Under pressure: the lifelong cardiovascular health of children and youth with primary hypertension

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Global cardiovascular health promotion across the lifespan requires a comprehensive approach prioritising early life interventions. Paediatric hypertension is an increasingly recognised public health issue and an important modifiable risk factor for reducing future cardiovascular morbidity and mortality. This Review discusses the epidemiology, risk factors, diagnosis, and management of paediatric hypertension. We highlight the increasing prevalence of paediatric hypertension, its higher rates in low-income and middle-income countries (LMICs), and review its multifactorial causes globally, including genetic, environmental, and lifestyle influences. Barriers to early detection, particularly in LMICs, such as poor awareness of childhood-onset hypertension among families and health-care providers, are elucidated. Studies emphasising the short-term and long-term consequences of paediatric and youth hypertension and evidence-based diagnostic and management strategies, including non-pharmacological and pharmacological interventions, are also discussed. The management of hypertension in youth requires integrating public health strategies with clinical care to establish a robust foundation to improve lifelong health outcomes.

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Introduction

Hypertension affects almost a third of adults and is a leading cause of preventable mortality and morbidity in the general population globally.[1] Childhood blood pressure tracks into adulthood and contributes to adult hypertension; however, the attributable proportion is modest compared with other risk factors such as high BMI and abnormal lipid profile (eg, ~10% in one cohort).[2] The proportion of hypertensive children who remain hypertensive in adulthood is variable and seen in a minority.[2,3] Overall, the prevalence of hypertension in adults is now higher in low-income and middle-income countries (LMICs) than in high-income countries, with the gap continuing to widen.

A recent systematic review and meta-analysis estimated the pooled prevalence of hypertension among children and young people (aged 6–19 years) at 4·28% (95% CI 3·71–4·90), with prevalence of 4·26% (3·37–5·25) in the Western Pacific Region and of 3·61% (2·74–4·60) in the region of the Americas.[4,5] Despite these data, the global prevalence of childhood hypertension remains poorly characterised due to suboptimal geographical representation, especially for sub-Saharan Africa and across several LMICs. A meta-analysis of 41 studies from ten African countries (n=52 918; aged 3–19 years) estimated the overall prevalence of hypertension (systolic or diastolic blood pressure, or ≥95% percentile) and elevated blood pressure (systolic or diastolic blood pressure, or both ≥90% and <95% percentile). The overall prevalence of hypertension was at 7·4% in 38 studies, elevated blood pressure was at 11·4% in 24 studies, and, when reported, both hypertension and elevated blood pressure combined was 21·7% (27 studies).[6]

The prevalence of hypertension varies across different population demographics, including age, sex, and levels of urbanisation, and remains highly under-recognised and under-reported in children and youth (19 years and younger).[6,7] The well documented differences in prevalence between rural and urban areas in Africa[8] appear to be attributable to the regional differences in the prevalence of underweight or obesity.[9] There is a higher prevalence of hypertension among youth with overweight or obesity (18·5%, 95% CI 10·2–28·5), than those categorised as underweight (1·0%, 0·1–2·6) or normal weight (4·8%, 2·9–7·1, p<0·001).[6] Similarly, south Asian children have a high prevalence of hypertension (6%, 4–7), as described in a systematic review including 70 studies among 313 167 children aged 5–17 years.[10] Children from Nepal had the highest median prevalence at 9·4% (95% CI 8·2–10·5), followed by Pakistan (7·6%, 2·6–22·7), Sri Lanka (6·7%, 6·7–6·7), India (5·9%, 3·2–9·8), and Bangladesh (3·2%, 1·5–5·1).[10]

Key messages

- The prevalence of hypertension in children and young people is increasing globally with striking geographical disparities, including particularly high burdens in low-income and middle-income countries, highlighting the need for tailored global prevention strategies
- A strong association has been shown between hypertension in children and young people and the effects of uncontrolled hypertension in later life, including cardiovascular morbidity and mortality and kidney disease, thereby necessitating early identification and intervention
- Major barriers for the early detection of paediatric hypertension include absence of instruments to measure blood pressure accurately in children, especially in those younger than 5 years, insufficient universal screening programmes, and poor awareness among health-care providers, policy makers, and families
- Approaches that combine public health policy changes, community-level screening, and practical lifestyle and pharmacological options are crucial to reducing lifelong risk
- Paediatric-specific research, including innovative trial designs and digital health tools, is needed to close key evidence gaps and guide effective treatment thresholds

Although explaining geographical variations in blood pressure is challenging, low socioeconomic status, malnutrition, and obesity—prevalent in many LMICs—likely contribute.[11]

Evaluating the association between blood pressure levels and health burden, a 2015 report estimated that systolic blood pressure greater than 115 mm Hg was associated with 8·5 million deaths globally. However, 88% of these occurred in LMICs, where blood pressure levels continue to increase at a faster rate than in high-income countries.[12] Hence, an urgent focus on LMICs globally is needed to improve cardiovascular health outcomes and to help manage the increasing burden of cardiovascular disease risk factors and health-care resource use.[13] To preserve cardiovascular health in children from LMICs, it is imperative to upscale policy change, public health initiatives, and primordial prevention efforts. Although adult-focused cardiovascular disease strategies are gaining traction,[14] a transformative shift is needed to include children in LMICs within these frameworks. Policies aimed at improving maternal health and health in early childhood might have downstream effects on childhood blood pressure and cardiovascular health. However, implementation is often hampered by resource-constrained health-care systems. The risk of future cardiovascular disease is further increased for children in LMICs due to substantial inequities in early life exposures, including adverse birth outcomes, environmental pollution, and insufficient nutrition and physical activity. The WHO Hearts package[15] and Helping Babies Breathe[16] are examples of proactive health-care policy initiatives incorporating child-centred methods into global health agendas, which can reduce the burden of cardiovascular disease before it manifests. This upstream investment can improve the long-term resilience of health systems in LMICs, and also protect the health of future generations.

