

Longitudinal Assessment of Blood Pressure in School-Aged Children: A 3-Year Follow-Up Study

M. L. Marcovecchio^{1,2} · A. Mohn^{1,2} · G. Diddi³ · N. Polidori¹ · F. Chiarelli^{1,2} · N. Fuiano³

Received: 2 June 2015 / Accepted: 18 September 2015 / Published online: 6 October 2015
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Abstract The purpose of this study was to assess the prevalence of abnormal blood pressure in a population of school children during a 3-year follow-up period and its relationship with obesity. Anthropometric and blood pressure data were collected from a population of Italian school children during three consecutive years. During each year blood pressure measurements were repeated three times, at intervals of 1 week. A total of 564 school-children [311 boys; mean (SD) age 8.8 ± 1.4 years] were recruited. During each year, systolic and diastolic blood pressure decreased from visit 1 to visit 3 ($p < 0.001$). This was associated with a decline in the percentage of prehypertension/hypertension from visit 1 to visit 3. An abnormal blood pressure value in at least one study visit was found in 8.8–17 % of children, whereas the prevalence of hypertension at all three study visits was between 5.2 and 7.8 %, and that of prehypertension at all three visits was between 2.8 and 3.8 %. High blood pressure was more frequent in obese children. In this population of school children the percentage of prehypertension/hypertension remarkably varied when based on one versus three annual assessments, thus emphasizing the importance of repeated measurement before making a diagnosis of abnormal blood pressure. Adiposity was confirmed to be a determinant of high blood pressure.

Keywords Blood pressure · Prehypertension · Hypertension · Schoolchildren · Adiposity

Introduction

Hypertension is a well-known cardiovascular risk factor in adult populations, being a key contributor for cerebrovascular events and ischemic heart disease [6]. Several studies have shown that high blood pressure is associated with adverse subclinical cardiovascular outcomes, such as left ventricular hypertrophy, increased pulse wave velocity and carotid intima-media thickness, already during childhood and adolescence [8, 18, 19, 24, 25]. In addition, a tracking of blood pressure from childhood to adulthood has been reported, and this underlines the burden associated with abnormal blood pressure in the pediatric age group [3, 13].

Recent data suggest that in children and adolescents, as in adults, not only hypertension, but also prehypertension, defined as blood pressure values between the 90th and 95th percentile, is a potential risk factor for organ damage [27]. Reports from national surveys clearly indicate that both prehypertension and hypertension in children and adolescents are on the rise [9, 10]. The prevalence of hypertension is around 3.5 % in the pediatric population, and these estimates are even higher among obese children [14, 21]. A direct relationship between the degree of obesity, as assessed by BMI and fat mass, and the prevalence of childhood hypertension has been repeatedly reported [16, 20, 28]. A recent meta-analysis has highlighted that obese children have higher systolic and diastolic blood pressure, by 7.5 and 4.1 mmHg respectively, than normal-weight children [12]. It is particularly alarming that the negative effect of overweight on blood pressure has been reported in children as young as 2–5 years-old [10]. Increased blood

✉ M. L. Marcovecchio
m.marcovecchio@unich.it

¹ Department of Paediatrics, University “G. d’Annunzio”, Chieti-Pescara, Via dei Vestini 5, 66100 Chieti, Italy

² Center of Excellence on Aging, “G. d’Annunzio” University Foundation, Chieti, Italy

³ Pediatric Unit, Prevention and Public Health, ASL FG, Foggia, Italy

pressure has been associated with BMI also in non-obese children, thus suggesting a continuous relationship between these two traits [15].

A correct diagnosis of prehypertension or hypertension relies on repeated blood pressure measurements, due to the variability of blood pressure in relation to several potential confounders, such as the white-coat effects as well as other environmental factors, which could be responsible for transient elevated blood pressure [1]. Up to now, only few studies have assessed the prevalence of prehypertension and hypertension over time based on repeated measurements, and they have highlighted that the prevalence of hypertension can be up to five times higher when comparing the first to a later assessment performed after a few weeks [7].

The aim of the present study was to assess the prevalence of abnormal blood pressure in a population of school children during a 3-year follow-up period. A secondary aim of the study was to assess the relationship between blood pressure and the presence of overweight/obesity.

