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(REVIEW ARTICLE)

Comparative growth outcomes in pediatric congenital heart disease: Analyzing the dichotomy between cyanotic and Acyanotic conditions

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Abstract

Introduction: Congenital heart disease (CHD), the most common birth defect, significantly affects nearly 1% of newborns, influencing their growth and developmental trajectories. Altered hemodynamics and oxygen delivery in CHD can severely impact fetal and postnatal growth, making early intervention crucial.

Objective: This review aims to synthesize existing literature on the growth patterns of children with CHD, focusing on comparing cyanotic and acyanotic conditions and their implications on early medical and nutritional interventions.

Methods: We conducted a systematic review, synthesizing data from studies that examined growth metrics in children with cyanotic and acyanotic CHD, emphasizing the need for early intervention.

Results: The review included comprehensive data analysis from studies highlighting significant growth failure in both cyanotic and acyanotic CHD patients. Cyanotic patients exhibited more pronounced stunting, related to chronic hypoxemia, whereas acyanotic patients showed a higher incidence of wasting. Notably, early catheter or surgical interventions, especially in acyanotic CHD, were associated with improved growth outcomes, as were nutritional support strategies. Cyanotic CHD children often faced severe growth challenges, exacerbated by complications like pulmonary hypertension. The acyanotic group, while similarly at risk for growth difficulties, showed different patterns, possibly due to a lack of hypoxemia. Longitudinal monitoring and tailored interventions, including nutritional support and timely surgical repair, are vital for optimizing growth and overall health outcomes in these populations.

Conclusion: The findings underscore the distinct growth challenges faced by children with cyanotic versus acyanotic CHD, highlighting the importance of tailored medical and nutritional interventions. Early recognition and appropriate intervention strategies are crucial for promoting optimal growth and development in this vulnerable population, thereby improving their long-term health and quality of life.

Keywords: Congenital Heart Disease; Growth Impairment; Cyanotic vs. Acyanotic; Nutritional Interventions; Surgical Intervention

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1. Introduction

Congenital heart disease (CHD), the most prevalent type of birth defect, affects nearly 1% of newborns and has significant implications on the growth and development of affected individuals. The relationship between compromised fetal growth and CHD has been well-documented, with studies suggesting that intrauterine growth restriction (IUGR) is more common in fetuses diagnosed with CHD compared to their healthy counterparts. This phenomenon is attributed to the altered hemodynamics and oxygen delivery associated with heart defects, which can impair nutrient and oxygen delivery to the developing fetus, leading to reduced fetal growth and potential long-term growth deficits. The impact of CHD on fetal growth underscores the importance of early diagnosis and intervention strategies aimed at mitigating these effects and promoting optimal fetal development. (1-4)

Beyond the fetal stage, infants and children with CHD continue to face challenges in achieving normal growth patterns. The first few years of life represent a critical period for growth and development, and children with CHD often exhibit delayed growth during this period. Factors such as reduced caloric intake, increased energy expenditure, frequent respiratory infections, hospitalization and prolonged illnesses contribute to these growth delays. Malnutrition and failure to thrive are particularly prevalent among infants with severe CHD, necessitating comprehensive nutritional support and close monitoring of growth parameters. The negative impact of CHD on infantile growth highlights the complex interplay between cardiac function, nutritional status, and overall health, reinforcing the need for multidisciplinary care approaches that address the unique needs of these children. (5-9)

As children with CHD transition into childhood and approach puberty, the potential for growth deficits persists. The pubertal growth spurt can be delayed or diminished in children with CHD, further compounding the challenges associated with achieving normal stature and weight gain. The mechanisms underlying these growth disturbances are multifactorial, involving not only ongoing nutritional challenges and reduced physical activity levels but also potential endocrine disruptions. Research indicates that children with CHD, particularly those with cyanotic defects, are at increased risk for delayed puberty and reduced final adult height. These findings highlight the necessity of longitudinal studies to understand the full spectrum of growth patterns in children with CHD, from infancy to adulthood, and to create tailored therapies to support normal growth and development across these critical stages in life (10-12).