Risk associations for hypertension

Relevance of cardiovascular disease risk factors: focus on blood pressure and hypertension

A substantial body of evidence highlights the link between paediatric cardiovascular disease risk factors and adverse outcomes in young adulthood. The presence of abnormal childhood adiposity (BMI ≥85th percentile), hypertension (blood pressure ≥95th percentile), and hyperlipidaemia is linked to negative cardiovascular outcomes later in life.[17] Although several other early life cardiovascular disease risk factors,[18] including nutrition and physical activity, have been identified, our understanding of their precise influence on cardiovascular disease in young adulthood remains poor (figure 1).[19] Furthermore, gaps persist regarding how cardiovascular disease risk factors in childhood populations in LMICs are associated with cardiovascular outcomes.

Evaluating the relative contribution of individual cardiovascular disease risk factors at different life stages and across the life course as the severity of these factors worsens, remains challenging. Furthermore, children and young people might present with multiple coexisting risk factors, which could compound their future risk. Data from the International Childhood Cardiovascular Cohort Consortium indicated that childhood BMI and LDL cholesterol showed clear direct effects on adult cardiovascular disease (direct incidence rate ratio [IRR] per 1-SD increase 1·18 for BMI and 1·16 for LDL cholesterol), whereas for childhood systolic blood pressure the association with adult cardiovascular disease was mainly through adult systolic blood pressure.[20] Specifically, the direct effect of childhood systolic blood

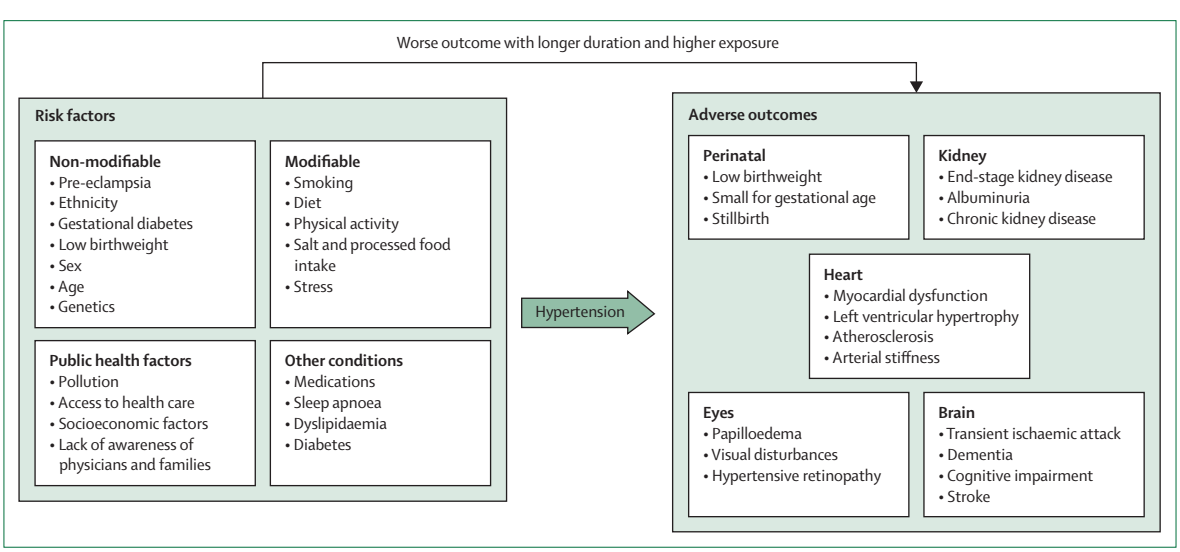

Figure 1: **Risk associations and consequences of paediatric hypertension**
Conceptual pathway summarising risk factors and downstream adverse consequences of paediatric hypertension across the life course. Arrows indicate direction of association, as synthesised from epidemiologic literature; not all links imply causality.

pressure was modest (IRR per 1-SD increase 1·10, 95% CI 0·99–1·23), and the indirect effect via adult systolic blood pressure was larger (1·15, 1·10–1·19); the total effect was 1·27 (1·15–1·41).[20] In life course models, adult blood pressure was the more influential exposure for cardiovascular disease risk than BMI, whereas childhood BMI contributed nearly as much as adult BMI. Similarly, in the Young Finns study, 84–92% of the contribution to arterial stiffness was attributable to mid-adult (age 40–56 years) blood pressure, with childhood years of high blood pressure contributing approximately 40%.[20–22] Although nutrition is certainly important to cardiovascular health, overnutrition or undernutrition are not the main drivers of hypertension risk in children living in LMICs. Harsh environmental conditions related to social and economic patterns, income, education, early exposure to maternal smoking, and unfavourable dietary behaviours, such as consumption of sweetened beverages and ultra-processed foods, play a much bigger role in contributing to hypertension risk in LMICs than in high-income countries.[23]

Childhood hypertension: risk factors

Birth cohort studies have shown that the presence or absence of various modifiable (smoking as adults and increased BMI) and non-modifiable (family history of hypertension, male sex, and low birthweight) risk factors can influence blood pressure trajectories from age 7 years.[24] Male individuals have steeper systolic blood pressure increases during puberty and young adulthood, whereas female individuals show increases later during mid-adulthood.

Blood pressure trajectories also reveal a connection between higher early life blood pressure levels and adult hypertension; a 1-SD increase in youth systolic blood pressure increases the odds of adult hypertension by 1·72 times (95% CI 1·50–1·95),[25] supporting the concept that blood pressure and cardiovascular disease risk have their origins in youth.