Patients and Methods

Study Population

The study population included children attending primary schools in San Marco in Lamis (Foggia) at the time of data collection. Children were assessed during three consecutive years, with three assessments during each year, repeated at 1-week intervals. Each school assessment was based on the same protocol, with a single examiner performing all clinical assessments and measurements. In order to make the children comfortable in a relaxed environment all visits were performed in the classroom with the presence of the teacher, a social assistant and the classmates and with the examiner wearing casual clothes.

Informed consent was obtained from the parents and assent from the children before starting the first study visit. The study was approved by the local Ethics Committee.

At the first visit 564 children were evaluated; 535 of them were re-assessed during visit 2, and 500 underwent all three study visits.

Anthropometric Assessments

Weight and height were measured with the child in light clothing and without shoes.

Body weight was measured to the nearest 0.1 kg with a calibrated scale (Salus, Inc., Italy).

Height was measured three times to the nearest 0.1 cm with a portable Harpenden stadiometer (Holtain, Wales,

UK). Each subject stood straight, with feet placed together and flat on the ground, heels, buttock and scapulae against the vertical backboard, arm loose and relaxed with the palms facing medially and the head positioned in the Frankfurt plane.

A flexible tape was used to measure waist circumference to the nearest 1 mm at the mid-point between the lower ribs and the pelvic bone. Three waist circumference measurements were taken at the midst of each respiratory cycle. The ratio between waist circumference and height was calculated for each child (waist to height ratio).

Blood Pressure Measurement

Blood pressure was measured by the same investigator at all study visits using a validated protocol. During each study visit, systolic (SBP) and diastolic blood pressure (DBP) were measured three times, at 5-min intervals, at the non-dominant arm, after 10 min rest using a calibrated sphygmomanometer. The cuff size, which was based on the length and circumference of upper arm was chosen to be as large as possible without having the elbow skin crease obstructing the stethoscope. An inflatable bladder width that was at least 40 % of the arm circumference at a point midway between the olecranon and the acromion and that was as length as to cover 80–100 % of the circumference of the arm was used. SBP was recorded as the first Korotkoff sound and DBP as the fifth Korotkoff sound. The mean of the three measurements was taken as the individual SBP and DBP. During each year, after the first study visit BP was re-assessed in the other two occasions after 1 and 2 weeks from the first assessment. During the second and third visits, the examiner was unaware of the previous BP results.

Hypertension and pre-hypertension were defined according to age-, sex- and height-specific percentiles from the Fourth Report of the Working Group on High Blood Pressure in children and Adolescents [22]. Pre-hypertension was defined as SBP or DBP between the 90th and the 95th percentile. Hypertension was defined as SBP or DBP equal or above the 95th percentile.

Calculations

BMI was calculated as the weight in kilograms divided by the square of the height in meters. All anthropometric parameters were converted in standard deviation scores (SDS) using published reference values for age and sex for the Italian population [2]. Overweight and obesity categories were defined according to the same reference values [2]. Percentiles and SDS for SBP and DBP were also calculated accordingly to reference values [22].

Statistical Analysis

Statistical analyses were performed using SPSS version 16 software for Windows. Data were analysed for normality using the Kolmogorov–Smirnov test, and log-transformed to normal distributions wherever necessary to allow use of parametric analysis. All data were expressed as percentages for categorical variables or as mean ± SD or median (interquartile range) for continuous variables unless otherwise specified. Two-tailed significance was set to $p < 0.05$.

Repeated measurement ANOVA was applied to assess differences across the three study visits. Distribution of BP category was compared by chi-squared or Fisher exact tests.

Results

General Characteristics of the Study Population

The general characteristics of the study population at the three study visits are reported in Table 1. Five hundred sixty four school-aged children [311 boys (55.1 %) and 253 girls (44.9 %)] were assessed during the first year, their mean age was 8.8 years, with a range between 6.0 and 11.9. Out of them, 535 were re-assessed during year 2 and 500 underwent all three yearly study visits. All data analyses were restricted to the 500 children completing the 3-year follow-up visits.

Prevalence of Abnormal Blood Pressure Over Time

During each year, there was a significant decline in mean SBP and DBP from visit 1 to visit 3 (Table 2), leading to a decreasing prevalence of prehypertension and hypertension from the first to the third visit (Fig. 1). At the initial study visit during year 1, 70.2 % of children were normotensive and this percentage increased to 82.8 % at the third study visit performed during the same year. This was associated with a progressive decline in the percentage of abnormal

blood pressure values from visit 1 to visit 3, e.g. prehypertension: 12.6 versus 8.2 versus 9.0 %; hypertension: 17.2 versus 12.6 versus 8.2 %, $p < 0.001$ (Fig. 1). A similar trend was detected across the three consecutive study visits performed at 1-week intervals during year 2 and year 3 (Fig. 1).

