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ARTICLE

Prevalence and subtypes of hypertension in normal-weight and obese Indian adolescents: a cross-sectional study

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This cross-sectional study examined the prevalence, stages, subtypes of hypertension, and the associated risk factors in adolescent school children in Western India. We screened 2,644 adolescents, from 10 different private and government schools in urban and rural areas for hypertension, as defined by the 2017 Clinical Practice Guidelines. The association of stages and subtypes with age, gender, body mass index, type of school, and place of residence was analysed. 197 children (7.5%) had hypertension; 170 (6.4%) had stage I, 27 (1%) had stage II and 76 (2.9%) had elevated blood pressure (EBP). The risk of EBP was higher in children > 15 years of age ($p = 0.006$). Compared with normal-weight children, obese, and overweight children had a higher risk of hypertension [odds ratio (OR) 9 (5.84, 13.88) and 3.77 (2.59, 5.48) respectively], whereas underweight children had a lower risk [OR 0.39 (0.16, 0.98)]. Normal-weight hypertension was seen in 5.2% and was higher in children from government schools (9.4%). Systolic-diastolic hypertension (SDH) was the most common subtype, seen in 136 (5.1%). SDH was more common in girls, in rural children, and in those with stage II hypertension. Isolated diastolic hypertension, seen in 51 (1.9%), was more common in boys, in urban children, and in those with EBP.

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INTRODUCTION

Childhood and adolescent hypertension often go undetected. Although overt, adverse cardiovascular outcomes may be rare in childhood, subclinical structural and functional changes in the heart and vasculature may be evident in the investigation in nearly forty percent of hypertensive children [1]. Childhood hypertension is known to track into adulthood, and subclinical atherosclerosis that begins in childhood may progress with age [2, 3]. The progression into adulthood is more likely to happen with hypertension in adolescence than in early childhood [4]. Hypertension in adults carries with it a significant risk of adverse cardiovascular outcomes and is responsible for nearly half of all strokes and ischemic heart diseases. It is the leading non-communicable disease responsible globally for 12.8% of all deaths in adults [5]. This risk may be attenuated if the blood pressure (BP) elevation is resolved during childhood [6].

The cardiovascular impact, as well as the tracking into adulthood may also vary with the subtype of hypertension [7]. The prevalence of different subtypes of hypertension, their progression, and cardiometabolic outcomes are well known in adults [8]. Studies on the prevalence of different subtypes in children are fewer and mainly from developed nations. These have shown that isolated systolic hypertension (ISH) is the most common subtype and is associated with significant potential for cardiovascular morbidity [9].

Studies on hypertension in Indian adolescents have shown a wide variation in prevalence. A recent meta-analysis of cross-sectional studies on hypertension in Indian adolescents that had more than one reading on the same visit included 27,682 children from 25 studies. The prevalence ranged from 2% to 20.5% with a pooled prevalence of 7.6% [9]. Only six out of the 25 studies were conducted in rural children and only three included both urban and rural children in the same study. Hypertension subtypes and their clinical correlates in children have not been addressed in Indian studies.

SUBJECTS AND METHODS

A cross-sectional study was undertaken to determine the prevalence, stages, and subtypes of hypertension and elevated BP in adolescent school children and to study the association of age, gender, body mass index (BMI), private or government school attendance, and rural or urban residence on the prevalence of hypertension and elevated BP. Approval from institutional ethics committees of the Lilavati Hospital and Research Centre, Mumbai and the King Edward Memorial Hospital, Pune, was taken for conducting the study in the Mumbai and Pune schools respectively. Signed consent from the school principal and the parents, as well as verbal assent from the child, was taken before the study.

Adolescent students from ten schools were studied. The schools included private schools that catered to children from middle-income families, and government or trust schools (referred to collectively as government schools in this paper), that catered to low-income families in urban and rural areas of Maharashtra, Western India. All students in classes eight and nine in these schools were evaluated. Children absent on the day

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of evaluation were excluded. The name, age, gender, and date of birth of the student were obtained from school records.

Height and weight were recorded by trained resident medical officers, with children standing barefoot in their school uniform using recommended methods [10]. Height was measured by a stadiometer, recorded in centimeters, and rounded off to the nearest 0.1 cm. Weight was taken using a standard digital weighing scale, with the measurement rounded off to the nearest 0.1 kg. Body mass index (BMI) was calculated by the formula BMI = Weight (kg)/ Height (m^2). Underweight was defined as, BMI-for- age and genderless than the fifth centile and overweight and obese as the adult equivalent of 23 and 27 kg/m^2 as recommended for Indian children [11]. Centiles of height, weight, and BMI were calculated from the growth charts of the Indian Academy of Paediatrics [12].

Blood pressure was measured manually by the auscultatory method using mercury sphygmomanometer in six schools and aneroid sphygmomanometer in the last four schools, mandated by a change in hospital policy, that led to the withdrawal of mercury sphygmomanometers, due to environmental concerns. Previous studies have confirmed that the BP readings from aneroid sphygmomanometer closely reflect the readings from the mercury sphygmomanometer within the limits specified by the Association for the Advancement of Medical Instrumentation and hence can be used for clinical and research purposes [13, 14]. Blood pressure measurements were done by trained paediatric residents, paediatricians, or paediatric nephrologists.