Obesity is a key risk factor for hypertension, with several population-based studies highlighting that those with overweight and obesity have higher rates of hypertension than peers without overweight or obesity.[26,27] Evaluating over 63 000 children (age 1·0–17·9 years) with overweight and obesity (BMI >30 kg/m^2) from Europe, hypertension was the most common comorbidity, being present in 35% of children and young people.[27] Overall, overweight adolescents have a 2·6-fold increased risk of hypertension, and those with obesity have an even greater risk.[28]

When metabolic abnormalities such as low HDL cholesterol, elevated triglycerides, fasting hyperglycaemia, and increased insulin are present simultaneously, the risk of atherosclerotic cardiovascular disease increases.[29] This clustering of cardiovascular disease risk factors, particularly when coexisting with hypertension and obesity, helps identify those at greatest risk, allowing for targeted, intensive risk reduction with lifestyle and medications. Other laboratory abnormalities that signal an increased risk for hypertension and cardiovascular disease include hyperuricemia,[30] decreased adiponectin, and elevated leptin.[31]

Insufficient physical activity and a sedentary lifestyle are recognised risk factors for childhood hypertension. Sedentary behaviours such as prolonged screen use are increasingly common in youth and, due to their association with reduced physical activity and development of hypertension, offer an additional area for intervention for cardiovascular health promotion.[32] Poor and insufficient sleep—with and without obstructive sleep apnoea—is also associated with hypertension in children and young people.[33] Reduced sleep and sleep disturbances can also contribute to obesity and future cardiovascular disease risk factor development, although this is reported inconsistently.[33,34]

Excess salt intake contributes to the development of hypertension. Globally, intake of sodium exceeds recommended values in children and young people. Most sodium intake in high-income countries comes from processed and packaged foods. Although this is also an important concern in LMICs, a major source in LMICs is also from discretionary use during cooking or while eating meals, which is an important distinction for targeted efforts to promote dietary changes.[35] A meta-analysis of ten trials evaluating the effect of salt reduction on blood pressure reported that a median reduction of 42% (IQR 7–58) in salt intake led to an immediate and meaningful fall in blood pressure, with the maximal reduction observed in those with hypertension and with systolic blood pressure decreasing more than diastolic blood pressure.[36] Other characteristics that might predict a greater response to dietary sodium reduction are obesity, history of low birthweight, and Black African ethnicity (in whom salt sensitivity is more common). Notably, these salt-sensitive individuals also have worse cardiovascular outcomes.[37] Diets high in sugar-sweetened beverages are a risk for increased blood pressure, whereas diets high in monounsaturated fat, olive oil polyphenols, fruits, and vegetables can reduce blood pressure levels.[38]

Other modifiable risk factors for hypertension and cardiovascular disease include youth smoking, passive smoking, stress, social determinants of health, and air pollution. However, data linking these exposures with childhood hypertension are not robust.

Perinatal factors, including low birthweight, preterm birth, and maternal health during pregnancy (eg, hypertension, pre-eclampsia, maternal age and education, undernutrition and overnutrition, and smoking during pregnancy) are also known risk factors for hypertension later in life. These observations support the Barker hypothesis that adult diseases can result from adverse perinatal events that impair fetal and neonatal development.[39] This has resulted in the developmental origin of health and disease concept, affecting the

approach to several diseases over the life course, including hypertension.[39]

Genetics and familial clustering reflect the well recognised tendency for parents, children, and siblings to have similar blood pressure.[40] Primary hypertension has a substantial polygenic component, with twin studies in particular highlighting a high degree of heritability of blood pressure components; systolic blood pressure and pulsatile components are more heritable than diastolic blood pressure and mean arterial pressure.[40,41] Genome-wide association studies allow simultaneous evaluation of thousands of gene variants, which has accelerated research in this area. Despite the increasing understanding of the genetic mechanisms of blood pressure regulation, there is no clinical value of genetic testing in the management of children and young people with primary hypertension.

Consequences of childhood hypertension

Hypertension-mediated target organ injury among children and young people

Similar to adult hypertension, childhood hypertension is associated with target organ injury (figure 1).[42] Although it is challenging to attribute target organ injury exclusively to hypertension in children, given the frequent coexistence of overweight or obesity, evidence suggests that hypertension independently contributes to subclinical target organ injury. In both children and adults, target organ injury might manifest in several organ systems. Cardiac organ injury can include left ventricular hypertrophy, as determined by increased left ventricular mass index, and myocardial dysfunction, identified as an abnormal ejection fraction or E/e' ratio; early atherosclerosis and vascular injury can affect the vascular system, indicated by carotid intima-media thickness and increased arterial stiffness defined by pulse wave velocity; albuminuria or proteinuria are hallmarks of renal involvement and might predict future kidney disease;[43] hypertensive retinopathy and papilloedema indicate ophthalmological injury; and altered mental status, seizures, hypertensive encephalopathy, and posterior reversible encephalopathy syndrome are indicators of CNS involvement.

Children and young people with primary ambulatory hypertension (ie, hypertension confirmed by ambulatory blood pressure monitoring) exhibit increased odds of left ventricular hypertrophy (odds ratio [OR] 4·69), greater left ventricular mass index (difference 5·13 g/m²), higher pulse wave velocity (difference 0·39 m/s), and greater carotid intima-media thickness (difference 0·04 mm), compared with normotensive peers.[44] Similarly, a meta-analysis including 5622 untreated hypertensive children and young people reported nearly a third had left ventricular hypertrophy.[45] Elevated clinic blood pressure in childhood is also substantially associated with subclinical target organ injury in adulthood, including increased pulse wave velocity (OR 1·83), elevated carotid intima-media thickness (1·60), and left ventricular hypertrophy (1·40).[46]

Timely intervention, including lifestyle modifications and pharmacological therapy, has been shown to reverse target organ injury. In a prospective study, Litwin and colleagues reported improvement in carotid intima-medial thickness and carotid wall remodelling after 12 months of lifestyle and pharmacological therapy in hypertensive adolescents.[47]

The threshold of blood pressure associated with target organ injury in children and young people remains under debate. Urbina and colleagues showed that a systolic blood pressure greater than or equal to the 90th percentile provides the best sensitivity and specificity for predicting left ventricular hypertrophy in adolescents.[22] However, data from the International Childhood Cardiovascular Cohort consortium indicate that the systolic blood pressure thresholds predictive of adult carotid intima-media thickness are potentially lower than the thresholds for diagnosis of hypertension in children currently stipulated in the American Academy of Pediatrics guidelines.[48,49] These observations underscore the importance of revisiting paediatric hypertension diagnostic thresholds to align with contemporary evidence.