During each year, the percentage of children with abnormal blood pressure values in at least one study visit was quite high, ranging between 8.8 and 17 %, whereas the percentage of children with abnormal BP at all three study visits was lower (Fig. 2). In particular, the percentage of children with BP in the hypertension range at all three yearly study visits was between 5.2 and 7.8 %, whereas the percentage of prehypertension at all three yearly visits was between 2.8 and 3.8 %. The percentage of prehypertension or hypertension at three or two yearly study visits was 4.2–7.4 and 3.4–7.4 %, respectively (Fig. 2).

Prevalence of Overweight and Obesity Over Time and Association with Blood Pressure

The prevalence of obesity in the study population during the 3 years was 10.0, 8.0 and 7.8 % and that of overweight was 26.6, 27.4 and 29.6 %, respectively.

The percentage of prehypertension and/or hypertension at all three yearly study visits increased across categories of BMI, being particularly high in children in the obesity category (Table 3).

Discussion

Two main findings emerged from this 3-year longitudinal study performed in a population of school-aged children: (1) during childhood blood pressure showed a high variability, with frequent oscillations, even from the normal to the pathological range within a strict time interval and (2) obesity was a main determinant of high blood pressure.

Hypertension is a key well-known cardiovascular risk factor [26] and it has been shown that there is a clear

Table 1 General characteristics of the study population

Characteristic	Year 1	Year 2	Year 3
N (M/F)	564 (311/253)	535 (294/241)	500 (278/222)
Age (years)	8.8 ± 1.4 [6.0–11.9]	9.7 ± 1.5 [6.8–13.0]	10.9 ± 1.5 [7.8–13.9]
Weight (kg)	33.8 ± 10.4	37.3 ± 11.0	42.7 ± 12.4
Height (cm)	132.7 ± 10.1	138.0 ± 10.7	144.4 ± 11.3
BMI (kg/m ²)	18.8 ± 3.8	19.3 ± 3.8	20.2 ± 3.8
BMI SDS	0.26 ± 1.11	0.20 ± 1.13	0.27 ± 1.06
Waist circumference (cm)	70.1 ± 10.4	72.7 ± 10.0	76.4 ± 9.8
Waist-to-height ratio	0.53 ± 0.06	0.53 ± 0.05	0.53 ± 0.05

BMI body mass index, SDS standard deviation score

Table 2 Systolic and diastolic blood pressure across study visits

Measure	Visit 1	Visit 2	Visit 3	<i>p</i> for trend
Year 1				
SBP (mmHg)	99.3 ± 10.8	97.0 ± 10.1	95.8 ± 9.5	<0.001
DBP (mmHg)	70.6 ± 8.8	68.7 ± 8.5	67.3 ± 7.9	<0.001
Year 2				
SBP (mmHg)	98.3 ± 9.5	96.1 ± 8.8	94.3 ± 8.7	<0.001
DBP (mmHg)	69.3 ± 8.3	67.0 ± 7.9	65.8 ± 7.7	<0.001
Year 3				
SBP (mmHg)	106.5 ± 13.4	103.6 ± 12.3	102.2 ± 11.7	<0.001
DBP (mmHg)	74.3 ± 10.1	71.5 ± 9.6	70.7 ± 8.7	<0.001

SBP systolic blood pressure, DBP diastolic blood pressure

Fig. 1 Prevalence of normotension, pre-hypertension and hypertension.

