Cuff size influences blood pressure measurement in obese children and adolescents

Muhamed, P. K.; Olsen, Michael Hecht; Holm, Jens-Christian; Ibsen, Hans; Hvidt, Kristian N

Published in:
Danish Medical Journal

Publication date:
2016

Document version
Publisher's PDF, also known as Version of record

Cuff size influences blood pressure measurement in obese children and adolescents

Parosh Kadir Muhamed[1], Michael Hecht Olsen[2], Jens-Christian Holm[3, 4], Hans Ibsen[5] & Kristian Nebelin Hvidt[3, 6]

ABSTRACT

INTRODUCTION: Recently, we established that a group of obese children and adolescents had a higher blood pressure (BP) than a healthy control group. In the present study, we investigate whether the higher BP in the obese group was influenced by BP cuff sizes.

METHODS: A total of 104 obese patients aged 10-18 years were compared with 50 controls. BP was measured with a validated oscillometric device using an appropriate cuff size depending on each person's arm circumferences (AC) according to the manufacturer's recommendation; small (AC < 23 cm), medium (23 ≤ AC < 32 cm) and large (AC ≥ 32 cm).

RESULTS: Cuff sizes had a significant impact on BP measurements. Despite the influence of cuff size, multiple regression analyses revealed that systolic BP was 6.8 mmHg higher and diastolic BP 3.2 mmHg higher in the obese group than in the control group. A step function, i.e. a sudden fall in BP, was seen at the point of switching from small to medium cuff size in the control group, which suggests that systolic BP was overestimated when using small cuff size and underestimated when using medium cuff size in subjects with an AC near 23 cm.

CONCLUSIONS: BP was higher in the obese group than in the control group although BP was influenced by BP cuff sizes.

FUNDING: The present project received funding from The Health Sciences Research Foundation of Region Zealand, The Danish Heart Foundation, Kathrine og Vigo Skovgaards Fond, Det Medicinske Selskab i København, Edith og Henrik Henriksens Mindelegat and LEO Pharma's Travel Grant.

TRIAL REGISTRATION: ClinicalTrials.gov id: NCT01310088.

Overweight is a growing problem in children and adolescents worldwide and is associated with high blood pressure (BP) and with an increased risk of cardiovascular disease in adulthood [1, 2].

Appropriate cuff size is essential for accurate BP measurement [3-7]. A cuff size that is too small in relation to the arm circumference (AC) is known to result in a falsely high BP measurement, while a too large cuff size in relation to AC results in a falsely low BP measurement [4-7]. BP cuffs in obese patients may be relatively small as obese patients have a large AC per se. In this respect, falsely high BP measurements may be frequent in obese patients if the influence of the BP cuff size is not evaluated and not taken into account [8]. This potential effect of cuff size on BP measurement in children has been investigated using auscultatory BP devices [5, 7]. Knowledge regarding the potential effect on oscillometric devices in obese children is, however, sparse.

BP and body mass index (BMI) are well-known measurements for the clinician. However, reference values for these measures are difficult to determine because of growth and development in children and adolescents. BP and BMI may therefore be standardised into z scores to adjust for gender, age, and height in standard normal populations in order to obtain estimates that can be compared across gender and age [9, 10].

Recently, using a validated oscillometric device, we found that a group of obese children and adolescents had a higher BP than a healthy control group [11].

The objective of the present study was to investigate to which extent the higher BP in the obese group was dependent upon differences in cuff sizes.

METHODS

Obese patients aged 10-18 years who were enrolled in the Children's Obesity Clinic, Holbaek Hospital, were invited to participate in the present study. The clinic receives paediatric patients with a BMI percentile above the 90th (equal to a z score of 1.28) for gender and age according to the Danish BMI charts [12]. The recruitment period was from January 2011 to January 2012. Difficulties in communication were the only exclusion criterion. A total of 104 obese patients were enrolled into the study. Concurrently, 50 age- and gender-matched controls with an assumed representative normal weight range were recruited among hospital staff's offspring and school children and adolescents in the region in the hospital's catchment area. Measurements were performed no later than two months after the patient's first outpatient visit.