An appropriate-sized BP cuff was used, and the blood pressure was recorded according to standard recommendations: systolic blood pressure (SBP) at Korotkoff-1 and diastolic blood pressures (DBP) at Korotkoff-5. If the Korotkoff sounds were heard till a very low level or up to 0 mmHg, the point at which the sound was muffled (phase IV Korotkoff) was taken as the diastolic blood pressure (DBP) The measurement was read to the nearest 2 mmHg. The BP recording was classified using the criteria recommended by the 2017 Current practice guidelines (CPG) using the actual height in centimeters. [15].

If the BP recording was above the 90th centile for age, gender, and height in children < 13 years of age or above 120/80 in children > 13 years of age, two additional readings were taken 10 min apart by the same person Mean SBP and mean DBP of the three readings were then calculated. If either the mean SBP or DBP was more than the cut-offs, the BP was considered high. The BP was categorized as normal if it was < 90th percentile, elevated if it was ≥ 90th percentile to < 95th percentile, stage 1 hypertension if it was ≥ 95th percentile to < 95th percentile + 12 mmHg, and stage II hypertension if it was ≥ 95th percentile + 12 mmHg. The subtype was classified as systolic diastolic hypertension (SDH) if both systolic and diastolic BP were above the cut-offs, isolated systolic hypertension (ISH) if only the systolic BP was above the cut-off and isolated diastolic hypertension (IDH) if only diastolic BP was above the cut-offs.

Statistical analysis

The optimal sample size was calculated using SAS 9.2 package considering the prevalence of hypertension (H0) as 3% with an anticipated prevalence (H1) of 5% [16]. Power analysis was used to determine the representative sample size required to study the difference in the prevalence of hypertension in the two types of schools. The minimal sample size calculated for each category (private schools representing middle income and government schools representing lower-income) was 942 assuming an alpha of 0.05 and power of 90% giving a total sample of 1884 children.

Data were presented as mean ± SD for continuous data and as frequency or percentage for categorical data. Prevalence of hypertension, elevated BP and the different subtypes of high BP were calculated and expressed as a percentage of total students evaluated. The distribution of elevated BP and hypertension in different categories determined by age, gender, BMI, school type, and location were compared by the chi-square test and the risks were expressed as an odds ratio. In case of categorical variables, chi-2 test was performed for comparison of means of two groups, F-statistic was used to determine the significance of the association. Multiple logistic regression was used to evaluate the significance of the association of selected variables including age, gender, BMI categories, government or private schools, and urban or rural residence with hypertension and elevated BP. The variance inflation factor (VIF) was used to examine multicollinearity. In general, if the value of VIF is below 10, it was considered to have no multicollinearity. VIF in our study was below 10 for each variable tested and hence multicollinearity was not present in our analysis. We reported p values for each test and 95% CI where applicable. The difference with a p value < 0.05 was considered significant. Data were analyzed on Stata software version 15.

RESULTS

Two thousand six hundred and forty-four students in classes eight and nine in the ten schools were included in the study (Fig. 1). The baseline characteristics of the students are summarised in Table 1. Figure 1 shows the flow chart of the adolescent children included in the screening program.

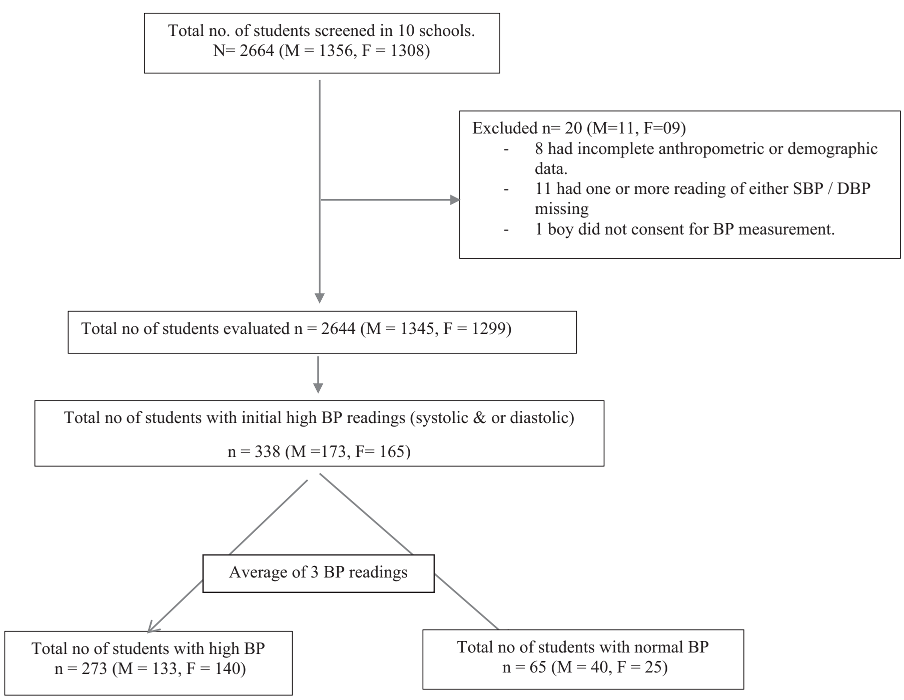

Fig. 1 Flow chart of adolescent children included in the screening program.

Prevalence of elevated blood pressure and hypertension

A total of 273 (10.3%) children had high blood pressure (hypertension plus elevated BP). Hypertension was seen in 197 children (7.5%): stage I hypertension in 170 (6.4%) and stage II in 27 (1%). Elevated BP was found in 76 (2.9%).

Table 1. Baseline characteristics of the students.

