Hypertension Research (2015) 38, 577–587

www.nature.com/hr

REVIEW

Strengths and limitations of current pediatric blood pressure nomograms: a global overview with a special emphasis on regional differences in neonates and infants

Massimiliano Cantinotti[1,2], Raffaele Giordano[1], Marco Scalese[2], Sabrina Molinaro[2], Bruno Murzi[1], Nadia Assanta[1], Maura Crocetti[1], Marco Marotta[1], Sergio Ghione[1,2] and Giorgio Iervasi[1,2]

The availability of robust nomograms is essential for the correct evaluation of blood pressure (BP) values in children. A literature search was conducted by accessing the National Library of Medicine by using the keywords BP, pediatric and reference values/nomograms. A total of 43 studies that evaluated pediatric BP nomograms were included in this review. Despite the accuracy of the latest studies, many numerical and methodological limitations still remain. The numerical limitations include the paucity of data for neonates/infants and for some geographic areas (Africa/South America/East Europe/Asia) and ethnicities. Furthermore, the data on ambulatory BP and response to exercise are extremely limited, and the criteria for stress-test interruption are lacking. There was heterogeneity in the methodologies employed to perform the measurements, in the inclusion/exclusion criteria (often not reported), in the data normalization and the data expression (*Z*-scores/percentiles/mean values). Although most studies adjusted the measurements for age and/or height, the classification by specific age/height subgroups varied. Gender differences were generally considered, whereas other confounders (that is, ethnicity/geographic area/environment) were seldom evaluated. As a result, nomograms were heterogeneous, and when comparable, at times showed widely different confidence intervals. These differences are most likely because of both methodological limitations and differences among the populations studied. Some robust nomograms exist (particularly those from the USA); however, it has been demonstrated that if adopted in other countries/continents, they may generate an unpredictable bias in the evaluation of BP values in children. Actual pediatric BP nomograms present consistent limitations that affect the evaluation of BP in children. Comprehensive nomograms, which are based on a large population of healthy children (including neonates/infants) and use standardized methodology, are warranted for every country/region.

Hypertension Research (2015) **38,** 577–587; doi:10.1038/hr.2015.45; published online 16 April 2015

Keywords: blood pressure; children; neonates; nomograms

INTRODUCTION

Arterial blood pressure (BP) is a basic vital parameter that is measured at all ages[1–48] (http://www.mercuryfreehealthcare.org). In adults, elevated BP is defined as a risk-related threshold, that is, as that level of BP above which clinical trials have shown (and international guidelines have agreed upon) that lowering BP reduces the likelihood of CV diseases and death.[47,48] This threshold is usually 140/90 mm Hg, and although it may be lower in higher risk conditions (for example, in diabetes), it is not considered to be dependent on other factors such as age, sex, body mass, ethnicity and so on.[3,4] However, an essential aspect of BP in the pediatric and adolescent populations is that it changes (increases) with growth, making BP measurements meaningful only if related to some indices of growth or body size.[4–46] As a result, BP values in children, as well as any other parameter,[49–53] need to be normalized according to age and somatic growth.[1–46] Thus, the availability of robust nomograms is essential for the correct evaluation of BP values in children.[49–53]

For the determination of reference values, of paramount importance is the selection of reference individuals based on extensively documented inclusion and exclusion criteria and the use of quality-controlled procedures to collect data.[49–53] When only small numbers of values are available, reference intervals (RIs) may be highly imprecise.[49–53]

From a clinical point of view, when multiple nomograms are available and no clear recommendations exist regarding the use of one nomogram over another, a clinician makes an arbitrary choice and relies on it in the decision making process.[49–51] As a result, if various nomograms present significant differences in RIs, this may generate

[1]Department of Pediatric Cardiology and Cardic Surgery, Tuscany Foundation G. Monasterio, Massa, Italy and [2]Department of Cardiology, Institute of Clinical Physiology, Pisa, Italy
Correspondence: Dr R Giordano, Tuscany Foundation ``G. Monasterio'', Pediatric Cardiology and Cardiac Surgery, Via Aurelia sud, Heart Hospital - Massa 54100, Italy.
E-mail: raf_jordan@inwind.it
Received 27 June 2014; revised 13 January 2015; accepted 9 February 2015; published online 16 April 2015

confusion in the estimation of disease severity,[49–51] thus affecting the management of children with hypo/hypertension.

The aim of this study was to critically review the strengths, accuracy and limitations of available pediatric blood pressure nomograms. New perspectives for research in the field are also described to convey the current knowledge gaps.

MATERIALS AND METHODS

Search strategy

Candidate studies for inclusion were identified by a systematic search of the National Library of Medicine (PubMed access to MEDLINE citations, http://www.ncbi.nlm.nih.gov/PubMed/) conducted in March 2013. The period searched covered 1985–2013. The search strategy included a combination of Medical Subject Headings (MeSH) and free text terms for the key concepts starting with BP, pediatric and reference values/nomograms. The search was further refined by adding the keywords neonates/infants/adolescent, range and intervals. In addition, we identified other potentially relevant publications using a manual search of the references from all eligible studies and review articles as well as from the Science Citation Index, expanded on Web of Science.

Titles and abstracts of all articles identified by the search strategy were evaluated and assessed independently by two reviewers; articles were excluded (1) if the studies included populations other than normal subjects or included adults with children ($N=6$), and (2) if the reports were published in languages other than English ($N=16$).

RESULTS

A total of 67 publications were identified for potential inclusion in the study. Twenty-two studies were excluded on the basis of the criteria listed above, leaving 45 publications for analysis; 36 surveys[2–4,6,8–13,16,19–21,25–35,39,40,44,45,54,55] were performed with the specific aim of providing reference BP values for children in a definite population, whereas the other surveys[1,5,18,23,24,36,37,42,43,46] were for other purposes, such as comparison with reference data, identification of time trends, comparison among different ethnicities and testing of the methodological issues related to BP normalization in the pediatric age group.

NUMERICAL ISSUES

Nomograms divided according to geographic area

In Table 1, major pediatric BP nomograms, divided according to the major region of origin, are detailed. For some countries/continents (North America, Europe, Middle East, part of Asia), there are one or more nomograms calculated over a wide sample of healthy children (from 2876 to 63 227 healthy children).[6,9,39,45,54,55] In contrast, some geographic areas, particularly Africa, East Europe, South America and wide areas of Asia (particularly China and Russia) are poorly/not represented.

Neonates and infants

The data on neonates and infants are extremely limited (0–12 months) with only nine studies[2,3,14,17,29–34] exhibiting a relatively good sample size of healthy subjects (over 400 subjects) (Table 2). Most of the above studies evaluated neonates at birth,[2,17,29–32,34] and the majority contained measurements repeated at 4 days of life.[2,30,32–34] Few data are available for days 2–3 of life,[17,30,32,34] and up to 6 months;[2,30,33] data at 6 and 12 months[2,31,33] are also limited. Some ethnicities, in particular black, are almost absent, and some geographic areas are not represented at all (East Europe, Asia, South America). Premature and full-term neonates have been considered separately only by a few authors,[29,34] and various age intervals have been used in different studies.

On the basis of available data, a progressive increase in systolic BP (SBP) and diastolic BP (DBP) seems to occur during the first week of life[2,3,17,34] with the highest variations during the first days[2,17,32,34] and with little variation thereafter up to 6–12 months of life.[2,17,31,33] Weak but significant positive correlations of SPB and DBP with birth weight,[2,17,29,32–34] birth length,[29,32] head circumference[29] and gestational age[17,29,34] were also found.

