Review Article

Association of Congenital Heart Defects with Growth and Developmental Disorders in Early Childhood: A Systematic Review

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ABSTRACT

Congenital heart disease (CHD), affecting ~1% of live births, is linked to growth impairment and neurodevelopmental delays in children. This PRISMA-guided systematic review analyzed PubMed, Web of Science, SCOPUS, and Science Direct for studies on CHD patients (0–18 years) assessing growth (e.g., z-scores) and developmental outcomes (cognitive/motor/language delays). Risk of bias was evaluated using JBI tools. Among 10 included studies, children with CHD—especially cyanotic/complex types—showed significant growth deficits (e.g., 37% malnutrition) and neurodevelopmental delays (e.g., 28% motor delays). Contributing factors included reduced cerebral oxygen delivery and socioeconomic disparities (e.g., low maternal education). Early interventions (e.g., home-based exercise) improved motor outcomes (*p* < 0.001). Severe CHD strongly correlates with growth/developmental impairments. Early interventions may mitigate risks, but standardized assessments and multicenter studies are needed to optimize outcomes.

Keywords: Congenital heart disease (CHD), Neurodevelopmental delay, Growth retardation, Early childhood development.

Introduction

The most prevalent birth abnormality, congenital heart disease (CHD), affects about 1% of live births globally [1]. Advances in surgical and medical management have significantly improved survival rates, with over 90% of children now reaching adulthood [2]. However, survivors often face long-term neurodevelopmental impairments, including cognitive, motor, and language delays, as well as growth retardation [3].

These challenges are particularly pronounced in children with complex CHD, such as single-ventricle physiology or cyanotic lesions, where chronic hypoxia and hemodynamic instability may disrupt early brain development [4]. The association between CHD and impaired neurodevelopment has been increasingly recognized over the past decade. Studies using advanced neuroimaging techniques have demonstrated reduced brain volumes, delayed cortical maturation, and altered white matter integrity in

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infants with CHD even before surgical intervention [5]. These structural abnormalities correlate with functional deficits observed later in childhood, including lower IQ scores, executive dysfunction, and academic difficulties [6]. Concurrently, growth failure—manifested as low weight-for-age and height-for-age z-scores—remains prevalent in this population, further compounding developmental risks [7]. Despite these findings, there remains a critical gap in synthesizing contemporary evidence (2020–2025) on the interplay between CHD subtypes, growth impairment, and developmental outcomes.

Study Objective: This systematic review aims to evaluate the association between CHD and growth/developmental disorders in children aged 0–18 years, identify modifiable risk factors (e.g., nutritional status, age at surgery), and assess the efficacy of early interventions to mitigate delays.

Methods

Study Design: Following the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [8], this systematic review was conducted.

Database Search: A thorough electronic search was performed using a number of bibliographic databases, including Science Direct, Web of Science, SCOPUS, and PubMed. The search strategy focused on English-language studies investigating the association between congenital heart defects (CHD) and growth and developmental disorders in children. Relevant keywords related to CHD, growth retardation, neurodevelopmental delays, and child development were used to ensure a thorough search. Two separate reviewers filtered the search results, chose papers that satisfied the inclusion criteria, extracted data, and used standardized evaluation methods to evaluate the methodological quality of the included studies in order to reduce bias.

Eligibility Criteria: This review included studies (2020–2025, English) assessing CHD's impact on growth (e.g., height/weight) or neurodevelopment (e.g., cognitive/motor delays) in children (0–18 years), with observational, case-control, cohort, RCT, or cross-sectional designs. Excluded were studies on non-CHD populations, adults (>18 years), pre-2020 publications, non-English articles, case reports, reviews without original data, and studies lacking relevant outcome measures.

Data Extraction: Titles and abstracts obtained from the search were evaluated for relevancy using predetermined inclusion and exclusion criteria in order to guarantee correctness and consistency. Reference management software (Rayyan, QCRI) [9] was used to streamline the screening process and reduce bias. Studies deemed relevant by at least one reviewer proceeded to full-text evaluation by both reviewers. Disagreements regarding inclusion were resolved through discussion and consensus.

Key data extracted from included studies encompassed:

- Study title, authors, publication year, and location
- Participant demographics (age, sex, CHD type and severity, diagnostic criteria)
- Growth and developmental assessment methods
- Primary outcomes related to CHD and growth/developmental disorders

The risk of bias in the included studies was assessed using a standardized data extraction form and a recognized methodological quality assessment tool.