Reviewing the research on growth in infants and children with CHD is critical due to the complicated interplay between heart defects and growth outcomes in this vulnerable population. In addition, understanding the nuances of linear growth and weight gain in children with cyanotic versus acyanotic congenital heart disease (CHD) is imperative for advancing pediatric healthcare. A comprehensive review of the literature on this subject is essential, as it sheds light on the distinct growth trajectories and nutritional needs inherent to these two groups. Children with cyanotic CHD often face more severe growth challenges, potentially exacerbated by chronic hypoxemia, leading to more pronounced growth retardation compared to their acyanotic counterparts. By thoroughly examining existing studies, healthcare professionals can identify critical growth trends, enabling the development of tailored monitoring and intervention strategies. This knowledge not only helps to optimize the nutritional status and overall growth of these vulnerable pediatric populations, but it also improves long-term outcomes by reducing growth-related complications, emphasizing the importance of targeted nutritional support and timely surgical interventions. Such a literature review is pivotal for establishing evidence-based guidelines that ensure improved health and quality of life for children with various forms of CHD.

Objectives

The objective of our review is to comprehensively analyze and synthesize current research findings on the growth patterns in infants and children with Congenital Heart Disease (CHD) focusing on the underlying causes of their unique growth challenges, the difference between cyanotic and acyanotic CHD, the effectiveness of existing nutritional and medical interventions, and the impact of these factors on their overall health and development.

2. Methods

Database Search: We conducted a comprehensive search in databases including PubMed, Scopus, Web of Science, and Google Scholar using keywords: “growth in congenital heart disease," "pediatric CHD and growth outcomes," "nutritional status in CHD children," and related terms.

Study Selection: Initial screenings based on titles and abstracts were followed by full-text reviews to assess the relevance of the studies.

Data Extraction: Key information such as study design, population, intervention details, outcomes related to growth, and nutritional interventions were systematically extracted and tabulated.

Quality Assessment: We evaluated the quality of the included studies using standardized checklists appropriate for each study design such as the Newcastle-Ottawa Scale for observational studies and the Cochrane Risk of Bias tool for randomized trials.

2.1. Inclusion Criteria

- Population: Studies involving infants and children diagnosed with CHD.
- Outcome of Interest: Research focusing on growth metrics, nutritional status, or developmental outcomes related to growth.
- Study Type: Peer-reviewed observational studies, clinical trials, cohort studies, and systematic reviews.
- Publication Date: Studies published in the last 20 years to ensure the relevance and timeliness of the data.
- Language: Articles published in English**.**

2.2. Exclusion Criteria

- Population: Studies focusing on adults or patients without a CHD diagnosis.
- Irrelevant Outcomes: Research not specifically addressing growth or nutritional outcomes in the CHD pediatric population.
- Study Type: Editorials, opinion pieces, case reports, and non-peer-reviewed literature.
- Incomplete Data: Studies with incomplete data or lacking specific outcomes relevant to the review's objectives.
- Language: Articles published in languages other than English without available translations.

2.3. Study Selection and Data Extraction

Two reviewers independently screened the titles and abstracts of the retrieved records, followed by a full-text review to determine eligibility based on the inclusion and exclusion criteria. Data extracted included study design, sample size, patient demographics, types of CHD, intervention details, and key findings related to growth and nutritional outcomes.

