High Blood Pressure in Children and Adolescents: Current Perspectives and Strategies to Improve Future Kidney and Cardiovascular Health

Cal H. Robinson¹ and Rahul Chanchlani²,³,⁴

¹Division of Pediatric Nephrology, Department of Pediatrics, The Hospital for Sick Children, Toronto, Ontario, Canada; ²ICES (Formerly known as Institute of Clinical Evaluative Sciences), Ontario, Canada; ³Department of Health Research Methods, Evidence and Impact, McMaster University, Hamilton, Ontario, Canada; and ⁴Division of Pediatric Nephrology, Department of Pediatrics, McMaster University, Hamilton, Ontario, Canada

Hypertension is one of the most common causes of preventable death worldwide. The prevalence of pediatric hypertension has increased significantly in recent decades. The cause of this is likely multifactorial, related to increasing childhood obesity, high dietary sodium intake, sedentary lifestyles, perinatal factors, familial aggregation, socioeconomic factors, and ethnic blood pressure (BP) differences. Pediatric hypertension represents a major public health threat. Uncontrolled pediatric hypertension is associated with subclinical cardiovascular disease and adult-onset hypertension. In children with chronic kidney disease (CKD), hypertension is also a strong risk factor for progression to kidney failure. Despite these risks, current rates of pediatric BP screening, hypertension detection, treatment, and control remain suboptimal. Contributing to these shortcomings are the challenges of accurately measuring pediatric BP, limited access to validated pediatric equipment and hypertension specialists, complex interpretation of pediatric BP measurements, problematic normative BP data, and conflicting society guidelines for pediatric hypertension. To date, limited pediatric hypertension research has been conducted to help address these challenges. However, there are several promising signs in the field of pediatric hypertension. There is greater attention being drawn on the cardiovascular risks of pediatric hypertension, more emphasis on the need for childhood BP screening and management, new public health initiatives being implemented, and increasing research interest and funding. This article summarizes what is currently known about pediatric hypertension, the existing knowledge-practice gaps, and ongoing research aimed at improving future kidney and cardiovascular health.

Kidney Int Rep (2022) 7, 954–970; https://doi.org/10.1016/j.ekir.2022.02.018
KEYWORDS: blood pressure; cardiovascular health; children; hypertension; kidney disease; pediatric

Hypertension is one of the most common causes of preventable global disease and death.¹–³ Global hypertension prevalence has doubled from 1990 to 2019, but less than half of the patients with hypertension are diagnosed and less than one-quarter are adequately controlled.² Significant global disparities exist, with lower rates of hypertension diagnosis, treatment, and control in low- and middle-income countries.²,⁴ There is strong evidence that pediatric hypertension tracks into adulthood and is associated with premature cardiovascular and kidney diseases.⁵–¹² Therefore, early detection and adequate management of pediatric hypertension should be prioritized.

Hypertension Prevalence
The prevalence of pediatric hypertension has increased in recent decades, contributed partly by rising childhood obesity.¹³,¹⁴ However, rates of pediatric hypertension depend on the definition used, which have changed over time and vary globally (Table 1).⁵,¹⁵,¹⁶,¹⁷ Without direct evidence linking specific BP thresholds to cardiovascular outcomes, pediatric hypertension is defined using normative distributions. Between 3% and 5% of children and adolescents have hypertension and 10% and 14% have elevated BP levels (“prehypertension”).¹³,¹⁴,¹⁸–²⁰ In a global meta-analysis, the pooled prevalence of hypertension was 4.0% and
Table 1. Classification of office-based BP in children and adolescents by the American Academy of Pediatrics 2017, European Society of Hypertension 2016, and Hypertension Canada 2020 guidelines

| Guidelines                      | American Academy of Pediatrics (2017) | European Society of Hypertension (2016) | Hypertension Canada (2020) |
|---------------------------------|--------------------------------------|-----------------------------------------|-----------------------------|
| BP screening and measurement    | - Annual BP measurement in children ≥3 yr of age, or at every visit if risk factors for hypertension - Oscillometric methods can be used for screening, but must be confirmed by auscultatory method - Elevated BP should be confirmed on 3 separate clinic visits - ABPM recommended | - BP measurement should be performed in children ≥3 yr of age, can repeat every 2 yr if BP normal - Auscultatory method preferred - Elevated BP should be confirmed on 3 separate clinic visits - ABPM recommended | - BP should be regularly measured in children ≥3 yr of age, no recommendation on screening frequency - Oscillometric methods can be used for screening, but must be confirmed by auscultatory method - Elevated BP should be confirmed on 3 separate clinic visits - ABPM should be considered |
| Hypertension threshold          | ≥95th percentile (<13 yr) Or ≥130/80 (≥13 yr) | ≥95th percentile (<16 y) Or ≥140/90 mm Hg (≥16 y) | ≥95th percentile Or >120/80 mm Hg (6–11 yr) Or >130/85 mm Hg (≥12 yr) |
| Target BP (general pediatric population) | <90th percentile (<13 yr) Or <130/80 (≥13 yr) | <95th percentile recommended <90th percentile should be considered | <95th percentile <90th percentile (for patients with risk factors or target organ damage) |
| Target BP (pediatric CKD) 24-h MAP (by ABPM) of <50th percentile | 24-h MAP (by ABPM) of <50th percentile (nonproteinuric CKD) | <75th percentile (proteinuric CKD) | <90th percentile |

ABPM, ambulatory blood pressure monitoring; BP, blood pressure; CKD, chronic kidney disease; MAP, mean arterial pressure.

prehypertension was 9.7%. Hypertension prevalence increased from 1.3% (1990–1999) to 6.0% (2010–2014).

State of Pediatric Hypertension Care

Despite the high prevalence, pediatric hypertension care remains suboptimal (Figure 1). There are conflicting recommendations on pediatric BP screening. Although the most recent guidelines of the American Academy of Pediatrics, European Society of Hypertension, and Hypertension Canada recommend yearly BP screening for healthy children ≥3 years old (Table 1), both the United States Preventive Services Taskforce and the United Kingdom National Screening Committee do not recommend screening. In theory, a good screening test should be safe, inexpensive, widely available, and able to detect preclinical disease with effective treatment. All of these characteristics apply to pediatric office-based BP measurement. Pediatric BP screening may also help detect hypertension comorbidities and causes of secondary hypertension. BP screening and follow-up are incomplete. In 2 Canadian studies of 9667 and 378,002 children, respectively, only 15% to 33% of children had annual BP measurement. Only 5% to 56% of children have appropriate follow-up after elevated BP level measurement. Less than 25% of children with hypertension are accurately diagnosed, less than half receive lifestyle counseling, and only 6% are prescribed antihypertensive medication. Clear challenges and knowledge-practice gaps exist in pediatric hypertension care (Figure 1).

Determinants of Pediatric Hypertension

The cause of increasing pediatric hypertension is multifactorial. Primary hypertension accounts for 50% to 90% of cases and is more common in older children and adolescents. However, secondary causes should be excluded after hypertension diagnosis, particularly in treatment-resistant and young children (Table 2).

Genetic and Perinatal Factors

Familial aggregation of hypertension is well known. Genetic factors significantly contribute, as demonstrated by the stronger association between parent/child BP than between spouses and lack of BP correlation between parents and adopted children. Familial and twin studies demonstrate that BP heritability is ~30% to 50%. Genome-wide association studies have identified many BP loci, although each individually accounts for small BP differences (<1 mm Hg). Epigenetic and gene-environment interactions are likely significant. Multiple perinatal factors are associated with childhood BP, including low birthweight, prematurity, and maternal factors (i.e., pre-eclampsia, BP, age, and body mass index). These factors can impair nephrogenesis, predisposing affected individuals to hypertension and salt sensitivity.

Obesity, Diet, and Physical Activity

Obesity is a major risk factor for pediatric hypertension. The risk of hypertension is 2.6× greater in overweight children (body mass index-for-age ≥50th percentile) and 9.2× greater in obese children (≥95th percentile)
Obesity-hypertension begins early in children (<5 years). The mechanisms of obesity-hypertension are complex but include impaired sodium handling, sympathetic nervous system over-activation, oxidative stress, hemodynamic changes, and renal/endocrine dysfunction. Physical activity is inversely associated with childhood obesity and directly counteracts obesity-hypertension mechanisms.

Dietary sodium intake is also closely associated with BP. In North American children, daily sodium intake is ~3000 mg to 3400 mg (approximately 2–3 times the recommended daily intake), and three-quarters of Canadian children exceed upper tolerable limits. Approximately 80% of dietary sodium comes from packaged and processed foods. Salt sensitivity (i.e., BP rise following sodium intake) is an important mediator. Individuals with hypertension, obesity, low birthweight, and African Americans have greater salt sensitivity, which is associated with increased target organ damage, cardiovascular disease, and mortality. However, assessing an individual’s salt sensitivity is still clinically impractical. Salt sensitivity testing requires either strict adherence to high and low sodium diets on a prolonged outpatient protocol, or i.v. sodium loading studies, neither of which are practical for most children with hypertension.

