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From the Bench to the Field: The Paradigm Shift in Sports Qualification for Pediatric Congenital Heart Disease

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Abstract

Background: Historical approaches to pediatric congenital heart disease (CHD) favored rigorous physical restrictions to prevent arrhythmias and sudden cardiac death. This clinical overprotection paradoxically drives the epidemic of obesity, physical deconditioning, and the psychosocial isolation of patients. **Objective:** To synthesize current evidence-based medicine (EBM) guidelines and provide a practical exercise prescription framework for clinicians, physical education teachers, and sports

professionals. **Methods:** A narrative literature review was conducted utilizing PubMed, Scopus, and regional academic databases. The analysis centered on the latest European Society of Cardiology (ESC) and American Heart Association (AHA) guidelines, supplemented by clinical trials detailing exertion hemodynamics and public health reports. **Results:** The clinical paradigm has shifted from absolute restrictions to individualized, safe activity. Children with mild, uncorrected defects or fully repaired simple anomalies require no limitations. In complex palliative states, such as Fontan circulation, activating the peripheral muscle and respiratory pumps is crucial. Objective risk stratification relies exclusively on cardiopulmonary exercise testing (CPET). EBM refutes the myth of a high risk of exercise-induced sudden cardiac death in stable CHD patients. **Conclusion:** Medical professionals must transition from issuing routine physical education exemptions. The FITT principle should be routinely applied in children with CHD to bridge the gap between cardiac safety and proper psychosocial development, ultimately improving their quality of life.

Keywords: Congenital Heart Disease; Physical Activity; Fontan Circulation; Sudden Cardiac Death; Health-Related Quality of Life; Sports Cardiology.

1. Introduction

Congenital heart disease (CHD) represents one of the most significant clinical challenges in pediatric cardiology, affecting nearly 1% of live births. For many decades, the historical therapeutic approach was heavily reliant on profound caution and the rigorous restriction of physical activity. Primary care physicians and specialists routinely issued absolute exemptions from physical education classes and strictly prohibited participation in competitive sports, driven primarily by the theoretical fear of precipitating life-threatening ventricular arrhythmias, decompensating heart failure, or inducing sudden cardiac death (SCD) during maximal exertion [1, 2].

However, contemporary clinical and epidemiological data conclusively demonstrate that this chronic clinical overprotection yields significantly more harm than benefit. The avoidance of movement leads to early and profound deconditioning of the cardiorespiratory system [3]. The lack of systematic physical exertion among children with CHD directly results in a drastic decline in health-related quality of life (HRQOL) across all studied domains: physical, emotional, and social [4]. The psychosocial burden of this population currently places them on par with patients suffering from end-stage renal disease, severe treatment-resistant asthma, or advanced obesity [4]. Furthermore, physical education classes play a fundamental role in the psychosocial integration of peers; their absence inhibits the development of motor skills, fosters feelings of isolation and stigmatization, and lowers self-esteem in young patients [2, 4].

The broader public health implications of physical inactivity in pediatric CHD patients align with modern epidemiological challenges observed across the general youth population. Systematic integration of health education and tailored physical activity is paramount in preventing secondary lifestyle diseases, a concern heavily emphasized in contemporary sports medicine and public health discourse [5]. Addressing these multifaceted health determinants requires a holistic approach that bridges specialized cardiac care with general health education frameworks [6]. The objective of this review is to synthesize contemporary EBM guidelines and establish a practical algorithm for the qualification and programming of safe physical exertion for children with structural congenital heart defects and those following complex palliative procedures.

2. Materials and Methods

Search Strategy A targeted narrative literature review was conducted to identify current guidelines, meta-analyses, and clinical trials regarding physical activity and sports participation in the pediatric CHD population. Electronic searches were performed using PubMed, MEDLINE, Scopus, and regional open-access journal databases (apcz.umk.pl). The primary review timeframe spanned from January 2013 to May 2026, capturing the publication of paradigm-shifting documents from the AHA and ESC, as well as their evolution into contemporary clinical standards.

Keywords and Search Syntax The search strategy utilized both Medical Subject Headings (MeSH) and free-text terms. The primary search queries included: ("Congenital Heart Defects"[Mesh] OR "Congenital Heart Disease") AND ("Exercise"[Mesh] OR "Sports"[Mesh] OR "Physical Education"). To address specific clinical niches, the search was expanded to include: "Fontan Circulation AND Respiratory Pump", "Transposition of Great Arteries AND Arterial Switch", "Bicuspid Aortic Valve AND Aortopathy", and "Cardiopulmonary Exercise Testing AND Pediatrics". To maintain a consistent narrative review framework, only peer-reviewed articles published in the English language were included. Isolated case reports and non-peer-reviewed clinical commentaries were explicitly excluded.