2.4. Analysis of Included Studies

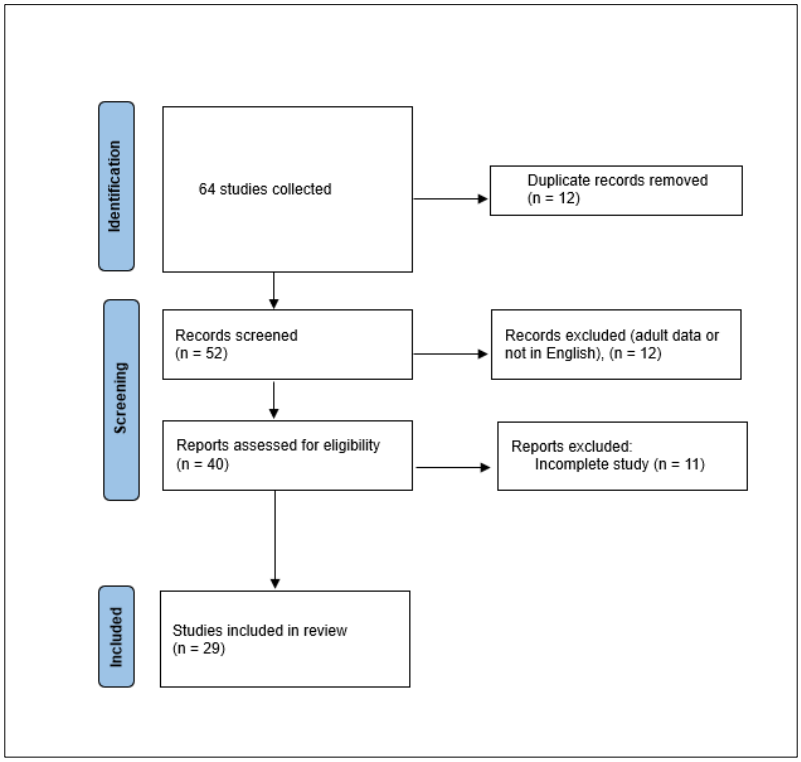

Figure 1 PRISMA Data of the Review

The review encompassed 30 studies, incorporating data from a significant patient cohort, with individual study sample sizes including 135, 363, 216, 551, 856, 10,027, and 14,319 patients, along with insights derived from 38 and 23 articles. Additional specific studies analyzed sample sizes of 291, 1,149, 228, 373, 194, 734, and 148 patients, as detailed in Table 1. Table 2 provided a comparative analysis of patients with cyanotic versus acyanotic congenital heart disease (CHD). The synthesized findings focused on evaluating the interplay between surgical interventions, enhancements in nutritional status, and their cumulative impact on growth outcomes, alongside exploring the factors that contribute to postoperative recovery and sustained growth in the long term.

3. Results

We reviewed and analyzed the key findings from the studies on growth patterns and nutritional status in children with congenital heart disease (CHD), particularly focusing on those with ventricular septal defect (VSD). (table 1)

Table 1 Synthesis of Research on Growth and Nutritional Status in Children with Congenital Heart Disease: A Comprehensive Overview

Author(s)	Year	Heart Disease	Key Findings	Number of Patients
da Silva, V. M., et al.(13)	2007	Congenital Heart Disease	Characterized growth and nutritional status, highlighting significant variables for malnutrition.	135
Jacobs, E., et al.(16)	2000	Symptomatic Congenital Heart Disease	Examined postnatal growth in Chinese children, revealing significant growth retardation.	363
Jiang, B., et al.(14)	2006	General	Found smaller coronary artery diameters in children with lower birth weight.	216
Aguilar, D. C., et al. (15)	2015	Various (including ToF, VSD)	Explored growth patterns, indicating the need for monitoring growth and metabolic risks.	551
Daymont, C., et al.(7)	2013	Congenital Heart Disease	Detailed growth patterns, indicating early decreases in growth trajectories.	856
Nembhard, W. N., & Loscalzo, M. L. (17)	2009	CHDs including VSD and ToF	Assessed fetal growth among infants with CHDs, exploring variations in SGA or LGA prevalence.	10,027
Nembhard, W. N., et al. (18)	2007	Congenital Heart Defects	Evaluated ethnic disparities in PTB risk among infants with CHDs, adjusting for fetal growth.	14,319
Ghanchi, A., et al.(19)	2020	Congenital Heart Defects	Conducted a meta-analysis on CHD and growth restriction, estimating the proportion of SGA among children with CHD.	38 studies
Aliasi, M., et al. (20)	2022	Isolated Congenital Heart Defects	Reviewed literature on birthweight in children with isolated CHD, finding impaired growth and a higher risk of SGA.	23 articles
Aliasi, M., et al.(21)	2023	Isolated Congenital Heart Disease	Compared the BW of isolated CHD cases to their siblings, showing significantly lower BW z scores in CHD cases.	291
Derridj, N., et al.(22)	2024	CHD (Preterm and Growth-Restricted)	Assessed neurodevelopmental risks among preterm and growth-restricted youth with CHD, suggesting specific subgroup risks.	19 studies
Murni, I. K., et al.(23)	2023	Congenital Heart Disease	Evaluated undernutrition factors among children with CHD, identifying several associated clinical and demographic factors.	1,149
Tsega, T., et al.(50)	2022	Congenital Heart Disease	Determined the nutritional status and associated factors of pediatric patients with	228

