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Cardiometabolic Risk in Stunted Children: A Literature Study

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Abstract: Global health and nutrition are undergoing an epidemiological transition with the emergence of the "Triple Burden of Malnutrition," which includes undernutrition, obesity, and micronutrient deficiencies. Children experiencing stunting are at high risk for long-term cardiometabolic diseases, including cardiovascular disease and diabetes. However, longitudinal studies exploring the relationship between stunting and cardiometabolic risk are still limited. This study aims to identify and examine the relationship between stunting in children and the associated cardiometabolic risks and evaluate interventions implemented to reduce these risks. A literature review approach was conducted by analyzing 22 research articles focusing on children aged 0-5 years with stunting status. Inclusion criteria included evaluating cardiometabolic risks such as hypertension, diabetes, and dyslipidemia. The literature search followed PRISMA guidelines and utilized PubMed, ScienceDirect, and Google Scholar databases. The research indicates that stunting significantly impacts the risk of cardiometabolic issues in the future. Early nutritional interventions, such as protein-energy supplementation and ongoing dietary counseling, have effectively reduced these risks; however, socioeconomic factors often influence their effectiveness. Addressing stunting should be a priority in preventing long-term health risks. A holistic approach is needed, integrating nutritional, health, and social aspects to tackle this issue, particularly in low- and middle-income countries.

Keywords: Cardiovascular; Intervention; Malnutrition; Metabolic Disorders; Stunted Children.

Introduction

The global shift in epidemiological trends of health and nutrition has led to the emergence of the Triple Burden of Malnutrition, which is characterized by the concurrent presence of undernutrition, overnutrition, and micronutrient deficiencies within the same population. Among these forms of malnutrition, stunting impaired linear growth due to chronic nutritional deprivation during early life remains a significant public health concern in many low and middle-income countries. Stunting impedes physical growth and has far reaching consequences for long-term metabolic health in adulthood (Dipasquale et al., 2020). A growing body of evidence indicates that individuals who experience stunting in childhood are at increased risk of developing metabolic disorders, such as hypertension, dyslipidemia, insulin resistance, and type 2 diabetes in later life (Li et al., 2023). The Fetal Origins Hypothesis supports this, also referred to as the Developmental Origins of Health and Disease (DOHaD), which posits that early-life malnutrition including that occurring in utero may lead to biological programming that induces permanent changes in body structure and function. Studies have shown that low birth weight, a proxy for intrauterine growth restriction, increases susceptibility to coronary heart disease and diabetes in adulthood (Marawan et al., 2019).

According to 2018 data from the United Nations Children's Fund (UNICEF), World Health Organization

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(WHO), and World Bank Group (WBG), the global prevalence of malnutrition among children under five years old includes 21.9% classified as stunted and 7.30% as wasted. Concurrently, the prevalence of cardiometabolic diseases such as cardiovascular disease and diabetes mellitus has been rising steadily and has become a leading cause of global mortality. These findings highlight the potential long-term link between early-life nutritional deficiencies and the increasing burden of non-communicable chronic diseases later in life (Tohi et al., 2022). Beyond physical health, stunting is also associated with diminished cognitive development, reduced economic productivity in adulthood, and perpetuation of intergenerational poverty (Fraser et al., 2021). Social determinants such as poverty, limited access to nutritious foods, low educational attainment, and poor sanitation further exacerbate the risk of stunting while concurrently increasing vulnerability to metabolic diseases (Arons & Seligman, 2024). Although the association between stunting and cardiometabolic risk has been extensively investigated, several critical gaps remain inadequately addressed in the current scientific literature (Thahir et al., 2023).

One major limitation is the scarcity of longitudinal studies (Maravé-Vivas et al., 2022; Noordewier et al., 2025). Much of the available evidence is derived from cross-sectional observational research, which limits the ability to infer causality or to understand the developmental trajectory of cardiometabolic risk from childhood through adulthood (Qin et al., 2021). Another significant gap lies in the limited understanding of the underlying biological mechanisms (Bendor et al., 2020). The connection between early-life chronic undernutrition and adult metabolic alterations particularly those involving oxidative stress, chronic inflammation, and epigenetic modifications remains poorly understood (Popkin et al., 2020). Furthermore, there is a notable lack of exploration into socioeconomic and psychosocial factors. Many studies fail to holistically incorporate social determinants such as economic disparities, maternal education, caregiving practices, and residential environments in their analyzes of cardiometabolic risk among stunted children (Sukmawati et al., 2023). Additionally, there is a paucity of long-term evaluations assessing the effectiveness of nutritional interventions, particularly those implemented during the critical window of the first 1. 000 days of life, in sustainably reducing cardiometabolic risk (Lawless et al., 2021). Another concern is the limited availability of contextual data from Indonesia and other middle-income countries. Most studies originate from Western or select regional contexts, while data from Southeast Asia where the burden of stunting and metabolic disease is still insufficiently represented (Baker et al., 2007).