3. Results and Discussion

3.1. The Paradigm Shift: From Absolute Restrictions to Targeted Exercise Prescriptions

The historical treatment model assumed the complete dominance of anatomy over functional capacity. This stemmed from an ingrained fear of exercise-induced sudden cardiac death. Contemporary evidence refutes this caution. A comprehensive decade-long registry of athlete deaths associated with the National Collegiate Athletic Association (NCAA) estimated the overall incidence

of SCD at 1 case per 53,703 athlete-years [7]. While these data are primarily derived from young adult collegiate athletes, they reflect a broader physiological trend applicable to the pediatric population: post-mortem examinations most frequently reveal autopsy-negative sudden unexplained death (AN-SUD – 25%), coronary artery anomalies (11%), previously undiagnosed myocarditis (10%), and hypertrophic cardiomyopathy (8%) [7]. Repaired congenital structural heart defects constitute merely a statistical margin and are not the primary triggers of SCD [7, 8].

In light of these data, the mathematical risk of a major cardiac event during sports in a child following successful CHD correction with preserved ventricular systolic function and no documented ventricular arrhythmias is negligible. The 2020 ESC documents formally codified this approach, shifting the clinician's key question from "what must the patient avoid?" to "what type of physical exercise can we safely prescribe?" [1].

3.2. Psychosocial Barriers: Vulnerable Child Syndrome and Teacher Anxiety

Unfortunately, shifting the official ESC and AHA guidelines encounters immense psychosocial resistance. Paradoxically, environmental conditioning often becomes a greater barrier to children's physical activity than the anatomical defects themselves [2]. This phenomenon, described in the literature as "Vulnerable Child Syndrome," manifests as excessive, irrational parental anxiety regarding the offspring's health, even after the complete cure of the defect [9]. From a pedagogical and psychological perspective, the attitudes of physical education teachers and sports instructors play a crucial role in shaping the child's physical confidence and willingness to participate in sports [10]. Current research highlights that the quality of sports instruction and the psychological preparedness of the pedagogical staff directly impact the health-related quality of life in chronically ill youth [11]. Parental overprotection directly restricts the child's acquisition of basic motor skills [12].

The second critical factor is the school environment. Even when provided with a clear clearance certificate from a pediatric cardiologist, students are often intentionally marginalized and excused from physical education classes under the guise of "safety". However, structured interventions prove that this barrier can be overcome; targeted exercise training programs have been shown to significantly improve daily activity levels and physical confidence in adolescents with CHD [13]. To bridge this clinical gap and empower educators, pediatric cardiologists should transition from writing vague notes to issuing a standardized "Sports Passport". To be effective in a school environment, such a document must clearly specify:

Clearance Status: Explicitly stating if the child is fully cleared, cleared with restrictions, or temporarily suspended.

Allowed and Prohibited Activities: Categorizing sports into permitted dynamic aerobic activities and forbidden high-risk isometric exercises.

Intensity Limits: Defining maximum effort using age-appropriate subjective tools (e.g., OMNI Scale limits) rather than maximum heart rate.

Emergency Protocol: Outlining red flag symptoms (e.g., exertional chest pain, syncope) and immediate actions required by the teacher.

3.3. The Fontan Paradox: Cooperation of the Peripheral Muscle and Respiratory Pumps

Managing patients with single-ventricle (SV) physiology requires a perfect understanding of their unique, non-physiological hemodynamics [14]. Following the definitive Fontan operation, pulmonary blood flow is entirely passive and depends completely on the transpulmonary gradient [14]. Because these patients lack a subpulmonary ventricle to actively pump blood to the lungs during exertion, their peak oxygen uptake (VO_{2peak}) is objectively reduced to approximately 50-65% of the peer norm [15].

Historically, this phenomenon led to the mandate of a sedentary lifestyle. However, recent findings in exercise physiology demonstrate that appropriate training is a mechanical necessity for post-Fontan patients [16]. The lack of a subpulmonary ventricle is functionally compensated by two distinct peripheral mechanisms:

- 1. The Skeletal Muscle Pump:** During dynamic lower-limb exercises, muscle contractions alternately compress the deep veins of the legs. This phenomenon potentially increases central venous pressure and physically "pushes" blood through the pulmonary capillary bed [17].
- 2. The Respiratory Pump:** Real-time flow magnetic resonance imaging has proven the critical role of deep breathing during exertion in Fontan circulation [18]. During forced inspiration, the drop in intrathoracic pressure mechanically "sucks" blood from the caval veins into the pulmonary space [18].