The study was recorded with ClinicalTrials.gov (NCT01310088), the Danish Data Agency and approved by The Scientific Ethical Committee of Region Zealand. Written informed consent was obtained from parents and subjects aged 18 or above according to the Declaration of Helsinki.

Height, weight and waist circumference (WC) were

ORIGINAL ARTICLE

1) Department of Medicine, Holbaek Hospital
2) The Cardiovascular and Metabolic Preventive Clinic, Department of Endocrinology, Centre for Individualised Medicine in Arterial Diseases (CIMA), Odense University Hospital
3) Hypertension in Africa Research Team (HART), School for Physiology, Nutrition and Consumer Sciences, North-West University, South Africa
4) The Children's Obesity Clinic, Department of Paediatrics, Holbaek Hospital
5) Division of Cardiology, Department of Medicine, Holbaek Hospital
6) Kokkedal Lægecenter, Denmark

Dan Med J 2016;63(1):A5183

TABLE 1

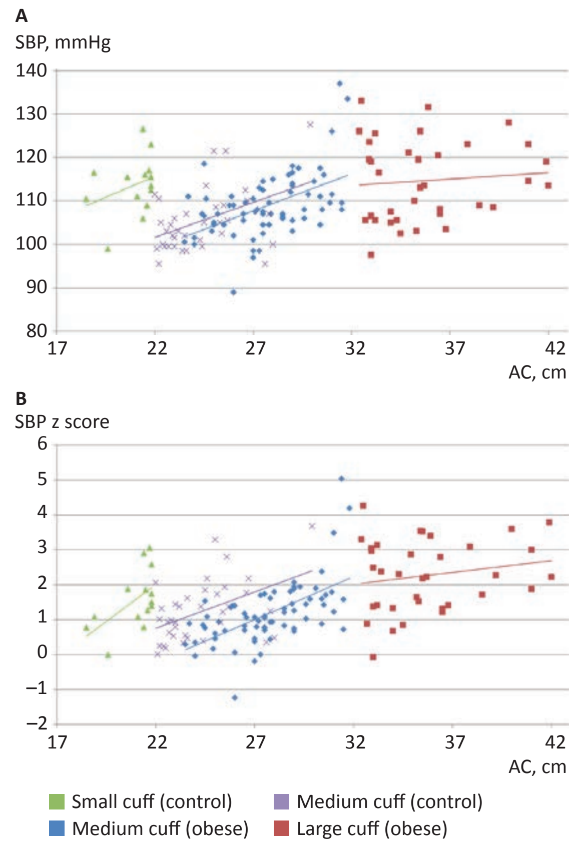
Basic characteristics and blood pressure.

	Obese group (N = 104)	Control group (N = 50)	p-value
Male/female, n	50/54	23/27	0.81
Age, yrs, median (interquartile range)	12.6 (11.4-15.0)	13.2 (11.7-14.9)	0.44
Height, cm, mean ± SD	159.9 ± 11.9	163.2 ± 12.1	0.11
Weight, kg, median (interquartile range)	66.9 (57.7-90.9)	50.7 (41.3-58.4)	< 0.0001
BMI, kg/m², median (interquartile range)	27.63 (24.1-32.4)	18.76 (16.7-20.1)	< 0.0001
BMI z score, mean ± SD	2.76 ± 0.68	0.08 ± 0.84	< 0.0001
Waist circumference, cm, median (interquartile range)	94.8 (85.3-107.5)	66.4 (62.7-69.6)	< 0.0001
AC, cm			
Total, mean ± SD	30.4 ± 4.5	23.4 ± 2.3	< 0.0001
Small cuff[a], median (interquartile range)	–	21.5 (20.6-21.8)	–
Medium cuff[b], median (interquartile range)	27.5 (26.0-29.0)	23.6 (22.8-25.5)	< 0.0001
Large cuff[c], median (interquartile range)	35.3 (33.2-36.8)	–	–
BP, mmHg, mean ± SD			
Systolic	110.9 ± 8.51	107.7 ± 8.0	0.03
Diastolic	61.8 ± 5.7	59.1 ± 5.3	0.004
BP z score, mean ± SD			
Systolic	1.55 ± 1.08	1.33 ± 0.87	0.21
Diastolic	0.42 ± 0.60	0.21 ± 0.51	0.04
Systolic hypertension, n (%)	38 (24.7)	16 (10.4)	0.58
Heart rate, bpm, mean ± SD	66.6 ± 9.5	63.4 ± 10.0	0.06