Naturally delivered neonates had higher mean BP values than neonates delivered by cesarean section[29] and a more rapid rate of increase was found in preterm compared with full-term infants.[17,34] As expected, BP was lower when measured during the sleep state than when the child was in a quietly awake state.[34]

Ambulatory blood pressure and response to stress test

Ambulatory blood pressure monitoring is of great relevance for the diagnosis of hypertension in children because of the white coat and masked hypertension phenomena.[56] However, only a few studies have tried to establish reference values for ambulatory BP in normal healthy children[57–65] and in disease states.[66] The only normative data generated in a relatively large number of healthy children and adolescents (1141 healthy children and adolescents) are from Germany,[62] and there are very limited data for infants and toddlers.[67–70] Special considerations are required for neonates and infants where important variations in BP values may occur depending on sleeping/awake state. In particular, infants frequently exhibit sudden hypotensive or hypertensive events during sleep because the autonomic nervous system is immature or may be altered in preterm babies.[69,70] Finally, data on BP response to exercise in children are extremely limited,[71–73] and no clear BP cut-off values exist to distinguish between the healthy and pathological states; in addition, there are no criteria for the interruption of stress tests in cases of excessive BP increases.[73]

METHODOLOGICAL ISSUES

Selection criteria

Inclusion/exclusion criteria have been reported in many but not all of the nomograms. In particular, studies involving neonates generally described the criteria employed to select the healthy subjects in some detail[3,14,17,29–32,34] with a few exceptions.[2,33] In contrast, in articles involving older children, the inclusion/exclusion criteria were often not reported.[6,9,10,12,19,24,26,28] Furthermore, data from the Fourth Report of the National Health and Nutrition Examination Surveys and from other US studies have been utilized by various authors with different selection criteria.[5,24] The National High Blood Pressure Education Program Working Group on High BP in Children and Adolescents decided to use height (rather than weight or body mass index (BMI)) in constructing the nomograms representing 63 227 American children to discourage the misinterpretation of relatively high BP as normal just because a child is overweight/obese.[9] In fact, overweight children tend to exhibit[19,21,24,36] higher BP values compared with normal weight children of the same age and height. However, overweight children were still included in the normative database.[7,9] To overcome this limitation, Rosner and colleagues, using the same data, rebuilt the nomograms excluding overweight children,[21] which produced only slightly lower nomograms.

Methods of BP measurement

Various methodological issues affected the evaluation of the method of BP measurement, including the use of different recorders, the cuff sizes, operator skill and the number of measurements (Table 3). Consistent with both US,[9] European[44] and Asian[74] guidelines, most of

Table 1 Major pediatric blood pressure nomograms dividedPI according to geographic area

Author	Numerosity	Age interval	W/H/BMI	G (M)	Groups	Region/ethnicity
America						
Nichols *et al.*[19]	3749	12–18 Years	M/F BMI 20.6 (4.2), 21.8 (5)	1610	1 Year groups 12–18 years	Region: Trinidad and Tobago ethnicity: nr
Paradis *et al.*[8]	3589	9–16 Years	nr		9 Years (*n*=1243, M 51%) 13 Years (*n*=1171 M 51%) 16 Years (*n*=1156 M 50%)	Region: Quebec ethnicity: nr
Park *et al.*[3]	1554	2 Weeks–5 years	nr	747	2–3 Weeks (*n*=105); 1–5 Months (*n*=232); 6–11 Months (*n*=183); 1 Years (*n*=245); 2 Years (*n*=212); 3 Years (*n*=193); 4 Years (*n*=226); 5 Years (*n*=158)	White 1203; Black 106; Hispanic 245
Park *et al.*[11]	7208	5–17 Years	nr	nr	nr	58.5% Mexican-American, 28.3% non-Hispanic White,13.2% African-American
Rosner *et al.*[13]	49 967[a]	1–17 Years	nr	25 651	1 Year groups 1–17 years	Caucasian 55%, African-Amreican 29%, Hispanic 9%, Asian 3%, Native America 1%, other 3%
Fourth report[9]	63 227	1–17 Years	nr	51%	1 Year groups 1–17 years	Nih 1963–1965 6–17 years (*n*=3647); Pittsburgh 1984 1–5 years (*n*=3647); Dallas 1976 13–17 years (*n*=11565); Bogalusa 1976 1–17 years (*n*=7358); Houston 1981 3–17 years (*n*=2834); South Carolina 1985 4–17 years (*n*=6430); Iowa 1970–1981 3–17 years (*n*=4092); Providence 1985 1–3 years (*n*=461); Minnesota 1986–1987 9–17 years (*n*=19409); NHANES 1988–1994 5–17 years (*n*=5042) NHANES 1999–2000 8–17years (*n*=2104) Caucasian 55%, African-American 29%, Hispanic 9%, Asian 3%, Native American 1%, Other 3%
Australia						
Blake *et al.*[12]	2876	1–6 Years	BMI 17.0 (1.4) 16.2 (1.3) 15.8 (1.8)	546	Age 1 (*n*=1090) Age 3 (*n*=976) Age 6 (*n*=1178)	Caucasian 89.7%; Age 3 *n* 976 M 465 Caucasian 90%; Age 6 *n* 1178 Caucasian 88%
Europe						
De Man *et al.*[10]	28 043	4–19 Years	nr	nr	Berlin breman 11–17 years *n*=1302 (731 M); Cologne 15–19 years *n*=2934 (1353 M); Copenhagen 6–18 years n=898 (447 M); Essen 4–18 years *n*=1471 (751 M) Nancy 4–17 years n=17 067 (8647 M); Zoetermeer 5–19 years n=4371 (2198 M)	Region: Germany, Denmark, France, Netherlands Ethnicity: nr
De Swiet *et al.*[33]	1895 born > 37 wg	4 Days–10 Years	nr	nr	4 Days, 6 weeks, 6 months, 1 year and yearly up to 10 year 4 days (*n*=1895), 6 weeks (*n*=1797), 6 months (*n*=1777), 1 year (*n*=1738), 2 years (*n*=1681), 3 years (*n*=1570), 4 years (*n*=1484), 5 years (*n*=1403), 6 years (*n*=1339), 7 years (*n*=1304), 8 years (*n*=1262), 9 years (*n*=1235), 10 years (*n*=1211)	Region Kent Ethnicity: nr

Table 1 (Continued)

Author	Numerosity	Age interval	W/H/BMI	G (M)	Groups	Region/ethnicity
Menghetti et al.[16]	11 519	5–17 Years	nr	6258	M/F 5 Years (n=195/145); 6 years (n=443/393); 7 years (n=349/344); 8 years (n=371/386); 9 years (n=882/795); 10 years (n=979/ 881); 11 years (n=688/511); 12 years (n=983/910); 13 years (n=893/621); 14 years (n=301/172); 15 years (n=126/34); 16 years (n=75/25); 17 years (n=76/44)	Region: Italy Ethnicity: nr
Sanchez et al.[6]	34 986	1–18 Years	nr		M/F 1 Years (n=52/43); 2 years (n=153/147); 3 years (n=244/183); 4 years (n=375/330); 5 years (n=811/745); 6 years (n=1739/1570); 7 years (n=1730/1530); 8 years (n=1679/1395); 9 years (n=1786/1517); 10 years (n=1870/1692); 11 years (n=2071/1712); 12 years (n=1611/1517); 13 years (n=1688/1277); 14 years (n=1159/829); 15 years (n=821/762); 16 years (n=699/455); 17 years (n=594/362); 18 years (n=236/204)	Madrid 1985 6–14 years (n=2003); Alicante 1984 1–14 years (n=2011); Malaga 1985 5–14 years (n=6922); Avila 1983 4–14 years (n=951); Madrid 1986 1–18 years (n=2419); Madrid 1984 2–18 years (n=3885); Madrid 1985 4–14 years (n=2069); Madrid;1984 4–18 years (n=6990) Cantabria 1984 5–18 years (n=1140); Madrid 1984 6–18 years (n=2947); Valencia 1986 5–14 years (n=559); Valencia 1987 6–14 years (n=684); Aragon 1984 4–14 years (n=837); Canarias 1984 5–14 years (n=439); Canarias1985 5–15 years (n=833) Ethnicity: Caucasian
Turner et al.[40]	5599	0–18 y.o.	nr	2835	0–2 Years (n=349/312); 2 years (n=147/120); 3 years (n=170/170); 4 years (n=16/164); 5 years (n=165/162); 6 years (n=190/156); 7 years (n=146/136); 8 years (n=163/177); 9 years (n=168/146); 10 years (n=158/162); 11 years (n=159/156); 12 years (n=160/145); 13 years (n=170/142); 14 years (n=125/ 139); 15 years (n=133/ 131); 16 years (n=132/133); 17 years (n=71/127); 18 years (n=68/86)	Region: Turkey Ethnicity: nr
Mead East						
Merhi et al.[45]	5710	5–15 Years	b	2918	M–F 5 Years (n=128/131); 6 years (n=320/315); 7 years (n=366-/378); 8 years (n=388/344); 9 years (n=364/356); 10 years (n=394/359); 11 years (364/375); 12 years (n=199/215); 13 years (n=193/140); 14 years (n= 164/161); 15 years (n=38/18)	Beirut 45.65%, Mount Lebanon 11.22%, North 14.71%, Bekaa 12.9% and South 15.41%.
Asian						
Chadha et al.[26]	8293	5–14 Years	BMI 14.4 (1.5)	4623	5 Years (n=311); 6 years (n=725); 7 years (n=894); 8 years (n=958); 9 years (n=1029); 10 years	Region: New Delhi Ethnicity: nr