Ethnic Differences, Socioeconomic Status, and the Developing World
Significant racial and ethnic BP differences are well characterized in adults. Minority ethnic groups are consistently shown to have more hypertension and worse BP control. BP level is also higher among Black, Hispanic, and Asian children. Associations are reported between low socioeconomic status, parental income, and education with childhood BP. Kelly et al. found that socioeconomic status improvement into adulthood significantly decreased BP level. In a meta-analysis by Beltrán et al., food insecurity was significantly associated with hypertension (odds ratio 1.44, 95% CI 1.16–1.79). Ethnic and socioeconomic differences may relate to diet (i.e., access to high-quality foods and salt intake), obesity, prenatal factors, timing of sexual maturity, psychological stress, and health care access. Although hypertension detection and management have improved significantly in high-income countries,
the same is not true in the developing world. High rates of tobacco use, salt intake, and obesity contribute to high hypertension prevalence, whereas low health literacy and limited health care access are major barriers to adequate hypertension control. These issues may be further exacerbated by rapid urbanization in low- and middle-income countries.

**Pediatric Hypertension Outcomes**

Although uncontrolled adult hypertension is clearly associated with cardiovascular disease and mortality, there is limited direct evidence for hard cardiovascular outcomes in pediatric hypertension. Demonstrating this association would require a large cohort of children with hypertension, many decades of follow-up, and high participant retention, which is neither financially nor practically feasible. However, there is substantial evidence that pediatric BP tracks into adulthood and that pediatric hypertension increases the risk of subclinical cardiovascular disease (“target organ damage”).

**BP Tracking**

Children with hypertension and adolescents are more likely to become adults with hypertension, although the correlation is incomplete. Reported correlation coefficients between childhood and adult BP are 0.2 to 0.5 (weak-to-moderate correlation). However, BP tracking between adolescence and adulthood and among obese individuals is stronger.Individuals with persistent hypertension (through childhood and adolescence) have a 7.6 greater odds of adult hypertension. Of note, many children with hypertension have BP normalization over time. In 1881 children with hypertension, nearly three-quarters had normal or only elevated BP level in the following 3 years. Factors associated with BP normalization include decreased body mass index, increased vegetable intake, decreased alcohol use, and improved socioeconomic status.

**Subclinical Cardiovascular Outcomes**

Pediatric hypertension is associated with target organ damage, which in turn is associated with future cardiovascular disease. Children with hypertension have higher left ventricular mass index and left ventricular hypertrophy (LVH). Between 5% and 50% of children with hypertension have LVH, and a dose-dependent relationship is shown with increasing BP severity. Children with hypertension also have increased carotid intima-media thickness, higher pulse-wave velocity, arterial calcification and atherosclerotic changes, retinal microvascular disease, and microalbuminuria. In a large cohort of Israeli military recruits (16–19 years old), adolescent hypertension was associated with an increased risk of long-term kidney failure, as defined

### Table 2. Causes of pediatric hypertension

| Risk factors: |
|--------------|
| Obesity      |
| Sedentary lifestyle |
| High sodium intake and sodium sensitivity |
| Low socioeconomic status and food insecurity |
| Tobacco use |
| Males |
| Minority ethnic groups (e.g., Black, Hispanic, and Asian children) |
| Family history of hypertension |
| Perinatal factors (e.g., low birthweight, prematurity, maternal BP, and age) |

| Renal disease |
|---------------|
| Acute kidney injury |
| Chronic kidney disease |
| Renal scarring (e.g., previous pyelonephritis, trauma) |
| Glomerulonephritis |
| Renal vasculitis |
| Nephrotic syndrome |
| Polycystic kidney disease |
| CAKUT |
| Hemolytic-uremic syndrome |

| Endocrine disease |
|-------------------|
| Congenital adrenal hyperplasia |
| Cushing syndrome |
| Familial hyperaldosteronism |
| Apparent mineralocorticoid excess |
| Liddle, Geier, and Gordon syndromes |
| Hyperthyroidism and hypothyroidism |
| Hyperparathyroidism |
| Diabetes mellitus |

| Vascular disease |
|------------------|
| Aortic coarctation |
| Renal artery stenosis |
| Renal vein thrombosis |
| Midaortic syndrome |
| Other genetic/syndromic conditions (e.g., nephrotic syndrome, Williams, Turner, Alagille) |

| Oncologic disease |
|-------------------|
| Wilms tumor |
| Phaeochromocytoma, paraganglioma |
| Neuroblastoma |
| Reninoma |

| Neurologic disease |
|--------------------|
| Raised intracranial pressure |
| Autonomic system dysfunction (e.g., Guillain-Barré syndrome) |

| Medications and toxins |
|-----------------------|
| Iatrogenic volume and sodium loading (e.g., excess 0.9% saline administration) |
| Corticosteroids |
| Stimulants |
| Sympathomimetics |
| Oral contraceptives |
| Nicotine |
| Cocaine |
| Caffeine |
| Licorice |
| Heavy metal toxicity (e.g., lead, cadmium, mercury) |

| Other causes |
|--------------|
| Obstructive sleep apnea |
| Pain, anxiety |

BP, blood pressure; CAKUT, congenital anomalies of the kidneys and urinary tract.
by dialysis and transplant registries (adjusted hazard ratio 1.98, 95% CI 1.42–2.77), although the absolute risk was low (0.5%). In a meta-analysis of 19 studies, Yang et al.° found that elevated office BP level in children was significantly associated with adult LVH, carotid intima-media thickness, and pulse-wave velocity, as well as cardiovascular events and mortality. In another meta-analysis by Chung et al., children with ambulatory hypertension (defined by ambulatory BP monitoring [ABPM]) had significantly increased carotid intima-media thickness, pulse-wave velocity, left ventricular mass index, and LVH rates. Overall, there is strong evidence that pediatric hypertension is associated with adverse subclinical cardiovascular outcomes. In adults, these subclinical cardiovascular outcomes are consistently associated with an increased risk of cardiovascular events. However, pediatric data demonstrating a direct association between these subclinical outcomes, mortality, and clinical cardiovascular events are lacking. To further explore these associations, the Study of High Blood Pressure in Pediatrics: Adult Hypertension Onset in Youth study is establishing a multiethnic cohort of adolescents to define optimal BP thresholds and evaluate markers of hypertensive target organ damage. Fortunately, antihypertensive treatment is shown to improve LVH in pediatric studies, including patients with CKD.¹³⁻¹⁴²

Hypertension in Pediatric CKD
Hypertension is strongly associated with CKD progression in children and adults, and BP lowering prevents CKD progression. In childhood CKD, hypertension is common (48%–70%), and <50% are adequately controlled. In the Chronic Kidney Disease in Children study, 83% of the participants had ambulatory hypertension (including abnormal BP load) and 35% had masked hypertension. The optimal BP target in pediatric CKD has not been established (Table 1). The Kidney Disease: Improving Global Outcomes 2021 guidelines recommend a systolic BP target <120 mm Hg for adults with hypertension and CKD. In children, the Kidney Disease: Improving Global Outcomes guidelines recommend targeting a 24-hour mean arterial pressure (MAP) <50th percentile (level 2C; weak recommendation, low-quality evidence). This is supported by the Effect of Strict Blood Pressure Control and ACE Inhibition on the Progression of CKD in Pediatric Patients (ESCAPE) trial (385 participants), which demonstrated lower CKD progression with intensive BP control, particularly in proteinuric kidney disease. Recent data from the Chronic Kidney Disease in Children study also found that high MAP (≥90th percentile) was associated with CKD progression. However, using ABPM-based targets for pediatric hypertension management is impractical and limits global applicability. The 2016 guidelines of the European Society of Hypertension instead recommend an office-based BP target of ≤75th percentile (nonproteinuric CKD) and of ≤50th percentile (proteinuric CKD).

Challenges in BP Measurement and Interpretation
Standardized, reliable BP measurement is critical to hypertension diagnosis. Unfortunately, pediatric BP measurement is challenging. In North America, pediatric BP screening, elevated BP level follow-up, and hypertension diagnosis are suboptimal (Figure 1). There are minimal data on the extent of pediatric hypertension screening in low- to middle-income countries, where underdiagnosis may be more prevalent.

Office-Based BP Measurement
Office-based BP was traditionally measured using mercury sphygmomanometers. These have been gradually replaced by aneroid sphygmomanometers, although there are limited pediatric validation data, and these require routine calibration. Oscillometric devices are popular, given their ease of use and consistency. They overcome observer bias and prevent terminal digit preference (i.e., rounding measurements to certain digits). However, oscillometric devices estimate systolic and diastolic BP levels using proprietary formulas by measuring MAP and pulse pressure. Significant differences may exist between oscillometric devices, and they tend to overestimate pediatric BP level by 3 to 10 mm Hg. Normative BP data are typically derived by auscultatory methods, so abnormal oscillometric BP should be confirmed by auscultation. Repeated or averaged BP measurements are also more reliable, because BP level can decrease during a single visit. Newer automated devices can repeat BP measurements in clinic without an observer present and have been shown to reduce white coat phenomenon in adults. Elevated BP level should be confirmed on 3 separate visits to diagnose hypertension. Interpretation of pediatric BP is also challenging; with large reference tables, changing normative data, and conflicting definitions of pediatric hypertension. The development of accessible tools, including simple BP screening tables and mobile applications (e.g., PedBP), has simplified diagnosis. Although convenient, office-based BP provides only a snapshot of a patient’s BP. In the Study of High Blood Pressure in Pediatrics: Adult Hypertension Onset in Youth, office-based BP level ≥85th percentile was most
predictive of ambulatory hypertension and may be considered as a threshold for ABPM.\(^\text{166}\)

**Home and ABPM**

Ambulatory BP is more reproducible and better associated with target organ damage than office-based BP.\(^\text{167–169}\) There are limited pediatric data on home BP monitoring (HBPM),\(^\text{170}\) although it is commonly used (70% of surveyed German pediatric nephrologists)\(^\text{171}\) and has gained popularity during the COVID-19 pandemic.\(^\text{172}\) HBPM provides a more longitudinal BP assessment than either office-based BP or ABPM, is cost-effective, and is well tolerated.\(^\text{173,174}\) Although not recommended for pediatric hypertension diagnosis, HBPM can help detect white coat or masked hypertension. HBPM is also useful for BP monitoring in patients with hypertension, especially when strict BP control is desired.\(^\text{5,15}\) However, there can be reporting bias, the optimal timing of measurements is unknown, and validated pediatric devices and cuff sizes are lacking.\(^\text{15}\) HBPM should be supported by adequate caregiver training and device calibration with office-based auscultatory BP.