The novelty of this study lies in its integrative approach, which examines the relationship between stunting and cardiometabolic risk through a multidimensional perspective while highlighting the gaps in nutritional and social interventions as part of an evidence-based prevention strategy. This research is designed as a systematic literature review, aiming to assess and synthesize relevant scientific findings on this critically important topic. The study's primary objective is to systematically identify and analyze the relationship between childhood stunting and the associated cardiometabolic risks. Additionally, the study aims to evaluate the effectiveness of various interventions implemented to mitigate these risks, encompassing nutritional, health, and social approaches. By thoroughly reviewing existing literature, this study seeks to provide a comprehensive understanding of the contributing factors and preventive strategies for cardiometabolic risks in stunted children. The anticipated benefits of this research are multifaceted. For researchers, it offers more profound insights into the mechanisms linking stunting with cardiometabolic diseases and contributes to advancing systematic review methodologies (Guo et al., 2022).

For policymakers, the findings are expected to inform the development of more targeted and effective policies to combat stunting and reduce the long-term health consequences it entails. For the wider community, this research is intended to raise awareness of the long-term health impacts of stunting and the importance of early prevention, ultimately providing information that can help improve the quality of life for future generations. In this way, the study contributes to scientific knowledge and broader public health and societal well-being. Stunting remains a major public health concern, particularly in low- and middle-income countries, including Indonesia (Kusumajaya et al., 2023; Supadmi et al., 2024). Its impact extends beyond impaired physical growth and cognitive development, posing long-term health risks such as type 2 diabetes, hypertension, and cardiovascular disease. Recent studies have revealed that stunted children may exhibit early signs of metabolic dysregulation, including insulin resistance, dyslipidemia, and abnormal visceral fat accumulation. These findings underscore that stunting is not merely a short-term nutritional issue, but a potential precursor to chronic non-communicable diseases, contributing to the double burden of malnutrition (Jalaludin et al., 2025; Morales et al., 2023). Understanding the cardiometabolic risks associated with stunting during childhood is therefore critical for

implementing timely, targeted interventions aimed at breaking this cycle.

This literature study presents a novel perspective by focusing on the link between chronic undernutrition (stunting) and cardiometabolic risk in children—an area often overshadowed by research centered on adolescents and adults. The originality lies in its synthesis of current evidence exploring metabolic biomarkers, growth patterns, and body composition changes in stunted children. This integrated review offers valuable insights that could inform the development of early preventive strategies and nutrition policies. By highlighting the long-term metabolic implications of stunting from a young age, this study aims to contribute to both theoretical understanding and practical action in public health and pediatric nutrition.

Method

This study employed a literature review approach to evaluate the association between childhood stunting and cardiometabolic risk. The process was conducted systematically, rigorously, and transparently to identify, appraise, and synthesize relevant literature from reputable sources. The following steps outline the methodology used in this study:

Definition of Objectives and Research Questions

The primary objective of this study was to examine the relationship between stunting in early childhood and the increased risk of cardiometabolic diseases, as well as to assess contributing factors. The research questions guiding this review were: "What is the association between early childhood stunting and the increased risk of cardiometabolic disorders?" and "How do psychosocial factors and nutritional interventions influence this risk?" Establishing clear objectives and questions was essential to guide the literature search in a targeted and focused manner.

Inclusion and Exclusion Criteria

To ensure the inclusion of only high-quality and relevant studies, strict inclusion and exclusion criteria were applied:

Inclusion criteria

Studies involving children aged 0–5 years with stunting; studies evaluating cardiometabolic risk indicators such as hypertension, diabetes, and dyslipidemia.

Exclusion criteria

Studies unrelated to the topic, with unclear methodology, not available in English or Indonesian, or those involving populations other than children.

Literature Search Strategy

The literature search followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Databases used included PubMed, ScienceDirect, Google Scholar, Karger, MGPI, AHA, JSTOR, Cochrane Library, Wiley Online Library, and NCBI. To ensure comprehensive coverage, searches were conducted using keywords such as "stunting," "cardiometabolic risk," "malnutrition," "children," and "nutritional interventions" in both English and Indonesian. Boolean operators (AND, OR) were employed to refine the search results. For example, "stunting AND cardiometabolic risk" yielded more specific articles addressing both topics, whereas "stunting OR malnutrition" provided broader coverage. Titles, abstracts, and full texts were screened for relevance.