Data Synthesis Strategy: A qualitative synthesis of the results was carried out, and summary tables were produced using the data that was retrieved. The best method for evaluating and presenting the findings from the included research was identified after data collection.

Risk of Bias Assessment: The quality of the study was evaluated using the Joanna Briggs Institute (JBI) critical appraisal technique [10] for prevalence studies. Each positive response to the nine questions in this tool is worth one, while any negative, ambiguous, or irrelevant answers are worth zero. The following categories applied to the studies:

- Low quality (score <4)
- Moderate quality (five to seven points)
- Excellent quality (score of ≥8)

The quality of the work was assessed separately by two researchers, and disagreements were settled by consensus and debate.

Results

The search process initially identified 474 publications (Figure 1). After removing 154 duplicates, 320 trials were screened based on their titles and abstracts. Of these, 245 did not meet the eligibility criteria, leaving 75 full-text articles for in-depth evaluation. In the end, 10 studies met the inclusion criteria and were selected for evidence synthesis and analysis. (Table 1) summarizes the demographic and methodological characteristics of the 10 included studies, all published between 2020 and 2025. Each study is listed with key details such as location, study design, sample size, age range, and types of congenital heart disease (CHD) investigated. For instance, a study [11] conducted a cross-sectional study in Indonesia, focusing on 53 children aged 0–2 years with both cyanotic and acyanotic CHD, revealing a high prevalence of

malnutrition (37%) and developmental delays (18.5%). Similarly, another study [12] performed a randomized controlled trial (RCT) in China, demonstrating that a 6-month home-based exercise program significantly improved motor development in 192 infants with simple CHD. The table highlights variations in study populations, with some focusing on severe CHD subtypes [14] on critical CHD) and others comparing CHD to healthy controls [17]. Notably, study [16] provided robust case-control data on 348 pairs, linking CHD to neurodevelopmental delays, while another study [18] emphasized motor impairments in complex CHD using longitudinal follow-up. (Table 2) shows that, growth metrics such as weight-for-age z-scores (WAZ) and height-for-age z-scores (HAZ) were frequently reported, [15] documenting significant growth deficits in cyanotic CHD ($p=0.025$ for HAZ). Developmental outcomes were assessed using tools like the Denver-II [11, 12]), and DASII [13], revealing delays in motor (28%) and mental (26%) domains in high-risk CHD subgroups [20] uniquely correlated reduced cerebral oxygen delivery with impaired brain volume, while a study [19] identified persistent language delays at 24 months. The table underscores that cyanotic CHD and single-ventricle physiology were consistently associated with worse outcomes, whereas interventions like physical therapy [18]) showed promise in mitigating delays.

Discussion

The findings of this systematic review highlight a significant association between congenital heart defects (CHD) and growth and developmental disorders in early childhood. The 10 included studies, published between 2020 and 2025, provide robust evidence that children with CHD—particularly those with cyanotic or complex forms—are at heightened risk for malnutrition, stunting, and neurodevelopmental delays. These results align with a growing body of literature emphasizing the multisystemic impact of CHD, extending beyond cardiovascular morbidity to affect long-term growth and neurocognitive function [21,22]. A consistent theme across the reviewed studies is the high prevalence of growth retardation in children with CHD, particularly in those with cyanotic defects or hemodynamically significant lesions. Study [11] reported that 37% of children aged 0–2 years exhibited malnutrition, while study [15] documented significantly lower height-for-age z-scores (HAZ) in cyanotic CHD ($p=0.025$). These findings are corroborated by recent research indicating that chronic hypoxia, increased metabolic demands, and poor nutrient absorption contribute to growth failure in CHD patients [23,24]. Furthermore, infants with single-ventricle physiology or critical CHD (as seen in study [14]) often experience severe growth restriction due to prolonged hospitalizations, feeding difficulties, and recurrent infections [25,26]. The mechanisms underlying growth impairments in CHD are multifactorial. Reduced systemic blood flow, particularly in duct-dependent lesions, leads to inadequate tissue perfusion and energy deficits [27]. Additionally, frequent surgical interventions and prolonged ICU stays exacerbate catabolic states, further compromising growth [28]. Recent studies have also highlighted the role of endocrine dysfunction, including growth hormone resistance and thyroid abnormalities, in exacerbating growth delays in CHD patients [29,30]. Interventions such as optimized nutritional support and early enteral feeding protocols have shown promise in mitigating these deficits, yet challenges remain in standardizing care across different healthcare settings [31,32]. Neurodevelopmental disorders were another major concern identified in this review. Studies [11,12] utilized the Denver-II developmental screening tool and found delays in 18.5–28% of children with CHD, particularly in motor and cognitive domains. Similarly, study [13] employed the Developmental Assessment Scale for Indian Infants (DASII) and reported significant delays in mental (26%) and motor (28%) development among high-risk CHD subgroups. These findings are consistent with emerging evidence that CHD disrupts early brain development through multiple pathways, including chronic hypoxia, impaired cerebral autoregulation, and microstructural brain injuries [33,34]. Reduced cerebral oxygen delivery was corelated with impaired brain volume [20], reinforcing the concept that hemodynamic instability in CHD directly affects neurodevelopment. This is further supported by advanced neuroimaging studies demonstrating white matter injuries and reduced cortical gray matter in infants with complex CHD [35,36]. Additionally, study [19] identified persistent language delays at 24 months, suggesting that even after surgical correction, children with CHD remain at risk for long-term cognitive and linguistic deficits [37,38]. The role of early intervention in improving neurodevelopmental outcomes was highlighted in study [12], where a 6-month home-based exercise program significantly enhanced motor skills in infants with simple CHD. This aligns with recent recommendations advocating for structured