In a longitudinal study over 4 years examining the association between central retinal arteriolar and venular diameters and blood pressure in 262 children aged 6–8 years at baseline,[50] children with higher baseline blood pressure had narrower arteriolar diameters at follow-up than those with lower baseline blood pressure. The same Swiss cohort of children were analysed in comparison to a South African cohort of children aged 5–9 years; children of Black African ancestry were found to have wider retinal venules than their White South African and Swiss peers, and the overall risk of arteriolar narrowing was driven by obesity (only in the White South African cohort), hypertension, and ethnicity, which suggest that inflammation and environmental risk factors might be responsible beyond traditional risk factors for microvascular impairments in Black children.[51] Moreover, hypertension was associated with decreased retinal thickness and increased retinal injury.[52]

Recommendations for target organ injury screening vary by guidelines. The US guidelines suggest performing a 2D echocardiography for left ventricular hypertrophy, whereas the European guidelines recommend a comprehensive assessment for target organ injury, additionally screening for carotid intima-media thickness, pulse wave velocity, and microalbuminuria, following a diagnosis of hypertension.[53–55] Such guidelines are scarce in LMICs, with challenges in terms of access to resources for additional clinical screening or diagnostics.

Pitfalls when considering current hypertension guidelines for children and young people with applicability in LMICs

Several concerns remain when applying guidelines developed in high-income countries for the management of hypertension in children and young people from

LMICs,[48] including absence of consensus on blood pressure measurement protocol, number of blood pressure measurements, and the required number of visits when considering the diagnosis of hypertension; absence of normative blood pressure values from children and young people in the different LMIC regions and local ethnicities; scarce data on the roles of genetic predispositions and epigenetic modifications in early life and their effect on health; and insufficient information on pharmacological treatment efficacy in various ethnic, geographical, and socioeconomic groups and the availability of such medications in LMICs.

Long-term consequences of hypertension in children and young people

Data from the International Childhood Cardiovascular Cohort consortium showed that the risk of a cardiovascular incident during adulthood (mean age 50 years) was 2-times higher for children with blood pressure greater than the 90th percentile compared with children with lower blood pressure.[17] Furthermore, each 1-SD increase in the combined score (based on BMI, systolic blood presure, triglycerides, cholesterol, and smoking) was associated with a roughly three-fold higher risk of fatal and non-fatal cardiovascular events decades later.[17] A population-based cohort study from Canada, evaluating data from 1996 to 2022, showed that children diagnosed with hypertension had a higher long-term risk of major adverse cardiac events than their non-hypertensive counterparts. Major adverse cardiac event incidence was 4·6 per 1000 person-years in hypertensive children versus 2·2 per 1000 person-years in controls (hazard ratio [HR] 2·1, 95% CI 1·9–2·2).[56]

Regarding kidney outcomes, registry analysis of otherwise healthy Israeli adolescents aged 16–19 years reported that hypertension (at least 50% of clinic blood pressure measurements performed over several weeks ≥140/90 mm Hg) was associated with nearly double the risk for end-stage kidney disease after a follow-up of approximately 20 years.[57] Findings from the Study of High Blood Pressure in Pediatrics: Adult Hypertension Onset in Youth (SHIP-AHOY) indicated that ambulatory hypertension in children (along with increased BMI and dyslipidaemia) was linked to an increased risk of proteinuria.[58] Recent analysis of the Ontario health administrative databases has highlighted a 3-times higher risk of major adverse kidney events among children with hypertension (n=26 324) than those with normal blood pressure (n=126 834; HR 3·03, 95% CI 2·86–3·21)[59] and increased health care use as indicated by hospitalisations and outpatient physician's visits.[60]

Hypertension in children and young people also affects cognitive abilities in adulthood, although the extent of these is varied. Children with high blood pressure show decreased executive function ratings reported by parents and exhibit more internalising behaviours, including depression and social isolation.[61] Children with untreated hypertension had clinically significant cognitive deficits, particularly in memory, attention, and executive functions, compared with those with normal blood pressure.[62] Findings from the SHIP-AHOY study suggest that higher systolic blood pressure was linked to poorer performance on non-verbal intelligence and verbal attention measures.[63] However, a 2022 systematic review, which included three cohort and two case-control studies among participants aged 3–30 years, did not show a link between early life higher-than-normal blood pressure and cognitive outcomes.[64]

Childhood hypertension: measurement and definitions

Current issues when measuring blood pressure in children and young people

Screening for hypertension with an accurate blood pressure measurement is key to cardiovascular health promotion. Paediatric hypertension guidelines recommend screening children and young people for hypertension at preventive care visits, with more frequent screening to occur for those at increased risk of cardiovascular disease, such as those with obesity or kidney disease.[53,54,65] Hypertension screening does not occur as frequently as advocated by guidelines,[66,67] especially in LMICs with no such health screening policies, highlighting missed opportunities for the diagnosis of hypertension and its adverse consequences. The definitions of hypertension and recommendations for screening by various guidelines,[68] including those from China[69] and Japan,[70] are detailed in table 1.