Table 1 (Continued)

Author	*Numerosity*	*Age interval*	*W/H/BMI*	*G (M)*	*Groups*	*Region/ethnicity*
					($n=1019$); 11 years ($n=917$); 12 years ($n=998$); 13 years ($n=892$); 14 years ($n=550$)	
Jafar *et al.*[24]	5641	5–14 Years	BMI 15.2 (4.3) M 15.3 (4.3) Fb	2974		Pakistan: Muhajir, Punjabi, Sindhi, Pasthun, Baluchi
Kelishadi *et al.*[39]	21 111	6–18 Years	BMI 18.53±3.84	10 253	6 Years ($n=814$); 7 years ($n=1330$); 8 years ($n=1499$); 9 years ($n=1435$); 10 years ($n=1638$); 11 years ($n=1755$); 12 years ($n=2116$); 13 years ($n=1939$); 14 years ($n=2246$); 15 years ($n=2131$); 16 years ($n=2036$); 17 years ($n=1410$); 18 years ($n=747$)	Persian 51%, Azeri 24%, Gilaki and Mazandarani 8%, Kurd 7%, Arab 3%, Lur 2%, Baloch 2%,Turkmen 2% and other 1%).
Krishna *et al.*[27]	2278	3–18 Years	nr	2500	M/F 3 Years ($n=42/56$); 4 years ($n=97/73$); 5 years ($n=43/27$); 6 years ($n=92/73$); 7 years ($n=105/138$); 8 years ($n=118/134$); 9 years ($n=109/147$); 10 years ($n=103/119$); 11 years ($n=183/179$); 12 years ($n=253/272$); 13 years ($n=318/469$); 14 years ($n=269/565$); 15 years ($n=298/402$); 16 years ($n=158/178$); 17 years ($n=34/60$); 18 years ($n=56/38$)	Region: Karnataka Ethnicity: nr
Sharma *et al.*[28]	2453	7–16 Years	b	159	1 Year groups 7–16 years	Region: Chandigarh Ethnicity: nr
Taghi Ayatollahi *et al.*[35]	2270	6.5–11.5 Years	nr	1174	Age group7: 6.5–7.49 years; Age group 8: 7.5–8.49 years; age group 9:8.5–9.49 years; age group 10: 9.5–10.49 years; age group 11: 10.5–11.5 years	Iranian Ethnicity: nr
Hashimoto*et al.*[54]	5316	2–6 Years	b	2808	Age groups 2 Years ($n=158$); 3 years ($n=553$); 4 years ($n=793$); 5 years ($n=856$); 6 years ($n=448$)	Niigata Prefecture (rural and city)

Abbreviations: A, ausculatory sphygmomanometry method; BMI, body mass index (kg m^{-2}); D, dinamap; F, females ; G, gender; h, height; M, males; nr, not reported; W, weight.
Every year BMI 5 years 13.9(1.0) 13.8(1.0) 13.7(1.1) 13.8(1.1) 13.9(1.3) 14.1(1.2) 14.5(1.4) 14.9(1.6) 15.3(1.7) 15.8(1.7) 14 years 14.4(1.5).
Height 12,7 (17.9) M, 126,7 (17.4) F; Weight 24.9 (9.1) M; 25.2 (9.7) F.
[a]From Fourth report database subjects have been included only if their BMI percentile was less than the 85th percentile.
[b]Measurements indicated for every age group.

the studies used the auscultatory manual method for BP measurement in older children, whereas the oscillometric method was employed in neonates and infants. Regarding recorders however, aneroid sphygmomanometers should be considered the method of choice, because mercury sphygmomanometers are being progressively banned worldwide (http://www.mercuryfreehealthcare.org) as a result of being poorly employed. Furthermore, only a few oscillometric devices have been validated in children.[1] Finally, regarding auscultatory measurements, in almost all recent surveys, the disappearance of Korotkoff sounds (K5) was established as the definition of DBP, whereas some older studies used K4.[9,26,45] In the majority of the surveys,[2,6,8,11,26–28,30–35,39] multiple cuff sizes were used according to arm size, although the criteria for selection of cuff length and width differed among the various studies.

A standard protocol[9] (right arm, sitting position and rest period preceding the measurement) was usually observed, with few exceptions.[10] In particular, the position was not always indicated[2,8,30,31] or it was supine,[10,32,34] especially in neonates (where there are obvious limitations in obtaining a fixed position). Multiple readings taken at a single visit were common in most studies, whereas in a few studies, the data were based on single readings.[9,21] Only a few reports indicated the time of the day (mostly in the morning)[2,8,16,54] and the seasons in which the data were collected.[6,17,40,54] Table 3. Finally, intra-observer and inter-observer variability were generally ignored, with only a few exceptions.[27]

Statistical issues

Data normalization and expression. In children, BP measurements must be adjusted for body size, age and/or some other parameter to compare the values with those from a healthy pediatric population.[9] Most of the studies had estimated values of BP according to age[2–6,8,11,12,14,16,17,19,28,31–33,39,40,45,54] or height[35] or both.[9,10,13,20,21,26,27,35] In the majority of the studies, significant linear correlations with age were observed both for systolic and DBP with widely ranging 'r' values[3,4,6,8,9,11,13,19,21,27,28,35,45,54] (SBP r: 0.26–0.64; DPB r: 0.018–0.56); in a few instances, statistically significant