			CHD, highlighting the prevalence of undernutrition.	
Woldesenbet, R., et al.(24)	2021	Congenital Heart Disease	Assessed nutritional status among children with CHD, finding a high prevalence of malnutrition.	373
Batte, A., et al. (25)	2017	Congenital Heart Disease	Described malnutrition prevalence among children with CHD, associating it with anaemia and heart failure.	194
Ruan, X., et al.(26)	2024	Congenital Heart Disease	Evaluated undernutrition prevalence and associated factors in CHD children pre-surgery, highlighting key demographic and clinical associations.	734
Tesfaye, K., & Tsega, T. (27)	2023	Congenital Heart Disease	Assessed the impact of cardiac intervention on nutritional status in malnourished CHD children, noting significant growth recovery post-intervention.	148
Soliman, A. T., et al. (5)	2012	Growth and IGF-I in Children with VSD Pre- vs. Post-Surgery	Improved height and BMI post-surgery correlated with increased IGF-I levels, indicating a role of the GH/IGF-I system in postoperative growth.	27
Soliman, A. T., et al. (28)	2001	Growth, Endocrine Function, and Echocardiographic Parameters in VSD Children	Growth failure correlated with the size of the shunt and abnormal hemodynamic, impacting nutrition and decreasing IGF-I synthesis.	88
Vaidyanathan, B., et al. (29)	2009	Nutritional Recovery in Malnourished Children Post-CHD Correction	Post-surgery nutritional status improvement was influenced by preoperative status, birth weight, and parental anthropometry.	476
Palleri, D., et al. (30)	2023	Growth Impact of Moderate and Severe CHD in Italian Children	CHD severity affected growth, with moderate and severe cases showing lower z-scores, especially notable in children under 2 years and over 5 years.	657
Okoromah, C. A. N., et al. (31)	2011	Malnutrition in Children with CHD	High prevalence of malnutrition in children with CHD, especially those with cyanotic forms, influenced by factors like anaemia and heart failure.	73
Ratanachu-Ek, S., et al. (32)	2011	Nutritional Status Pre- and Post-Cardiac Surgery in CHD Patients	Cardiac surgery significantly improved the nutritional status, although complete catch-up growth was not achieved by all.	161
Varan, B., et al. 934) (33)	1999	Malnutrition and Growth Failure in CHD with/without Pulmonary Hypertension	Malnutrition and growth failure were more prevalent in patients with pulmonary hypertension, especially in cyanotic patients.	89
Dinleyici, E. C., et al. (34)	2007	IGF-1, IGFBP-3, GH Levels in CHD Children: Relation to Nutritional Status and Cardiac Functions	Cyanosis and abnormal left ventricular functions influenced serum IGF-1 levels, which were associated with malnutrition.	50

Uke, P., et al.(35)	2023	Neurodevelopmental Assessment of Children with CHD	Developmental delays were prevalent in CHD children, more in cyanotic than acyanotic, highlighting the need for early intervention.	94
El-Koofy, N., et al.(36)	2017	Nutritional Rehabilitation in CHD Children with Left to Right Shunt	Nutritional counselling and rehabilitation significantly improved the nutritional status and clinical outcomes in CHD children.	50
He, Q., et al. (37)	2024	Failure to thrive (FTT) in Pediatric CHD Patients	High prevalence of FTT in CHD patients, with risk factors including preoperative anemia, more complex CHD types, and lower birth weight.	13,256
Robyn, S., et al. (38)	2024	Undernutrition in CHD Children in Low-Income Environments	Persistent undernutrition pre- and post-cardiac surgery associated with poor growth and development outcomes in a low-income setting.	40

These studies spanning over two decades have shown that children with CHD, including VSD, exhibit significant growth and nutritional challenges. These issues are particularly pronounced in children with symptomatic congenital heart disease, where substantial growth retardation has been observed (Jacobs, E., et al., 2000).(1)

Research indicates a strong correlation between lower birth weight, smaller coronary artery diameters, and congenital heart conditions, suggesting that fetal growth restrictions might influence postnatal cardiac structure (Jiang, B., et al., 2006).

