors may constrain sustained engagement. Future work should prioritize longer follow-up, standardized HRQoL instruments, and objective activity monitoring, alongside pragmatic, multicomponent rehabilitation models that integrate individualized training with behavioral support, education, and family-informed strategies. Clinically, the evidence supports shifting from restrictive counseling toward proactive, tailored promotion of physical activity as a routine component of lifelong CHD care.

Disclosures

Supplementary Materials

Table 1. summary of the results of studies (1,2,3…).

Author's contribution:

Conceptualization: AC, AA, KZ;

Methodology: AA, MSl, PC;

Formal analysis: AC, MSl, MSi, KZ;

Investigation: MS, KZ, IG;

Resources: AA, MK, PC, AP;

Data curation: MK, MSi**;**

Writing – original draft: AC**,** PC, AA;

Writing – review & editing: AP, MSl, KZ;

Visualization: AC, MS, AP;

Supervision: AC;

Project administration: AC.

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