Table 2 Major blood pressure nomograms for neonates and infants

Author	*Numerosity*	*Age*	*Gender/ race*	*Age*	*BW Weight (g)*
Europe					
De Swiet *et al.*[33]	1895 Born > 37 wg	4 Days–10 years	81 M Cucasian 97%	4 Days (*n* = 1895), 6 weeks (*n* = 1797), 6 m (*n* = 1777), 1 year (*n* = 1738), 2 years (*n* = 1681)	—
Gemelli *et al.*[2]	514	0–12 Months	260 M	Groups 0–12 months; 1 day (*n* = 260); 4 days (*n* = 260); 1 month (*n* = 258); 3 months (*n* = 220); 6 months (*n* = 171); 9 months (*n* = 132); 12 months (*n* = 144)	3402 ± 451
Pejovic *et al.*[34]	373 292 Pre-term 81 term	1 Day of life	178 M	Age groups (WG): A < 28 (*n* = 62); B = 29–32 (*n* = 146); C = 33–36 (*n* = 81); D ⩾ 37 (*n* = 81)	Groups: I 600–999 (*n* = 44); II 1000–1240 (*n* = 78); III 1250–1499 (*n* = 94); IV 1500–1999 (*n* = 76); V ⩾ 200 (*n* = 100)
Salihoglu *et al.*[29]	982 34–43 WG	At born	513 M	WG 39.01 ± 1.49 range 34–43	BW group (g): A < 2500 (*n* = 45); B 2500–4000 (*n* = 873), > 4000 g (*n* = 64)
Australia					
Kent *et al.*[31]	406 Term infants 150 followed at 6 M, and 118 at 12 m	1 Day–12 months	218 M	Median GW 40 weeks (range 37–42 weeks). 406 1 day, 6 months 150 (83 M), 12 months 118 (65 M)	3535.0 (range 2425–4990
Kent *et al.*[30]	147 Premature 28–36 WG	1–28 Days	81 M	Median WG 31.9 (2.4) 1, 2, 3, 4, 7.14, 21, 28 days	Median 1797 (620) range 850–4990
America					
Park *et al.*[3]	1554	2 Week–5 years	747 M	2–3 Week (*n* = 105); 1–5 months (*n* = 232); 6–11 months (*n* = 183); 1 year (*n* = 245); 2 year (*n* = 212); 3 year (*n* = 193); 4 year (*n* = 226); 5 year (*n* = 158)	—
Second Task Force on Blood Pressure in Children[14]	7643	0–12 Months	3887 M	< 7 Days (*n* = 2880) 8 days ⩽ 1 months (n = 686) 1 ⩽ 6 months (*n* = 2374) 6 ⩽ 12 month (*n* = 1783)	—
Africa					
Sadoh *et al.*[32]	473 Babies	1–4 Days	229 M	WG 39.3±1.4 range 37–43 1, 2, 3, 4 days	BW group (g): A < 2500 (*n* = 33); B 2500–4000 (*n* = 402), > 4000 g (*n* = 38)

Abbreviations: BW, birth weight; g, grams; WG, gestation weeks.

correlations were found for systolic but not DBP.[11] An acceleration of the increase in BP values during puberty was also reported.[39]

In some studies, linear correlations with height[9,11,13,19,21,27,28,33,35,39,40,45] were demonstrated more strongly than with age (SBP *r*: 0.11–0.64; DBP *r*: 0.13–0.65).[14,35,45] The use of age and height to normalize data was confronted with a number of potential problems. First, the age range and the height intervals used, as well as the number of subjects enrolled for various age/height subgroups differed widely (Table 1). In particular, the lower ages (that is, < 5–6 years) were generally less well represented, and for some age groups (especially neonates and infants), the data were very limited. Furthermore, the choice to rank BP according to just age and height implies, by definition, no consideration of body weight. BP, however, was found to strongly correlate with body weight,[2,28,33,39,40,45] BM,[8,12,25,36,45] body surface area (BSA)[28,31] and waist circumference.[39,75]

Data expression also varied among the publications. The data were generally expressed by percentile table[2,6,8,9,11,13,26,27,29,35,39,45]

Table 3 Methodologies of major nomograms

Study	*Sphygmomanometer*	*Criteria for cuff lenght selection*	*Criteria for cuff width selection*	*Time of the day*	*Time of the year*	*Observer training*	*Nr observer*	*Place*
America								
Fourth Report[9]								
NII	MS	2 Cuff 9.5 and 13 mm	—	Trough-out day	Trough-year	No	Multiple; all physician	Special vans
Pittsburgh	Doppler	Multicuff	At least 75% of upper circum.	Trough-out day	Trough-year	—	—	Home
Dallas	RZ (HawksleyTechnology, London, UK)	Four cuff size	Most of the circ upper arm	Trough-out day	October-December	Yes	Multiple	School
Bogalusa	MS	2/3 Of upper arm lenght	At least 50% of upper arm	Morning	Trough-year	Yes	3	School
Houston	MS	Multicuff	At least 75% of upper arm	Trough-out day	Trough-year	Yes	Multiple	Health Cl
South Carolina	MS	Four cuff size	—	Trough-out day	Trough-year	Yes	Multiple	School
Iowa	RZ	2/3 Of upper arm lenght	—	Afternoon	February-March	Yes	Multiple	School
Providence	Arteriosnde and RZ	Five cuff size	—	Trough-out day	Trough-year	Yes	Multiple	Clin
Minessota	MS		At least 90% of upper arm	Trough-out day	Trough-year	Yes	Multiple	School
Park *et al.*[11]	OD, Critikon Co, Tampa, FL	Multiple	40–50% Of upper arm	Trough-out day	Trough-year	Yes	Multiple	
Nichols *et al.*[19]	MS	Multiple	40–50% Of upper arm	Trough-out day	Sept-Jan	Yes	Multiple	School
Paradis *et al.*[8]	OD (Dinamap XL, model CR9340, Critikon)	Multicuff	At least 75% of upper arm	Trough-out day	Jan-May	Yes	Multiple	School
Australia								
Blake *et al.*[12]	D 8100 AOD (CritiKon)	Two cuff size	Cuff width to arm circumference ratio of 40–50	Trough-out day	Trough-year	Yes	Multiple	Clinic
Europe								
De Man *et al.*[10]								
Berlin-Bremen	RZ	3 Cuff size	—	—	—	—	—	School
Cologne	LSH	1 Size	—	—	—	—	—	School
Copenhagen	RZ	3 Size	—	—	—	—	—	School
Essen	LSH	2 Size	2/3 Arm circumference	—	—	—	—	School
Nancy	MS	2 Size	2/3 Arm circumference	—	—	—	—	Open
Zoetermeer	RZ	2 Size	—	—	—	—	—	Open
De Swiet *et al.*[33]	MS	Multiple	—	Trough-out day	Trough-year	Yes	Multiple	Home/clinical
Gemelli *et al.*[2]	OD Critikon	Multiple	—	Morning	Trough-year	Yes	Multiple	Clinic
Menghetti *et al.*[16]	SM	2 Cuff size	—	Trough-out day	Trough-year	Yes	Multiple	Clinic
Sanchez *et al.*[6]	SM 14 Automatd 1	Multicuff 14 Not ment 1	—	Trough-out day	Trough-year	Yes	Multple 14 1 not mentionated	School
Turner *et al.*[40]	MS	Multiple	½ Arm	Trough-out day	Trough-year	Yes	Multiple	—
Asia								
Sharma *et al.*[28]	MS	Multiple	—	Trough-out day	Trough-year	Yes	Multiple	School
Merhi *et al.*[45]	MS	Multiple	50% Of arm	Trough-out day	Trough-year	Yes	Multiple	School
Ayatollahi *et al.*[35]	DA Model 500 C, Osaka Japan	Multiple	—	Trough-out day	Trough-year	Yes	Multiple	School
Kelishadi *et al.*[39]	MS	Multiple	40% Of arm	Trough-out day	Trough-year	Yes	Multiple	School
Krishna *et al.*[27]	MS	Multiple	2/3 Of arm	Trough-out day	Trough-year	Yes	4 dottor for 5° pts inter-observer variab	School
Chadha *et al.*[26]	MS	Multiple	40%	Trough-out day	Trough-year	Yes	Multiple	School
Hashimoto *et al.*[54]	OD Critikon	Multiple	—	Morning	Trough-year	Yes	Multiple	Pre-school
Neonates								
Kent *et al.*[30,31]	OD Hewlett Packard Merlin Multiplanar Monitor (Phillips, Sydney, NSW, Australia)	Multiple	2/3 Of arm	Trough-out day	Trough-year	Yes	Multiple	Clinical
Pejovic *et al.*[34]	OD 555 Corometric Medical System, Wallingford, CT, USA	Multiple	85% Of arm	Trough-out day	Trough-year	Yes	Multiple	Clinical
Salihoglu *et al.*[29]	OD Automated indirect oscillometer tecnique (Life scope, Nhihon Kohden, Tokyo	Multiple	80% Of arm	Trough-out day	Trough-year	Yes	Multiple	Clinical
Sadoh *et al.*[32]	OD Dinamap 8100 monitor (Critikon)	2 Size	80% Of arm	Trough-out day	Trough-year	Yes	Multiple	Clinical