	Total	Boys	Girls
n (%)	2644 (100)	1345 (50.9)	1299 (49.1)
Age and Anthropometric profile (mean +/−SD)			
Age (years)	13.87 ± 1.01	13.99 ± 1.04	13.75 ± 0.97
Height (cms)	153.39 ± 8.46	155.92 ± 9.52	150.72 ± 6.21
Weight (kg)	43.17 ± 9.87	43.78 ± 10.72	42.54 ± 8.85
BMI (kg/m^2)	18.25 ± 3.47	17.86 ± 3.44	18.66 ± 3.45
BMI categories, *n* (%)			
Obese	135 (5.1)	76 (5.6)	59 (4.5)
Overweight	309 (11.6)	149 (11)	160 (12.3)
Underweight	213 (8)	125 (9.2)	88 (6.7)
Normal	1987 (75.1)	995 (73.9)	992 (76.3)
Type of school (*n* = 10), *n* (%)			
Private (*n* = 3)	1210 (45.8)	591(22.4)	619 (23.5)
Government (n = 7)	1434 (54.2)	754 (28.5)	680 (25.7)
Location of government schools (*n* = 7), *n* (%)			
Government urban (*n* = 3)	560 (21.2)	303 (11.5)	257 (9.7)
Government Rural (*n* = 4)	874 (33.1)	451 (17.1)	423 (16)

Risk factors for elevated BP and hypertension

Age and gender. The prevalence of elevated BP was higher in children ≥ 15 years of age when compared with children < 15 years of age ($p = 0.006$). The prevalence of elevated BP and hypertension was comparable in boys and girls (Table 2).

BMI categories. Univariate analysis showed a significant association between obesity and overweight with elevated BP and hypertension (Table 2). Compared to children with normal BMI, the odds of an obese child having elevated BP were 4.60 (2.25, 9.41) and an overweight child 2.72 (1.54, 4.82). Similarly, the odds ratio (OR) of an obese child having hypertension was 8.22 (5.38, 12.56) and an overweight child 3.42 (2.37, 4.94). Underweight showed no association to high BP.

The odds for stage I hypertension [OR 3.17 (2.15,4.68)] and stage II hypertension [OR 6.57(2.36,18.2)] in the overweight children were significantly higher than for normal-weight children. Similarly, the odds for having stage 1 [OR 6.45 (4.03,10.3)] and stage 2 hypertension [OR 29.65 (11.62, 5.63)] were even higher for the obese as compared with normal-weight children.

Type of schools: government and private schools. The prevalence of hypertension was not significantly different between the private and government schools. However, the risk of elevated BP was lower in children from private schools as compared with those from government schools [OR 0.5 (0.3,0.82)] (Table 2).

Government urban and rural schools. There was no significant difference in the prevalence of elevated BP, hypertension, and

Table 2. Prevalence of elevated BP and hypertension and its distribution in the different categories.

Total number of students (*n* = 2644)	Elevated BP *n* = 76 (2.9 %)			Hypertension *n* = 197 (7.5%)		
Category	***n* (%)**	**OR (95% CI)**	***p* value**	***n* (%)**	**OR (95% CI)**	***P* value**
Gender						
Boys (*n* = 1345)	41 (3.1)	1.12 (0.71. 1.77)	0.627	92 (6.8)	0.81 (0.61,1.09)	0.16
Girls (*n* = 1299)	35 (2.7)	(reference)		105 (8.1)	(reference)	
Age						
< 15 years (*n* = 2100)	50 (2.4)	(reference)		150 (7.4)	(reference)	
≥ 15 years (*n* = 544)	26 (4.8)	1.97 (1.21, 3.22)	**0.006**	47(8.9)	1.22 (0.86, 1.72)	0.265
BMI categories						
Obese (*n* = 135)	10 (7.4)	4.6 (2.25, 9.41)	**<0.001**	40 (29.6)	8.22 (5.38, 12.56)	**<0.001**
Overweight (*n* = 309)	16 (5.2)	2.72 (1.54, 4.82)	**<0.001**	48 (15.5)	3.42 (2.37, 4.94)	**<0.001**
Underweight (*n* = 213)	2 (0.9)	0.38 (0.09, 1.57)	0.155	5 (2.3)	0.42 (0.17, 1.05)	0.06
Normal BMI (*n* = 1987)	48 (2.4)	(reference)		104 (5.2)	(reference)	
School Type						
Private (*n* = 1210)	22 (1.8)	0.5 (0.3, 0.82)	**0.006**	85 (7)	0.86 (0.64, 1.16)	0.33
Government (*n* = 1434)	54 (3.8)	(reference)		112 (7.8)	(reference)	
Government school location						
Government Urban (*n* = 560)	22 (3.9)	1.1 (0.63, 1.91)	0.75	39 (7)	0.81 (0.54, 1.21)	0.31
Government Rural (*n* = 874)	32 (3.7)	(reference)		73 (8.4)	(reference)	

Statistically significant *p*-values are in bold.

Table 3. High BP (elevated BP and hypertension) in the different BMI categories according to school type and location.