Telemedicine strategies for hypertension management, including BP telemonitoring, have been shown to be feasible and associated with improved BP control in adults with hypertension.\(^\text{175}\) However, there are minimal data on the use of BP telemonitoring in children. Incorporation of these strategies could improve access to pediatric hypertension care, may promote disease self-management, and enhance lifestyle modification. However, these potential benefits are balanced against limited access to validated pediatric home BP devices, a lack of standardized protocols for HBPM, few pediatric telemedicine services, regulatory and privacy issues, and provider reimbursement considerations.\(^\text{175}\) Further research on the clinical application of HBPM in children is needed to facilitate BP telemonitoring programs.\(^\text{170}\)

ABPM is the gold standard for adults and is recommended by the European Society of Hypertension and the American Academy of Pediatrics for children (\(\geq 5\) years).\(^\text{5,13}\) ABPM is well correlated with target organ damage\(^\text{167–169}\) and is reliable in pediatric CKD.\(^\text{144}\) It can detect nocturnal and masked hypertension, which are both more common in CKD.\(^\text{158,159}\) An “ABPM-first” approach for pediatric hypertension referrals (i.e., performing ABPM in all new referrals to confirm hypertension before consultation and to avoid unnecessary expensive secondary hypertension workups) is a potential cost-saving strategy.\(^\text{176}\) However, there are limitations to widespread pediatric ABPM utilization. There are few validated pediatric devices, costs are prohibitive, and global access is limited. Existing ABPM normative data are also problematic. Current normative data were derived from a relatively small Caucasian German population.\(^\text{177,178}\) There are minimal data for children \(< 120\) cm in height, and concerns exist regarding low diastolic BP variation in this cohort. BP varies by ethnicity and geographic region. Xi et al.\(^\text{179}\) attempted to create international normative BP data from 52,636 children in 7 countries using office-based BP methods. Median systolic/diastolic BP levels varied up to 10 mm Hg between countries, with India and Poland having the highest BP level. Based on these differences in BP by ethnicity, existing ABPM normative data may not be applicable to non-Caucasian children. Yip et al.\(^\text{180}\) developed ABPM normative data for East Asian children in Hong Kong, and BP values were 5 to 6 mm Hg higher than those in Caucasian children. There are ongoing efforts to develop validated normative data sets in other ethnicities, including South Asian children in Canada in the Ambulatory blood pressure monitoring for South Asian children study.\(^\text{181}\)

Another limitation is the existing pediatric ABPM classification. In adults, ambulatory hypertension is defined by simple thresholds (i.e., mean wake BP > 130/80 mm Hg, sleep BP > 110/65, or 24-hour BP > 125/75), that predict cardiovascular events.\(^\text{182,183}\) In the pediatric American Heart Association guidelines, ambulatory hypertension is categorized by mean BP and BP load.\(^\text{169}\) However, up to 20% to 40% of children are unclassified using these criteria and hypertension thresholds may be higher than adult thresholds for children \(\geq 12\) years old.\(^\text{184–186}\) There is emerging evidence that isolated elevated BP load is not significantly associated with target organ damage.\(^\text{185,187,188}\)

Removing BP load criteria and using adult thresholds for adolescents would simplify ABPM interpretation.\(^\text{186,188}\) Because oscillometric ABPM devices measure MAP, it may also be preferable to classify ABPM using MAP, instead of calculated systolic/diastolic BP.

**Pediatric Hypertension Management**

Optimal pediatric BP thresholds are unknown (Table 1), but the goal is to reduce BP to a level that minimizes cardiovascular and kidney disease risks. In adults with hypertension, the Systolic Blood Pressure Intervention Trial demonstrated that intensive BP control (systolic BP target \(< 120\) mm Hg) was associated with a significantly lower risk of cardiovascular outcomes,\(^\text{189}\) which has led to the incorporation of lower BP targets in recent adult hypertension guidelines.\(^\text{182,190}\) Strategies to improve pediatric hypertension typically address the individual level. However, pediatric hypertension is a growing pandemic, and effective population-based interventions are essential to address the global disease burden (Figure 2). Improving awareness of pediatric hypertension among primary care physicians, community organizations, and families may increase...
detection, provide earlier treatment opportunities, and mitigate adverse consequences.

**Population-Based Strategies**
Population-based sodium reduction strategies are highly cost-effective. In Finland and the United Kingdom, public health campaigns, food industry regulations, and product labeling have successfully decreased population sodium intake by 15% to 40%. Public health strategies should also address childhood obesity and sedentary lifestyles, including awareness campaigns, creating safe spaces for physical activity, and integrating exercise into schools and communities.

**Figure 2.** Strategies to improve global pediatric hypertension care. ACEi, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; CCB, calcium channel blocker.
activity, integrating exercise into schools and communities, and improving access to high-quality nutrition (e.g., through food taxes, subsidies, and school-based programs). In 2013, the World Health Organization created a Global Action Plan for the control of non-communicable diseases and described a series of “best buy” interventions, considered to be the most cost-effective and feasible. These include reducing tobacco and alcohol use, reducing salt and transfat intake, and public health physical activity campaigns. In rural South Asia, the COBRA-BPS trial found that a multicomponent community hypertension intervention (including community health education, BP monitoring, provider training in hypertension management, designated hypertension clinics, and additional funding) significantly improved hypertension control and was cost-effective. Strategies to improve pregnancy outcomes, early childhood education, and nutrition are also critical. The Carolina Abecedarian Project found that an early childhood education and nutrition program significantly decreased adult hypertension.

**Nonpharmacologic Management**

Effective nonpharmacologic strategies for pediatric BP lowering include weight loss (for overweight children), regular physical activity, reduced sodium intake, the Dietary Approaches to Stop Hypertension diet, and smoking/alcohol avoidance (Figure 2). There is strong evidence in both adults and children that dietary sodium reduction is associated with improved BP control, in a dose-dependent relationship. In 2 pediatric meta-analyses (966 and 58,531 patients respectively), reduced dietary sodium intake was associated with small, but significant BP reductions (≈1 mm Hg). The association between BP and sodium intake was stronger in overweight children and children with low potassium intake. Achieving sustainable sodium reductions is challenging, given the sodium content in processed foods. Although optimal sodium reduction targets for children are uncertain, the National Academies of Sciences, Engineering and Medicine have recommended Chronic Disease Risk Reduction Intake limits, based on extrapolated adult data (1–3 years: <1200 mg/d; 4–8 years: <1500 mg/d; 9–13 years: <1800 mg/d; 14–18 years: <2300 mg/d). A practical approach for sodium reduction is to recommend a no-added salt diet, a reduction of high-salt, processed foods, and to provide education to families regarding food label interpretation. Self-reported sodium intake is also inaccurate. Urine sodium excretion is more reliable, and novel formulas to estimate sodium excretion from spot urine samples are available. Higher sodium excretion is associated with major cardiovascular events.

The Dietary Approaches to Stop Hypertension diet was designed in the 1990s as an optimal BP-lowering diet for adults. The Dietary Approaches to Stop Hypertension diet promotes consumption of vegetables, fruit, lean meat, and dairy, and reduces intake of sodium, saturated fat, added sugars, and highly processed foods. The Dietary Approaches to Stop Hypertension diet has also been shown to improve BP in children and adolescents, although there are limited published data. Regular physical activity has also been shown to reduce BP in children and adolescents with hypertension. However, the results of published studies are inconsistent and the effect size is generally small. Physical activity interventions appear to be more effective when combined with diet or weight loss programs.