Abbreviations: AOD, automated osillator device; LSH, London School of Hygiene spygmomanometer; OD, oscillometric device; MS, mercury spygmomanometer; RZ, random zero.

and/or percentile charts[3,10–12,28,29,35,39] and/or mean values plus s.d.,[2–4,6,8,11,12,16,19,25,27–29,32–35,37,39,42,45,54,55,74] without parametric normalization. Nonparametric methods do not assume that the response variable adopts a given distribution and are therefore less prone to bias.[49–51] However, because BP reference ranges change as the body grows, if one wants to define precise reference ranges across growth using non-parametric methods, one must compute the percentiles for several growth strata (from birth to adulthood) of the studied population.[49] Parametric normalization (where the dependent variables were SBP and DBP) has only been performed by a few authors[8,12,25–27,35] by using different types (and numbers) of independent variables. The regressions were the same only in two studies,[26,27] but the age groups evaluated were different, making comparisons among the studies difficult. Furthermore, quantile regressions, which offer a greater flexibility and the best fit[21] compared with polynomial/spline models, have been seldom employed. Lastly, the issue of heteroscedasticity, a statistical term used to describe the behavior of variance of the residuals, which may create important bias especially when using parametric normalization, has never been addressed.[49–51]

Confounders

Other methodological limitations are represented by the different attention to some relevant confounders including gender, ethnicity and geographic regions and socio-economic factors.[2,3,8,11,27,28,30,31,34,35,39,75–79]

Gender

The data have usually been presented separately regarding gender with limited exceptions.[27,30,31,34] Gender differences in BP were found in some[2,3,35,39] but not all studies.[28] Generally higher BP values have been reported in boys,[8,11,33] although a few authors[29,35] reported higher values in girls.

Ethnicity

Controversies remain regarding the specific influence of ethnicity on BP values in children. A major issue is whether the higher prevalence of hypertension found in black compared with white adults in the US[9] and the UK[42] is reflected in BP differences in the pediatric age group. In some series, only slight differences between black and white subjects have been shown, with a prevalence of BP elevation in Hispanic and black male youth compared with white male youth in the USA.[25] It is supposed, however, that ethnic differences in the prevalence rates of pediatric BP elevation may be not entirely explained by obesity; rather, they may be because of genetic or environmental factors.[77]

Geographic areas: continents, countries and regions

Geographic influence may be even more relevant than ethnicity. In fact, several studies highlighted region specific childhood BP distributions. There were important differences among continents, countries and even within same the country among various regions.[20,45] Therefore, for instance, studies indicate that BP may be higher in European and Asian children than in their American counterparts.[6,16,40] Sanchez *et al.*[6] found that SBP and DBP values were higher in 34 946 Spanish children than in their US counterparts. Furthermore, Tobagonian adolescents had SBP and DBP that were 10 mm Hg lower and higher, respectively, than their UK counterparts, whereas Jamaican adolescents had DBP consistently lower than Tobagonians.[19] Additionally, it has been demonstrated that in Lebanese children, normal US values were too high and neither the European normal standards nor the Italian standards were suitable for this population.[45] Heterogeneity within the same country between diverse regional areas has also been reported.[20,41]

Other confounders

Many other factors have been reported to variably influence childhood BP; they include school attendance,[39] physical activity,[39] breastfeeding,[39] dietary habits[25,39] and familiarity.[25,39] In particular, in American children, a significant and independent association between high sodium intake and elevated BP has been recently demonstrated.[78] Sleep duration (that is, >8.5 h) was also positively associated with high BP in female adolescents.[79] However, it is most likely doubtful that all these factors should be taken into account in the construction of BP nomograms or reference tables.

DISCUSSION

In the past 30 years, several surveys[2,5,6,8,11–13,19–36,39,40] and a few reviews[4,9,10] that provide normative data of childhood BP have been published. Nevertheless, many numerical and methodological limitations still remain. For some geographic areas (North America, Europe, India, Japan), there are one or more robust nomograms providing normative percentiles based on the large size of healthy children, especially for children >5 years of age. The data for many other geographic areas (South America, Africa, East Europe, wide areas of Asia) and for some ethnicities however are extremely limited or even absent. Furthermore, globally, there is a paucity of data for neonates and infants. Finally, data on ambulatory BP and BP response to exercise in children are extremely limited,[57–73] and no clear BP cut-off values exist to distinguish between healthy and pathological states. Additionally, the criteria for interruption of stress tests in the presence of excessive BP increases are lacking, which could because for concern.[73]

There are also various methodological limitations including the lack of clear inclusion/exclusion criteria with a few exceptions,[9,13,30–32,39,45] differences in the method employed for measuring BP (for example, manual *vs.* automated devices), heterogeneity in the data normalization (according to age and/or height) and units of expression (percentile/mean value). The choice to express data according to age and/or height and not according to BMI was made to avoid the assumption that being overweight may be a justification for high BP at a given age/height.[9,21] The inclusion of overweight/obese in the database however, implies a bias in the nomograms that some authors have tried to overcome by excluding the lowest and highest BMI percentiles.[21] The inclusion of data collected over multiple decades (in reviews), also represents another potential bias. As observed by Munter and colleagues[7] and more recently by Rosner *et al.*[78] an increase in childhood BP over the past decade has occurred, which may be partially attributable to an increased prevalence of overweight children.

Interestingly, no studies reported BP values normalized for BSA, which is the parameter that is commonly used to normalize some pediatric data (such as cardiac structure dimensions).[50] Usually, parametric normalization by percentile has been used, because it is easy to understand and is very familiar to most pediatricians. However, an insufficient number of healthy subjects have been evaluated at times, especially in the case of neonates and infants.[47,48] Furthermore, the use of percentiles in a pediatric population implies a division (from 0 to 18 years) in growth strata,[49] but no clear rules exist on how this division should be performed. Conversely, non-parametric methods of normalization (that is, *z* scores) have been rarely used.[21,47] *Z*-scores (that is, the number of s.d. from the mean) however, may help in eliminating a number of the sources of variance

Table 4A Example of blood pressure normal values for a male child of 3 y.o. according to different nomograms

Author	*SPB (mm Hg)*	*DPB (mm Hg)*
America		
Fourth report[9]	50th height p.	50th height p.
	50th p. 89	50th p. 46
	95th p. 107	95th p. 65
Rosner *et al.*[13]	50th height p.	50th height p.
	50th p. 103	50th p. 59
	(5th p. 101–95th p. 105)	(5th p. 58–95th p. 61)
Australia		
Blake *et al.*[12]	50th p. 99 (5th p. 86–95th p. 113)	50th p 52 (5th p. 40–95th p. 65)
Europe		
de Swiet *et al.*[33]	Mean s.d. 96.8 (9.7)	
Sanchez *et al.*[6]	Mean s.d. 93.0 (7.1)	Mean s.d. 53.5 (7.6)
Asia		
Krishna *et al.*[7]	Mean s.d. 98 (11)	Mean s.d. 63 (11)
Hashimoto *et al.*[54]	Mean s.d. 97.1 (9.9)	Mean s.d. 52.4 (9.6)

Abbreviations: p., percentile; y.o., years old.