	School Type			Government School Location		
	Privaten (%)	Governmentn (%)	*p*-value	Government Urban n (%)	Government Rural n (%)	p-value
Total students	1210	1434		560	874	
Distribution of BMI categories in the different schools						
Obese	80 (6.6)	55 (3.8)	**0.001**	22 (3.9)	33 (3.8)	0.883
Overweight	194 (16)	115 (8)	**<0.001**	49 (8.8)	66 (7.6)	0.415
Underweight	69 (5.7)	144 (10)	**<0.001**	52 (9.3)	92 (10.5)	0.446
Normal BMI	867 (72)	1120 (78)	**<0.001**	437 (78)	683 (78)	0.961
Distribution of high BP (elevated BP and hypertension) in the different BMI categories						
Obese	25 (31.3)	25 (45.5)	0.095	11 (50)	14 (43.4)	0.581
Overweight	33 (17)	31 (27)	0.051	13 (26.5)	18 (27.3)	0.929
Underweight	1 (1.4)	6 (4.2)	0.3	3 (5.8)	3 (3.3)	0.475
Normal BMI	48 (5.5)	104 (9.4)	**0.002**	34 (7.8)	70 (10.4)	0.144

Statistically significant *p*-values are in bold.

Table 4. Prevalence of high blood pressure based on type of sphygmomanometer.

	Total n (%)	Mercury n (%)	Aneroid n (%)	p-value
Students tested	2644 (100)	1698 (64.2)	964 (36.4)	0.96
Elevated BP (%)	76 (2.9)	51 (3.0)	25 (2.6)	0.54
Hypertension (%)	197 (7.5)	126 (7.4)	71 (7.5)	0.96

stages of hypertension between government schools in urban and rural locations (Table 2).

Subgroup analysis of BMI categories in the different types of schools. Obesity and overweight were significantly higher in private schools while the risk of being underweight was higher in government schools ($p < 0.001$). The number of normal-weight children was also higher in government schools ($p < 0.001$). The prevalence of hypertension and elevated BP in the obese and overweight children was comparable in private and government school children. The prevalence of hypertension in normal-weight children was higher at 9.4% in government schools compared with 5.5% in private schools ($p = 0.002$) (Table 3).

Subgroup analysis of BMI categories based on the location of government schools (urban or rural). The prevalence of obesity, overweight, underweight, and normal-weight children was comparable in the government urban and rural schools. The prevalence of elevated BP and hypertension in the overweight and obese were also comparable in these two categories of schools (Table 3).

Blood pressure measuring device. There was no difference in the prevalence of elevated BP or hypertension on comparing the BP measurements obtained from schools where mercury or aneroid sphygmomanometers were used. (Table 4).

Prevalence of different subtypes of elevated blood pressure and hypertension. In the combined high BP group (elevated BP plus hypertension), the predominant subtype was SDH seen in 136 (5.1%), ISH was seen in 86 (3.25%), and IDH in 51 (1.9%).

Association of sub-types with risk factors

Gender and BMI. SDH was seen more commonly in girls ($p +$ 0.006) while IDH was more in boys ($p = 0.001$) whereas ISH was seen in both. The prevalence of the subtypes in hypertensive children and in those with elevated BP was comparable in obese, overweight and normal-weight children (Table 5).

School type and location. The prevalence of IDH was higher in private schools compared with government schools ($p = 0.025$). Children from rural government schools had a significantly higher prevalence of SDH ($p = 0.001$) and lower prevalence of IDH ($p = 0.001$) when compared with urban government school children (Table 5).

Impact on systolic and diastolic values

Stages of hypertension. The prevalence of the different subtypes had a significant association with the stages of high BP. Children with stage II hypertension had a higher prevalence of SDH as compared with children with stage I hypertension ($p = 0.005$) and those with elevated BP ($p < 0.001$). The subtype ISH was higher in children with elevated BP when compared with stage I ($p = 0.001$), however, it was similar to those with stage II hypertension ($p = 0.087$). IDH was significantly higher in those with elevated BP when compared with those with stage II hypertension ($p = 0.048$). However, IDH had a similar prevalence in those with elevated BP and stage I hypertension ($p = 0.382$) (Fig. 2). Figure 2 depicts the prevalence of the different subtypes of hypertension in children with EBP, stage 1 and stage 2 hypertension.

Risk factor analysis. Multivariate logistic regression was used for the association of hypertension and elevated BP with age, gender, BMI categories, private or government school attendance, and urban and rural residence (Table 6).

For hypertension, only BMI categories showed a significant association. Obesity and overweight were significant high-risk factors for hypertension with ORs of 9 (5.84, 13.88) and 3.77 (2.59,5.48) respectively, whereas underweight had a significantly lower risk with an OR of 0.39 (0.16, 0.98) (Table 6).

For elevated BP, age, BMI category, and type of school (government or private) showed significant association. Age >15 years [OR 2.09 (1.23, 3.54)], obesity [OR 5.71 (2.72, 11.97)], and overweight [OR 3.35 (1.86, 6.01)] had significantly higher prevalence of elevated BP, whereas children from private schools had a lower risk [OR 0.44 (0.24, 0.83)]. Gender and urban or rural

Table 5. Prevalence of subtypes of high BP and their distribution in different categories.