AC = arm circumference; BMI = body mass index; BP = blood pressure; bpm = beats /min.; SD = standard deviation.
a) AC < 23 cm.
b) 23 ≤ AC < 32 cm.
c) AC ≥ 32 cm.

FIGURE 1

A. Systolic blood pressure (SBP) in relation to arm circumference (AC) for each cuff size. **B.** SBP z score in relation to AC for each cuff size. The medium cuff size is the only overlapping cuff size between the obese and the control group. Both figures display a "step function" in which a sudden fall in BP is observed at the point of switching from the small to the medium cuff size in the control group. No step function is found when switching from the medium to the large cuff size in the obese group.



measured as described previously [11]. BMI (kg/m²) was calculated and converted into z scores with reference to the distribution of BMI in a Danish standard population with the same age and gender [12]. AC was measured to the nearest 0.1 cm at the midpoint of the upper arm.

BP was measured with the oscillometric device Omron 705IT (Omron Healthcare Europe), which has been validated for use in children and adolescents [13]. Appropriate cuff sizes were used in conformity with the manufacturer's recommendation: small (AC < 23 cm), medium (23 ≤ AC < 32 cm), and large (AC ≥ 32 cm). With the given appropriate cuff size, individuals had three BP measurements made after a minimum of ten minutes of rest in the supine position in a quiet room. The mean of the last two of the three BP measurements made was reported and z scores calculated according to an American standard population based on the person's gender, age and height [9]. Systolic hypertension was defined as systolic BP (SBP) > 95th percentile (equal to a z score of 1.64) for gender, age and height.

ABBREVIATIONS

AC = arm circumference
BMI = body mass index
BP = blood pressure
DBP = diastolic blood pressure
SBP = systolic blood pressure
WC = waist circumference

Statistics

Statistical analyses were performed using SAS software (version 9.2, SAS Institute). Comparisons of continuous variables between the obese and the control group were performed with unpaired t tests when normally distributed; otherwise, the Wilcoxon rank sum tests were used. Differences in categorical variables were investigated with the chi-squared test or Fisher's exact test if an expected frequency was less than five in any cell of a contingency table.

Relationships between variables were described with linear regression analyses and Pearson's correlation coefficient (rP) when linear regression model assumptions could not be met. In multiple regressions analyses, the association between BP measurement (outcome) and a group variable (obese versus control group) was investigated when adjusting for cuff size and relevant confounding explanatory variables (gender, age, height and heart rate).

The obese and the control group were recruited based on the degree of obesity (BMI z score). Hence, the group variable (obese versus control group) encompasses the differences in obesity body composition measures due to the design of the study. Potential interrelationships, i.e. collinearity ($r_P > 0.8$), between the obesity body composition measures were investigated.

Trial registration: ClinicalTrials.gov id: NCT01310088.

RESULTS

Characterisation of obese and controls

No differences in gender, age and height were found between the obese group and the control group (**Table 1**). Weight, BMI, BMI z score and WC were higher in the obese group. Also, AC was higher in the obese group, even among participants who used the medium cuff size – the only overlapping cuff size used by both groups.

SBP and diastolic BP (DBP) in mmHg were higher in the obese group than in the control group. SBP z scores did not differ between the obese group and the control group, whereas DBP z scores were higher in the obese group. No difference was found in systolic hypertension between the obese group and the control group.

The prevalence of smoking (n_{obese} = 5 (5.4%) versus $n_{control}$ = 0 (0%), p = 0.12) or individuals receiving medication (n_{obese} = 17 (16.3%) versus $n_{control}$ = 9 (18.0%), p = 0.61) did not differ between the obese group and the control group. Use of medication was described previously [11].