**Pharmacologic Management**

Nonpharmacologic interventions should be optimized before antihypertensive treatment. Antihypertensive medications should be selected based on underlying hypertension pathophysiology, anticipated efficacy, side effects, available formulations, and associated costs. Long-acting medications and simplified dosing schedules can improve compliance. Few pediatric trials compare antihypertensive medications. A systematic review by Simonetti et al. found that angiotensin-converting enzyme inhibitors, angiotensin II receptor blockers, and calcium channel blockers had similar antihypertensive efficacy. A 2014 Cochrane review found that angiotensin-converting enzyme inhibitors, angiotensin II receptor blockers, and beta-blockers each significantly reduced BP versus placebo, whereas calcium channel blockers did not. A subsequent network meta-analysis by Burrello et al. found similar BP reductions across antihypertensive classes, but only renin-angiotensin-aldosterone system inhibitors significantly reduced BP versus placebo. Generally, renin-angiotensin-aldosterone system inhibitors are considered first-line pediatric antihypertensives, particularly in CKD. Calcium channel blockers are considered for sexually active adolescent females or if laboratory surveillance (for renin-angiotensin-aldosterone system inhibitors) is poorly tolerated. Samuel et al. described a novel antihypertensive selection approach, by conducting serial n-of-1 trials in 42 children with ABPM, identifying each patient’s “preferred” medication (49% lisinopril, 24% amlodipine, and 12% hydrochlorothiazide).

**Future Directions and Knowledge Gaps**

Despite significant advances in pediatric hypertension research, knowledge gaps persist. It is unclear what BP thresholds are associated with cardiovascular outcomes.
and should be targeted. We must determine the optimal intermediate markers (e.g., LVH) for predicting cardiovascular events. Because BP tracking and target organ damage are incomplete, we must identify relevant predictive factors. We should also evaluate the effect of hypertension duration on cardiovascular outcomes. It remains unclear if transient hypertension (i.e., during childhood chemotherapy) has long-term risks and warrants treatment. The optimal role and timing of HBPM and ABPM are unclear, and progress is needed to validate and improve access to pediatric devices. Additional ABPM normative data sets are needed, in diverse ethnic populations. Finally, further trials are needed to evaluate various antihypertensive medications, particularly among specific populations (e.g., obesity, nonproteinuric CKD, and congenital heart disease). Fortunately, ongoing research will help answer some of these questions, including the Study of High Blood Pressure in Pediatrics: Adult Hypertension Onset in Youth study,138 further Chronic Kidney Disease in Children analyses (https://statepi.jhsph.edu/ckid), the Ambulatory blood pressure monitoring for South Asian children study, the Pediatric Hypertension Registry, prospective longitudinal cohorts including the Young Finns study (https://youngfinnsstudy.utu.fi), and novel intervention trials (e.g., pharmacist- or youth-led programs, n-of-1 medication trials, and clinical decision support tools).

**REFERENCES**

1. Danaei G, Ding EL, Mozaffarian D, et al. The preventable causes of death in the United States: comparative risk assessment of dietary, lifestyle, and metabolic risk factors. *PLoS Med.* 2009;6:e1000058. https://doi.org/10.1371/journal.pmed.1000058
2. Zhou B, Perel P, Mensah GA, Ezzati M. Global epidemiology, health burden and effective interventions for elevated blood pressure and hypertension. *Nat Rev Cardiol.* 2021;18:785–802. https://doi.org/10.1038/s41569-021-00559-8
3. Forouzanfar MH, Liu P, Roth GA, et al. Global burden of hypertension and systolic blood pressure of at least 110 to 115 mmHg, 1990-2015. *JAMA.* 2017;317:165–182. https://doi.org/10.1001/jama.2016.19043
4. Schutte AE, Srinivasapura Venkatashmurthy N, Mohan S, Prabhakaran D. Hypertension in low- and middle-income countries. *Circ Res.* 2021;128:808–826. https://doi.org/10.1161/CIRCRESAHA.120.318729
5. Flynn JT, Kaelber DC, Baker-Smith CM, et al. Clinical practice guideline for screening and management of high blood pressure in children and adolescents. *Pediatrics.* 2017;140:e20171904. https://doi.org/10.1542/peds.2017-1904
6. Yang L, Magnussen CG, Yang L, Bovet P, Xi B. Elevated blood pressure in childhood or adolescence and cardiovascular outcomes in adulthood: a systematic review. *Hypertension.* 2020;75. https://doi.org/10.1161/HYPERTENSIONAHA.119.14168, 2020;948–955.
7. Thompson M, Dana T, Bougatsos C, Blazina I, Norris SL. Screening for hypertension in children and adolescents to prevent cardiovascular disease. *Pediatrics.* 2013;131:490–525. https://doi.org/10.1542/peds.2012-3523
8. Leiba A, Fishman B, Twig G, et al. Association of adolescent hypertension with future end-stage renal disease. *JAMA Intern Med.* 2019;179:517–523. https://doi.org/10.1001/jamainternmed.2018.7632
9. Juhola J, Magnussen CG, Viikari JSA, et al. Tracking of serum lipid levels, blood pressure, and body mass index from childhood to adulthood: the Cardiovascular Risk in Young Finns Study. *J Pediatr.* 2011;159:584–590. https://doi.org/10.1016/j.jspeds.2011.03.021
10. Chen X, Wang Y. Tracking of blood pressure from childhood to adulthood: a systematic review and meta-regression analysis. *Circulation.* 2008;117:3171–3180. https://doi.org/10.1161/CIRCULATIONAHA.107.730366
11. Theodore RF, Broadbent J, Nagin D, et al. Childhood to early-midlife systolic blood pressure trajectories: early-life predictors, effect modifiers, and adult cardiovascular outcomes. *Hypertension.* 2015;66:1108–1115. https://doi.org/10.1161/HYPERTENSIONAHA.115.05831
12. Urbina EM, Khoury PR, Bazzano L, et al. Relation of blood pressure in childhood to self-reported hypertension in adulthood: the international childhood cardiovascular cohort consortium. *Hypertension.* 2019;73:1224–1230. https://doi.org/10.1161/HYPERTENSIONAHA.118.12334
13. Rosner B, Cook NR, Daniels S, Falkner B. Childhood blood pressure trends and risk factors for high blood pressure: the NHANES experience 1988-2008. *Hypertension.* 2013;62:247–254. https://doi.org/10.1161/HYPERTENSIONAHA.111.00831
14. Song P, Zhang Y, Yu J, et al. Global prevalence of hypertension in children: a systematic review and meta-analysis. *JAMA Pediatr.* 2019;173:1154–1163. https://doi.org/10.1001/jamapediatrics.2019.3310
15. Lurbe E, Agabiti-Rosei E, Cruickshank JK, et al. 2016 European Society of Hypertension guidelines for the management of high blood pressure in children and adolescents. *J Hypertens.* 2016;34:1887–1920. https://doi.org/10.1097/HJH.0000000000001039
16. National High Blood Pressure Education Program working group on high blood pressure in children and adolescents. The fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents. *Pediatrics.* 2004;114(suppl):555–576.
17. Dionne JM, Harris KC, Benoit G, et al. Hypertension Canada’s 2017 guidelines for the diagnosis, assessment, prevention, and treatment of pediatric hypertension. *Can J Cardiol.* 2017;33:577–585. https://doi.org/10.1016/j.cjca.2017.03.007
18. Koebnick C, Black MH, Wu J, et al. The prevalence of primary pediatric prehypertension and hypertension in a real-world managed care system. J Clin Hypertens (Greenwich). 2013;15:784–792. https://doi.org/10.1111/jch.12173

19. de Moraes ACF, Lacerda MB, Moreno LA, Horta BL, Carvalho HB. Prevalence of high blood pressure in 122,053 adolescents: a systematic review and meta-regression. Medicine (Baltimore). 2014;93:e232. https://doi.org/10.1097/MD.0000000000000232

20. Aliarzadeh B, Meaney C, Moineddin R, et al. Hypertension screening and follow-up in children and adolescents in a Canadian primary care population sample: a retrospective cohort study. CMAJ Open. 2016;4:E230–E235. https://doi.org/10.9787/cmaj.20150016

21. Rabi DM, McBrien KA, Sapir-Pichhadze R, et al. Hypertension screening and recognition in primary care clinics in Canada. Paediatr Child Health. 2006;8(1):cprl1-0601

22. US Preventive Services Task Force, Krist AH, Davidson KW, et al. Screening for high blood pressure in children and adolescents: US Preventive Services Task Force recommendation statement. JAMA. 2020;324:1878–1883. https://doi.org/10.1001/jama.2020.20122

23. Shapiro DJ, Hersh AL, Cabana MD, et al. Hypertension in adults and children. Hypertension. 2000;36:596–624. https://doi.org/10.1161/01.HYP.35.2.574

24. Herman C. What Makes a Screening Exam “good”? AMA J Ethics. 2006;8:34–37. https://doi.org/10.1001/virtualmentor.2006.8.1.crm1-0601

25. Ding L, Singer A, Kosowan L, Dart A. Pediatric hypertension screening and recognition in primary care clinics in Canada. Paediatr Child Health. Published online October 11, 2021. https://doi.org/10.1093/pch/pxab81

26. Shapiro DJ, Hersh AL, Cabana MD, et al. Hypertension screening during ambulatory pediatric visits in the United States, 2000-2009. Pediatrics. 2012;130:604–610. https://doi.org/10.1542/peds.2011-3888

27. Rea CJ, Brady TM, Bundy DG, et al. Pediatrician adherence to guidelines for diagnosis and management of high blood pressure. J Pediatr. 2022;242:12–17e1. https://doi.org/10.1016/j.jpeds.2021.11.008

28. Daley MF, Sinaiko AR, Reifler LM, et al. Patterns of care and persistence after incident elevated blood pressure. Pediatrics. 2013;132:e349–e355. https://doi.org/10.1542/peds.2012-2437