Study Selection

After conducting the literature search, studies were screened in two stages: title and abstract screening, followed by full-text review for articles meeting the inclusion criteria. The selection process was carried out systematically and documented according to PRISMA guidelines. Reference management software such as Mendeley organized and managed the selected studies.

Data Extraction

Relevant information was extracted systematically from each eligible study, including research methodology, population characteristics, outcomes related to cardiometabolic risk in stunted children, and psychosocial or intervention-related factors. Extracted data were categorized by theme to facilitate subsequent analysis.

Data Synthesis

Extracted data were analyzed to identify recurring patterns, relationships, and significant trends related to cardiometabolic risk in stunted children. Both qualitative and, where applicable, quantitative approaches were used. If sufficient data were available, meta-analysis was considered to provide a more robust statistical understanding of the association.

Reporting of Findings

Findings were reported using PRISMA standards, ensuring transparency and accuracy in presenting the results. The report included key outcomes, health policy implications, and future research recommendations. All findings were discussed about the research questions outlined at the beginning.

Conclusion and Implications

The conclusions drawn from this review provide critical insights into the association between childhood stunting and cardiometabolic risk, emphasizing the importance of early interventions. The implications were discussed in the context of clinical practice, public health policy, and nutritional strategies aimed at reducing cardiometabolic risks in stunted children.

References and Bibliography

All references used in this review were compiled using the APA citation style. Mendeley reference management software ensured accuracy and efficiency in handling references throughout the review process.

Terminology Clarification

In this literature review, "author" refers to the individual conducting the current analysis and interpretation. At the same time, "researcher" denotes individuals or teams responsible for reviewing the original studies. This distinction aims to clarify readers regarding the source and interpretation of the findings presented.

Conceptual Framework

As part of the analytical approach, this study developed a conceptual framework depicting the relationship between early childhood stunting (independent variable) and cardiometabolic risk (dependent variable), with moderating variables including nutritional interventions, psychosocial factors, and environmental influences. This framework elucidates the biological and social mechanisms mediating the link between chronic undernutrition and metabolic disorders. A detailed discussion of variable interrelationships is provided in the discussion section.

Result and Discussion

Childhood stunting remains a significant global public health concern, with implications that extend beyond impaired physical growth to include long-term cardiometabolic health consequences. Emerging evidence indicates that stunted children are at a heightened risk of developing cardiometabolic disorders such as obesity, type 2 diabetes, and cardiovascular diseases in adulthood. Understanding the linkage between stunting and cardiometabolic risk is crucial for identifying modifiable risk factors and designing targeted, effective interventions. This literature review aims to systematically examine existing evidence on the impact of stunting on cardiometabolic health in children. Furthermore, the study evaluates various interventions implemented to mitigate such risks, particularly nutritional, health, and social strategies. The findings are expected to offer deeper insights into this association and inform the development of more tailored public health policies and intervention programs. The relationship between early childhood body mass index (BMI) trajectories, cardiometabolic risk factors, and body composition populations (Megersa et al., 2024). This longitudinal study adopted a data-driven approach to identify BMI growth patterns, independent of predefined categories, using an average of nine anthropometric measurements per child over five years (Mondal et al., 2023).

The results demonstrated that rapid BMI gain during infancy was associated with elevated triglyceride levels and increased waist circumference, indicative of future cardiometabolic risk. These findings align with the current study's focus on understanding how early impaired growth, such as stunting, may predispose children to adverse metabolic outcomes (Kiosia et al., 2024). The strength of Meyer et al.'s study lies in its longitudinal design and the flexible analytic approach, which allows for the capture of real-time growth dynamics (Quarta et al., 2024). However, it does not directly address the contribution of stunting, despite evidence from other studies suggesting that stunted children remain vulnerable to metabolic disorders even when their BMI falls within the normal range. Additionally, the potential for selection bias due to attrition in follow-up visits may limit the validity of the findings (Kim et al., 2024). The study also supports the notion that rapid fat accumulation during early growth may induce unfavorable metabolic changes such as insulin resistance and hypertension. These implications underscore the importance of initiating nutritional, health, and social interventions within the first 1. 000 days of life, in line with the objective of this study to inform preventive strategies against cardiometabolic risk among stunted children.