Blood pressure by cuff size

SBP in mmHg was higher in the obese group (n = 69) than in the control group (n = 36) for those individuals who used the overlapping medium cuff size (109 ± 7.5 mmHg versus 105 ± 7.3 mmHg, p = 0.02).

In **Figure 1**A, SBP in mmHg is plotted in relation to AC for each cuff size. In obese persons using the medium cuff size, SBP in mmHg was related to AC (r_P = 0.50, p < 0.0001.), whereas no relationship (r_P = 0.09, p = 0.61) was found in obese persons using the large cuff (n = 35). Obese persons using the large cuff size had a higher SBP in mmHg than obese persons who used the medium cuff size (115 ± 9.3 mmHg versus 109 ± 7.5 mmHg, p = 0.001) (**Figure 2**A).

In controls using the medium cuff size, SBP in mmHg was related to AC (r_P = 0.44, p = 0.007), whereas in controls using the small cuff size (n = 14), no significant relationship was found between AC and SBP in mmHg (r_P = 0.32, p = 0.26). For a given AC, SBP in mmHg seemed higher for controls who used the medium cuff size than for obese persons who used the medium cuff size (Figure 1A). Controls using the small cuff size had a higher SBP in mmHg than controls who used the medium cuff size (114 ± 6.8 mmHg versus 105 ± 7.3 mmHg, p = 0.0005) (Figure 2A).

FIGURE 2

A. Systolic blood pressure (SBP) with SD by cuff size in the obese group and the control group. The obese group had a higher SBP than the control group as seen in Table 1. Obese persons who used the large cuff size had a higher SBP than obese persons who used the medium cuff size. Controls who used the small cuff size had a higher SBP than controls who used the medium cuff size. **B.** SBP z score with SD and percentage of systolic hypertensives by cuff size in the obese and the control group. p-values relate to potential differences in SBP z scores. Contrary to findings in SBP in A, no difference was found in SBP z score when the obese and the control group were compared as seen in Table 1. Furthermore, no difference was found in SBP z score for control individuals who used the small and medium cuff size. In the obese group, a higher frequency of systolic hypertensives was found for those who used the large cuff than for those who used the medium cuff size ($n_{large\ cuff}$ = 23 (65.7%) vs $n_{medium\ cuff}$ = 15 (21.7%), p < 0.0001). In the control group, no difference in systolic hypertension was found between persons who used the small and medium cuff size ($n_{small\ cuff}$ = 6 (42.9%) vs $n_{medium\ cuff}$ = 10 (27.8%), p = 0.33).