29. Hansen ML, Gunn PW, Kaelber DC. Underdiagnosis of hypertension in children and adolescents. JAMA. 2007;298:874–879. https://doi.org/10.1001/jama.298.8.874

30. Brady TM, Neu AM, Miller ER, Appel LJ, Siberry GK, Solomon BS. Real-time electronic medical record alerts increase high blood pressure recognition in children. Clin Pediatr (Phila). 2015;54:667–675. https://doi.org/10.1177/000992281559379

31. Kaelber DC, Liu W, Ross M, et al. Diagnosis and medication treatment of pediatric hypertension: a retrospective cohort study. Pediatrics. 2016;138:e20162195. https://doi.org/10.1542/peds.2016-2195

32. Dionne JM. Evidence gaps in the identification and treatment of hypertension in children. Can J Cardiol. 2020;36:1384–1393. https://doi.org/10.1016/j.cjcard.2020.02.076

33. Robinson RF, Batsky DL, Hayes JR, Nahata MC, Mahan JD. Body mass index in primary and secondary pediatric hypertension. Pediatr Nephrol. 2004;19:1379–1384. https://doi.org/10.1007/s00467-004-1588-8

34. Silverstein DM, Champoux E, Aviles DH, Vehaskari VM. Treatment of primary and secondary hypertension in children. Pediatr Nephrol. 2006;21:820–827. https://doi.org/10.1007/s00467-006-0087-5

35. Havlik RJ, Feinleib M. Epidemiology and genetics of hypertension. Hypertension. 1982;4:III121–III127. https://doi.org/10.1161/01.hyp.4.5_pt.iii121

36. Biron P, Mongeau JG, Bertrand D. Familial aggregation of blood pressure in 558 adopted children. Can Med Assoc J. 1976;115:773–774.

37. Annest JL, Sing CF, Biron P, Mongeau JG. Familial aggregation of blood pressure and weight in adoptive families. II. Estimation of the relative contributions of genetic and common environmental factors to blood pressure correlations between family members. Am J Epidemiol. 1983;117:492–506. https://doi.org/10.1093/oxfordjournals.aje.a113567

38. Snieder H, Hayward CS, Perks U, Kelly RP, Kelly PJ, Spector TD. Heritability of central systolic pressure augmentation: a twin study. Hypertension. 2000;35:574–579. https://doi.org/10.1161/01.hyp.35.2.574

39. Levy D, Larson MG, Benjamin EJ, et al. Framingham Heart Study 100K Project: genome-wide associations for blood pressure and arterial stiffness. BMC Med Genet. 2007;8(suppl 1):S3. https://doi.org/10.1186/1471-2350-8-S1-S3

40. Miaill WE, Oldham PD. The hereditary factor in arterial blood-pressure. Br Med J. 1963;1:75–80. https://doi.org/10.1136/bmj.1.5323.75

41. Xu X, Ding X, Zhang X, et al. Genetic and environmental influences on blood pressure variability: a study in twins. J Hypertens. 2013;31:690–697. https://doi.org/10.1097/HJH.0b1013e32835ae4a

42. Girl A, Heilwege JN, Keaton JM, et al. Trans-ethnic association study of blood pressure determinants in over 750,000 individuals. Nat Genet. 2019;51:51–62. https://doi.org/10.1038/s41588-018-0303-9

43. Evangelou E, Warren HR, Mosen-Ansorena D, et al. Genetic analysis of over 1 million people identifies 535 new loci associated with blood pressure traits. Nat Genet. 2018;50:1412–1425. https://doi.org/10.1038/s41588-018-0205-x

44. Zhu X, Feng T, Tayo BO, et al. Meta-analysis of correlated traits via summary statistics from GWASs with an application in hypertension. Am J Hum Genet. 2015;96:21–36. https://doi.org/10.1016/j.ajhg.2014.11.011

45. Davis EF, Lazdam M, Lewandowski AJ, et al. Cardiovascular risk factors in children and young adults born to pre-eclamptic pregnancies: a systematic review. Pediatrics. 2012;129:e1552–e1561. https://doi.org/10.1542/peds.2011-3093

46. Law CM, Shiell AW. Is blood pressure inversely related to birth weight? The strength of evidence from a systematic review of the literature. J Hypertens. 1996;14:935–941.
47. Huxley RR, Shiell AW, Law CM. The role of size at birth and postnatal catch-up growth in determining systolic blood pressure: a systematic review of the literature. J Hypertens. 2000;18:815–831. https://doi.org/10.1097/00004872-200018070-00002

48. Leon DA, Koupilova I, Lithell HO, et al. Failure to realise sodium restriction on blood pressure. J Hypertens. 1997;29:1015–1020. https://doi.org/10.1097/00004872-199706001-00007

49. Keller G, Zimmer G, Mall G, Ritz E, Amann K. Nephron number in patients with primary hypertension. N Engl J Med. 2003;348:101–108. https://doi.org/10.1056/NEJMoa020649

50. Bertram JF, Douglas-Denton RN, Diouf B, Hughson MD, Hoy WE. Human nephron number: implications for health and disease. Pediatr Nephrol. 2011;26:1529–1533. https://doi.org/10.1007/s00467-011-1843-8

51. Simonetti GD, Raio L, Surbek D, Nelle M, Frey FJ, Mohaupt MG. Salt sensitivity of children with low birth weight. Hypertension. 2008;52:625–630. https://doi.org/10.1161/HYPERTENSIONAHA.108.114983

52. Ruyts CA, Rotteveel J, van de Lagemaat M, Lafeber HN, Finken MJJ. Salt sensitivity of blood pressure at age 8 years in children born preterm. J Hum Hypertens. 2018;32:367–376. https://doi.org/10.1038/s41371-018-0045-2

53. Rabe H, Bhatt-Mehta V, Bremmer SA, et al. Antenatal and perinatal factors influencing neonatal blood pressure: a systematic review. J Perinatol. 2021;41:2317–2329. https://doi.org/10.1038/s41371-021-01169-5

54. Martin RM, Ness AR, Gunnell D, Emmett P, Davey Smith G. Does breast-feeding in infancy lower blood pressure in childhood? The Avon longitudinal study of parents and children (ALSPAC). Circulation. 2004;109:1259–1266. https://doi.org/10.1161/01.cir.0000118468.76447.ce

55. Lawlor DA, Najman JM, Sterne J, Williams GM, Ebrahim S, Davey Smith G. Associations of parental, birth, and early life characteristics with systolic blood pressure at 5 years of age: findings from the Mater-University study of pregnancy and its outcomes. Circulation. 2004;110:2417–2423. https://doi.org/10.1161/01.CIR.0000145165.80139.B5

56. Mliku K, Moraes TJ, Becker AB, et al. Breastfeeding in the first days of life is associated with lower blood pressure at 3 years of age. J Am Heart Assoc. 2021;10:e019067. https://doi.org/10.1161/JAHA.120.019067

57. Amorim R de, Coelho AF, de Lira PI, Lima Mde C. Is breastfeeding protective for blood pressure in schoolchildren? A cohort study in northeast Brazil. Breastfeed Med. 2014;9:149–156. https://doi.org/10.1089/bfm.2013.0118

58. Hosaka M, Asayama K, Staessen JA, et al. Breastfeeding leads to lower blood pressure in 7-year-old Japanese children: Tohoku study of child development. Hypertens Res. 2013;36:117–122. https://doi.org/10.1038/hr.2012.128

59. Horta BL, Loret de Mola C, Victorio CG. Long-term consequences of breastfeeding on cholesterol, obesity, systolic blood pressure and type 2 diabetes: a systematic review and meta-analysis. Acta Paediatr. 2015;104:30–37. https://doi.org/10.1111/apa.13133

60. Geleijnse JM, Hofman A, Witteman JC, Hazebroek AA, Valkenburg HA, Grobbee DE. Long-term effects of neonatal sodium restriction on blood pressure. Hypertension. 1997;29:913–917. https://doi.org/10.1161/01.hyp.29.4.913

61. McNiece KL, Poffenbarger TS, Turner JL, Franco KD, Sorof JM, Portman RJ. Prevalence of hypertension and prehypertension among adolescents. J Pediatr. 2007;150:640–644.e1. https://doi.org/10.1016/j.jpeds.2007.01.052

62. Tu W, Eckert GJ, DiMeglio LA, Yu Z, Jung J, Pratt JH. Intensified effect of adiposity on blood pressure in overweight and obese children. Hypertension. 2011;58:818–824. https://doi.org/10.1161/HYPERTENSIONAHA.111.176695

63. Jago R, Harrell JS, McMurray RG, Edelstein S, El Ghormli, Bassin S. Prevalence of abnormal lipid and blood pressure values among an ethnically diverse population of eighth-grade adolescents and screening implications. Pediatrics. 2006;117:2065–2073. https://doi.org/10.1542/peds.2005-1716

64. Wirix AJ, Nauta J, Groothoff JW, et al. Is the prevalence of hypertension in overweight children overestimated? Arch Dis Child. 2016;101:998–1003. https://doi.org/10.1136/archdischild-2015-309869

65. Dasgupta K, O’Loughlin J, Chen S, et al. Emergence of sex differences in prevalence of high systolic blood pressure: analysis of a longitudinal adolescent cohort. Circulation. 2006;114:2663–2670. https://doi.org/10.1161/CIRCULATIONAHA.106.624536

