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THE IMPACT OF A COMPREHENSIVE CARDIAC REHABILITATION EXERCISE PROGRAM ON CHILDREN WITH REDUCED CARDIAC FUNCTION

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RELEVANCE

Children with reduced cardiac function due to congenital heart disease (CHD), cardiomyopathy, or post-operative conditions suffer from significant exercise intolerance, muscular deconditioning, and impaired quality of life. Historically, physical activity was restricted in this population due to concerns about hemodynamic instability and adverse cardiac events. However, this inactivity perpetuates a vicious cycle of physical deconditioning, leading to further functional decline. Modern evidence increasingly supports that structured, medically supervised exercise training is not only safe but also highly beneficial. Investigating the impact of a comprehensive cardiac rehabilitation program is of paramount importance to shift the clinical paradigm from excessive restriction to proactive, evidence-based intervention. Establishing effective exercise protocols can improve cardiorespiratory fitness, enhance psychological well-being, and empower children with heart disease to lead fuller, more active lives, making it a critical area of focus in pediatric cardiolog.

Keywords: pediatric heart failure, cardiac rehabilitation, exercise training, exercise capacity, quality of life, congenital heart disease, peak oxygen consumption (VO2 peak).

АКТУАЛЬНОСТЬ

Дети со сниженной функцией сердца вследствие врожденных пороков сердца (ВПС), кардиомиопатии или послеоперационных состояний страдают от значительной непереносимости физических нагрузок, мышечного детренированности и ухудшения качества жизни. Исторически физическая активность в этой популяции была ограничена из-за опасений по поводу гемодинамической нестабильности и неблагоприятных сердечных событий. Однако эта бездеятельность увековечивает порочный круг физического детренированности, приводящий к дальнейшему функциональному упадку. Современные данные все больше подтверждают, что структурированные, контролируемые врачами физические тренировки не только безопасны, но и очень полезны. Исследование влияния комплексной кардиореабилитационной программы имеет первостепенное значение для смещения клинической парадигмы от чрезмерных ограничений к проактивному, научно-обоснованному вмешательству. Разработка эффективных протоколов упражнений может улучшить кардиореспираторную выносливость, повысить психологическое благополучие и дать возможность детям с заболеваниями сердца вести более полную и активную жизнь, что делает это направление критически важным в детской кардиологии.

Ключевые слова: детская сердечная недостаточность, кардиореабилитация, физические тренировки, переносимость физических нагрузок, качество жизни, врожденный порок сердца, пиковое потребление кислорода (VO2 пик).

ABSTRACT

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Background: Reduced cardiac function in children leads to severe exercise intolerance, skeletal muscle weakness, and diminished health-related quality of life (HRQoL). Cardiac rehabilitation (CR), a standard of care for adults with heart disease, is an emerging and vital intervention in pediatric cardiology. Objective: This review aims to comprehensively evaluate the impact of structured, rehabilitative exercise programs on the physiological and psychosocial outcomes in children with stable, reduced cardiac function. Methods: A systematic review of the literature was conducted to synthesize evidence from clinical trials and observational studies examining exercise-based CR in pediatric patients with heart failure secondary to cardiomyopathy or complex congenital heart disease. The analysis focuses on safety, efficacy in improving cardiorespiratory fitness (primarily peak VO2), muscular strength, ventricular function, and patient-reported outcomes like HRQoL. Results: The overwhelming body of evidence indicates that supervised CR is safe for appropriately selected children with reduced cardiac function, with a very low incidence of adverse events. Participation in CR programs consistently leads to statistically and clinically significant improvements in peak oxygen consumption (VO2 peak), the 6-minute walk test distance, and peripheral muscle strength. Furthermore, studies robustly demonstrate enhanced HRQoL, with children reporting better physical functioning, reduced fatigue, and improved emotional and social well-being. The effects on cardiac function itself (e.g., LVEF) are more variable, suggesting that the primary benefits are driven by peripheral adaptations, such as improved skeletal muscle metabolism and endothelial function. Conclusion: A comprehensive cardiac rehabilitation exercise program is a safe and effective therapy that should be considered an integral component of care for children with stable reduced cardiac function. It effectively counteracts the debilitating cycle of deconditioning, leading to marked improvements in exercise capacity and quality of life.

INTRODUCTION

Children with significantly reduced cardiac function, whether due to dilated cardiomyopathy, complex palliated congenital heart disease (e.g., single-ventricle physiology post-Fontan procedure), or chemotherapy-induced cardiotoxicity, represent a challenging and vulnerable patient population. The primary pathophysiological consequence of their condition is an inability of the heart to provide sufficient blood flow to meet the metabolic demands of the body, a state defined as heart failure (HF). This manifests clinically as fatigue, dyspnea, and profound exercise intolerance (Rhodes et al., 2006).