The studies collectively suggest that the degree of malnutrition and growth failure in children with CHD can be influenced by a range of factors, including the size of the shunt, presence of cyanosis, and pulmonary hypertension. These factors contribute to the complex interplay between cardiac physiology, nutritional status, and growth outcomes (Varan, B., et al., 1999; (33) and Dinleyici, E. C., et al., 2007) (35)

However, the impact of CHD on growth is not uniform across all conditions; for example, research focused on Tetralogy of Fallot and VSD has revealed unique patterns of growth impairment and undernutrition, often correlated with the severity of the defect, and associated hemodynamic changes (Nembhard, W. N., et al., 2007(17) ; Nembhard, W. N., and Loscalzo, M. L., 2009).(18)

Surgical or catheter interventions have been shown to significantly improve growth parameters and nutritional status in children with CHD. Postoperative increases in height and BMI have been linked to elevated levels of insulin-like growth factor-I (IGF-I), underscoring the importance of timely surgical intervention in mitigating growth retardation (Soliman, A. T., et al., 2012; (5) and Vaidyanathan, B., et al., 2009).(29)

The persistence of malnutrition and failure to thrive (FTT) post-cardiac surgery remains a significant concern, with several studies indicating that a considerable proportion of children do not achieve complete catch-up growth even after successful surgical correction of the defect (He, Q., et al., 2024; (37) and Robyn, S., et al., 2024) (38).

Multiple studies have highlighted the necessity of regular monitoring for growth and metabolic risks in children with various CHD, as growth disturbances are often early indicators of underlying cardiac issues (Aguilar, D. C., et al., 2014; (15) and Daymont, C., et al., 2013).(7)

In conclusion, the reviewed literature underscores the critical interdependence of cardiac health, nutritional status, and growth in children with CHD, advocating for integrated care approaches that address both the cardiac and nutritional needs of this vulnerable population.

A comparison between growth of children with cyanotic versus acyanotic heart disease is presented in table 2.

Table 2 Linear growth and weight gain in children with cyanotic CHD versus those with acyanotic CHD.

Author(s)	Date of Publication	Number of Patients	Important Findings
Chowdhury et al. (39)	2018	60 (30 cyanotic, 30 acyanotic)	Both groups showed significant growth failure, but stunting was higher in cyanotic patients, whereas wasting was higher in acyanotic patients.
Jacobs et al. (1)	2000	363 (divided into cyanotic and acyanotic groups)	Growth retardation was common; children with acyanotic lesions were more affected in growth than those with cyanotic lesions.
Ulfah et al.(40)	2017	46 (23 cyanotic, 23 acyanotic)	Children with acyanotic CHD had a higher risk of growth velocity failure than those with cyanotic CHD.
Noori et al. (41)	2017	310 with CHD	CHD children had lower weight and head circumference; growth issues were more pronounced in cyanotic patients without pulmonary hypertension.
Maya et al. (42)	2020	52 (aged 24–69 months)	Cyanotic children showed significant growth problems and lower quality of life compared to acyanotic.
Masood & Mehrnoosh (43)	2010	400 with CHD	Growth disorders were more common and severe in cyanotic patients, especially those with pulmonary hypertension.
Soliman et al.(5)	2012	27 with acyanotic CHD	Post-surgical intervention showed increased height and IGF-I levels, indicating improvement in growth after correction of the heart defect.
Soliman et al. (44)	2022	Not specified	Early surgical repair of TOF improved weight gain and ensured normal linear growth but did not result in post-surgical catch-up in length.
Cheung et al. (45)	2003	45 patients	Early TOF repair resulted in normalization of long-term growth and fulfillment of genetic growth potential.
Marino et al. (46)	2020	44 infants (Intervention) vs. 38 (Control)	Implementation of a nutritional pathway improved growth outcomes in infants with acyanotic CHD and reduced PICU-LOS .
Soliman et al.(47)	2022	12 infants with TGA	Variable growth patterns observed post-ASO in infants; most showed improvement in WLZ.
Zhang et al.(48)	2020	3252 patients with CHD	Identified risk factors of malnutrition in acyanotic CHD children; significant improvement in growth post-surgery.
Tsega et al. (50)	2022	228 children with CHD	High prevalence of malnutrition; associated with pulmonary hypertension and older age.
Elsisi A et al. (6)	2009	Not specified	Children with cyanotic CHD experienced early, simultaneous decreases in growth trajectory across weight, length, and head circumference.