66. Redwine KM, Acosta AA, Poffenbarger T, Portman RJ, Samuels J. Development of hypertension in adolescents with pre-hypertension. J Pediatr. 2012;160:98–103. https://doi.org/10.1016/j.jpeds.2011.07.010

67. Falkner B, Gidding SS, Ramirez-Garnica G, Wiltrout SA, West D, Rappaport EB. The relationship of body mass index and blood pressure in primary care pediatric patients. J Pediatr. 2006;148:195–200. https://doi.org/10.1016/j.jpeds.2005.10.030

68. Belfort MB, Rifas-Shiman SL, Rich-Edwards J, Kleinman KP, Gillman MW. Size at birth, infant growth, and blood pressure at three years of age. J Pediatr. 2007;151:670–674. https://doi.org/10.1016/j.jpeds.2007.05.010

69. Vale S, Trost SG, Régo C, Abreu S, Mota J. Physical activity, obesity status, and blood pressure in preschool children. J Pediatr. 2015;167:98–102. https://doi.org/10.1016/j.jpeds.2015.04.031

70. Susic D, Varagic J. Obesity: a perspective from hypertension. Med Clin North Am. 2017;101:139–157. https://doi.org/10.1016/j.mcna.2016.08.008

71. Strambi M, Giussani M, Ambruzzi MA, et al. Novelty in hypertension in children and adolescents: focus on hypertension during the first year of life, use and interpretation of ambulatory blood pressure monitoring, role of physical activity in prevention and treatment, simple carbohydrates and uric acid as risk factors. Ital J Pediatr. 2016;42:69. https://doi.org/10.1186/s13052-016-0277-0

72. He FJ, Marrero NM, Macgregor GA. Salt and blood pressure in children and adolescents. J Hum Hypertens. 2008;22:4–11. https://doi.org/10.1038/sj.jhh.1002268

73. Yang Q, Zhang Z, Kuklina EV, et al. Sodium intake and blood pressure among US children and adolescents. Pediatrics. 2012;130:611–619. https://doi.org/10.1542/peds.2011-3870

74. Gowrishankar M, Blair B, Rieder MJ. Dietary intake of sodium by children: why it matters. Paediatr Child Health. 2020;25:47–61. https://doi.org/10.1093/pch/pzx153
75. National Academies of Sciences, Engineering, and Medicine, Health and Medicine Division, Food and Nutrition Board. Committee to review the dietary reference intakes for sodium and potassium. In: Oria M, Harrison M, Stallings VA, eds. Dietary Reference Intakes for Sodium and Potassium. National Academies Press (US); 2019.

76. Balafa O, Kalaizidis RG. Salt sensitivity and hypertension. *J Hum Hypertens*. 2021;35:184–192. https://doi.org/10.1038/s41371-020-00407-1

77. Weinberger MH, Fineberg NS, Fineberg SE, Weinberger M. Salt sensitivity, pulse pressure, and death in normal and hypertensive humans. *Hypertension*. 2001;37:429–432. https://doi.org/10.1161/01.hyp.37.2.429

78. Mu J, Zheng S, Lian Q, Liu F, Liu Z. Evolution of blood pressure from adolescents to youth in salt sensitivities: a 18-year follow-up study in Hanzhong children cohort. *Nutr J*. 2012;11:70. https://doi.org/10.1186/1475-2891-11-70

79. Bihorac A, Tezcan H, Ozener C, Oktay A, Akoglu E. Association between salt sensitivity and target organ damage in essential hypertension. *Am J Hypertens*. 2000;13:864–872. https://doi.org/10.1016/S1074-7516(00)00253-3

80. Sanders PW. Dietary salt intake, salt sensitivity, and cardiovascular health. *Hypertension*. 2009;53:442–445. https://doi.org/10.1161/HYPERTENSIONAHA.109.120303

81. Ong KL, Cheung BM, Man YB, Lau CP, Lam KS. Prevalence, awareness, treatment, and control of hypertension among United States adults 1999–2004. *Hypertension*. 2007;49:69–75. https://doi.org/10.1161/01.HYP.0000252676.46043.18

82. Wright JD, Hughes JP, Ostchega Y, Yoon SS, Nwankwo T. Mean systolic and diastolic blood pressure in adults aged 18 and over in the United States, 2001–2008. *Natl Health Stat Report*. 2011;(35):1–24.

83. Lackland DT. Racial differences in hypertension: implications for high blood pressure management. *Am J Med Sci*. 2014;348:135–138. https://doi.org/10.1097/MAJ.0000000000000308

84. Gasevic D, Ross ES, Lear SA. Ethnic differences in cardiovascular disease risk factors: a systematic review of North American evidence. *Can J Cardiol*. 2015;31:1169–1179. https://doi.org/10.1016/j.cjca.2015.06.017

85. Fei K, Rodriguez-Lopez JS, Ramos M, et al. Racial and ethnic subgroup disparities in hypertension prevalence, New York City health and nutrition examination survey, 2013–2014. *Prev Chronic Dis*. 2017;14:E33. https://doi.org/10.5888/pcd14.160478

86. Gillespie CD, Hurvitz KA, Centers for Disease Control and Prevention (CDC). Prevalence of hypertension and controlled hypertension - United States, 2007-2010. *MMWR Suppl*. 2013;62:144–148.

87. Cheung EL, Bell CS, Samuel JP, Poffenbarger T, Redwine KM, Samuels KM, Samuels JA. Race and obesity in adolescent hypertension. *Pediatrics*. 2017;139:e20161433. https://doi.org/10.1542/peds.2016-1433

88. Rosner B, Cook N, Portman R, Daniels S, Falkner B. Blood pressure differences by ethnic group among United States children and adolescents. *Hypertension*. 2009;54:502–508. https://doi.org/10.1161/HYPERTENSIONAHA.109.134049

89. Lo JC, Sinaiko A, Chandra M, et al. Prehypertension and hypertension in community-based pediatric practice. *Pediatrics*. 2013;131:e415–e424. https://doi.org/10.1542/peds.2012-1292

90. Kaczmarek M, Stawińska-Witoszyńska B, Krzyżaniak A, et al. Who is at higher risk of hypertension? Socioeconomic status differences in blood pressure among Polish adolescents: a population-based ADOPOLNOR study. *Eur J Pediatr*. 2015;174:1461–1473.

91. Fallah Z, Kelishadi R, Heshmat R, et al. A nationwide report on blood pressure of children and adolescents according to socioeconomic status: the CASPIAN-IV study. *J Res Med Sci*. 2015;20:646–655. https://doi.org/10.4103/1735-1995.166210

92. van den Berg G, van Eijden M, Galindo-Garre F, et al. Explaining socioeconomic inequalities in childhood blood pressure and prehypertension: the ABCD study. *Hypertension*. 2013;61:35–41. https://doi.org/10.1161/HYPERTENSIONAHA.111.00106

93. Leng B, Jin Y, Li G, Chen L, Jin N. Socioeconomic status and hypertension: a meta-analysis. *J Hypertens*. 2015;33:221–229. https://doi.org/10.1097/HJH.0000000000000428

94. Kelly RK, Thomson R, Smith KJ, Dwyer T, Venn A, Magnuussen CG. Factors affecting tracking of blood pressure from childhood to adulthood: the childhood determinants of adult health study. *J Pediatr*. 2015;167:1422–1428.e2. https://doi.org/10.1016/j.jpeds.2015.07.055

95. Beltrán S, Pharel M, Montgomery CT, López-Hinojosa IJ, Arenas DJ, DeLisser HM. Food insecurity and hypertension: a systematic review and meta-analysis. Chokesuwattanaskul R, ed. *PloS One*. 2020;15:e0241628. https://doi.org/10.1371/journal.pone.0241628

96. Vos T, Lim SS, Abbafati C, et al. Global burden of 368 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet*. 2020;396:1204–1222. https://doi.org/10.1016/S0140-6736(20)30925-9

97. Cohen B. Urbanization in developing countries: current trends, future projections, and key challenges for sustainability. *Technol Soc*. 2006;28:63–80. https://doi.org/10.1016/j.technosoc.2005.10.005

98. Yach D, Hawkes C, Gould CL, Hofman KJ. The global burden of chronic diseases: overcoming impediments to prevention and control. *JAMA*. 2004;291:2616–2622. https://doi.org/10.1001/jama.291.21.2616

99. Chung J, Yu A, Bamhraz A, et al. Risk of subclinical-cardiovascular outcomes in children with ambulatory hypertension: a systematic review and meta-analysis. In: Vol 32; 2021:13.