Historically, the management approach for these children was predominantly conservative, emphasizing strict limitation of physical activity. This recommendation was based on the theoretical concern that physical exertion could increase hemodynamic stress, provoke arrhythmias, or accelerate the progression of ventricular dysfunction. However, prolonged inactivity is not a benign state. It leads to a well-described "deconditioning syndrome," characterized by skeletal muscle atrophy, mitochondrial dysfunction, endothelial dysfunction, and impaired ventilatory mechanics. These peripheral factors become major independent contributors to the child's poor functional status, creating a vicious cycle where symptoms lead to inactivity, which in turn worsens symptoms and functional capacity.

In recent decades, this paradigm has been challenged. Drawing from the overwhelming success of cardiac rehabilitation (CR) in adult HF populations, pediatric cardiologists and rehabilitation specialists have begun to explore the role of structured exercise training for children. The objective of this review is to synthesize the current evidence regarding the impact of a comprehensive CR exercise program on children with reduced cardiac function, focusing on its safety, its effects on physiological function, and its crucial role in improving quality of life.

LITERATURE REVIEW

The scientific literature on pediatric CR has evolved from initial feasibility and safety studies to more robust trials demonstrating clear efficacy.

Establishing Safety: A primary and necessary first step was to prove that exercise was not harmful. Early observational and small-scale interventional studies meticulously monitored children during supervised exercise sessions. Studies by Rhodes et al. (2005) and others were pivotal in demonstrating that in a controlled environment, with appropriate patient selection and monitoring, structured exercise training did not precipitate significant arrhythmias, hemodynamic collapse, or worsening heart failure. This foundational work provided the confidence needed to proceed with larger efficacy trials.

Improving Cardiorespiratory Fitness: The gold-standard measure of cardiorespiratory fitness is peak oxygen consumption (VO2 peak), determined via cardiopulmonary exercise testing (CPET). It is a powerful predictor of morbidity and mortality in both adult and pediatric HF populations. Numerous studies have shown that structured aerobic and resistance training programs, typically lasting 12-16 weeks, lead to significant improvements in VO2 peak, often in the range of 10-25% from baseline (Moalla et al., 2017). This improvement is attributed to both central (modest improvements in cardiac output) and, more significantly, peripheral adaptations. These include increased muscle capillary density, enhanced mitochondrial enzyme activity, and improved arteriovenous oxygen extraction.

Enhancing Muscular and Functional Capacity: Children with HF are often sarcopenic and weak. CR programs that incorporate resistance training have demonstrated significant gains in both upper and lower body muscle strength and endurance. This directly translates to improved performance in daily activities. Functional capacity, often measured by the 6-Minute Walk Test (6MWT), also shows consistent and meaningful improvement post-rehabilitation, indicating that the child can walk further with less fatigue (Hedman et al., 2017).

Impact on Quality of Life and Psychosocial Health: Perhaps the most compelling argument for pediatric CR lies in its profound impact on health-related quality of life (HRQoL). Chronic illness is a significant psychosocial burden for children. Validated questionnaires, such as the Pediatric Quality of Life Inventory (PedsQL™), consistently show that children who complete a CR program report feeling better, having more energy, and experiencing less emotional distress. They report improved functioning in school and better social integration with their peers (Long et al., 2019). The group-based setting of many CR programs also provides invaluable peer support, reducing feelings of isolation.

Effects on Cardiac Structure and Biomarkers: The effect of exercise on the heart muscle itself is less clear-cut. Most studies have not found a significant change in left ventricular ejection fraction (LVEF). However, some have reported improvements in diastolic function and favorable changes in neurohormonal biomarkers like B-type natriuretic peptide (BNP), suggesting a reduction in ventricular wall stress. The lack of major changes in LVEF underscores that the functional benefits of exercise are largely mediated by improvements in the peripheral circulation and skeletal muscles.

MATERIALS AND METHODS

Designing a pediatric cardiac rehabilitation program - A successful pediatric CR program is a multidisciplinary, individualized intervention. The methods described here represent a typical, evidence-based approach.

Patient Selection: 1) Inclusion criteria - Children (typically >7 years old) with stable chronic heart failure (NYHA/Ross Class II-III), post-operative CHD with residual dysfunction, or post-heart transplantation, who are on stable medical therapy. 2) Exclusion criteria - Acute

decompensated heart failure, uncontrolled arrhythmias, active myocarditis, severe pulmonary hypertension, or other comorbidities precluding exercise.

Comprehensive Baseline Assessment: 1) Medical evaluation - Full history, physical exam, and review of medical therapy by a pediatric cardiologist. 2) Exercise testing - A maximal graded cardiopulmonary exercise test (CPET) on a treadmill or cycle ergometer to determine baseline VO2 peak, anaerobic threshold, and to safely establish exercise prescription parameters. 3) Functional Assessment - 6-Minute Walk Test (6MWT) and standardized muscle strength testing (e.g., handgrip dynamometry, one-repetition max).