Total High BP	Systolic diastolic hypertension		Isolated systolic hypertension		Isolated diastolic hypertension	
	n **(%)**	***P*** **value**	***n*** **(%)**	***P*** **value**	***n*** **(%)**	***P*** **value**
$n = 273$	136 (49.8)		86 (31.5)		51 (18.7)	
Blood pressure categories						
Hypertension ($n = 197$)	115 (58.4)	**<0.001**	49 (24.9)	**<0.001**	33 (16.8)	0.18
Elevated blood pressure ($n = 76$)	21 (27.6)		37 (48.7)		18 (23.7)	
Gender						
Boys ($n = 133$)	55 (41.4)	**0.006**	43 (32.3)	0.773	35 (26.3)	**0.002**
Girls ($n = 140$)	81 (57.9)		43 (30.7)		16 (11.4)	
BMI categories						
Obese ($n = 50$)	31 (62)	0.104	10 (20)	0.666	9 (18)	0.95
Overweight ($n = 64$)	29 (45.3)	0.651	23 (35.9)	0.08	12 (18.8)	0.955
Underweight ($n = 7$)	2 (28.57)	N/A	3 (42.86)	N/A	2 (28.57)	N/A
Normal BMI ($n = 152$)	74 (48.7)	reference	50 (32.9)	reference	28 (18.4)	reference
School type						
Private ($n = 107$)	49 (45.8)	0.285	31(28.9)	0.47	27 (25.2)	**0.025**
Government ($n = 166$)	87 (52.4)		55 (33)		24 (14.5)	
Government school location						
Government-urban ($n = 61$)	22 (36.1)	**0.001**	23 (37.7)	0.34	16 (26.2)	**0.001**
Government-rural ($n = 105$)	65 (61.9)		32 (30.4)		8 (7.6)	

N/A Not available for underweight due to insufficient sample size in that category.
Statistically significant *p*-values are in bold.

residence showed no significant association with either elevated BP or hypertension (Table 6).

DISCUSSION

In our study in urban and rural adolescent school children from Western India, hypertension was seen in 7.5% of the students. This is similar to the global pooled prevalence of 7.89% for sustained hypertension at 14 years of age, reported in a recent metanalysis, and the pooled prevalence of 7.6% noted in an Indian metanalysis of adolescent hypertension [9, 17]. Stage II hypertension was seen in 14% of our hypertensive children accounting for 1% of all adolescents studied. This is again similar to the reported global pooled prevalence of 0.95% [18]. The prevalence of elevated BP was 2.9%, again comparable to the reported prevalence of 2.2–3.5% from the US [15]. We used the actual height in centimeters to classify BP instead of the centiles, as the height classified by the IAP reference charts fell into a higher centile than by the CDC growth charts and would have led to an under-estimation of the BP stage.

Of the 338 blood pressure values, that were high at the initial measurement, 65 were normal in the second and third measurements, confirming that nearly 20% of children would have been wrongly diagnosed as hypertensive if only the first measurement was taken. In a nationwide survey conducted in adults in India (National Family Health Survey), it was found that there was a 63% higher prevalence of hypertension when only the first reading was considered for diagnosis in comparison with the mean of the second and third readings [18].

In our study, although age was not a significant risk factor for hypertension, children above fifteen years of age were twice as likely to have elevated BP compared with children less than fifteen years of age. Elevated BP is not an innocuous finding and needs tracking as it is associated with several intermediate adverse cardiovascular markers, cardiovascular disease, and mortality in adults [19]. Late adolescent hypertension has been shown to have a significant association with early adult coronary artery disease and stroke [20].

The most significant risk factor for hypertension seen in our study was obesity and overweight, which has also been noted in many earlier studies [21, 22] Thirty percent of obese and 16% of overweight children had hypertension and together accounted for 45% of all hypertensives and two-thirds of all children with stage II hypertension. This is comparable to the 34% prevalence noted in obese Chinese children when using the CPG guidelines [23] However, it is much higher than 20% prevalence of hypertension seen in obese American schoolchildren at initial evaluation [24]. The lower prevalence in the above study could be partly due to the use of the Fourth Task Force as a reference standard. Dong et al. showed that prevalence calculated using the fourth task force as a reference standard was significantly lower than with the CPG and that this difference was more marked in children with higher BMI [23].

On subgroup analysis, we found that the prevalence of obesity and overweight was significantly lower in children attending government schools that cater to low-income families when compared with children from private schools (11.8% vs. 22.6%). This has also been noted in other Indian studies [16, 25]. This is in contrast to the finding in many countries where children from low-income families have a higher prevalence of obesity [26, 27]. Despite a significantly lower prevalence of obesity, the mean prevalence of hypertension was similar in children from government and private schools, drawing attention to risk factors beyond obesity for primary hypertension in children from low-income families.

The prevalence of hypertension in normal-weight children was 5.2% which is far higher than the pooled global prevalence of 1.8% [17]. Significant hypertension of 14.5% in normal-weight children between the ages of five and fifteen years has been reported from the north-eastern region of India [28]. A study done in prepubertal children in Eastern India a decade ago, found a similar prevalence of hypertension in normal-weight children, as in our study. Urinalysis done to rule out secondary causes in the

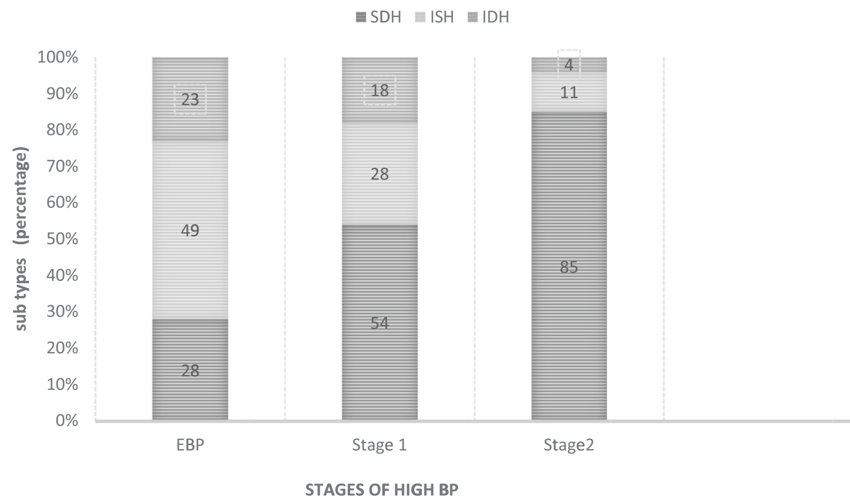

Fig. 2 Prevalence of different subtypes in children with EBP, stage 1, and stage 2 hypertension.

above study was normal in more than 90% of all hypertensives, suggesting that most of these children had primary hypertension [29]. A higher prevalence of normal weight hypertension has also been noted in other races such as African-Americans [24].