100. Becket LA, Rosner B, Roche AF, Guo S. Serial changes in blood pressure from adolescence into adulthood. *Am J Epidemiol*. 1992;135:1166–1177. https://doi.org/10.1093/oxfordjournals.aje.a116217

101. Sun SS, Grave GD, Siervogel RM, Pickoff AA, Arslanian SS, Daniels SR. Systolic blood pressure in childhood predicts hypertension and metabolic syndrome later in life. *Pediatrics*. 2007;119:237–246. https://doi.org/10.1542/peds.2006-2543

102. Lauer RM, Anderson AR, Beaglehole R, Burns TL. Factors related to tracking of blood pressure in children. U.S. National Center for Health Statistics Health Examination Surveys Cycles II and III. *Hypertension*. 1984;6:307–314. https://doi.org/10.1161/01.hyp.6.3.307
103. Bao W, Threefoot SA, Srinivasan SR, Berenson GS. Essential hypertension predicted by tracking of elevated blood pressure from childhood to adulthood: the Bogalusa heart study. *Am J Hypertens.* 1995;8:657–665. https://doi.org/10.1016/0895-7061(95)00116-7

104. Li Z, Snieder H, Harsh. 2014;64:1580–1587. https://doi.org/10.1016/j.jacc.2014.05.072

105. Kaelber DC, Localio AR, Ross M, et al. Persistent hypertension in children and adolescents: a 6-year cohort study. *Pediatrics.* 2020;146:e20193778. https://doi.org/10.1542/peds.2019-3778

106. Daniels SR, Witt SA, Glascock B, Khoury PR, Kimball TR. Left ventricular hypertrophy: the Bogalusa heart study. *J Am Cardiol.* 2008;101:1621–1625. https://doi.org/10.1016/j.amjcard.2008.01.045

107. Daniels SR, Witt SA, Glascoc, B, Khoury PR, Kimball TR. Left atrial size in children with hypertension: the influence of obesity, blood pressure, and left ventricular mass. *J Pediatr.* 2002;141:186–190. https://doi.org/10.1016/S0022-3476(02)125851

108. Toprak A, Wang H, Chen W, Paul T, Srinivasan S, Berenson GS. Relation of childhood risk factors to left ventricular hypertrophy (eccentric or concentric) in relatively young adulthood (from the Bogalusa Heart Study). *Am J Cardiol.* 2014;64:1580–1587. https://doi.org/10.1016/j.jacc.2014.05.072

109. Zhang H, Zhang T, Li S, et al. Long-term excessive body weight and adult left ventricular hypertrophy are linked through later-life body size and blood pressure: the Bogalusa heart study. *Circ Res.* 2017;120:1614–1621. https://doi.org/10.1161/CIRCRESAHA.116.310421

110. Zhang T, Li S, Bazzano L, He J, Whelton P, Chen W. Trajectories of childhood blood pressure and adult left ventricular hypertrophy: the Bogalusa heart study. *Hypertension.* 2018;72:93–101. https://doi.org/10.1161/HYPERTENSIONAHA.118.10975

111. Pieruzzi F, Antolini L, Salerno FR, et al. The role of blood pressure, body weight and fat distribution on left ventricular mass, diastolic function and cardiac geometry in children. *J Hypertens.* 2015;33:1182–1192. https://doi.org/10.1097/HIJ.0000000000000552

112. Urbina EM, Khoury PR, McCoy C, Daniels SR, Kimball TR, Dolan LM. Cardiac and vascular consequences of prehypertension in youth: cardiovascular consequences of pre-hypertension in youth. *J Clin Hypertens.* 2011;13:332–342. https://doi.org/10.1111/j.1751-7176.2011.00471.x

113. Hao G, Wang X, Treiber FA, Harshfield G, Kapuku G, Su S. Blood pressure trajectories from childhood to young adulthood associated with cardiovascular risk: results from the 23-year Longitudinal Georgia stress and heart study. *Hypertension.* 2017;69. 2017:435–442. https://doi.org/10.1161/HYPERTENSIONAHA.116.08312

114. Lai CC, Sun D, Cen R, et al. Impact of long-term burden of excessive adiposity and elevated blood pressure from childhood on adulthood left ventricular remodeling patterns: the Bogalusa Heart Study. *J Am Coll Cardiol.* 2014;64:1580–1587. https://doi.org/10.1016/j.jacc.2014.05.072

115. Kavey RE. Left ventricular hypertrophy in hypertensive children and adolescents: predictors and prevalence. *Curr Hypertens Rep.* 2013;15:453–457. https://doi.org/10.1007/s11906-013-0370-3

116. Woroniecki RP, Kahnauth A, Panesar LE, Supe-Markovkina K. Left ventricular hypertrophy in pediatric hypertension: a mini review. *Front Pediatr.* 2017;5:101. https://doi.org/10.3389/fped.2017.00101

117. Juhola J, Magnussen CG, Berenson GS, et al. Combined effects of child and adult elevated blood pressure on subclinical atherosclerosis: the International Childhood Cardiovascular Cohort Consortium. *Circulation.* 2013;128:217–224. https://doi.org/10.1161/CIRCULATIONAHA.113.001614

118. Baroncini LAV, Sylvestre Lde C, Baroncini CV, Pecorits R. Assessment of carotid intima-media thickness as an early marker of vascular damage in hypertensive children. *Arg Bras Cardiol.* 2017;108:452–457. https://doi.org/10.5935/abc.20170043

119. Lande MB, Carson NL, Roy J, Meagher CC. Effects of childhood primary hypertension on carotid intima media thickness: a matched controlled study. *Hypertension.* 2006;48:40–44. https://doi.org/10.1161/01.HYP.0000227029.10536.e8

120. Sorof JM, Alexandrov AV, Cardwell G, Portman RJ. Carotid artery intimal-medial thickness and left ventricular hypertrophy in children with elevated blood pressure. *Pediatrics.* 2003;111:61–66. https://doi.org/10.1542/peds.111.1.61

121. Li S, Chen W, Srinivasan SR, Berenson GS. Childhood blood pressure as a predictor of arterial stiffness in young adults: the Bogalusa heart study. *Hypertension.* 2004;43:541–546. https://doi.org/10.1161/01.HYP.0000115922.98155.23

122. Aatola H, Magnussen CG, Koivistoinen T, et al. Simplified definitions of elevated pediatric blood pressure and high adult arterial stiffness. *Pediatrics.* 2013;132:e70–e76. https://doi.org/10.1542/peds.2012-3426

123. Tracy R, Newman WP, Wattigney WA, Srinivasan SR, Strong JP, Berenson GS. Histologic features of atherosclerosis and hypertension from autopsies of young individuals in a defined geographic population: the Bogalusa Heart Study. *Atherosclerosis.* 1995;116:163–179. https://doi.org/10.1016/0021-9150(95)05525-2

124. Homma S, Ishii T, Malcom GT, et al. Histopathological modifications of early atherosclerotic lesions by risk factors—findings in PDAY subjects. *Atherosclerosis.* 2001;156:389–399. https://doi.org/10.1016/s0021-9150(00)00669-9

125. McGill HC Jr, McMahan CA, Herderick EE, Malcom GT, Tracy RE, Strong JP. Origin of atherosclerosis in childhood and adolescence. *Am J Clin Nutr.* 2000;72(5)(suppl):1307s–1315a. https://doi.org/10.1093/ajcn/72.5.1307s

126. Mahoney LT, Burns TL, Stanford W, et al. Coronary risk factors measured in childhood and young adult life are associated with coronary artery calcification in young adults: the Muscataine Study. *J Am Coll Cardiol.* 1996;27:277–284. https://doi.org/10.1016/0735-1077(95)00461-0

127. Davis PH, Dawson JD, Mahoney LT, Lauer RM. Increased carotid intimal-medial thickness and coronary calcification are related in young and middle-aged adults. *The Muscataine study. Circulation.* 1999;100:838–842. https://doi.org/10.1161/01.cir.100.8.838
128. Li LJ, Cheung CYL, Liu Y, et al. Influence of blood pressure on retinal vascular caliber in young children. *Ophthalmology*. 2011;118:1459–1465. https://doi.org/10.1016/j.ophtha.2010.12.007

129. Gopinath B, Wang JJ, Kifley A, Tan AG, Wong TY, Mitchell P. Influence of blood pressure and body mass index on retinal vascular caliber in preschool-aged children. *J Hum Hypertens*. 2013;27:523–528. https://doi.org/10.1038/jhh.2013.15

130. Murgan I, Beyer S, Kotliar KE, et al. Arterial and retinal vascular changes in hypertensive and prehypertensive adolescents. *Am J Hypertens*. 2013;26:400–408. https://doi.org/10.1093/ajh/hps091

131. Seeman T, Pohl M, Palyzova D, John U. Microalbuminuria in children with primary and white-coat hypertension. *Pediatr Nephrol*. 2012;27:461–467. https://doi.org/10.1007/s00467-011-2019-2

132. Flynn JT. Microalbuminuria in children with primary hypertension. *J Clin Hypertens*. 2016;18:962–965. https://doi.org/10.1001/jch.12858

133. Brown DW, Giles WH, Croft JB. Left ventricular hypertrophy as a predictor of coronary heart disease mortality and the effect of hypertension. *Am Heart J*. 2000;140:848–856. https://doi.org/10.1067/mhj.2000.111112

134. Desai CS, Ning H, Lloyd-Jones DM. Competing cardiovascular outcomes associated with electrocardiographic left ventricular hypertrophy: the Atherosclerosis Risk in Communities Study. *Heart*. 2012;98:330–334. https://doi.org/10.1136/heartjn-2011-300819

135. Vlachopoulos C, Aznouridis K, Stefanadis C. Prediction of cardiovascular events and all-cause mortality with arterial stiffness: a systematic review and meta-analysis. *J Am Coll Cardiol*. 2010;55:1318–1327. https://doi.org/10.1016/j.jacc.2009.10.061