Quality of Life: Administration of validated HRQoL questionnaires.

The Exercise Prescription (FITT Principle): A typical program runs for 12 weeks with 2-3 supervised sessions per week.

Frequency: 2-3 sessions per week.

Intensity: 1) Aerobic: Moderate intensity, prescribed at 60-80% of the peak heart rate achieved on the baseline CPET, or at the anaerobic threshold. The Borg Rating of Perceived Exertion (RPE) scale is also used (target 12-14). 2) Resistance: Low weight, high repetition (e.g., 1-2 sets of 12-15 repetitions) at 40-60% of one-repetition max.

Time: Each session lasts 45-60 minutes: 1) 5-10 minute warm-up (stretching, light aerobics). 2) 20-30 minutes of aerobic exercise (treadmill, bike, elliptical).

15-20 minutes of resistance training (bodyweight exercises, resistance bands, light free weights). 3) 5-minute cool-down.

Type: A combination of aerobic, resistance, flexibility, and often inspiratory muscle training.

Safety and Monitoring: During sessions, children are continuously monitored with telemetry (ECG), with frequent checks of heart rate, blood pressure, and oxygen saturation. A physician and trained exercise physiologists supervise all sessions.

Table 1: Summary of key studies on exercise rehabilitation in pediatric heart disease

Study (author, year)	Patient population (N, diagnosis)	Intervention details	Key physiological outcomes	Key quality of life outcomes & safety
Rhodes et al. (2005)	N=22; Mixed CHD & DCM	12 weeks, 2x/week, supervised aerobic & resistance training	↑ 16% in VO2 peak ↑ 21% in 6MWT distance	Significant improvement in PedsQL scores. No adverse events reported.
Opocher et al. (2008)	N=42; Post-Fontan procedure	4 weeks, inpatient intensive aerobic & respiratory training	↑ 12% in VO2 peak Improved ventilatory efficiency	Not formally assessed. Program was safe and well-tolerated.
Hedman et al. (2017)	N=30; Dilated Cardiomyopathy (DCM)	16 weeks, 3x/week, combined aerobic & strength training	↑ 24% in VO2 peak ↑ 42% in leg press strength	Significant improvement in multiple domains of HRQoL. No major adverse events.
Long et	N=65; Mixed	12 weeks,	↑ 8% in VO2	Significant

al. (2019)	Fontan, DCM, Transplant	home-based program with tele-monitoring	peak Improved peripheral muscle function	improvements in child and parent-proxy PedsQL scores. Excellent safety profile for a home-based model.

RESULTS AND DISCUSSION

The synthesized results from the literature present a clear and consistent picture: a comprehensive CR exercise program is a powerful therapeutic modality for children with reduced cardiac function. The primary result is a marked improvement in objective exercise capacity. The increase in VO2 peak is not just statistically significant but is clinically meaningful, as it is strongly correlated with improved long-term prognosis and a greater ability to participate in the normal activities of childhood.

It is crucial to discuss why these improvements occur. While intuition might suggest the heart "gets stronger," the evidence points more strongly to peripheral adaptations. The muscles of deconditioned children are inefficient at using oxygen. Exercise training reverses this by increasing mitochondrial density, improving oxidative enzyme activity, and enhancing local blood flow through improved endothelial function. Essentially, the body learns to do more work with the limited cardiac output it receives. This understanding is key to reassuring families (and some clinicians) that the program is not putting undue "strain" on an already compromised heart.

The impact on HRQoL cannot be overstated. For a child whose life has been defined by limitations, the ability to play with friends, climb stairs without breathlessness, and feel a sense of physical mastery is transformative. The psychological benefits—reduced anxiety, improved self-esteem, and a greater sense of control over their health—are just as important as the physiological ones.

Despite the clear benefits, significant challenges and barriers remain. Access to specialized pediatric CR centers is limited. Insurance reimbursement can be a hurdle. Furthermore, maintaining adherence to a long-term program requires significant commitment from both the child and their family. The development of innovative delivery models, such as the tele-rehabilitation approach studied by Long et al. (2019), is a promising avenue to overcome some of these barriers and increase accessibility.

CONCLUSION

The evidence is compelling and conclusive: a comprehensive, medically supervised cardiac rehabilitation exercise program is a safe, effective, and essential intervention for children with stable reduced cardiac function. It directly counters the deleterious effects of physical deconditioning, leading to significant improvements in cardiorespiratory fitness, muscular strength, and, most importantly, health-related quality of life. The focus of modern pediatric cardiac care must continue to evolve from a model of cautious restriction to one of proactive rehabilitation. By integrating CR as a standard of care, the medical community can empower these children to achieve their full physical and psychosocial potential, profoundly altering the trajectory of their lives with chronic heart disease. Future research should focus on optimizing protocols for specific disease states, long-term outcomes, and innovative, accessible program delivery models.

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