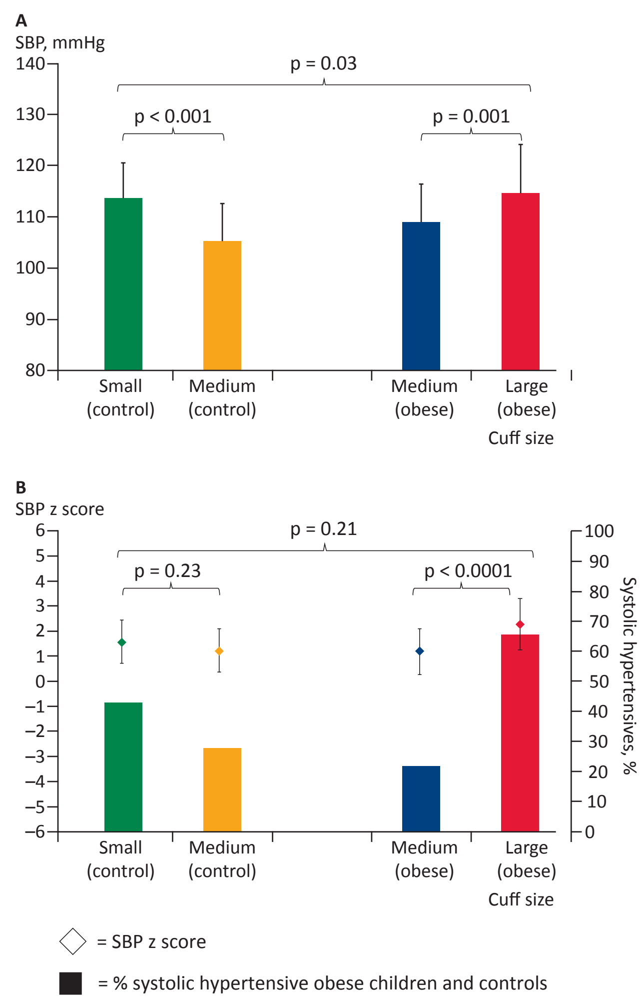


TABLE 2

Multiple regression models for systolic and diastolic blood pressure. The medium cuff was the only overlapping cuff size between the obese and the control group. Data from the obese and the control group were eligible for pooling in multiple regression analyses as no interaction was found between the group variable (obese vs. control group) and any of the other explanatory variables.

	Systolic blood pressure			Diastolic blood pressure		
	β (95% CI), mmHg	r^2	p-value	β (95% CI), mmHg	r^2	p-value
Group (obese vs. control)	6.8 (3.4-10.2)	–	0.0001	3.2 (0.8-5.5)	–	0.01
Gender (male vs. female)	0.1 (–2.4-2.5)	–	0.96	–1.4 (–3.1-0.4)	–	0.13
Age (per yr increase)	0.3 (–0.6-1.1)	–	0.54	0.8 (0.2-1.4)	–	0.007
Height (per cm increase)	0.3 (0.1-0.4)	–	0.0005	–0.1 (–0.1-0.1)	–	0.37
Heart rate (per bpm increase)	0.1 (–0.06-0.2)	–	0.28	0.2 (0.1-0.2)	–	< 0.0001
Cuff size						
Small vs. medium	11.9 (7.0-16.8)	–	< 0.0001	3.1 (–0.4-6.5)	–	0.08
Large vs. medium	–1.40 (–2.3-5.0)	–	0.45	0.4 (–3.0-2.2)	–	0.75
Model	–	0.286	< 0.0001	–	0.230	< 0.0001

β = beta coefficient; bpm = beats/min.; CI = confidence interval.

Findings for SBP in mmHg in Figure 1A were reproduced when SBP z score was plotted in relation to AC for each cuff size in Figure 1B. However, a correlation between SBP z score and AC existed in controls who used the small cuff (r_P = 0.56, p = 0.04). Furthermore, no difference was found between controls who used the small and the medium cuff size. The percentage of systolic hypertensives in the obese group and the control group for each cuff size is presented in Figure 2B.

Multiple regression analyses of blood pressure

Collinearity was found when the obese and the control group were pooled as intended for the multiple regression analyses (WC and AC: r_P = 0.92, p < 0.0001/BMI z score and AC: r_P = 0.82, p < 0.0001). Hence, the anthropometric measures were not included in the multiple regression analyses which by study design included the group variable (obese versus control group).

SBP was 6.8 mmHg higher in the obese than in the control group when adjusted for cuff size and relevant confounding explanatory variables (**Table 2**). At the same time, SBP in mmHg was associated with the cuff size. The small cuff size was associated with an 11.9 mmHg higher SBP than the medium cuff size, whereas the large cuff size was not associated with the SBP in mmHg when compared with the medium cuff size.

DBP was 3.2 mmHg higher in the obese group than in the control group independently of cuff size and relevant confounding variables. The cuff sizes were not associated with the DBP in mmHg.

The higher SBP and DBP in mmHg in the obese group were reproducible when smokers and individuals receiving medication were excluded. In multiple regression analyses, SBP and DBP z scores did not differ between the obese and the control group, but in these analyses, the large cuff size was significantly associated with a higher both SBP and DBP z score when compared with the medium size.

DISCUSSION

The main finding of the present study was that cuff size had an impact on the BP measurement when the obese group and the control group were compared. Both SBP and DBP in mmHg were higher in the obese group than in the control group despite the fact that cuff size influenced the BP measurement. These findings support that correct cuff size is essential for BP measurement as stated in clinical guidelines [3, 9], and measurement of AC is essential to determine the correct cuff size [14].