The comparison of growth between infants with acyanotic and cyanotic congenital heart diseases (CHD) reveals several important findings: (table 2)

- Growth Failure Common in CHD: Both groups, cyanotic and acyanotic, often experience growth failure, but the patterns and severity may differ. The studies indicate that growth challenges are a prevalent concern for children with both types of CHD, impacting weight, height, and head circumference. Jacobs et al. (2000),(1) Elmoghazy et al. (2018)(49)
- Impact of Surgical Intervention: Surgical or catheter interventions appear to have a significant positive impact on the growth of children with acyanotic CHD, as shown by increased height and insulin-like growth factor-I

(IGF-I) levels post-intervention. Early repair, particularly in cyanotic conditions like tetralogy of Fallot (TOF), has been associated with improved growth metrics post-surgery, suggesting that timely surgical intervention can mitigate some of the growth delays associated with these heart defects. Soliman et al. (2012),(5) , and Cheung et al. (2003)(45)

- Differential Effects on Growth Patterns: Cyanotic children often show more pronounced growth retardation compared to their acyanotic counterparts. This could be due to the greater severity of hypoxemia (low blood oxygen levels) in cyanotic CHD, which might contribute to poor growth. The literature suggests that while acyanotic patients also face growth challenges, the severity and implications can be distinct, with cyanotic patients often experiencing more severe growth impairments. Maya et al. (2020), (42) and Masood & Mehrnoosh (2010).(43)
- Role of Nutritional Interventions: The studies underline the importance of nutritional support for children with CHD, especially before surgical interventions. Nutritional pathways and interventions have shown promise in improving growth outcomes in these patients, emphasizing the need for a multidisciplinary approach to their care, incorporating dietary support alongside medical and surgical treatments. Marino et al. (2020), (46) and Zhang et al. (2020).(48)
- Long-term Growth Outcomes: The long-term growth outcomes post-surgical intervention tend to be more favorable, with many children showing catch-up growth, especially in weight and height. However, some children, especially those with cyanotic CHD, might not achieve complete catch-up growth, indicating a need for ongoing monitoring and support. Soliman et al. (2022) (44,47) and Cheung et al. (2003) (45)
- Variability in Growth Responses: The response to interventions and the overall growth trajectory can vary widely among children with CHD. Factors such as the timing of the surgery, the presence of other health issues, and the specific type of CHD can influence growth outcomes, highlighting the importance of individualized care plans. Soliman et al (2022), (44,47) and Tsega et al. (2022). (50)
- In conclusion, the comparison elucidates that those children with cyanotic and acyanotic CHD face significant growth challenges, with cyanotic CHD often associated with more severe growth retardation. Surgical interventions, especially when conducted early, can significantly improve growth outcomes, underscoring the importance of timely and multidisciplinary care in managing these complex conditions. The insights call for a proactive approach in monitoring and supporting the growth of children with CHD, tailored to the specifics of their heart defects and overall health status.

4. Discussion

Various factors appear to contribute to growth retardation in children with congenital cyanotic and acyanotic heart diseases. (table 3) Growth retardation in these children is influenced by a variety of complex mechanisms, including metabolic demands, nutritional challenges, and the physiological impacts of their specific heart conditions. By examining the distinct and overlapping causes in cyanotic versus acyanotic heart diseases, healthcare providers can better understand the challenges these children face and develop more targeted strategies for managing their growth and overall health. (39-50)

Table 3 Comparison of Growth Retardation Causes in Children with Congenital Cyanotic and Acyanotic Heart Diseases