A sedentary lifestyle leads to limb muscle atrophy and respiratory muscle weakness, which directly decreases venous return and precipitates Fontan circulation failure [16]. Furthermore, chronotropic incompetence (due to postoperative sinus node damage) is common in these children. This necessitates abandoning target heart rate zones. Exertion should be qualified subjectively using age-appropriate scales, such as the visual OMNI Scale or modified 0-10 RPE scale for younger children, reserving the classic 15-point Borg scale for older adolescents [16].

3.4. CPET-Based Qualification and Lesion-Specific Prescriptions

Cardiopulmonary exercise testing (CPET) has become the EBM gold standard in sports cardiology, without which reliable risk stratification is impossible [19]. The updated guidelines for key structural defects are presented below.

Tetralogy of Fallot (ToF): The main issue years post-correction is free pulmonary valve regurgitation, leading to right ventricular (RV) dilation. Regular moderate-intensity training is highly recommended [20]. Clearance for competitive sports requires ruling out dangerous arrhythmias via 24-hour Holter ECG and CPET [20].

Coarctation of the Aorta (CoA): Due to the loss of aortic arch elasticity post-surgery, these patients can develop massive, pathological hypertension even with moderate exertion, despite normal resting blood pressure [21]. CPET is absolutely obligatory. They are strictly prohibited from participating in maximal static and isometric sports (e.g., weightlifting), which pose a risk of sudden pressure spikes and aortic dissection [21].

Transposition of the Great Arteries (TGA): The arterial switch operation involves reimplantation of the coronary arteries. In many young patients, asymptomatic stenosis of the proximal coronary vessels may develop over the years [22]. CPET is utilized to search for hidden myocardial ischemia [22].

Bicuspid Aortic Valve (BAV) and Aortopathies: BAV is a genetically determined disease of the aortic wall predisposing to ascending aorta aneurysms [23]. Heavy resistance training generates wall stress, creating a rupture risk [23]. When aortic dimensions exceed normal z-scores, only moderate dynamic sports are recommended [24].

Simple Shunt Lesions (ASD, VSD, PDA): Patients without symptoms of pulmonary hypertension following structural closure and an appropriate recovery period return to the status of the "healthy population" and can participate in sports without restrictions [1, 25].

3.5. Application of the FITT Principle in Pediatric Cardiology

To translate ESC guidelines into actionable recommendations, the FITT principle (Frequency, Intensity, Time, Type) must be rigorously applied, with careful stratification based on defect severity [26, 27].

Frequency: Patients with simple, fully repaired lesions should adhere to standard WHO guidelines, aiming for at least 60 minutes of daily physical activity. For patients with complex palliative states (e.g., Fontan), structured sessions 3 to 5 times a week are recommended, prioritizing spontaneous outdoor play in younger patients [26].

Intensity: In patients with complex defects, HRmax calculations should be abandoned. Intensity must be guided by subjective scales (e.g., 4-6 on a 10-point OMNI scale for children, or 11-14 on the Borg scale for adolescents), targeting moderate exertion [16, 27].

Time: The minimum duration of continuous exertion aimed at improving the VO2peak parameter in compromised patients is 30 to 60 minutes. An obligatory warm-up and cool-down section is critical to prevent post-exercise blood pressure drops and vasovagal syncope [26, 27].

Type: The desired profile includes dynamic and aerobic exertion (swimming, brisk walking, cycling) [26]. Specific, isolated resistance training of small leg muscle groups is prescribed to SV patients to power the peripheral muscle pump [17]. Crucially, any isometric exercises utilizing heavy resistance must strictly avoid the Valsalva maneuver. Sustained breath-holding generates massive spikes in intrathoracic pressure, which acutely shuts down the passive venous return in Fontan circulation, predisposing the young patient to instantaneous syncope.

4. Conclusions

1. The historical paradigm based on fear, resulting in absolute physical restrictions in children with CHD, is medically harmful and must be permanently replaced by targeted, individualized training programs based on CPET evaluations [1, 2].
2. Environmental overprotection currently constitutes a more significant barrier to sports participation than actual cardiological contraindications. Establishing targeted exercise programs and issuing detailed "Sports Passports" can effectively alleviate school educators' anxiety and improve patients' activity levels [9, 13].
3. In children with complex Fontan physiology, applying leg resistance training and breathing exercises triggers a crucial peripheral and respiratory suction pump effect, saving the patient from physiological deconditioning [17, 18].
4. Rigorous CPET monitoring is mandatory in high-risk patients to detect dormant exercise-induced pulsatile hypertension post-CoA, arrhythmias in ToF, and ischemia risks in TGA [20, 21, 22].

5. The design of a training session for children with complex CHD should incorporate FITT criteria, explicitly utilizing age-appropriate perceived exertion scales (e.g., OMNI) instead of maximum heart rate to safely bypass chronotropic incompetence [16, 27].

Disclosures

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