Yr year, *V* visit; Yr1-V1: visit 1 during year 1; Yr1-V2: visit 2 during year 1; Yr1-V3: visit 3 during year 1; Yr2-V1: visit 1 during year 2; Yr2-V2: visit 2 during year 2; Yr2-V3: visit 3 during year 2; Yr3-V1: visit 1 during year 3; Yr3-V2: visit 2 during year 3; Yr3-V3: visit 3 during year 3

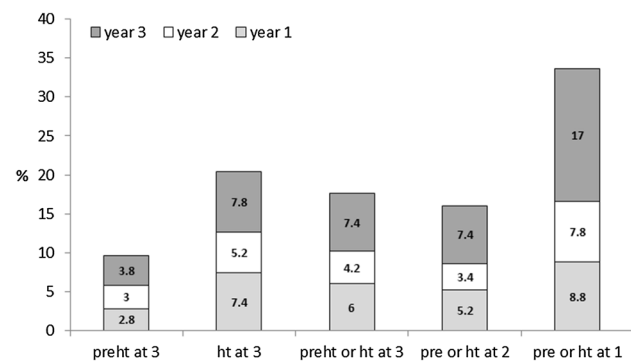
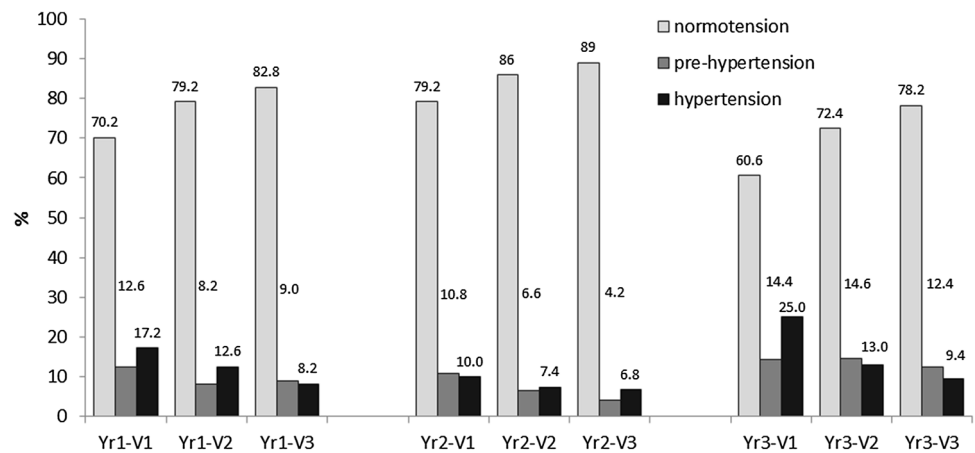


Fig. 2 Prevalence of transient/persistent hypertension/prehypertension during the study period. preht at 3: prehypertension at all 3 visits performed each year; ht at 3: hypertension at all 3 visits performed each year; preht or ht at 3: prehypertension or hypertension at all 3 visits performed each year; preht or ht at 2: prehypertension or hypertension at 2 visits performed each year; preht or ht at 1: prehypertension or hypertension at 1 visit performed each year

Table 3 Prevalence of pre-hypertension and hypertension at three study visits during each year across the BMI categories (normal-weight–overweight–obese)

Measure	Normal-weight	Overweight	Obese
Year 1			
Pre-hypertension (%)	1.9	3.0	8.0
Hypertension (%)	2.3	8.2	16.0
Year 2			
Pre-hypertension (%)	1.5	3.4	5.0
Hypertension (%)	2.5	2.9	35.0
Year 3			
Pre-hypertension (%)	2.6	3.5	4.7
Hypertension (%)	4.8	8.1	30.8

tracking of blood pressure from childhood to adulthood [13]. In addition, high blood pressure during early life is an independent risk factor for future cardiovascular disease [17], and even more alarmingly, it is associated with abnormal cardiovascular findings, such as endothelial

dysfunction, increased pulse wave velocity and carotid intima-media thickness, as early as during childhood and adolescence [8, 19, 24, 25]. Overall these data highlight the relevance of the problem and underline the importance of identifying abnormal blood pressure values early in life. In

this context, the term ‘abnormal blood pressure’ includes not only values above the 95th percentile for age, sex and height, fulfilling the diagnosis of hypertension, but also values in the so-called ‘prehypertension range’, that is, values between the 90th and 95th percentiles, which have been linked to increased risk of developing hypertension and future negative vascular outcomes [21, 23].

Blood pressure is known to be a very variable parameter, particularly in children, where more than one reading in repeated occasions is generally recommended to be obtained in order to avoid a wrong diagnosis of high blood pressure due to the white coat effect or other confounding factors [22]. Previous studies have assessed whether abnormal blood pressure readings are persistent across visits or are more likely to be transient. In this context, Chiolerio et al. found that the proportion of children with elevated blood pressure based on a single visit was five times higher than that based on three measurements taken at intervals of a few weeks [13]. Similar findings of a decrease in abnormal blood pressure values over subsequent visits have been reported in other studies performed in children [4]. However, a limitation of previous studies has been the fact that the blood pressure re-assessments were performed only in subjects who had abnormal readings at the first screening visit [5, 21]. This represents a limitation based on the finding of the study from Bovet et al. [1], who assessed blood pressure in an adult population at four subsequent visits, and found that its values decreased substantially during follow-up visits, both in subjects with and without hypertension at the first assessment.