Contrary to most Indian studies that found a lower prevalence of hypertension in rural children, our study failed to show a significant difference between urban and rural children [30]. Although not statistically significant, the prevalence of hypertension in normal-weight children was higher in rural schools. Dietary factors evaluated in a recent Indian study have shown no difference in the diet between normotensive and hypertensive urban children whereas rural hypertensive children had a higher intake of junk food, sodium, and fat than their normotensive counterparts [31]. Population studies in adults have shown that salt intake is greater than the recommended five grams a day in 90% of Indians and the habit of adding more salt while eating was higher in rural than in urban areas [32, 33]. Other risk factors that need to be considered include but are not limited to low birth weight, maternal pre-conception health, pregnancy-related factors such as pre-eclampsia, gestational hypertension, neonatal adverse events, dietary sodium intake, renal handling of sodium, psychosocial stressors, as well as genetic predisposition [34].

The predominant subtype of high blood pressure in our study was SDH seen in 5.1% of adolescents. This has also been reported in an earlier study conducted in India and was much higher than the reported global prevalence of 1.25% in children [29]. It was the most common subtype seen in both obese and normal-weight hypertensives. Its prevalence was 49.8% of all children with high BP and increased directly with increasing severity of blood pressure accounting for 85% of stage II hypertension. It was seen more commonly in girls, and in rural children.

Globally, ISH is the most common subtype, seen with a prevalence of 1.5%. The prevalence of ISH in our study was 3.2% and was the second common subtype seen in nearly one-third of all children with hypertension [18]. ISH is reported as the predominant subtype in obese children accounting for 94% of cases [21]. In our study, ISH comprised only 20% of obese hypertensives. The hemodynamic basis for ISH in children has been attributed to increased sympathetic activity and vascular resistance in obese hypertensives [8]. Elevated systolic blood pressures in normal-weight children have shown an association with structural changes such as increased carotid intima-media thickness and left ventricular hypertrophy. Systolic hypertension may predict a future increase in left ventricular mass index [5, 35].

Isolated elevation of diastolic BP was the rarest subtype seen in 1.9% of all adolescents. Like ISH, its prevalence was highest in children with elevated BP and was rarely seen in stage II hypertension. It was more common in boys and in urban children. Analysis of normative data from a previous study conducted in South India had shown that Indian children had higher diastolic pressures compared with their western counterparts [36].

A nationwide survey in Chinese children shows that the prevalence of IDH to be 3.3% and was more common in girls [37]. The pooled global prevalence is less than 1% [17]. The underlying hemodynamic mechanisms and the cardiovascular consequences of IDH in children are undefined. The impact of IDH on cardiovascular outcomes in adults and the need for treatment is controversial [18, 38]. The follow-up of the Framingham study in adults showed that over a period of ten years IDH tracked into SDH in 82% of the cases and was associated with an increase in BMI [7].

Our study has several limitations. In the absence of national reference data for pediatric blood pressure, we used the CPG 2017 as our reference standard which is based on normative data in American children and thus could lead to under or over-estimation of hypertension in Indian children. Due to reluctance on the part of the school authorities, we did not repeat blood pressure measurements on three separate visits to determine the prevalence of sustained hypertension. We tried to limit the degree of overestimation by taking two additional readings after a rest period in all those whose initial reading was high and classified them based on the mean of the three readings. We did not perform three readings in those with initial normal readings. Although the subsequent readings are known to be usually lower, there could have been cases with higher readings, and these could have been missed. We did not assess the effect of puberty on BP as we did not do pubertal staging or obtain history of menarche.

A change in the type of BP instrument used was made in the latter part of the study, due to changes in the hospital policy. Since the methodology of blood pressure measurement is critical to the diagnosis and classification of hypertension, this may introduce an element of bias. However, the prevalence of both elevated BP and hypertension was similar in the schools screened with the two instruments. As ours was a cross-sectional study, the temporal effect of the risk factors could not be assessed.

Moreover, our study was not designed to evaluate risk factors for normal-weight hypertension. Larger studies, as well as repeated measures, are needed in adolescents from different regions of India to ascertain the generalizability of these findings. Studies are also needed to assess the hemodynamic changes, the

Table 6. Multivariate analysis of the risk factors for elevated BP and hypertension.