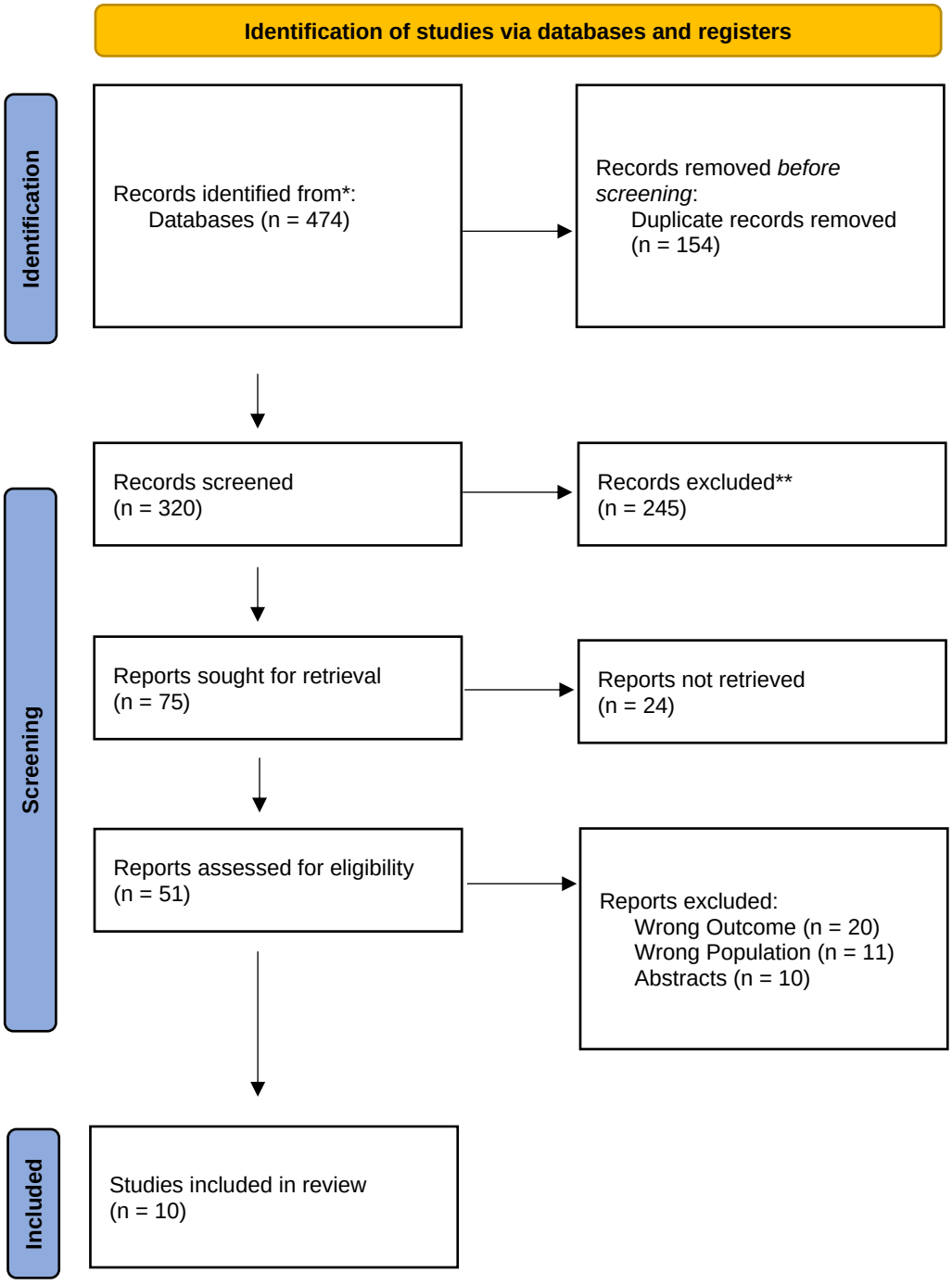

Figure 1: PRISMA 2020 flow diagram for included searches.

Table 1: Demographic and Study Characteristics.

Study (Author, Year) [Ref]	Location	Study Design	Sample Size	Age Range	CHD Types	Key Demographic Notes
Amelia et al. (2023) [11]	Medan, Indonesia	Cross-sectional	53	0–2 years	Cyanotic, acyanotic	61.1% female, malnutrition prevalent
Du et al. (2024) [12]	China	RCT (single-blinded)	192	0–5 years	Simple CHD	Post-cardiac catheterization intervention
Saini et al. (2023) [13]	Central India	Cross-sectional	NM	6–24 months	Cyanotic, acyanotic	High mental/motor delay in cyanotic CHD
Martyniuk et al. (2024) [14]	Ukraine	Longitudinal	62	0–3 years	Critical vs. non-critical	Neurodevelopmental delays post-surgery
Maya et al. (2020) [15]	Indonesia	Cross-sectional	52	24–69 months	Cyanotic, acyanotic	Lower QoL in cyanotic CHD
Wang et al. (2022) [16]	China	Case-control	348 pairs	12–36 months	ASD, VSD, other CHD	Neurodevelopmental delays vs. controls
Sarac & Derelioglu (2025) [17]	Turkey	Cross-sectional	108 CHD, 111 controls	6–15 years	Acyanotic CHD	Delayed dental age in CHD
Huisenga et al. (2023) [18]	Netherlands	Longitudinal	69	6–18 months	CCHD	Motor delays in single-ventricle physiology
Fourdain et al. (2020) [19]	Canada	Longitudinal	49	12–24 months	Mixed CHD	Language delays in CHD infants