Previous studies have found a higher BP in obese children than in normal-weight children by use of oscillometric BP devices [15, 16]. However, the effect of cuff size on the results of BP measurements was not considered in these studies.

In agreement with the present study, others have demonstrated that bias can be introduced when more than one cuff size is being used even when appropriate cuff sizes are used [5, 17]. A study by Whincup et al [5] using both auscultatory and oscillometric devices demonstrated that a change from one cuff size to a larger cuff size resulted in a step function, i.e. a sudden fall in BP. We found a similar step function at the point of changing from the small cuff size to the medium cuff size in the control group, but this was not seen at the point of changing from the medium cuff size to the large cuff size in the obese group (Figure 1A and Figure 1B). These findings suggest that in the obese group, the BP increased with increasing AC and BMI even when taking the influence of cuff sizes into account. SBP in mmHg seemed higher for control individuals than for obese subjects for those using the medium cuff size at a given AC. This may be explained by a lower height in the obese children than in controls. Likewise, leanness and a higher height may explain the higher SBP in mmHg in controls when the small cuff size is used compared with controls in whom a medium cuff size is used.

In our adjusted analyses, the small cuff size was associated with a higher SBP in mmHg than when the medium cuff was used, whereas the large cuff size was associated with higher both SBP and DBP z scores compared with the medium cuff. The varying influence of the cuff sizes on either SBP in mmHg or z scores may appear contradictive. The association between the small cuff size and a higher SBP in mmHg may be due to the imprecision of the oscillometric device when used with the small cuff size, which was discussed in the validation paper on the Omron 705IT [13]. The association between the large cuff size and the BP z scores may be explained as a physiological phenomenon of obesity-related elevated BP. However, the validation study of Omron 705IT did not include the large cuff size and only eleven out of 197 study participants were obese [13]. In this respect, validation of oscillometric BP devices in children is rare, and validation of subgroups such as obese children is even more seldom.

In the present study, each multiple regression model was constructed in order to control for growth measures, and BP was consistently associated with cuff size. Differences between SBP in mmHg and z scores may be explained by differences in the methodology of the BP measurements (including cuff sizes) with respect to the American standard population from where the BP z scores are calculated [9]. Furthermore, differences in AC may explain part of the varying influence of cuff size on BP in mmHg and z scores. However, the strong interrelationship between the anthropometric measures complicates this evaluation.

The significant effect of cuff size on the BP in mmHg measurements has been discussed in previous papers. However, recommendations as to the most suitable cuff size are not consistent [8, 18, 19]. Recommendations apply to the conventional auscultatory methods, whereas less is known about cuff sizes and oscillometric devices [8].

The limitations of the present study include the relatively small sample size which limits detection of small BP differences. Each person's BP was measured by only one cuff size. The study is therefore based on between-person comparisons rather than within-person comparisons using all available cuff sizes – which would be a superior design [20]. In this respect, the present study is a post hoc analysis of individuals using appropriate cuff sizes as recommended by the manufacturer, and the potential influence of cuff sizes on BP was investigated in the original study.

CONCLUSIONS

We found that cuff size had a significant impact on the BP measurement when obese children and adolescents were compared with an age- and gender-matched control group. Despite the influence of cuff size, BP in mmHg was higher in the obese group than in the control group. Our data indicate that a step function existed for the used oscillometric device as BP was over- and underestimated, respectively, in persons who had an AC size close to the switch from small to medium cuff size. This may be due to imprecision of the used oscillometric device when used with the small cuff size. In future studies focusing on BP differences between obese and normal-weight children, the effect of the cuff sizes on the result of BP measurement should be considered as a BP device may be imprecise at a given cuff size.