Cause	Cyanotic Heart Diseases	Acyanotic Heart Diseases
Chronic Hypoxemia	Prolonged low oxygen levels impair growth.	Not typically present.
Increased Metabolic Demand	Heart works harder due to low oxygen levels.	Increased cardiac workload from left-to-right shunts.
Nutritional Deficiencies	Feeding difficulties and poor appetite.	Feeding difficulties can also be present.
Frequent Infections	Recurrent respiratory infections due to decreased oxygenation.	Risk from pulmonary over circulation and heart failure.
Pulmonary Hypertension	Can worsen heart function and growth.	Can develop from over circulation, affecting growth.
Reduced Exercise Tolerance	Limits physical activity, affecting growth.	Congestive heart failure can reduce exercise tolerance.
Delayed Puberty	Hypoxemia can delay puberty, affecting growth spurts.	Less commonly associated with delayed puberty.

Failure to Thrive	Due to increased metabolic demands and poor feeding.	Common due to similar reasons as cyanotic conditions.
Malnutrition	Feeding difficulties can lead to malnutrition.	Especially in severe cases or post-surgery.
Respiratory Distress	Can impair feeding and growth due to infections or hypoxemia.	Pulmonary edema or infections can cause distress.
Surgical Interventions	Multiple surgeries impact growth.	Same impact as in cyanotic conditions.
Chronic Illness Stress	Affects growth hormone axis and nutritional status.	Chronic illness stress impacts overall growth.

4.1. Effect of CHD on Birth Size and Infantile Growth

Congenital Heart Disease (CHD) is associated with significant growth challenges starting from birth. Infants with CHD often present with reduced birth size, including low birth weight and shorter length, which are crucial indicators of their overall health and developmental prospects. Studies by da Silva et al. (2007) (13) and Nembhard et al. (2009)(18) have highlighted a notable trend towards small for gestational age (SGA) metrics in this population, suggesting that the hemodynamic alterations and oxygen delivery disruptions common in CHD may impede fetal growth (da Silva, V. M., et al., 2007); (13) (Nembhard, W. N., & Loscalzo, M. L., 2009). (17) Moreover, Jacobs et al. (2000) (1) found that postnatal growth in children with symptomatic CHD was significantly retarded, emphasizing the enduring impact of CHD on growth beyond the fetal stage (Jacobs, E., et al., 2000).(1)

4.2. Effect of CHD on Childhood Growth in Weight and Stature

During childhood, the influence of CHD extends, affecting both weight and stature negatively. The study by Daymont et al. (2013) (7) detailed the persistent growth deficits experienced by children with CHD, marked by early and sustained decreases in growth trajectories. Such growth impairments are further corroborated by Aguilar et al. (2014), who noted that children with various forms of CHD, including Tetralogy of Fallot and Ventricular Septal Defect, showed altered growth patterns necessitating ongoing growth and metabolic risk monitoring (Daymont, C., et al., 2013); (7) and (Aguilar, D. C., et al., 2014). (17) The chronic cardiac stress, experiencing more frequent and prolonged illnesses, alongside the metabolic demands posed by CHD, is likely contributors to the compromised growth observed in this demographic.

4.3. Effect of CHD on Pubertal Growth and Nutrition

Puberty is a critical growth phase that can be significantly disrupted by CHD. The interplay between growth hormone (GH)/Insulin-like Growth Factor-1 (IGF-I) axis and CHD is pivotal, with Soliman et al. (2012) (5) illustrating that postoperative enhancements in height and Body Mass Index (BMI) were associated with increased IGF-I levels. Such findings underscore the role of the GH/IGF-I system in facilitating catch-up growth during the postoperative period (Soliman, A. T., et al., 2012). (5) Additionally, growth failure in this group has been linked to the size of the cardiac shunt and abnormal hemodynamics, which can affect nutritional status and decrease IGF-I synthesis, as noted by Soliman et al. (2001) (Soliman, A. T., et al., 2001).(28)