Blood pressure measurement is infrequently performed despite clinical practice guidelines. When hypertension screening does occur, measurement error can make it challenging to precisely identify those at risk. There are many potential reasons for measurement error, including a scarcity of training, busy or challenging clinical environments with competing demands, and suboptimal equipment (lack of validated devices, and available cuff sizes).[71–73] Non-adherence to preparatory and correct positioning steps before blood pressure measurement has shown errors of up to 30 mm Hg,[74] which can have notable clinical implications, leading to underdiagnosis or overdiagnosis of hypertension. Similarly, cuff size selection can also contribute to measurement error between 7 mm Hg and 13 mm Hg.[75] The importance of cuff size on blood pressure measurement accuracy was shown in a randomised crossover trial exploring differences in blood pressure readings with a too-small or too-large blood pressure cuff in an adult population: systolic blood pressure was overestimated by 4·8 mm Hg (95% CI 3·0–6·6) when a regular adult cuff was used for individuals requiring a large adult cuff (one size too small) and by 19·5 mm Hg (16·1–22·9) for individuals requiring an extra-large cuff (two sizes too small).[76]

	American Academy of Pediatrics (2017)[53]	European Society of Hypertension (2016)[54]	Hypertension Canada (2020)[55]	HyperChildNET and the European Academy of Pediatrics[68]	China (2018)[69]	Japan (2019)[70]
Blood pressure screening	Annually in all children ≥3 years; at every visit in children with comorbid conditions	Every other year for children ≥3 years if initial blood pressure normal	No recommendation on screening frequency; regular (time period undefined) measurement in children ≥3 years	Regular (time period undefined) blood pressure screening from 3 years at well child visits	No age cutoff defined	No age cutoff defined
Measurement	Screening: an automated device can be used for screening, but elevations must be confirmed by auscultatory method; hypertension diagnosis: ABPM recommended	Screening: auscultatory method preferred; hypertension diagnosis: ABPM recommended	Screening: an automated device can be used for screening, but elevations must be confirmed by auscultatory method; hypertension diagnosis: ABPM should be considered	Screening: auscultatory or validated oscillometric; hypertension diagnosis: ABPM suggested (grade B recommendation)	Screening: auscultation preferred; hypertension diagnosis: clinic blood pressure, ABPM only for those with persistently high blood pressure	Screening: auscultation is desirable, but the use of an oscillometric method is also permitted
Hypertension threshold for clinic blood pressure	≥95th percentile (<13 years) or ≥130/80 mm Hg (≥13 years)	≥95th percentile (<16 years) or ≥140/90 mm Hg (≥16 years)	≥95th percentile, >120/80 mm Hg (6–11 years), or >130/85 (≥12 years)	≥95th percentile (<16 years) or ≥140/90 mm Hg (≥16 years)	Stage 1 ≥95th to <99th percentile +5 mm Hg; stage 2: ≥99th percentile +5 mm Hg	Preschool ≥120/70 mm Hg (<6 years); grade 1–3 ≥130/80 mm Hg; grade 4–6 ≥135/80 mm Hg; junior high school boys ≥140/85 mm Hg, girls ≥135/80 mm Hg
Hypertension threshold for ABPM	≥95th percentile (<13 years); ≥125/75 mm Hg 24 h average, ≥130/80 mm Hg awake measurement, or ≥110/65 mm Hg sleep (≥13 years)	≥95th percentile (<16 years); ≥130/80 mm Hg 24 h average, ≥135/85 mm Hg awake, or ≥120/70 mm Hg sleep (≥16 years)	Not clearly defined	≥95th percentile (<16 years); ≥130/80 mm Hg 24 h average, ≥135/85 mm Hg awake, or ≥120/70 mm Hg sleep (≥16 years)	Not clearly defined	Not clearly defined
Target blood pressure (general paediatric population)	<90th percentile (<13 years), or <130/80 mm Hg (≥13 years)	<95th percentile (children and adolescents)	<95th percentile but <90th percentile to be considered for those with risk factors or target organ injury	Recommended office blood pressure target for treatment is a blood pressure <95th percentile (<18 years)	<95th percentile; for hypertensive children combined with kidney disease, diabetes, or target-organ damage, blood pressure should be reduced to <90th percentile	Not clearly defined

Clinic blood pressure thresholds are based on sex, age, and height-specific percentiles unless a fixed threshold is specified by the guideline. ABPM=ambulatory blood pressure monitoring. HyperChildNET=European network for blood pressure research in children and adolescents.

Table 1: **Comparison of global hypertension screening guidelines and definitions**

Elevated blood pressure should be confirmed by replicate measurements obtained by manual auscultation. Manual auscultation is a highly skilled task that requires staff who have been trained and certified every 6 months for measurements to be maximally accurate. Skill decay in all cadres of health-care providers is of great concern. With manual measurements, there is also a concern for terminal digit bias—particularly for the number zero.[77] Another barrier to hypertension diagnosis is recognition of elevated blood pressure. Multiple study designs in various settings have revealed that providers do not recognise or act on elevated blood pressures optimally.[72] Interventions that include quality improvement strategies, electronic medical record tools (alerts or percentile information), and education can improve recognition.

Paediatric blood pressure measurement guidelines advocate for out-of-office blood pressure monitoring to identify children and young people with white coat hypertension.[53,54,65] In the USA, the only recommended method for ruling out white coat hypertension is 24 h ambulatory blood pressure monitoring, whereas in Canada and Europe, home blood pressure monitoring according to a protocol is considered acceptable for this purpose. Implementing this confirmation step can be challenging. Barriers to successful ambulatory blood pressure monitoring include difficulties with transportation, taking time off from other commitments to pick up and return the monitor to the health-care facility, and device discomfort. Home blood pressure monitoring requires families to identify and purchase an accurate, validated device with an appropriate cuff size, learn how to use the monitor, and have a means to provide the measurements to the health-care provider, essential steps that require considerable resources and literacy. Current clinical practice guidelines do not recommend confirming the diagnosis of paediatric hypertension solely through home blood pressure measurements.[53,54] Children and young people in low-resource settings are particularly vulnerable to receiving non-guideline-adherent care as a result.