136. Iribarren C, Sidney S, Sternfeld B, Browner WS. Calcium intake and left ventricular hypertrophy in children and adolescents with primary hypertension during ramipril monotherapy. *Am J Hypertens*. 2007;20:990–996. https://doi.org/10.1038/ajh.2011.218

137. Seeman T, Gopinath B, Wang JJ, et al. Regression of left ventricular hypertrophy in children and adolescents with hypertension during ramipril monotherapy. *Am J Hypertens*. 2012;25:389–395. https://doi.org/10.1038/ajh.2011.218

138. Seeman T, Gopinath B, Wang JJ, et al. Regression of left ventricular hypertrophy in children and adolescents with hypertension during ramipril monotherapy. *Am J Hypertens*. 2007;20:990–996. https://doi.org/10.1038/ajh.2011.218

139. Seeman T, Dostálek L, Gilík J, et al. Regression of left ventricular hypertrophy in children and adolescents with hypertension during ramipril monotherapy. *Am J Hypertens*. 2012;25:389–395. https://doi.org/10.1038/ajh.2011.218

140. Seeman T, Pohl M, Palyzova D, John U. Microalbuminuria in children with primary and white-coat hypertension. *Pediatr Nephrol*. 2012;27:461–467. https://doi.org/10.1007/s00467-011-2019-2

141. Flynn JT. Microalbuminuria in children with primary hypertension. *J Clin Hypertens*. 2016;18:962–965. https://doi.org/10.1001/jch.12858

142. Brown DW, Giles WH, Croft JB. Left ventricular hypertrophy as a predictor of coronary heart disease mortality and the effect of hypertension. *Am Heart J*. 2000;140:848–856. https://doi.org/10.1067/mhj.2000.111112

143. Desai CS, Ning H, Lloyd-Jones DM. Competing cardiovascular outcomes associated with electrocardiographic left ventricular hypertrophy: the Atherosclerosis Risk in Communities Study. *Heart*. 2012;98:330–334. https://doi.org/10.1136/heartjn-2011-300819

144. Vlachopoulos C, Aznouridis K, Stefanadis C. Prediction of cardiovascular events and all-cause mortality with arterial stiffness: a systematic review and meta-analysis. *J Am Coll Cardiol*. 2010;55:1318–1327. https://doi.org/10.1016/j.jacc.2009.10.061

145. Iribarren C, Sidney S, Sternfeld B, Browner WS. Calcium intake and left ventricular hypertrophy in children and adolescents with primary hypertension during ramipril monotherapy. *Am J Hypertens*. 2007;20:990–996. https://doi.org/10.1038/ajh.2011.218

146. Seeman T, Gopinath B, Wang JJ, et al. Regression of left ventricular hypertrophy in children and adolescents with hypertension during ramipril monotherapy. *Am J Hypertens*. 2012;25:389–395. https://doi.org/10.1038/ajh.2011.218

147. Seeman T, Gopinath B, Wang JJ, et al. Regression of left ventricular hypertrophy in children and adolescents with hypertension during ramipril monotherapy. *Am J Hypertens*. 2007;20:990–996. https://doi.org/10.1038/ajh.2011.218

148. Seeman T, Gopinath B, Wang JJ, et al. Regression of left ventricular hypertrophy in children and adolescents with hypertension during ramipril monotherapy. *Am J Hypertens*. 2012;25:389–395. https://doi.org/10.1038/ajh.2011.218

149. Seeman T, Gopinath B, Wang JJ, et al. Regression of left ventricular hypertrophy in children and adolescents with hypertension during ramipril monotherapy. *Am J Hypertens*. 2007;20:990–996. https://doi.org/10.1038/ajh.2011.218
children and adolescents. J Hypertens. 2014;32:606–619. https://doi.org/10.1097/HJH.0000000000000662

181. Nazarali S, Robinson C, Khan F, et al. Deriving normative data on 24-hour ambulatory blood pressure monitoring for South Asian children (ASHA): a clinical research protocol. Can J Kidney Health Dis. 2022;9:205435812111072329. https://doi.org/10.1177/205435812111072329

182. Whelton PK, Carey RM, Aronow WS, et al. 2017 ACC/AHA/ AAPA/ABC/ACPM/AGS/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice guidelines. Hypertension. 2018;71:1269–1324. https://doi.org/10.1161/HYP.0000000000000666

183. Cheng YB, Thijs L, Zhang ZY, et al. Outcome-driven thresholds for ambulatory blood pressure based on the new American College of Cardiology/American Heart Association classification of hypertension. Hypertension. 2019;74:776–783. https://doi.org/10.1161/HYPERTENSIONAHA.119.13512

184. Lubrano R, Paoli S, Spiga S, et al. Impact of ambulatory blood pressure monitoring on the diagnosis of hypertension in children. J Am Soc Hypertens. 2015;9:780–784. https://doi.org/10.1016/j.jsh.2015.07.016

185. Lee J, McCulloch CE, Flynn JT, et al. Prognostic value of ambulatory blood pressure load in pediatric CKD. Clin J Am Soc Nephrol. 2020;15:493–500. https://doi.org/10.2215/CJN.10130819

186. Mitsnefes M, Flynn JT, Brady T, et al. Pediatric ambulatory blood pressure classification: the case for a change. Hypertension. 2021;78:1206–1210. https://doi.org/10.1161/HYPERTENSIONAHA.121.18138

187. Hamdani G, Mitsnefes MM, Flynn JT, et al. Pediatric and adult ambulatory blood pressure thresholds and blood pressure load as predictors of left ventricular hypertrophy in adolescents. Hypertension. 2021;78:30–37. https://doi.org/10.1161/HYPERTENSIONAHA.120.16896

188. Campbell F, Shah S, Srivaths P, Sigler K, Acosta A. Elevated load with normal mean in pediatric hypertension (HTN): what does it mean? In: J Am Soc Nephrol. 2021;32:51.

189. The SPRINT Research Group, Wright JT, Williamson JD, et al. A randomized trial of intensive versus standard blood-pressure control. N Engl J Med. 2015;373:2103–2116. https://doi.org/10.1056/NEJMoa1511939

190. Williams B, Mancia G, Spiering W, et al. 2018 ESC/ESH guidelines for the management of arterial hypertension. Eur Heart J. 2018;39:3021–3104. https://doi.org/10.1093/eurheartj/ehy339

191. Smith-Spangler CM, Juusola JL, Enns EA, Owens DK, Garber AM. Population strategies to decrease sodium intake and the burden of cardiovascular disease: a cost-effectiveness analysis. Ann Intern Med. 2010;152:481–487. https://doi.org/10.7326/0003-4819-152-8-201004200-00212

192. World Health Organization. Impact of salt reduction in Finland and the United Kingdom. World Health Organization. Published 2014. Accessed November 9, 2021. https://www.euro.who.int/en/health-topics/disease-prevention/nutrition/news/news/2014/12/reducing-salt-consump
206. Couch SC, Saelens BE, Khoury PR, et al. Dietary approaches to stop hypertension dietary intervention improves blood pressure and vascular health in youth with elevated blood pressure. *Hypertension*. 2021;77:241–251. https://doi.org/10.1161/HYPERTENSIONAHA.120.16156

207. Zafarmand MH, Spanjer M, Nicolaou M, et al. Influence of dietary approaches to stop hypertension-type diet, known genetic variants and their interplay on blood pressure in early childhood: ABCD study. *Hypertension*. 2020;75:59–70. https://doi.org/10.1161/HYPERTENSIONAHA.118.12292

208. Kelley GA, Kelley KS, Tran ZV. The effects of exercise on resting blood pressure in children and adolescents: a meta-analysis of randomized controlled trials. *Prev Cardiol*. 2003;6:8–16. https://doi.org/10.1520/j.1520-037x.2003.01224.x

209. Cai L, Wu Y, Wilson RF, Segal JB, Kim MT, Wang Y. Effect of childhood obesity prevention programs on blood pressure: a systematic review and meta-analysis. *Circulation*. 2014;129:1832–1839. https://doi.org/10.1161/CIRCULATIONAHA.113.005666

210. Kim N, Seo DC, King MH, Lederer AM, Sovinski D. Long-term predictors of blood pressure among adolescents during an 18-month school-based obesity prevention intervention. *J Adolesc Health*. 2014;55:521–527. https://doi.org/10.1016/j.jadohealth.2014.04.011

211. Simonetti GD, Rizzi M, Donadini R, Bianchetti MG. Effects of antihypertensive drugs on blood pressure and proteinuria in childhood. *J Hypertens*. 2007;25:2370–2376. https://doi.org/10.1097/HJH.0b013e3282efeb7e

212. Chaturvedi S, Lipszyc DH, Licht C, et al. Pharmacological interventions for hypertension in children. *Evid Based Child Health*. 2014;9:498–580.

213. Burrello J, Erhardt EM, Saint-Hilary G, et al. Pharmacological treatment of arterial hypertension in children and adolescents: a network meta-analysis. *Hypertension*. 2018;72:306–313. https://doi.org/10.1161/HYPERTENSIONAHA.118.10862

214. Samuel JP, Tyson JE, Green C, et al. Treating hypertension in children with n-of-1 trials. *Pediatrics*. 2019;143:e20181818. https://doi.org/10.1542/peds.2018-1818