4.4. Postoperative Change in Growth and Nutrition in Children with CHD

The postoperative phase in children with CHD can be a transformative period with respect to growth and nutrition, albeit with varying degrees of success. While some children experience significant improvements, a complete catch-up in growth is not universal. Vaidyanathan et al. (2009) (29) emphasized that the amelioration in nutritional status post-surgery is significantly influenced by the preoperative nutritional condition, birth weight, and parental anthropometry. This highlights the importance of a comprehensive preoperative assessment and the potential for nutritional interventions to enhance postoperative outcomes (Vaidyanathan, B., et al., 2009). (29) , Palleri et al. (2023) (30) further elaborated on how the severity of CHD impacts growth, with children suffering from moderate to severe forms displaying notably lower growth z-scores, especially among specific age groups (Palleri, D., et al., 2023).(30)

4.4.1. Cyanotic vs. Acyanotic CHD: Growth Implications

Children with cyanotic CHD, as reported by Chowdhury et al. (2018) (39) and Maya et al. (2020), tend to exhibit pronounced stunting, a manifestation likely tied to chronic hypoxemia, increased pulmonary blood flow while decreasing systemic blood flow and its metabolic consequences. The compounded effect of decreased oxygen saturation and potential complications such as pulmonary hypertension, as highlighted by Masood & Mehrnoosh (2010), (43)

intensifies the risk of severe growth disorders in this group. These children not only face challenges in linear growth but also encounter broader health issues that can diminish their quality of life.

Conversely, acyanotic patients, while also experiencing growth challenges, often present a different pattern of growth impairment, predominantly characterized by wasting, as noted by Chowdhury et al. (2018) (39) and Ulfah et al. (2017). (40) The disparity in growth velocity failure rates between acyanotic and cyanotic children could be reflective of the differences in cardiac physiology and the associated metabolic demands or caloric deficits.

4.4.2. Necessity for Early Intervention

The elucidated growth discrepancies between cyanotic and acyanotic children with CHD underscore the imperative for early, tailored medical interventions. Soliman et al. (2012, 2022) (5,47) demonstrate the potential for post-surgical improvement in growth metrics, particularly following corrective interventions for defects like Tetralogy of Fallot (TOF). These interventions not only address the immediate cardiac anomalies but also set the stage for improved growth and development, highlighting the transformative impact of timely surgical or catheter-based corrections.

Moreover, the role of nutritional supplementation cannot be overstated. Marino et al. (2020) provide evidence that a structured nutritional pathway can significantly enhance growth outcomes, particularly in the critical postoperative period. This aligns with the broader literature advocating for integrated early nutritional strategies to combat the multifaceted growth challenges faced by children with CHD.

5. Conclusion

The breadth of research underscores the complex and multifaceted impact of CHD on growth and nutritional status, spanning from infancy through puberty. It emphasizes the need for an early, proactive, continuous, and multidisciplinary approach to manage the unique challenges faced by this population, aiming to optimize their growth and overall health outcomes.

The review distinctly reveals that while all children with CHD are at risk for growth impairments, those with cyanotic conditions often bear a heavier burden, exacerbated by the complexities of their underlying cardiac anomalies. It reinforces the necessity for a proactive, multidisciplinary approach encompassing early surgical or catheter interventions and robust nutritional support to mitigate the adverse growth outcomes associated with CHD. By understanding the specific growth trajectories and underlying risk factors in cyanotic and acyanotic CHD patients, clinicians can better tailor interventions to support optimal growth and improve the overall prognosis for these children.

Recommendations

- Early Surgical Intervention: Given the evidence of improved growth outcomes following surgical corrections, particularly in children with acyanotic CHD, it is recommended to prioritize timely surgical or catheter-based interventions. These procedures can alleviate hemodynamic compromises, thereby potentially mitigating growth impairments and enhancing postoperative recovery of normal growth patterns.
- Integrated Nutritional Support: The studies highlight the critical importance of comprehensive nutritional strategies, especially for children with cyanotic CHD who exhibit more pronounced growth challenges. Implementing tailored nutritional interventions, including dietary counseling and supplemental feeding, should be an integral part of the management plan to ensure optimal growth and development outcomes.
- Longitudinal Monitoring and Multidisciplinary Care: Continuous growth monitoring and a multidisciplinary care approach are crucial for children with CHD, recognizing the dynamic nature of their growth trajectories. Regular follow-ups with a team encompassing cardiologists, nutritionists, endocrinologists, and pediatricians can help in early identification and management of growth delays, ensuring timely interventions and holistic care.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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