One way to address this inequity in under-resourced communities is to partner with community health workers and pharmacists to share tasks in the

management of hypertension. These efforts have been successfully studied in adult populations.[78] In paediatric populations, school-based nurses hold promise in assisting with blood pressure management of children and young people.[79] More work is needed to establish the effectiveness of employing community members (pharmacists, school nurses, and community health workers) to screen, diagnose, treat, and monitor children and young people with hypertension. In LMICs, advancing diagnostic and screening methods through validated automated measurements offers a promising approach to improving health-care outcomes. Although the CHIEDZA trial focused on HIV and reproductive health services,[80] it showed the feasibility of standardised blood pressure measurements by trained non-clinicians in community settings in Zimbabwe. Using available community resources, such as schools and community health workers, could meaningfully enhance accessibility and continuity of care, and hence increase the feasibility of scalable screening programmes in LMIC settings.

Although risk assessment scores exist for adults, there is no equivalent tool for children and young people, which limits targeted interventions for those at the highest risk of hypertension-related complications. The American Heart Association's Life's Essential 8 Metrics offers a framework for assessing cardiovascular health across all ages, with recent findings showing that youth aged 8–19 years score moderately (~70%) on this scale.[81] Given that low-to-moderate cardiovascular health in adults accounts for 70% of cardiovascular events,[82] refining risk assessment tools for young people could improve early prevention strategies. In addition to individual risk assessment, population-wide approaches are essential for creating environments that support cardiovascular health and ensure broader, equitable outcomes across diverse communities, especially in LMICs.

Universal screening remains the sole method for identifying youth with high blood pressure and those who are at risk for future cardiovascular events. Current guidelines highlight groups at particular risk for hypertension and cardiovascular disease, and advocate for screening these individuals at each health-care encounter, rather than yearly at preventive visits. Tools to identify children at greatest risk for hypertension to enable more targeted screening are not yet available. Therefore, although not the most efficient approach, universal screening is necessary to identify those at risk.

Evaluating for secondary hypertension in children and young people

Although this Review focuses on primary hypertension, clinicians should consider secondary causes in younger children (particularly <6 years); children with stage 2, resistant hypertension; symptomatic hypertension; or those with evidence of acute, severe, or malignant hypertension associated with target organ injury. Common causes include renal parenchymal, renovascular disease, coarctation of the aorta, endocrine disorders, monogenic forms, obstructive sleep apnoea, and medications. The initial approach to diagnosing secondary hypertension should include a detailed history and examination (including 4-limb blood pressure), urinalysis, serum electrolytes, serum creatinine, and renal ultrasound; abnormal findings or red flags following clinical assessments warrant early referral for further evaluation. Detailed diagnostic evaluation for secondary hypertension is beyond the scope of this Review and is covered in paediatric hypertension guidelines.[53]

Treatment of hypertension in children and young people

Treatment thresholds and targets

The absence of outcome-based research has resulted in difficulties in identifying goals for antihypertensive treatment in children and young people.[28] The primary aim is to reach and maintain blood pressure below the 90th percentile for age, sex, and height, or below 130/80 mm Hg in children 13 years and older, whichever is lower (based on the American Academy of Pediatrics guidelines), or lower than the 95th percentile based on the European Society of Hypertension guidelines.[53,54] However, more stringent blood pressure targets are recommended for children with secondary hypertension or high-risk conditions, such as chronic kidney disease.[54,83] Early intervention can improve long-term cardiovascular outcomes and promote overall health in this high-risk population.[28]

Tailored treatment strategies are essential, taking into account each child's unique risk factors, comorbidities, and developmental stage.[84] Non-pharmacological interventions represent an important and often first-line approach in managing paediatric hypertension, especially among children with overweight.[85–87] Before starting antihypertensive medications, a 6-month trial of non-pharmacological management is typically recommended in most cases.[88] Importantly, even when antihypertensive medications are initiated, maintaining lifestyle changes remains crucial for achieving blood pressure control.

Population-level strategies

Salt and sugar reduction strategies at the population level hold pivotal promise in mitigating hypertension and cardiovascular health on a broader scale and are likely to be effective in LMICs. Family-targeted and school-targeted education campaigns have proven effective in reducing sodium intake among children.[89,90] Another effective strategy is reformulating processed foods to decrease sodium content, with evidence suggesting a potential 1–3 mm Hg reduction in population mean systolic blood pressure.[28] These interventions need collaboration between public health organisations, policy