Liu et al. (2021), further emphasized that children with low BMI are typically undernourished—are not exempt from cardiometabolic risks, challenging the assumption that thinness equates to metabolic health. This is particularly relevant to the present study, which explores the association between stunting and cardiometabolic risk, as stunting may affect metabolic function beyond linear growth impairment. Drawing upon data from the nationally representative Comprehensive National Nutrition Survey in India, the study revealed that poor nutritional status does not necessarily confer protection against non-communicable diseases (NCDs). These findings are consistent with (Higuera-Domínguez et al., 2025), who reported that early childhood stunting increases the risk of adult-onset NCDs such as type 2 diabetes and cardiovascular diseases. Highlighted the need for a holistic nutritional

approach, taking into account poor dietary practices, physical inactivity, and environmental factors as key contributors to metabolic risk—a perspective also reinforced by the systematic review conducted by (Dave et al., 2023). Although the study did not examine specific interventions in detail, it called for multidimensional strategies that integrate nutritional, social, and healthcare components.

One of the primary strengths of this study lies in its broad and representative dataset, as well as its contribution to challenging the conventional assumption that a low Body Mass Index (BMI) indicates protection against non-communicable diseases (NCDs). However, certain limitations must be acknowledged. These include its geographical confinement to India, which may limit the generalizability of findings to other regions (Wells, 2021) and limited exploration of other potential risk factors, such as genetic predispositions and lifestyle behaviors. The authors recommend further longitudinal studies to investigate the long-term metabolic impacts of stunting and to evaluate the effectiveness of interventions that incorporate social and environmental determinants. These findings underscore the urgency of understanding stunting as a multifaceted and complex nutritional disorder and call for a more holistic approach in efforts to prevent cardiometabolic risks in stunted children. The study "Early and Long-term Consequences of Nutritional Stunting: From Childhood to Adulthood" highlights the significant short- and long-term impacts of stunting on child health. Stunted children are more vulnerable to morbidity, mortality, infections, and metabolic disorders such as insulin resistance, diabetes, hypertension, and dyslipidemia.

The risk of overweight and obesity in adulthood also increases, particularly when rapid weight gain occurs after the age of two years. The intrauterine period and the first two years of life are critical for brain development. Factors such as maternal anemia, tobacco exposure, and environmental pollution may compromise fetal growth. Catch-up growth after age two is rarely optimal, and deficits in linear growth tend to persist into adulthood. The mTORC1 pathway, essential for childhood growth, depends on the availability of essential amino acids. In stunted children, deficiencies in these amino acids may impair bone and muscle development and cognitive function. Autophagy mechanisms triggered by such deficiencies may further suppress immune responses and lead to anemia (Ni et al., 2024). Neurological consequences include delayed myelination, reduced synapse formation, impaired behavior, and academic performance. Hormonal disruptions in stunted children, such as reduced insulin-like growth factor 1 (IGF-1) and elevated growth hormone (GH) levels, are associated with decreased physical capacity and obstetric complications during adolescence, particularly among females (Doknic et al., 2024).

High-quality protein intake particularly from dairy products has been shown to support catch-up growth, primarily through essential amino acids such as lysine and arginine. However, micronutrient supplementation alone is often insufficient to reduce stunting significantly. Stunting also increases the risk of chronic diseases in adulthood, such as diabetes, due to hormonal alterations, including elevated cortisol levels and pancreatic beta-cell dysfunction (Kumar et al., 2020). The strength of this study lies in its comprehensive overview of stunting's health impacts, which is highly relevant for informing nutritional policies in countries with high prevalence rates. Nevertheless, the study's limitations include a lack of clarity regarding the methodology and sources of the reviewed literature, which complicates the assessment of data validity. Future research should incorporate greater geographic diversity to capture contextual variation and enhance the generalizability of the findings. Stunting represents a form of chronic malnutrition due to inadequate nutrient intake during the critical periods of early childhood, typically defined as a height-for-age below the WHO standard (Associations of Stunting in Early Childhood with Cardiometabolic Risk Factors in Adulthood).

Beyond impairing linear growth, stunting carries long-term health consequences, including increased risks of obesity, diabetes, hypertension, and cardiovascular disease resulting from early-onset metabolic dysregulation. Several studies have demonstrated that stunting affects body composition, including increased visceral fat accumulation and central obesity. Gerber & Pienaar (2025), reported that stunted children tend to store fat around vital organs, even when total body fat does not significantly increase. A longitudinal study by Mulyani et al. (2025), also revealed that stunting is associated with elevated BMI and insulin resistance in adulthood. However, research findings are not always consistent. For example, (Pingali et al., 2019) found no significant association between stunting and hypertension. Such variations may be attributable to differences in study populations, measurement methods, and socioeconomic factors. In addition to body composition, changes in metabolic biomarkers have also been observed. Reid et al. (2018), found that individuals with a history of stunting exhibited higher insulin resistance, suggesting a greater risk for type 2 diabetes and metabolic syndrome. Nonetheless, outcome variability remains due to different study designs and external factors such as socioeconomic status, which, according to Rolfe et al.