Table 4B Example of blood pressure normal values for a female child of 9 y.o. according to different nomograms

Author	*SPB (mm Hg)*	*DPB (mm Hg)*
America		
Fourth Report[9]	50th height p.	50th height p.
	50th p. 100	50th p. 59
	95th p. 117	95th p. 77
Paradis *et al.*[8]	Mean s.d.	Mean s.d.
	50th p. 102 (101–104)	50th p. 57 (56–58)
	95th p. 121 (118–123)	95th p- 67 (66–68)
Rosner *et al.*[13]	50th height p.	50th height p.
	50th p. 111	50th p. 73
	(5th p. 108-95th p. 114)	(5th p. 71–95th p. 73)
Europe		
De Swiet et al.[33]	Mean s.d. 92.3 (8.7)	Mean s.d. 60.2 (7.6)
Menghetti *et al.*[16]	Mean s.d. 106.6 (13.3)	Mean s.d. 65.7 (12.5)
Sanchez *et al.*[6]	Mean s.d. 106.2 (10.5)	Mean s.d. 59.9 (9.5)
Mead East		
Merhi*et al.*[45]	Mean s.d. 97.0 (9.9)	Mean s.d. 55.7 (6.7)
	90th p. 110	90th p. 70
Asia		
Kelishadi *et al.*	Mean s.d. 99.83 (12.4)	Mean s.d. 62.79 (9.9)
Krishna *et al.*	Mean s.d. 105 (11)	Mean s.d. 71 (9)

Abbreviations: DBP, diastolic blood pressure; p. percentile; SBP, systolic blood pressure; y.o., years old.

in raw numbers, especially when there is a significant variation in body size, and they allow for a further simplification of data interpretation, also based on the use of electronic computation.[49–51]

Among the confounders, the issue of ethnicity remains debatable. In fact, differences among nomograms from various continents have been highlighted;[6,18,19,25,38] however conversely, in American children, the influence of ethnicity/race did not seem to be relevant for BP values.[46] In fact, the higher BP values encountered in black male youths[7,24,46] seem to be more attributable to the incidence of overweight in this subgroup rather than to ethnicity *per se*.[37]

All these numerical and methodological issues are not self-limiting but may have a series of important consequences for clinicians.[49–51] In fact, the lack of clear recommendations regarding the nomogram that should be employed (with the exception of the USA) forces the clinician to arbitrarily chose one (or more nomograms) among those available. Secondly, clinicians interpret blood pressure values and make decisions regarding diagnosis (hyper/hypotensive or not?) and management (to treat or not to treat?) according to the proposed RIs, which at times may have been substantially different. In fact, actual nomograms are heterogeneous, difficult to compare and, when comparable, sometimes show considerably different confidence intervals (Tables 4A and B). For instance, according to different authors, a 3-year-old boy, at the 50th percentile of SBP (mm Hg), may vary from 89 (9) to 105.9 (6), whereas at the 95th percentile, the range is from 100.1 (6) to 109.2 (9). Nomograms from the Fourth Report present various advantages: (i) a solid methodological structure despite a few limitations (that is, the lack of clear inclusion/exclusion criteria, the use of data obtained at more than one age *vs.* cross-sectional data, the use of single readings for some studies, the employment of mercury manometers); and (ii) a good sample size (with the exception of neonates and infants).[21] As a result, data from the Fourth report have been frequently adopted worldwide.[20,45] The simple adoption of nomograms from the USA, however, may not be suitable for other geographic areas/countries/ethnic groups[20,44,45] where they may introduce an unpredictable bias in the evaluation of BP values resulting in significant over/underestimation of hypo/hypertensive values.[20,44,45] As a result, calls for the development of country/region specific nomograms have been made by multiple sources.[20,44,45]

Limitations

This review is limited to results from reports written in English. However, there have been several non-English publications showing pediatric BP nomograms especially in Japan and China where English is not an official language. Review and meta-analysis of the data from publications written in a local language could add helpful information to define the pediatric BP ranges of normality for a given country/geographic area.

CONCLUSION

Various pediatric BP nomograms exist, but many numerical and methodological limitations still persist. For some geographical areas (particularly the USA), there are nomograms of sufficiently good quality, whereas for others, data are limited/absent. Furthermore, worldwide there is a paucity of data specific to the neonatal age group. Various nomograms are difficult to compare, and when comparable, they sometimes show different RIs that may lead to confusion in the interpretation of the BP values in children and in estimating disease severity. Nomograms from the Fourth Report are of good quality but are not universally applicable.

For every country, the development of new nomograms based on a wide range of healthy children including a sufficient number of neonates and infants is recommended. New nomograms should define detailed exclusion/inclusion criteria, standardized protocols (that is, right arm, sitting position, resting period preceding the measurements and multiple readings), methods (that is, the auscultatory manual method in older children *vs.* the oscillometric method in neonates and infants) and instruments (that is, aneroid sphygmomanometers and

Table 5 Definition of hyper- and hypotension in children

	Definition
Hypertension	
Pre-hypertension[9]	1. Average SBP or DBP >90th percentile but <95th percentile. 2. Adolescent if BP>120
Hypertension[9]	SBP and/or DBP>95th percentile for gender, age and height on three occasions.
White coat hypertension[9]	A patient who BP levels >95th percentile in a physician's office or clinic, who is normotensive outside a clinical setting
Hypotension	
Hypotension[72]	60 mm Hg in term neonates (0–28 days) 70 mm Hg in infants (1–12 months) 70 mm Hg (2 years of age) in children 1–10 years 90 mm Hg in children 10 years of age

Abbreviations: BP, blood pressure; DBP, diastolic blood pressure; SBP, systolic blood pressure.

multiple cuff sizes) to measure BP. A rigorous statistical approach is mandatory for the building of solid nomograms as well as the evaluation of a series of confounders. In particular, a special attention to gender, ethnicity and geographic area is required and regional differences among the same countries should be evaluated. Lastly, systems to classify the severity of hyper/hypotension (including clear cut-off values) in pediatric patients need to be implemented as well as nomograms for ambulatory and stress BP values. Table 5.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

We thank Karin Tyack for English correction and editing.