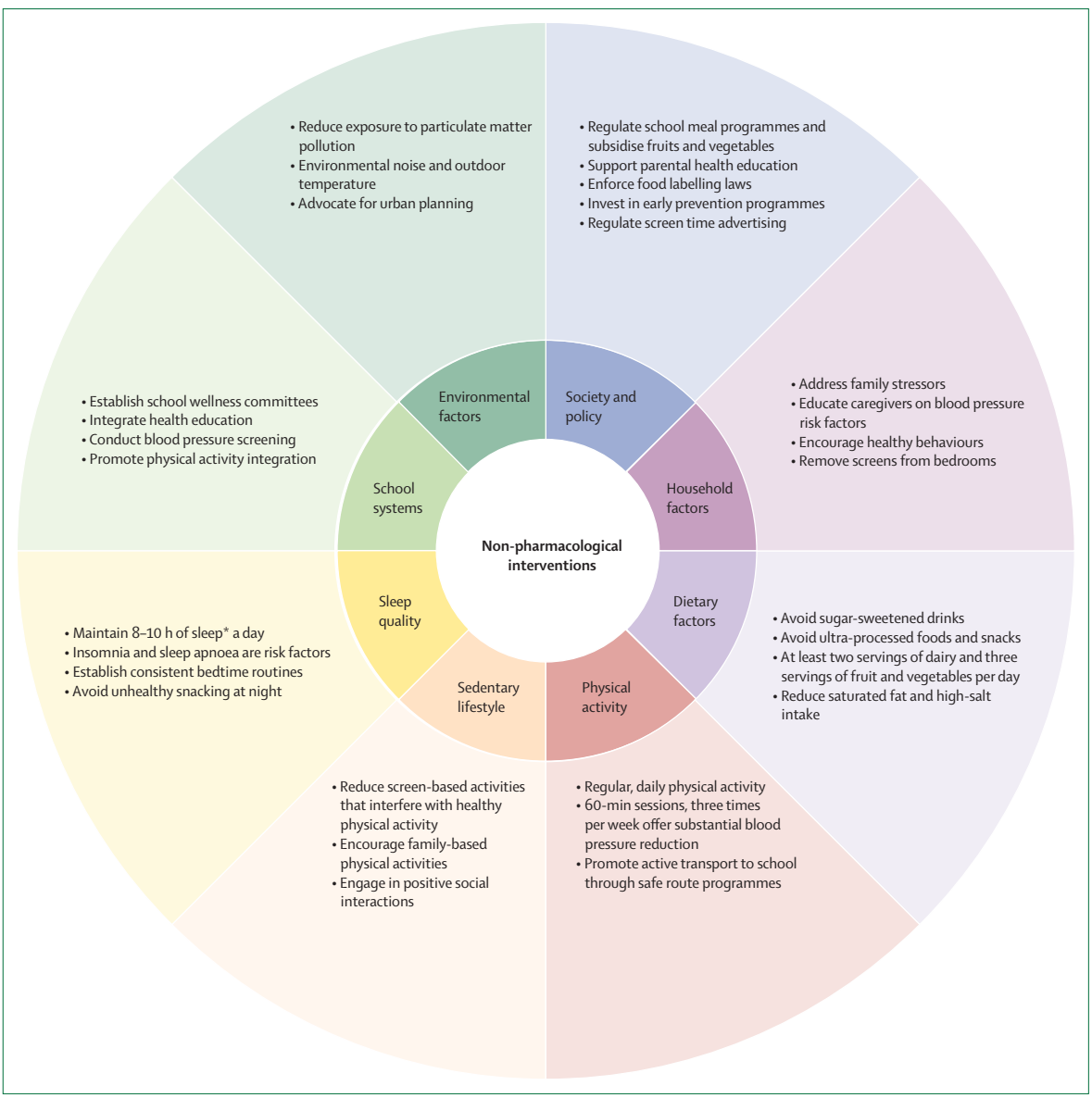

Figure 2: **Summary of non-pharmacological interventions in the management of paediatric hypertension**
Overview of non-pharmacological interventions for paediatric hypertension (dietary sodium reduction, dietary changes including sodium restriction, weight management, increased potassium intake, and physical activity). Expected blood pressure effects vary by baseline blood pressure, adiposity, sodium and potassium intake, and programme intensity and duration. *Recommended sleep duration (adolescents aged 13–18 years: 8–10 h per night; children aged 6–12 years: 9–12 h per night).

makers, and food manufacturers to achieve widespread and equitable implementation.

Excess unhealthy weight reduction strategies incorporating diet or physical activity programmes can reduce both systolic (1·64 mm Hg) and diastolic blood pressure (1·44 mm Hg), with more pronounced effects seen in programmes that combine diet and physical interventions, than those that focus on only one intervention.[91]

Non-pharmacological interventions are summarised in figure 2 and table 2. Dietary changes play an important role in managing paediatric hypertension.[92] Practical strategies to reduce sodium include replacing processed and packaged foods with low-sodium alternatives, encouraging home-cooked meals, teaching families to read food labels, and minimising the consumption of canned and boxed food items.[88] Increasing potassium intake has also been shown to have a positive effect on blood pressure.[93] Physical activity and dietary modifications are found to be effective independently of BMI changes.[87] A network meta-analysis to establish the effectiveness of physical activity interventions on blood

	Blood pressure reduction based on reported studies	Effectiveness
Weight loss[85]	7–10 mm Hg in children with obesity; less pronounced in normal-weight children	Highly effective for children with overweight and obesity; magnitude of blood pressure reduction depends on the amount of weight lost
Dietary sodium reduction[35]	4–6 mm Hg	Small but meaningful reductions in both systolic and diastolic blood pressure; particularly effective in salt-sensitive individuals (eg, children with obesity or of African ancestry)
DASH diet[92]	5–7 mm Hg	Meaningful reductions in blood pressure, beyond the effects of potassium, magnesium, and fibre alone; emphasises fruits, vegetables, and low-fat dairy products, and reducing saturated and total fat; larger reductions can be observed when combined with weight loss and physical activity
Increased potassium intake[93]	2–4 mm Hg	Blood pressure reductions are pronounced among individuals with high sodium intake or low potassium intake
Physical activity[94]	3–5 mm Hg in general population; up to 9 mm Hg in hypertensive children with structured aerobic programmes	Moderate to vigorous aerobic activity can improve systolic blood pressure and prevent vascular dysfunction; aerobic exercises have shown greater efficacy in reducing blood pressure compared with resistance training alone; longer studies with larger sample sizes are needed

Reported blood pressure reductions reflect approximate mean changes (typically systolic) from interventional and observational studies and vary by baseline blood pressure, adherence, weight status, dietary sodium and potassium intake, and programme intensity and duration. Effects might be additive when interventions are combined (eg, diet plus weight loss and physical activity). DASH=dietary approaches to stop hypertension.

Table 2: **Non-pharmacological management interventions and estimated effects on blood pressure reduction**

pressure in children and young people showed physical activity combined with nutrition and behaviour change was the most effective intervention in reducing systolic blood pressure (mean difference [MD] –8·64, 95% CI –11·44 to –5·84) and diastolic blood pressure (–6·75, –10·44 to –3·11).[94]

Implementation of dietary and other lifestyle changes is often challenging and requires a multidisciplinary team, including physicians, dietitians, social workers, psychologists, and nurses, to deliver tailored recommendations.[85] Other techniques, such as motivational interviewing and caregiver modelling, have also proven effective in facilitating behavioural change in a few studies.[95] Parental participation is crucial for implementing and sustaining lifestyle modifications, especially if the strategies are tailored to cultural and socioeconomic contexts.[96] Behavioural interventions, such as mindfulness-based stress reduction, yoga, and meditation, are less extensively researched in children, but might augment lifestyle changes by addressing stress-related elevations in blood pressure.[85,88] Sleep quality and hygiene, reducing screen time, and mitigating sedentary behaviour also play important roles in blood pressure control.[88] The integration of digital tools, such as wearable devices and mobile apps, can enhance adherence to lifestyle modifications; however, research is scarce in the paediatric population, especially in LMICs.[85]