(2018) significantly influences the relationship between stunting and cardiometabolic risk.

The methodologies employed in these studies range from BMI assessments to advanced techniques such as dual-energy X-ray absorptiometry (DEXA) and biomarker analysis involving insulin, glucose, and lipid profiles. Using tools like ultrasound for measuring visceral fat and analytical chemistry techniques enhances the precision and validity of these measurements. The strengths of these studies include their global relevance in addressing both obesity and undernutrition particularly in low- and middle-income countries the use of longitudinal data from the 30-year Pelotas Birth Cohort, accurate measurement methods, and regression analyzes accounting for confounding variables such as sex, birth weight, and socioeconomic status. However, this study is not without limitations. Among them are the controversial nature of some findings, the use of non-fasting blood samples that may compromise the accuracy of triglyceride measurements, and the study's observational design, which precludes causal inference. Furthermore, biochemical markers of metabolic disease may not yet be evident in young adulthood (at age 30), indicating that long-term effects may only become apparent later in life.

In conclusion, childhood stunting may increase cardiometabolic risk through mechanisms such as altered fat distribution and insulin resistance. Nonetheless, given the variability in current evidence, further research is warranted to elucidate the underlying biological mechanisms and evaluate early nutritional interventions' effectiveness in preventing these long-term consequences. Future studies should consider employing more precise methods of body fat assessment, such as MRI or CT scanning, and conducting long-term nutritional interventions in stunted children to assess their impact on preventing future cardiometabolic risks. The study titled "Severe Malnutrition or Famine Exposure in Childhood and Cardiometabolic Non-Communicable Disease Later in Life: A Systematic Review" investigated the association between childhood exposure to severe malnutrition or famine and the risk of developing cardiometabolic non-communicable diseases (NCDs) in adulthood, particularly in low- and middle-income countries (LMICs) (Ndubuisi, 2021).

This review is highly relevant in light of the high prevalence of childhood undernutrition and the rising incidence of NCDs, such as diabetes and cardiovascular disease, in these settings the review aimed to systematically evaluate the long-term cardiometabolic consequences of childhood malnutrition. Using a systematic review approach following PRISMA guidelines, literature searches were conducted in Medline, Embase, Global Health, and CINAHL. Of 2,765 articles identified, 57 studies (retrospective cohorts, prospective cohorts, and cross-sectional studies) were included. The results showed consistent associations between early-life malnutrition or famine and increased risks of cardiovascular disease, hypertension, and impaired glucose metabolism. For example, exposure during critical growth periods was linked to a heightened risk of heart disease, and eight of eleven studies reported a significant association with hypertension. The risk of glucose metabolism disorders and type 2 diabetes was also elevated, especially among women who experienced childhood families (Denton & Fernandez, 2021). However, findings related to lipid profiles and obesity were less consistent. Proposed mechanisms include accelerated post-malnutrition growth, epigenetic changes influencing gene expression (Randunu & Bertolo, 2020), and pancreatic β-cell dysfunction leading to glucose intolerance.

The study's strengths are its systematic methodology, global scope, and differentiation between malnutrition and famine exposures. Nevertheless, it has several limitations, such as heterogeneity in malnutrition definitions across studies, inadequate consideration of prenatal factors, and potential measurement bias and residual confounding. Overall, the study reinforces the critical importance of preventing childhood malnutrition to reduce future burdens of cardiometabolic disease. Further research is recommended to explore biological mechanisms and account for age, duration, and intensity of exposure in greater detail. The study “Early Life Adversity with Height Stunting Is Associated with Cardiometabolic Risk in Adolescents Independent of Body Mass Index” demonstrated that early-life adversity such as stress, undernutrition, and trauma was significantly associated with increased cardiometabolic risk in adolescents with stunting, even in the absence of overweight (i.e., with normal BMI). These findings support earlier studies indicating that stunting contributes to long-term cardiometabolic disease risk. A notable strength of the study is its use of comprehensive risk markers including blood pressure, lipid profiles, and insulin indices providing a holistic view of metabolic risk.