CORRESPONDENCE: *Kristian Nebelin Hvidt.*
E-mail: kristiannebelinhvidt@gmail.com

ACCEPTED: 29 October 2015

CONFLICTS OF INTEREST: Disclosure forms provided by the authors are available with the full text of this article at www.danmedj.dk

ACKNOWLEDGEMENTS: Financial support was kindly provided by The Health Sciences Research Foundation of Region Zealand, The Danish Heart Foundation, Kathrine og Vigo Skovgaards Fond, Det Medicinske Selskab i København, and Edith og Henrik Henriksens Mindelegat. The research activities of the present study form part of The Danish Childhood Obesity Biobank (ClinicalTrials.gov: NCT00928473), TARGET (www.target.ku.dk), and BIOCHILD (www.biochild.ku.dk).

LITERATURE

1. Lo JC, Chandra M, Sinaiko A et al. Severe obesity in children: prevalence, persistence and relation to hypertension. Int J Pediatr Endocrinol 2014; 2014(1):3.
2. Reilly JJ. Obesity in childhood and adolescence: evidence based. Postgrad Med J 2006;82:429-37.
3. Winding L, Wason M, Nørgaard H et al. DPS – Klaringsrapport. Hypertension hos børn. www.researchgate.net/publication/250615210_DPS_Klarringsrapport_Hypertension_hos_brn.
4. Akpolat T. Obesity, hypertension and home sphygmomanometer cuffs. Eur J Intern Med 2010;21:338-40.
5. Whincup PH, Cook DG, Shaper AG. Blood pressure measurement in children: the importance of cuff bladder size. J Hypertens 1989;7:845-50.
6. Sprafka JM, Strickland D, Gómez-Marín O et al. The effect of cuff size on blood pressure measurement in adults. Epidemiol 1991;2:214-7.
7. Hill GE, Machin RH. Doppler determined blood pressure recordings: the effect of varying cuff sizes in children Can Anaesth Soc J 1976;23:323-6.
8. Palatini P, Frick GN. Cuff and bladder: overlooked components of BP measurement devices in the modern era. Am J Hypertens 2012;25:136-8.
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;114:555-76.
10. Cole TJ, Faith MS, Pietrobelli A et al. What is the best measure of adiposity change in growing children: BMI, BMI %, BMI z-score or BMI centile? Eur J Clin Nutr 2005;59:419-25.
11. Hvidt KN, Olsen MH, Holm JC et al. Aortic stiffness in obese children and adolescents: comparison of two distance measures of carotid femoral pulse wave velocity. Artery Res 2013;7:186-93.
12. Nysom K, Mølgaard C, Hutchings B et al. Body mass index of 0 to 45-y-old Danes: reference values and comparison with published European reference values. Int J Obes Relat Metab Disord 2001;25:177-84.
13. Stergiou GS, Yiannes NG, Rarra VC. Validation of the Omron 705 IT oscillometric device for home blood pressure measurement in children and adolescents: the Arsakion School Study. Blood Press Monit 2006;11:229-34.
14. Prineas RJ, Ostchega Y, Carrol M et al. US demographic tends in mid-arm circumference and recommended blood pressure cuffs for children and adolescents: data from the national health and nutrition examination survey 1988-2004. Blood Press Monit 2007;12:75-80.
15. Polderman J, Gurgel RQ, Barreto-Filho JA et al. Blood pressure and BMI in adolescents in Aracaju, Brazil. Public Health Nutr 2011;14:1067-70.
16. Abdulle A, Al-Junaibi A, Nagelkerke N. High blood pressure and its association with body weight among children and adolescents in the United Arab Emirates. PLoS One 2014 20;9:e85129.
17. Jenner DA, Vandongen R, Beilin LJ. Blood pressure and body composition in children: importance of allowing for cuff size. J Hum Hypertens 1992; 6:367-74.
18. Pickering TG, Hall JE, Appel LJ et al. Recommendations for blood pressure measurement in humans: an AHA scientific statement from the council on high blood pressure research professional and public education subcommittee. J Clin Hypertens 2005;7:102-9.

19. Clausen LR, Olsen CA, Olsen JA et al. Influence of cuff size on blood pressure among schoolchildren. Blood Press 1999;8:172-6.
20. Hvidt KN, Ibsen H, Holm JC. After weight loss a child fits a smaller blood pressure cuff but gets elevated blood pressure. Ugeskr Læger 2014;176: V10120590.