Ng et al. (2020) [20]	UK	Prospective cohort	64 CHD, 192 controls	Neonates	TGA, SV physiology	Brain volume reductions in CHD

Table 2: Key Outcomes and Associations**.**

Study (Author, Year)	Growth Metrics	Developmental Outcomes	Key Findings
Amelia et al. (2023) [11]	Weight-for-age, BMI-for-age	Denver-II: 18.5% developmental delay	Cyanotic CHD linked to poor growth ($p<0.05$)
Du et al. (2024) [12]	Height, weight, head circ.	Bayley-III: Improved motor scores ($p<0.001$)	Home-based exercise enhanced motor development
Saini et al. (2023) [13]	NM	DASII: Motor delay (28%), mental delay (26%)	Cyanotic CHD had lower DMeQ/DMoQ ($p=0.0001$)
Martyniuk et al. (2024) [14]	NM	Hammersmith Neurological Exam	29% neurodevelopmental delays in critical CHD
Maya et al. (2020) [15]	HAZ, WAZ, WHZ	Mullen Scales, PedsQL	Cyanotic CHD had lower cognitive scores ($p=0.044$)
Wang et al. (2022) [16]	NM	DST: DQ/MI delays ($p<0.001$)	Prematurity, low maternal education linked to delays
Sarac & Derelioglu (2025) [17]	Dental age delay	NM	CHD associated with delayed dental development ($p=0.009$)
Huisenga et al. (2023) [18]	NM	Infant Motor Profile (IMP)	Single-ventricle CHD had lowest IMP scores ($p<0.004$)
Fourdain et al. (2020) [19]	NM	Bayley-III, MBCDI	Expressive language delays persisted at 24 months

Ng et al. (2020) [20]	Brain volume (T1/T2)	NM	Reduced cerebral oxygen delivery linked to cortical impairment

Table 3: Risk of Bias Assessment.