Risk factors	Elevated BP $n = 76$			Hypertension $n = 197$		
	n (%)	OR (95%CI)	*p*-value	*n* (%)	OR (95%CI)	*p*-value
Gender						
Female (reference)	35 (2.7)			105 (8.1)		
Male	41 (3.1)	1.00 (0.63, 1.6)	1.000	92 (6.8)	0.78 (0.58, 1.06)	0.116
Age						
<15 years (reference)	50 (2.4)			150 (7.4)		
>=15 years	26 (4.8)	2.09 (1.23, 3.54)	**0.006**	47 (8.9)	1.37 (0.95, 1.99)	0.096
BMI categories						
Normal (reference)	48 (2.4)			104 (5.2)		
Overweight	16 (5.2)	3.35 (1.86, 6.01)	**0.000**	48 (15.5)	3.77 (2.59, 5.48)	**0.000**
Obese	10 (7.4)	5.71 (2.2, 11.97)	**0.000**	40 (29.6)	9.00 (5.84,13.88)	**0.000**
Underweight	2 (0.9)	0.32 (0.08, 1.33)	0.118	5 (2.3)	0.39 (0.16, 0.98)	**0.046**
Type of school						
Government (reference)	54 (3.8)			112 (7.8)		
Private	22 (3.9)	0.44 (0.24, 0.83)	**0.011**	85 (7)	0.81 (0.53, 1.23)	0.318
Residence						
Rural (reference)	32 (3.7)			73 (8.4)		
Urban (Government + Private)	22 (3.9)	0.83 (0.45, 1.51)	0.534	39 (7)	0.71 (0.46, 1.10)	0.128

Statistically significant *p*-values are in bold.

trajectories, and the cardiometabolic impact associated with the different subtypes of high BP, as well as to identify risk factors for hypertension in normal-weight children so that modifiable risk factors may be addressed.

In conclusion, our study showed that one in ten Indian adolescent school children had high blood pressure at initial evaluation and this risk was one in five for the overweight and one in three for the obese adolescents. Findings unique to our study were the identification of SDH as the commonest subtype, the prevalence of which increased with increasing levels of blood pressure, and the identification of significant prevalence of hypertension in normal-weight children.

Summary Table

What is known about this topic

- The prevalence of high blood pressure in Indian adolescents ranges from 2% to 20.5% with a pooled prevalence of 7.6%.
- Overweight and obesity are significant risk factors for high blood pressure in adolescent Indian children. 16
- Globally, isolated systolic hypertension is the most common subtype seen in adolescent children, with a prevalence of 1.9%.

What this study adds

- Systolic diastolic hypertension was the most common subtype of hypertension seen in our study, with the prevalence increasing with increasing levels of blood pressure.
- 2.4% and 5.2% respectively, of normal-weight children, had elevated blood pressure and hypertension.

REFERENCES

1. Kollias A, Dafni M, Poulidakis E, Ntineri A, Stergiou GS. Out-of-office blood pressure and target organ damage in children and adolescents: A systematic reviewand meta-analysis. J Hypertens. 2014;32:2315–31.
2. Chen X, Wang Y. Tracking of blood pressure from childhood to adulthood: A systematic review and meta-regression analysis. Circulation 2008;117:3171–80.
3. Urbina EM, Khoury PR, Mccoy C, Daniels SR, Kimball TR, Dolan LM. Cardiac and vascular consequences of pre-hypertension in youth. J Clin Hypertens. 2011;13:332–42.
4. 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;75:948–55.
5. World Health Organisation. Global Health risks. Mortality and burden of disease attributable to selected major risks. 2009. Available from: https://www.who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_full.pdf [Accessed 6 July 2021].
6. Juhola J, Magnussen CG, Berenson GS, Venn A, Burns TL, Sabin MA, et al. Combined effects of child and adult elevated blood pressure on subclinical atherosclerosis: The international childhood cardiovascular cohort consortium. Circulation 2013;128:217–24.
7. Koskinen J, Juonala M, Dwyer T, Venn A, Petkeviciene J, Čeponienė I, et al. Utility of different blood pressure measurement components in childhood to predict adult carotid intima-media thickness: The i3C consortium study. Hypertension 2019;73:335–41.
8. Franklin SS, Pio JR, Wong ND, Larson MG, Leip EP, Vasan RS, et al. Predictors of new-onset diastolic and systolic hypertension: The framingham heart study. Circulation 2005;111:1121–7.
9. Sorof JM, Poffenbarger T, Franco K, Bernard L, Portman RJ. Isolated systolic hypertension,obesity, and hyperkinetic hemodynamic states in children. J Pediatr. 2002;140:660–6.
10. Daniel RA, Haldar P, Prasad M, Kant S, Krishnan A, Gupta SK, et al. Prevalence of hypertension among adolescents (10-19 years) in India: A systematic review and meta-analysis of crosssectional studies. PLoS One. 2020;15(10):e0239929.
11. Center for Health Statistics N. Anthropometry Procedures Manual. 2009. Available from: https://www.cdc.gov/nchs/data/nhanes/nhanes_09_10/BodyMeasures_09.pdf [Accessed 10 July 2021].
12. Khadilkar VV, Khadilkar AV, Borade AB, Chiplonkar SA. Body mass index cut-offs for screening for childhood overweight and obesity in Indian children. Indian Pediatr. 2012;49:29–34.
13. Khadilkar V, Yadav S, Agrawal KK, Tamboli S, Banerjee M, Cherian A, et al. Revised IAP growth charts for height, weight and body mass index for 5- to 18-year-old Indian children. Indian Pediatr. 2015;52:47–55.
14. Shah AS, Dolan LM, D'Agostino RB, Standiford D, Davis C, Testaverde L, et al. Comparison of mercury and aneroid blood pressure measurements in youth. Pediatrics 2012;129:e1205–10.
15. Canzanello VJ, Jensen PL, Schwartz GL. Are aneroid sphygmomanometers accurate in hospital and clinic settings? Arch Intern Med. 2001;161:729–31.