Nonetheless, the study is limited by its cross-sectional design and small sample size, which precludes causal interpretation and the lack of lifestyle behavior data. The study recommends early, multidisciplinary nutritional and psychosocial interventions to prevent the long-term cardiometabolic effects of stunting. Future longitudinal research is suggested to clarify causal pathways better while considering socioeconomic status and healthcare access. A retrospective study in Uganda, “The Effect of Childhood Stunting and Wasting on

Adolescent Cardiovascular Diseases Risk and Educational Achievement," found that childhood stunting affects cardiovascular health and educational outcomes during adolescence. While stunted children exhibited lower blood pressure, recovery from wasting was associated with increased diastolic blood pressure, potentially elevating cardiovascular risk. These results partly contradict earlier studies such as Asiki et al. (2019), which linked stunting to higher hypertension risk. The findings are consistent with evidence from the Dutch Hunger Study and the Finnish Birth Cohort, which suggests that recovery from malnutrition may have adverse effects if not adequately monitored.

The study found a correlation between stunting and lower educational achievement, even among children who had recovered from undernutrition. This supports findings from Fotso et al. (2012), which demonstrated that early malnutrition impairs cognitive and social development, perpetuating cycles of poverty. Recommended interventions include school feeding programs beginning in early childhood, as advocated by (Barnabas et al., 2024). Moreover, a multisectoral approach is needed, integrating nutritional, social, and educational interventions and closely monitoring children recovering from wasting to prevent long-term cardiometabolic consequences. The study's strengths include its longitudinal design and the incorporation of sociocultural contextual data. However, limitations include the absence of birth weight data and potential selection bias, as the sample only included children who remained in rural villages. The study "Childhood stunting and the metabolic syndrome components in young adults from a Brazilian birth cohort study" aimed to explore the association between childhood stunting and components of metabolic syndrome in adulthood to understand long-term cardiometabolic risks. Stunting remains a major global health issue, affecting approximately 161 million children under five in 2013.

The researchers emphasized that childhood malnutrition may increase the risk of metabolic diseases later in life. However, the study provided limited discussion on other contributing factors, such as genetic and environmental influences, and did not articulate a specific hypothesis to clarify the research direction. Employing a longitudinal cohort design, the study assessed stunting status and components of metabolic syndrome including waist circumference, triglyceride levels, and HDL cholesterol from infancy through adulthood. While this design allows for tracking long-term changes, data validity was slightly compromised by inconsistencies in fasting duration before blood sampling. Preliminary findings indicated an association between stunting and several components of metabolic syndrome; however, this association dissipated after adjusting for confounding variables, suggests that stunting may not be a strong predictor of metabolic syndrome. The researchers highlighted the importance of considering additional factors such as dietary patterns, urbanization, and environmental exposures. They recommended further investigating potential gender differences in these associations. Although the findings were not statistically significant, the importance of early nutritional interventions in preventing future cardiometabolic risk was underscored. Overall, the study contributes to the growing body of literature on stunting and metabolic risk, with strengths in its cohort design and confounder adjustment.

Nonetheless, to enhance the implications, further work is needed in policy translation and exploration of gender-specific effects. These findings reinforce the relevance of my research aims to evaluate nutrition-, health-, and social-based interventions in mitigating cardiometabolic risks associated with childhood stunting.

The study titled "Exposure to improved nutrition from conception to age 2 years and adult cardiometabolic disease risk: a modeling study" assessed the effects of early-life protein-energy supplementation (Atole) from conception through age two on adult cardiometabolic disease risk in Guatemala. As one of the first studies in this context, it reported mixed outcomes: on one hand, increased adiposity was observed among those exposed to Atole, which may elevate cardiometabolic risk. On the other hand, there was an inverse association with diabetes risk not mediated by adiposity, suggesting potential benefits of supplementation in reducing diabetes risk. These findings are consistent (Ogata et al., 2018), who reported reduced plasma glucose levels following early-life Atole exposure, and (Ojo et al., 2023), who found no increase in the prevalence of cardiovascular risk factors associated with the intervention. However, methodological limitations such as reliance on single plasma glucose measurements and absence of glucose tolerance tests may affect result accuracy. Additionally, the lack of differentiation between severely and moderately malnourished children complicates interpretation.

A key strength of this study lies in its longitudinal design spanning over 40 years and its use of comprehensive biomarkers, including fasting and post-challenge glucose levels, along with anthropometric assessments distinguishing between muscle and fat mass. Nevertheless, low variability in cardiometabolic risk among women and ambiguity in exposure classification remain notable limitations. Overall, this study provides valuable insights into how early-life nutritional supplementation may potentially enhance

growth and reduce diabetes risk while increasing the likelihood of obesity. Therefore, nutritional interventions must be carefully balanced to prevent stunting without inducing long-term metabolic consequences. The study "Nutritional Status, Energy and Fiber Intake as Cardiometabolic Risk Factors in Short-Statured Adolescents" examined the association between height status and BMI, energy, and fiber intake as cardiometabolic risk factors in short-statured adolescents aged 10–14 years. This cross-sectional study employed 3×24-hour dietary recall data, analyzed using Nutrisurvey, and Mann–Whitney U tests to compare means between groups. Results showed that short-statured adolescents had lower BMI, energy intake, and fiber intake compared to their normal-height peers factors associated with increased cardiometabolic risk due to reduced metabolic adaptation.