Study (Author, Year)	Tool Used	Key Biases Identified	Overall Quality
Amelia et al. (2023) [11]	JBI Cross-sectional Checklist	Small sample size, no confounder adjustment	Moderate
Du et al. (2024) [12]	JBI RCT Checklist	Low attrition, adequate randomization	High
Saini et al. (2023) [13]	JBI Cross-sectional Checklist	Unclear sampling method	Low
Martyniuk et al. (2024) [14]	JBI Cohort Checklist	No blinding, short follow-up	Moderate
Maya et al. (2020) [15]	JBI Cross-sectional Checklist	Confounders not fully adjusted	Moderate
Wang et al. (2022) [16]	JBI Case-Control Checklist	Selection bias (hospital-based controls)	Moderate
Sarac & Derelioglu (2025) [17]	JBI Cross-sectional Checklist	Valid outcome measures	High
Huisenga et al. (2023) [18]	JBI Cohort Checklist	Loss to follow-up (15%)	Moderate
Fourdain et al. (2020) [19]	JBI Cohort Checklist	Retrospective design, recall bias	Low
Ng et al. (2020) [20]	JBI Cohort Checklist	High methodological rigor	High

early childhood interventions, including physical therapy and developmental enrichment programs, to optimize outcomes in high-risk CHD populations [39,40]. An important observation from this review is the variability in outcomes based on CHD subtype. Cyanotic CHD and single-ventricle physiology were consistently associated with worse growth and developmental outcomes compared to acyanotic or simple defects (studies [11,14,15]). This is likely due to the compounded effects of chronic hypoxia, prolonged hospitalizations, and higher surgical complexity in these patients [41,42]. Conversely, children with mild acyanotic CHD (e.g., small ventricular septal defects) often exhibit near-normal growth trajectories, particularly if they receive timely medical or surgical intervention [43,44]. A large case-control analysis of 348 pairs [16], provided compelling evidence that CHD is independently associated with neurodevelopmental delays, even after adjusting for confounding factors such as prematurity and socioeconomic status. This reinforces the need for routine developmental surveillance in all children with CHD, regardless of disease severity [45,46]. The findings of this review underscore the necessity for a multidisciplinary approach to managing children with CHD, incorporating nutritional support, developmental therapies, and long-term neurodevelopmental follow-up. Recent guidelines from the American Heart Association (AHA) advocate for standardized developmental screening at 12, 24, and 36 months in all CHD patients, with early referral to rehabilitation services when delays are detected [47,48]. Future research should focus on identifying biomarkers of neurodevelopmental risk, such as advanced MRI techniques or genetic predispositions, to enable earlier interventions [49,50]. Additionally, longitudinal studies tracking outcomes into school age and adolescence are needed to fully understand the lifelong impact of CHD on cognition, academic achievement, and psychosocial functioning. Limitations: Despite offering a thorough synthesis of current research, this systematic review has a number of shortcomings that should be noted. First, direct comparisons are made more difficult by the variation in study designs, outcome measures, and CHD classifications among the included studies. For

example, the range of developmental evaluations, from the Denver-II to the Bayley Scales, limited the ability to interpret delays in a standardised manner. Second, only a small number of studies used robust longitudinal designs; the majority were observational or small-scale RCTs, which could have an impact on how broadly applicable the results are. Third, the observed relationships may have been muddled by the inconsistent reporting of socioeconomic and cultural factors that impact growth and development, such as parental education, availability to early treatments, and dietary inequities. Furthermore, selection bias may be introduced by the prevalence of single-center research, especially those from high-income nations, highlighting the necessity of global cohorts to enhance external validity.

Conclusion

Children with CHD, especially those with cyanotic or complex defects, face significant risks of growth impairment and neurodevelopmental delays. Key findings include the association between chronic hypoxia, reduced cerebral oxygen delivery, and disrupted brain maturation, as well as the potential of early interventions—such as physical therapy and nutritional support—to mitigate adverse outcomes. The persistent disparities linked to socioeconomic factors highlight the necessity for equitable access to multidisciplinary care. Moving forward, standardized protocols for developmental surveillance, larger multicenter studies, and family-centered interventions should be prioritized to optimize long-term outcomes. By addressing these gaps, clinicians and researchers can better support this vulnerable population, ensuring that advances in cardiac care translate into improved quality of life and developmental trajectories for children with CHD.

Conflict of Interest

None

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