Pharmacological management

When non-pharmacological measures are insufficient or when blood pressure is severely elevated, pharmacological treatment becomes necessary in a stepped-care method.[53] When selecting a first-line medication based on individual or clinician preference, it is recommended to begin with the lowest dose and monitor blood pressure. If blood pressure remains elevated above the target level, the dose should be incrementally increased until either blood pressure is controlled or the maximum dose is reached. Once the maximum dose is attained without reaching the desired blood pressure control, a medication from an alternative class should be introduced.[97] Antihypertensive medications that are routinely prescribed in children include angiotensin-converting enzyme inhibitors, angiotensin receptor blockers, long-acting calcium channel blockers, diuretics, and beta-blockers.[42] Unfortunately, few studies have directly compared different classes of medications in children. Moreover, data related to long-term outcomes of children on antihypertensive treatment, including effects on target organ injury and cardiovascular morbidity, remain scarce.[28]

A network meta-analysis showed that in children and young people, angiotensin-converting enzyme inhibitors and angiotensin receptor blockers are superior to placebo for blood pressure reduction.[98] However, the risk of adverse effects must be carefully considered.[42,53] Tailoring medication choices to individual needs by considering factors such as age, comorbidities, and potential drug interactions can be crucial to minimising risks and improving outcomes. A detailed review of various classes of antihypertensive agents used in paediatrics is beyond the scope of this Review.

New treatments and considerations for future research

Emerging treatments include GLP-1 receptor agonists, and sodium–glucose cotransporter 2 inhibitors. The injectable RNA interference treatment, therapeutic agent Zilebesiran, is also attractive because it has a prolonged duration of action. These treatments highlight the opportunity for innovative approaches and the need for robust clinical trails in paediatric hypertension and related comorbidities; however, there are currently no clinical data for these in hypertensive youth. One promising field is the application of n-of-1 trials, in which a systematic comparison of the effects of different medications on a single participant is done, using a randomised crossover design.[99] This allows clinicians to directly evaluate the effect of each medication on blood pressure, reduce the interparticipant variability, and

Panel: Knowledge gaps in paediatric primary hypertension

Suboptimal screening
- Inconsistent blood pressure screening recommendations across guidelines
- Low adherence to screening guidance in primary care
- Poor awareness among primary-care providers and families

Diagnostic challenges
- Absence of validated automated blood pressure devices for children younger than 5 years and those with obesity
- Underuse of ambulatory blood pressure monitoring despite diagnostic and prognostic value
- Scarce data on accuracy and reliability of home blood pressure devices for use in children
- Measurement and protocol errors (eg, cuff selection, positioning, and thresholds)

Risk factors and outcomes
- Underestimated prevalence and risk-factor burden (eg, social determinants, obesity, genetics, and environmental exposures), especially in low-income and middle-income countries (LMICs)
- Childhood-to-adult trajectories for cardiovascular and kidney outcomes remain poorly characterised

Management of hypertension
- Uncertain blood pressure treatment targets across ages and risk strata
- Inadequate evidence for effectiveness and implementation of lifestyle interventions
- Scarcity of clinical trials to guide first-line and step-up pharmacotherapy
- Paediatric dosing and formulations remain suboptimal, with reliance on adult titration paradigms

Implementation and policy
- Need for pragmatic delivery models (eg, school nurses, pharmacists, and community health workers)
- Context-specific guidance for LMICs given diagnostic and supply constraints

Prevention and risk stratification
- Few validated tools to identify children at highest risk of hypertension
- Potential of digital and artificial intelligence-enabled approaches remains underexplored

Search strategy and selection criteria

References were identified through searches of PubMed with combinations of the terms "pediatric hypertension treatment", "childhood blood pressure", "primary hypertension", "cardiovascular risk", "target organ injury", "childhood obesity", "implementation science", and "adolescent hypertension", from database inception until June 5, 2025. Additional references were identified through review of relevant articles. Only articles published in English were included. Studies were selected based on relevance to the epidemiology, diagnosis, management, and long-term outcomes of paediatric primary hypertension.

identify the most effective treatment for that particular child.[99,100] An alternative method is target trial emulation, where researchers design a hypothetical randomised trial, replicate its protocol when assembling the cohort and defining study components, and ultimately perform an analysis that simulates random treatment assignment.[101] However, these innovative study designs remain uncommon in the field of hypertension research in children and young people.

Conclusion

Primary hypertension is a growing health concern in children globally, with a rapid increase over the past two decades. Despite this concern, there are substantial knowledge gaps in the diagnosis and management of hypertension, which are summarised in the panel. The prevalence is largely underestimated, with the highest numbers of children with hypertension likely in LMICs. Hypertension during childhood is linked with target organ injury, especially the heart, and strong evidence associating childhood-onset hypertension with major adverse cardiovascular and renal outcomes as young adults. Although earlier detection is key and the risk factors contributing to the development of hypertension during childhood are largely modifiable, key knowledge gaps remain to help achieve desired outcomes. Collaborative work between health-care providers, policy makers, and children and young people and their families is needed to develop practical and sustainable interventions for effective blood pressure screening and control to prevent the long-term complications of hypertension. Paediatric-specific clinical trials should be done to fill existing evidence gaps and allow the development of standardised treatment protocols. Importantly, the use of emerging technologies, such as digital health tools, has the potential to enhance diagnostic and therapeutic strategies. By situating paediatric hypertension within the context of global cardiovascular health promotion across the lifespan, these initiatives have the potential to change the course of disease burden and enhance outcomes globally for children and adults.

Contributors
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Declaration of interests
We declare no competing interests.

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