1 Chiolero A, Bovet P, Paradis G. Screening for elevated blood pressure in children and adolescents: a critical appraisal. *JAMA Pediatr* 2013; **167**: 266–273.
2 Gemelli M, Manganaro R, Mamì C, De Luca F. Longitudinal study of blood pressure during the 1st year of life. *Eur J Pediatr* 1990; **149**: 318–320.
3 Park MK, Menard SM. Normative oscillometric blood pressure values in the first 5 years in an office setting. *Am J Dis Chil* 1989; **143**: 860–864.
4 Brotons C, Singh P, Nishio T, Labarthe DR. Blood pressure by age in childhood and adolescence: a review of 129 surveys worldwide. *Int J Epidemiol* 1989; **18**: 824–829.
5 Midgley PC, Wardhaugh B, Macfarlane C, Magowan R, Kelnar CJ. Blood pressure in children aged 4–8 years: comparison of Omron HEM 711 and sphygmomanometer blood pressure measurements. *Arch Dis Child* 2009; **94**: 955–958.
6 Sanchez RG, Labarthe DR, Forthofer RN, Fernandez-Cruz A. National standards of blood pressure for children and adolescents in Spain: international comparisons. The Spanish Group for the Study of Cardiovascular Risk Factors in Childhood and Youth. *Int J Epidemiol* 1992; **21**: 478–487.
7 Muntner P, He J, Cutler JA, Wildman RP, Whelton PK. Trends in blood pressure among children and adolescents. *JAMA* 2004; **291**: 2107–2113.
8 Paradis G, Lambert M, O'Loughlin J, Lavallée C, Aubin J, Delvin E, Lévy E, Hanley JA. Blood pressure and adiposity in children and adolescents. *Circulation* 2004; **110**: 1832–1838.
9 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**: 555–576.
10 de Man SA, Andre JL, Bachmann H, Grobbee DE, Ibsen KK, Laaser U, Lippert P, Hofman A. Blood pressure in childhood: pooled findings of six European studies. *J Hypertens* 2004; **9**: 109–114.
11 Park MK, Menard SW, Schoolfield J. Oscillometric blood pressure standards for children. *Pediatr Cardiol* 2005; **26**: 601–607.
12 Blake KV, Gurrin LC, Evans SF, Newnham JP, Landau LI, Stanley FJ, Beilin LJ. Reference ranges for blood pressure in preschool Australians, obtained by oscillometry. *J Paediatr Child Health* 2000; **36**: 41–46.
13 Rosner B, Prineas RJ, Loggie JM, Daniels SR. Blood pressure nomograms for children and adolescents, by height, sex, and age, in the United States. *J Pediatr* 1993; **123**: 871–886.
14 Report of the Second Task Force on Blood Pressure Control in Children–1987. Task Force on Blood Pressure Control in Children. National Heart, Lung, and Blood Institute, Bethesda, Maryland. *Pediatrics* 1987; **79**: 1–25.
15 Roy LP, Tiller DJ, Jones DL. The range of blood pressures in Australian children. *Med J Aust* 1984; **141**: 9–12.
16 Menghetti E, Virdis R, Strambi M, Patriarca V, Riccioni MA, Fossali E, Spagnolo A. Blood pressure in childhood and adolescence: the Italian normal standards. Study Group on Hypertension of the Italian Society of Pediatrics. *J Hypertens* 1999; **17**: 1363–1372.
17 Zubrow AB, Hulman S, Kushner H, Falkner B. Determinants of blood pressure in infants admitted to neonatal intensive care units: a prospective multicenter study. Philadelphia Neonatal Blood Pressure Study Group. *J Perinatol* 1995; **15**: 470–479.
18 Burke GL, Arcilla RA, Culpepper WS, Webber LS, Chiang YK, Berenson GS. Blood pressure and echocardiographic measures in children: the Bogalusa Heart Study. *Circulation* 1987; **75**: 106–114.
19 Nichols S, Cadogan F. Blood pressure and its correlates in Tobagonian adolescents. *West Indian Med J* 2006; **55**: 305–312.
20 Bassareo PP, Marras AR, Mercuro G. About the need to use specific population references in estimating paediatric hypertension: Sardinian blood pressure standards (age 11-14 years). *Ital J Pediatr* 2012; **38**: 1.
21 Rosner B, Cook N, Portman R, Daniel S, Falkner B. Determination of blood pressure percentiles in normal-weight children: some methodological issues. *Am J Epidemiol* 2008; **167**: 653–666.
22 Hwang B, Chu NW. Normal oscillometric blood pressure values in Chinese children during their first six years. *Zhonghua Min Guo Xiao Er Ke Yi Xue Hui Za Zhi* 1995; **36**: 108–112.
23 Law CM, Egger P, Dada O, Delgado H, Kylberg E, Lavin P, Tang GH, von Hertzen H, Shiell AW, Baker DJ. Body size at birth and blood pressure among children in developing countries. *Int J Epidemiol* 2001; **30**: 52–57.
24 Jafar TH, Islam M, Poulter N, Hatcher J, Schmid CH, Levey AS, Chaturvedi N. Children in South Asia have higher body mass-adjusted blood pressure levels than white children in the United States: a comparative study. *Circulation* 2005; **111**: 1291–1297.
25 Rosner B, Prineas R, Daniels SR, Loggie J. Blood pressure differences between blacks and whites in relation to body size among US children and adolescents. *Am J Epidemiol* 2000; **151**: 1007–1019.
26 Chadha SL, Vasan RS, Sarma PS, Shekhawat S, Tandon R, Gopinath N. Age- and height-specific reference limits of blood pressure of Indian children. *Natl Med J India* 1999; **12**: 150–156.
27 Krishna P, PrasannaKumar KM, Desai N, Thennarasu K. Blood pressure reference tables for children and adolescents of Karnataka. *Indian Pediatr* 2006; **43**: 491–501.
28 Sharma BK, Sagar S, Wahi PL, Talwar KK, Singh S, Kumar L. Blood pressure in schoolchildren in northwest India. *Am J Epidemiol* 1991; **134**: 1417–1426.
29 Salihoğlu O, Can E, Beşkardeş A, BŞ Koç, Tan I, Can G, Hatipoğlu S. Delivery room blood pressure percentiles of healthy, singleton, liveborn neonates. *Pediatr Int* 2012; **54**: 182–189.
30 Kent AL, Meskell S, Falk MC, Shadbolt B. Normative blood pressure data in non-ventilated premature neonates from 28-36 weeks gestation. *Pediatr Nephrol* 2009; **24**: 141–146.
31 Kent AL, Kecskes Z, Shadbolt B, Falk MC. Blood pressure in the first year of life in healthy infants born at term. *Pediatr Nephrol* 2007; **22**: 1743–1749.
32 Sadoh WE, Ibhanesebhor SE. Oscillometric blood pressure reference values of African full-term neonates in their first days postpartum. *Cardiovasc J Afr* 2009; **20**: 344–347.
33 de Swiet M, Fayers P, Shinebourne EA. Blood pressure in first 10 years of life: the Brompton study. *BMJ* 1992; **304**: 23–26.
34 Pejovic B, Peco-Antic A, Marinkovic-Eric J. Blood pressure in non-critically ill preterm and full term neonates. *Pediatr Nephrol* 2007; **22**: 249–257.
35 Ayatollahi SM, Zare M. Blood pressure standards for Shiraz (Southern Iran) school children in relation to height. *Iran J Pediatr* 2012; **22**: 223–230.
36 Lu Q, Ma C, Yin F, Wang R, Lou D, Liu X. Blood pressure-to-height ratio as a screening measure for identifying children with hypertension. *Eur J Pediatr* 2013; **172**: 99–105.
37 Bansal N, Ayoola O, Gemmell I, Vyas A, Koudsi A, Oldroyd J, Clayton PE, Cruickshank JK. Effects of early growth on blood pressure of infants of British European and South Asian origin at one year of age: the Manchester children's growth and vascular health study. *J Hypertens* 2008; **26**: 412–418.
38 Lurbe E, Cifkova R, Cruickshank JK, Dillon MJ, Ferreira I, Invitti C, Kuznetsova T, Laurent S, Mancia G, Morales-Olivas F, Rascher W, Redon J, Schaefer F, Seeman T, Stergiou G, Wühl E, Zanchetti A. Management of high blood pressure in children and adolescents: recommendations of the European Society of Hypertension. *J Hypertens* 2009; **27**: 1719–1742.
39 Kelishadi R, Ardalan G, Gheiratmand R, Majdzadeh R, Delavari A, Heshmat R, Gouya MM, Razaghi EM, Motaghian M, Mokhtari MR, Barekati H, Arabi MS. Blood pressure and its influencing factors in a national representative sample of Iranian children and adolescents: the CASPIAN Study. *Eur J Cardiovasc Prev Rehabil* 2006; **13**: 956–963.