16. Flynn JT, Kaelber DC, Baker-Smith CM, Blowey D, Carroll AE, Daniels SR, et al. Clinical practice guideline for screening and management of high blood pressure in children and adolescents. Pediatrics 2017;140:e20171904.
17. Patil RR, Garg BS. Prevalence of hypertension and variation in blood pressure among school children in rural area of Wardha. Indian J Public Health. 2014;58:78–83.
18. Song P, Zhang Y, Yu J, Zha M, Zhu Y, Rahimi K, et al. Global prevalence of hypertension in children: A systematic review and meta-analysis. JAMA Pediatrics. 2019;173:1154–63.
19. Jose AP, Awasthi A, Kondal D, Kapoor M, Roy A, Prabhakaran D. Impact of repeated blood pressure measurement on blood pressure categorization in a population-based study from India. J Hum Hypertens. 2019;33:594–601.
20. Falkstedt D, Koupil I, Hemmingsson T. Blood pressure in late adolescence and early incidence of coronary heart disease and stroke in the Swedish 1969 conscription cohort. J Hypertens. 2008;26:1313–20.
21. Sorof J, Daniels S. Obesity hypertension in children: A problem of epidemic proportions. Hypertension 2002;40:441–7.
22. Zhao Y, Wang L, Xue B, Wang Y. Associations between general and central obesity and hypertension among children: The childhood obesity study in China mega-cities. Sci Rep. 2017;7:1–7.
23. Dong Y, Song Y, Zou Z, Ma J, Dong B, Prochaska JJ. Updates to pediatric hypertension guidelines: Influence on classification of high blood pressure in children and adolescents. J Hypertens. 2019;37:297–306.
24. Cheung EL, Bell CS, Samuel JP, Poffenbarger T, Redwine KMN, Samuels JA. Race and obesity in adolescent hypertension. Pediatrics 2017;139:e20161433.
25. Goel M, Pal P, Agrawal A, Ashok C. Relationship of body mass index and other life style factors with hypertension in adolescents. Ann Pediatr Cardiol. 2016;9:29–34.
26. Kaczmarek M, Stawińska-Witoszyńska B, Krzyżaniak A, Krzywińska-Wiewiorowska M, Siwińska A. 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;174:1461–73.
27. Ewald DR, Bond SH, Haldeman LA. Hypertension in low-income adolescents. Glob Pediatr Heal. 2017;4:2333794×17741819.
28. Singh Thangjam R, Indrajit Singh A, Cindy L, Rameshchandra T. The profile of blood pressure (BP) and the prevalence of hypertension in school going children aged 5-15 years of Manipur, a North-Eastern hilly Indian state. Int J Contemp Pediatr. 2017;4:2151–7.
29. Genovesi S, Antolini L, Gallieni M, Aiello A, Mandal SKB, Doneda A, et al. High prevalence of hypertension in normal and underweight Indian children. J Hypertens. 2011;29:217–21.
30. Kumar J, Deshmukh PR, Garg BS. Prevalence and correlates of sustained hypertension in adolescents of rural wardha, central India. Indian J Pediatr. 2012;79:1206–12.
31. Vispute S, Shaikh N, Mandlik R, Gondhalekar K, Patwardhan V, Khadilkar A. Are rural Indian children and adolescents ages 9–18 years at risk of hypertension? A multicenter study. Curr Dev Nutr. 2021;5:192.
32. Tripathy JP, Thakur JS, Jeet G, Chawla S, Jain S, Prasad R. Urban rural differences in diet, physical activity and obesity in India: are we witnessing the great Indian equalisation? Results from a cross-sectional STEPS survey. BMC Public Health. 2016;16:816.
33. Thakur J, Jeet G, Nangia R, Singh D, Grover S, Lyngdoh T, et al. Non-communicable diseases risk factors and their determinants: A cross-sectional state-wide STEPS survey, Haryana, North India. PLoS One. 2019;4:e0208872.
34. Falkner B. Maternal and gestational influences on childhood blood pressure. Pediatr Nephrol. 2020;35:1409–18.
35. 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;111:61–6.
36. Raj M, Sundaram KR, Paul M, Deepa AS, Kumar RK. Obesity in Indian children: time trends and relationship with hypertension. Natl Med J India. 2007;20:288–93.
37. Yang Y, Dong B, Wang S, Dong Y, Zou Z, Fu L, et al. Prevalence of high blood pressure subtypes and its associations with BMI in Chinese children: A national cross-sectional survey. BMC Public Health. 2017;17:598.
38. McEvoy JW, Daya N, Rahman F, Hoogeveen RC, Blumenthal RS, Shah AM, et al. Association of isolated diastolic hypertension as defined by the 2017 ACC/AHA blood pressure guideline with incident cardiovascular outcomes. JAMA. 2020;323:329–38.

AUTHOR CONTRIBUTIONS

USA: concept, study design, protocol, data acquisition, data analysis, review of literature, ethics clearance for Mumbai schools, and writing the final draft of the article. HAP: protocol, ethics clearance for Mumbai schools, data analysis and literature review, training of medical officers in procedures [height, weight, and blood pressure]. RGP: data acquisition, data analysis, data formatting, tables, and revisions. VBM: study design, protocol, implementation, and data acquisition, literature review, drafting of article JS: ethics clearance for Pune schools, data acquisition, literature review. training of medical officers in procedures [height, weight, and blood pressure] drafting of article JSS: ethics clearance for Pune schools, data acquisition, literature review, training of medical officers in procedures [height, weight, and blood pressure], drafting of the article. PSC: data acquisition, data analysis, literature review VSK: data acquisition, data analysis, literature review, drafting of article PS: study design, protocol, data acquisition, data analysis, drafting of the article, and responding to reviewers' comments.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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