The study also found a higher proportion of short-statured males compared to normal-height males, whereas the opposite was true among females. This difference is related to hormonal maturation affecting body composition, as discussed by (Schorr et al., 2018), who noted that males tend to develop more lean mass, while females accumulate more fat mass. Data from the 2013 Indonesian National Health Survey (Riskesdas) supports these findings, reporting a higher prevalence of short stature among 10–11-year-old girls. Mean energy intake among short-statured adolescents (1.488.83 kcal) was lower than that of normal-height adolescents (1.704.32 kcal), aligning with (Jimoh et al., 2018), who emphasized the close relationship between undernutrition and growth. Iddir et al. (2020), further highlighted that low BMI may be linked to protein deficiency, potentially impairing immune function and increasing the risk of non-communicable diseases. The critical role of nutritional and energy status in children's long-term development and health. Strengths of the study include a relatively large sample size (106 subjects), enhancing estimation accuracy and generalizability, and the use of appropriate non-parametric analysis (Mann–Whitney U test) for non-normally distributed data.

However, key limitations include the absence of gold-standard assessments such as detailed dietary history and laboratory biomarkers, which may reduce measurement validity. These findings emphasize the importance of nutritional interventions to prevent stunting and associated cardiometabolic risks in adolescents. To ensure accuracy and broader applicability. The long-term health benefits of nutrition interventions in stunted children. Clinically, these findings can inform more effective nutritional recommendations for short-statured adolescents to reduce future cardiometabolic risk. The journal Early-Life Nutrition Interventions and Associated Long-Term Cardiometabolic Outcomes, highlights the significant impact of early nutritional interventions in reducing cardiometabolic risks among children, particularly within the context of stunting. One of the key findings indicates that protein-energy supplementation in malnourished children leads to a reduction in fasting glucose levels, thereby supporting the development of metabolic organs such as the pancreas. However, such interventions may also increase body mass index (BMI), potentially heightening the risk of obesity in stunted children. The study underscores that sustained, individualized dietary counseling remains the most consistently effective intervention in improving cardiometabolic outcomes, the necessity of a personalized approach for children with special nutritional needs.

Additionally, breastfeeding has been shown to be more beneficial than formula feeding in preventing metabolic disorders, decreasing risk of obesity and type 2 diabetes among breastfed children. Timing of intervention is also a critical factor. Nutritional exposure during early life proves more effective in preventing long-term metabolic diseases compared to delayed interventions. Nonetheless, study results reveal heterogeneity, implying that findings may not be universally generalizable. Therefore, context-specific approaches that consider social and environmental conditions are essential. Overall, this review affirms the importance of early-life nutritional interventions, personalized dietary counseling, and breastfeeding promotion in mitigating cardiometabolic risks among stunted children. However, further research is needed to tailor interventions to local contexts and elucidate the underlying long-term biological mechanisms involved. Childhood stunting has serious long-term health consequences, including increased risk of cardiometabolic disorders. A review of the study Critical Windows for Nutritional Interventions Against Stunting reveals that while prenatal nutritional interventions are crucial, they do not always lead to significant improvements in fetal growth.

For example, meta-analytic findings report only a modest increase in birth weight (approximately 49 grams), with effectiveness constrained by factors such as maternal height and pre-pregnancy nutritional status. Protein-energy supplementation during pregnancy reduces the proportion of small-for-gestational-age infants but has limited impact on preventing stunting. In early childhood, supplementary feeding interventions yield limited improvements in linear growth, although they are beneficial for micronutrient status and anemia reduction. A key limitation is the high burden of infectious diseases and poor environmental conditions

in low-resource settings. In general, a combination of prenatal and postnatal interventions remains insufficient to effectively prevent stunting, indicating the need for more comprehensive strategies. This includes considering socioeconomic factors, environmental health, and cross-sectoral approaches. The reviewed evidence supports the author's objective to investigate the association between stunting and cardiometabolic risk, and emphasizes that risk reduction requires multidimensional strategies, encompassing nutrition, health, and social components. Strengths of the reviewed studies include their relevance to the global stunting issue, the use of meta-analytical methods to clarify intervention effectiveness, and a focus on vulnerable groups such as pregnant women and children. Moreover, these studies consider contextual factors such as maternal nutritional status and environmental conditions, which influence intervention outcomes.