40 Tümer N, Yalçinkaya F, Ince E, Ekim M, Köse K, Cakar N, Kara N, Ozkaya N, Ensari C, Onder S. Blood pressure nomograms for children and adolescents in Turkey. *Pediatr Nephrol* 1999; **13**: 438–443.
41 Okamura T, Tajima H, Iijima Y, Gomi H, Tominaga S, Nishinari H, Oyamada T. Standard blood pressure curves of schoolboys and schoolgirls in Akita prefecture. *Tohoku J Exp Med* 1981; **135**: 419–422.
42 Agyemang C, Bhopal R. Is the blood pressure of people from African origin adults in the UK higher or lower than that in European origin white people? A review of cross-sectional data. *J Hum Hypertens* 2003; **17**: 523–534.
43 Schachter J, Kuller LH, Perfetti C. Blood pressure during the first five years of life: relation to ethnic group (black or white) and to parental hypertension. *Am J Epidemiol* 1984; **119**: 541–553.
44 Munkhaugen J, Lydersen S, Wideroe T-E, Hallan S. Blood pressure reference values in adolescents: methodological aspects and suggestions for Northern Europe tables based on the North Trondelag Health Study II. *J Hypertens* 2008; **26**: 1912–1918.
45 Merhi BA, Al-Hajj F, Al-Tannir M, Ziade F, El-Rajab M. A survey of blood pressure in Lebanese children and adolescence. N. *Am J Med Sci* 2011; **3**: 24–29.
46 Gutgesell M, Terrell G, Labarthe D. Pediatric blood pressure: ethnic comparison in a primary care center. *Hypertension* 1981; **3**: 39–49.
47 Collins R, Peto R, MacMahon S, Hebert P, Fiebach NH, Eberlein KA, Godwin J, Qizilbash N, Taylor JO, Hennekens CH. Blood pressure, stroke, and coronary heart disease: part 2, short-term reductions in blood pressure: overview of randomised drug trials in their epidemiological context. *Lancet* 1990; **335**: 827–838.
48 MacMahon S, Peto R, Cutler J, Collins R, Sorlie P, Neaton J, Abbott R, Godwin J, Dyer A, Stamier J. Blood pressure, stroke, and coronary heart disease: part 1, prolonged differences in blood pressure: prospective observational studies corrected for the regression dilution bias. *Lancet* 1990; **335**: 765–774.
49 Mawad W, Drolet C, Dahdah N, Dallaire F. A review and critique of the statistical methods used to generate reference values in pediatric echocardiography. *J Am Soc Echocardiogr* 2013; **26**: 29–37.
50 Cantinotti M, Scalese M, Molinaro S, Murzi B, Passino C. Limitations of current echocardiographic nomograms for left ventricular, valvular, and arterial dimensions in children: a critical review. *J Am Soc Echocardiogr* 2012; **25**: 142–152.
51 Colan S. The why and how of *z* scores. *J Am Soc Echocardiog* 2013; **26**: 38–40.
52 Solberg HE. The IFCC recommendation on estimation of reference intervals. The RefVal program. *Clin Chem Lab Med* 2004; **42**: 710–714.
53 Geffre A, Friedrichs K, Harr K, Concordet D, Trumel C, Braun JP. Reference values: a review. *Vet Clin Pathol* 2009; **38**: 288–298.
54 Hashimoto N, Kawasaki T, Kikuchi T, Uchiyama M. Criteria of normal blood pressure and hypertension in Japanese preschool children. *J Hum Hypertens* 1997; **11**: 351–354.
55 Kikuchi T, Yamazaki H, Kameda K, Hiura M, Nishina M, Uchiyama M. Examination of reference blood pressure values with respect to gender and school age in Japanese children (Mitsuke Study) Tokyo. *Jpn J Pediatr Hypertens* 2011; **8**: 21–25.
56 Karpettas N, Nasothimiou E, Kollias A, Vazeou A, Stergiou GS. Ambulatory and home blood pressure monitoring in children and adolescents: diagnosis of hypertension and assessment of target-organ damage. *Hypertens Res* 2013; **36**: 285–292.
57 Wühl E, Witte K, Soergel M, Mehls O, Schaefer FGerman Working Group on Pediatric Hypertension. Distribution of 24-h ambulatory blood pressure in children: normalized reference values and role of body dimensions. *J Hypertens* 2002; **20**: 1995–2007.
58 Khan IA, Gajaria M, Stephens D, Balfe JW. Ambulatory blood pressure monitoring in children: a large center's experience. *Pediatr Nephrol* 2000; **14**: 802–805.
59 Krull F, Buck T, Offner G, Brodehl J. Twenty-four hour blood pressure monitoring in healthy children. *Eur J Pediatr* 1993; **152**: 555–558.
60 Harshfield GA, Pulliam DA, Somes GW, Alpert BS. Ambulatory blood pressure patterns in youth. *Am J Hypertens* 1993; **6**: 968–973.
61 Reusz GS, Hobor M, Tulassay T, Sallay P, Miltenyi M. Twenty-four hour blood pressure monitoring in healthy and hypertensive children. *Arch Dis Child* 1994; **70**: 90–94.
62 Soergel M, Kirschstein M, Busch C, Danne T, Gellermann J, Holl R, Krull F, Reichert H, Reusz GS, Rascher W. Oscillometric twenty-four-hour ambulatory blood pressure value in healthy children and adolescents: a multicenter trial including 1141 subjects. *J Pediatr* 1997; **13**: 178–184.
63 O'Sullivan JJ, Derrick G, Griggs P, Foxall R, Aitkin M, Wren C. Ambulatory blood pressure in school children. *Arch Dis Child* 1999; **80**: 529–532.
64 Lurbe E, Redon K, Liao Y, Tacons J, Cooper RS, Alvarez V. Ambulatory blood pressure monitoring in normotensive children. *J Hypertens* 1994; **12**: 1417–1423.
65 Gellermann J, Kraft S, Ehrich JHH. Twenty-four-hour ambulatory blood pressure monitoring in young children. *Pediatr Nephrol* 1997; **11**: 707–710.
66 Bald M, Lettgen B, Wingen AM, Bonzel KE. Twenty-four hour blood pressure monitoring in children and adolescents after recovery from the hemolytic uremic syndrome. *Clin Nephrol* 1996; **46**: 50–53.
67 Varda NM, Gregoric A. Twenty-four-hour ambulatory blood pressure monitoring in infants and toddlers. *Pediatr Nephrol* 2005; **20**: 798–802.
68 Menghetti E, Cellitti R, Marsili D, Ferri M, Liberti A, Mucedola G. Twenty-four-hour monitoring of blood pressure in premature and full-term new born babies. *Eur Rev Med Pharmacol Sci* 1997; **1**: 189–191.
69 Yiallourou SR, Witcombe NB, Sands SA, Walker AM, Horne RS. The development of autonomic cardiovascular control is altered by preterm birth. *Early Hum Dev* 2013; **89**: 145–152.
70 Yiallourou SR, Sands SA, Walker AM, Horne RS. Maturation of heart rate and blood pressure variability during sleep in term-born infants. *Sleep* 2012; **35**: 177–186.
71 van der Cammen-van Zijp MH, Ijsselstijn H, Takken T, Willemsen SP, Tibboel D, Stam HJ, van den Berg-Emons RJ. Exercise testing of pre-school children using the Bruce treadmill protocol: new reference values. *Eur J Appl Physiol* 2010; **108**: 393–399.
72 van der Cammen-van Zijp MH, van den Berg-Emons RJ, Willemsen SP, Stam HJ, Tibboel D, IJsselstijn H. Exercise capacity in Dutch children: new reference values for the Bruce treadmill protocol. *Scand J Med Sci Sports* 2010; **20**: e130–e136.
73 Washington RL, Bricker JT, Alpert BS, Daniels SR, Deckelbaum RJ, Fisher EA, Gidding SS, Jones JI, Kavey REW, Marx GR, Strong WB, Teske DW. From the Committee on Atherosclerosis and Hypertension in Children Council on Cardiovascular Disease in the Young, the American Heart Association.*Circulation* 1994; **90**: 2166–2179.
74 Shimamoto K, Ando K, Fujita T, Hasebe N, Higaki J, Horiuchi M, Imai Y, Imaizumi T, Ishimitsu T, Ito M, Ito S, Itoh H, Iwao H, Kai H, Kario K, Kashihara N, Kawano Y, Kim-Mitsuyama S, Kimura G, Kohara K, Komuro I, Kumagai H, Matsuura H, Miura K, Morishita R, Naruse M, Node K, Ohya Y, Rakugi H, Saito I, Saitoh S, Shimada K, Shimosawa T, Suzuki H, Tamura K, Tanahashi N, Tsuchihashi T, Uchiyama M, Ueda S, Umemura S. The Japanese Society of Hypertension Guidelines for the Management of Hypertension (JSH 2014). *Hypertens Res* 2014; **37**: 253–387.
75 Rich C, Griffiths LJ, Dezateux C. Seasonal variation in accelerometer-determined sedentary behaviour and physical activity in children: a review. *Int J Behav Nutr Phys Act* 2012; **9**: 49.
76 Knowles G, Pallan M, Thomas GN, Ekelund U, Cheng KK, Barrett T, Adab P. Physical activity and blood pressure in primary school children: a longitudinal study. *Hypertensio* 2013; **61**: 70–75.
77 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.
78 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.
79 Paciência I, Barros H, Araújo J, Ramos E. Association between sleep duration and blood pressure in adolescents. *Hypertens Res* 2013; **36**: 747–752.