In the present 3-year follow-up study we found that, during each study year, blood pressure values declined, leading to a reduced prevalence of pre-hypertension and hypertension from the first to the third study visit, although the time interval between each of them was restricted to 1 week. If we had relied on blood pressure detected only at the first study visit, the prevalence of hypertension would have been almost double compared to the prevalence based on the third visit. In the present study, blood pressure was assessed around the same time of the day at each study visit (first part of the morning), and therefore timing does not seem to be a confounder. The same equipment was used at each study visit and the same investigators did all assessments, ruling out other potential confounders. We did not assess dietary intakes but it seems unlikely that there could have been significant changes during only a 1-week interval related to diet, although the latter is a known contributor to blood pressure [11]. The most likely explanation for the within-year/between visits differences in blood pressure is the so-called white coat effect. Thus, decreasing mean blood pressure values across yearly visits could indicate that

subjects became more confident with the investigator from week 1 to week 3 and therefore there was a calmer environment for the blood pressure assessment. This seems likely mainly as the same trend was observed during all three study years.

When comparing blood pressure values across the 3-year follow-up period, there was an expected increase in both SBP and DBP, reflecting the known blood pressure changes with age and height.

Remarkable was the finding that the percentage of abnormal blood pressure based on a single study visit was as high as 17 %, whereas the prevalence of persistent high blood pressure at all three yearly study visits was significantly lower.

Altogether, these findings reiterate the important concept that, when high blood pressure readings are detected during an office or hospital visit, it is mandatory to re-assess blood pressure during the following weeks, before a final diagnosis of hypertension is made and further investigations are undertaken. Based on the present study, assessments made at intervals of 1 week allow having a better pattern of blood pressure in pediatric subjects and selecting those at risk.

This study also confirmed previous findings of a direct association between increased body weight and blood pressure. Previously, our group and others showed that excess body weight during childhood and adolescence is directly associated with increased blood pressure [16, 20]. The novelty of this study is related to the reported higher prevalence of persistent high blood pressure at three consecutive visits in obese children compared to those with normal weight.

The main strengths of the study include the longitudinal study design, as it is the only study exploring the temporal changes in blood pressure in a population of school children over a 3-year period. The large sample size and the small loss of study participants during follow-up are additional study strengths together with the well-standardized study anthropometric and blood pressure assessments, made by the same investigators over the 3-year study period.

Limitations of the study could be the lack of direct cardiovascular measurements to assess the impact of potential different effects of transient vs persistent high blood pressure on the vascular system. In addition, it needs to be acknowledged that the chosen manual method for the BP assessment might have influenced the study results and made them difficult to be compared to those from studies using an automated device. The manual method was chosen for its well-recognized accuracy and validity [22], although it could lead to potential human/methodological errors, which were limited by the assessments being performed all by the same well-trained examiner.

It would be of particular interest to assess the long-term outcomes of subjects with increased blood pressure and to assess whether only persistent prehypertension/hypertension is a predictor of future hypertension and cardiovascular events or also transient high blood pressure values should be considered predictors of future events. Answering this question would be of paramount importance in terms of patient stratification in risk categories, as well as for the implementation of treatment strategies. Therefore, a long-term re-assessment of the same study cohort would provide important information.

Conclusions

This 3-year longitudinal study performed in a population of school children showed that blood pressure is a variable parameter during childhood, with frequent oscillations, even within a strict time interval, thus highlighting the importance of repeated assessments before making a true diagnosis of abnormal blood pressure. Adiposity was confirmed to be a key determinant of blood pressure during childhood, thus reiterating the importance of fighting the epidemics of childhood obesity to improve the future of children.

Acknowledgments We would like to thank all study participants, their families and the personnel of the schools participating to the study. M.L.M. is the recipient of the 2014 “L’Oréal Italia per le Donne e la Scienza” (For Women in Science) fellowship.

Compliance with Ethical Standards

Conflict of interest None.

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