Nevertheless, limitations include small and nonsignificant intervention effects, variable methodological quality, and limited exploration of non-nutritional interventions such as improved sanitation and health education. Further research is warranted to explore the role of social and economic determinants in addressing stunting and its long-term consequences. The study titled The Effectiveness of Nutritional Interventions Implemented through Lady Health Workers on the Reduction of Stunting in Children under 5 in Pakistan: The Difference-in-Difference Analysis was reviewed to assess the effectiveness of nutrition programs delivered by Lady Health Workers in reducing stunting and associated cardiometabolic risks in Pakistani children. Although the intervention did not significantly mitigate stunting prevalence, it did lead to a significant reduction in underweight prevalence, which is associated with lower long-term risks of hypertension and type 2 diabetes. The study has several strengths, including a large sample size (3.39 children aged 6–59 months) and the use of a robust Difference-in-Differences (DID) methodology.

It also highlights differential effectiveness across wealth quintiles, emphasizing the importance of socioeconomic context. Moreover, Behavior Change Communication (BCC) strategies were critical for the success of nutrition programs, as (Rotella et al., 2025) indicated. However, the study also presents limitations. No significant impact was observed on wasting prevalence among children aged 6–23 months. This suggests that the nutritional intervention alone may not meet the needs during the critical first 1.000 days of life. Additionally, the cross-sectional design limits causal inference. Environmental factors such as sanitation and food access also influence intervention efficacy, as emphasized by. This review is particularly relevant to studies investigating the link between stunting and cardiometabolic risk. Nutritional interventions can serve as preventive measures against future metabolic diseases. However, a multisectoral approach is essential to address nutrition, health, social, and environmental dimensions. The analysis also highlights the need for gender-sensitive strategies, given that intervention effects are often greater among boys. Overall, the study underscores the importance of holistic approaches and the need for further research to better understand the underlying causes of stunting and associated cardiometabolic risks.

Multiple studies support the role of nutritional interventions in reducing cardiometabolic risk among stunted children. Supplementation with high-quality protein and micronutrients such as iron, zinc, and vitamin A during growth periods improves physical growth and enhanced metabolic health, including reduced risks of hypertension and insulin resistance in adulthood. The benefits of omega-3 fatty acid supplementation in reducing systemic inflammation and improving lipid profiles, particularly triglyceride levels, which are closely linked to cardiovascular disease prevention. A balanced diet also plays a key role (Ashraf et al., 2024). demonstrated that consuming complex carbohydrates and dietary fiber helps maintain stable blood glucose levels, lowering the risk of obesity and insulin resistance in children with a history of stunting. Beyond nutrition, family-based nutrition education has also proven effective. Nutrition education programs involving families can improve children's knowledge of healthy foods while encouraging physical activity beneficial to cardiovascular health.

Environmental factors are equally important. highlighted that access to clean water, adequate sanitation, and basic healthcare can mitigate the long-term negative impacts of stunting on child health. These findings advocate for a holistic intervention framework encompassing nutrient supplementation, family education, physical activity promotion, and environmental improvements as effective strategies to reduce cardiometabolic risk in children affected by stunting.

Conclusion

This study focused on identifying and systematically examining the relationship between childhood stunting and the associated cardiometabolic risks, as well as evaluating interventions aimed at mitigating these risks through nutritional, health, and social approaches. The findings from the reviewed literature underscore that stunting, as a manifestation of

chronic malnutrition, is closely linked to an increased risk of cardiometabolic diseases including obesity, type 2 diabetes, and hypertension which may persist into adulthood. Critical determinants of long-term health outcomes include birth size, prenatal growth, and maternal nutritional status during pregnancy. Early-life nutritional interventions, particularly protein-energy supplementation and sustained dietary counseling, have positively reduced cardiometabolic risk, especially among malnourished populations. However, the efficacy of such interventions is frequently influenced by socioeconomic and environmental factors. Despite providing valuable insights, existing research presents limitations in exploring the full scope of interventions and the biological mechanisms underlying the stunting–cardiometabolic risk nexus. Therefore, further research is warranted to identify more effective strategies and better understand the role of environmental and genetic determinants. Addressing stunting should be prioritized as part of broader efforts to prevent long-term health risks. Emphasis should be placed on holistic interventions that integrate nutritional, health, and social dimensions. More comprehensive and timely interventions are essential to break the cycle of stunting and associated cardiometabolic risks, particularly in low- and middle-income countries.

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