Human Biology

Volume 84 | Issue 4 Article 10

2012

Results of Epidemiological Studies of Blood Pressure Are Biased by Continuous Variation in Arm Size Related to Body Mass

Stanley J. Uluaszek
UBVO, Institute of Social and Cultural Anthropology, University of Oxford

Maciej Hennberg
Wood Jones Chair of Anthropological and Comparative Anatomy, School of Medical Sciences, University of Adelaide

Results of Epidemiological Studies of Blood Pressure Are Biased by Continuous Variation in Arm Size Related to Body Mass

Abstract

In cross-sectional epidemiological studies, blood pressure (BP) is often found to be positively correlated with fatness. Usually sphygmomanometers with only one cuff size for adults are used to measure BP while arm circumference (AC) influences BP readings. We have studied cross-sectional anthropometric and BP data of adult men and women from three populations: Cook Islanders (n = 259), Papua New Guinean: Purari (n = 295), and Ok Tedi (n = 274). These were selected because of their diverse socio-economic, anthropometric, and BP characteristics. Partial correlations and regressions were used to analyze these data. Systolic and diastolic pressures (SBP, DBP) showed dependence on AC, body mass index (BMI), and skinfold thickness. Stature had some effect on SBP and DBP, independent of BMI and AC. When effects of AC and stature were statistically controlled, BMI did not correlate with either SBP or DBP. People of larger body mass have greater AC, and this biases BP readings. Average values of SBP and DBP in groups of underweight, normal, overweight, and obese people predicted by AC (sex, age, and BMI being statistically controlled) closely matched observed SBP and DBP averages in those groups. Out of 24 pairwise comparisons (3 samples from different populations x 4 groups of BMI x 2 pressure readings) of predicted and actual BP, only two produced statistically significant differences while 21 of the differences were 5 mm Hg or less. Correlations between BP and obesity found in epidemiological studies may be severely biased by effects of variation in AC. Sphygmomanometric measurements of BP should be corrected for continuous variation in AC.

Cover Page Footnote

The collection of the data was funded by the Japanese Ministry of Education, Science and Culture (Cook Island samples), the University of Cambridge, United Kingdom (Purari samples), and the University of Oxford, United Kingdom (Ok Tedi samples).

Results of Epidemiological Studies of Blood Pressure Are Biased by Continuous Variation in Arm Size Related to Body Mass

STANLEY J. ULIJASZEK[1] AND MACIEJ HENNEBERG[2]*

Abstract In cross-sectional epidemiological studies, blood pressure (BP) is often found to be positively correlated with fatness. Usually sphygmomanometers with only one cuff size for adults are used to measure BP while arm circumference (AC) influences BP readings. We have studied cross-sectional anthropometric and BP data of adult men and women from three populations: Cook Islanders ($n = 259$), Papua New Guinean: Purari ($n = 295$), and Ok Tedi ($n = 274$). These were selected because of their diverse socio-economic, anthropometric, and BP characteristics. Partial correlations and regressions were used to analyze these data. Systolic and diastolic pressures (SBP, DBP) showed dependence on AC, body mass index (BMI), and skinfold thickness. Stature had some effect on SBP and DBP, independent of BMI and AC. When effects of AC and stature were statistically controlled, BMI did not correlate with either SBP or DBP. People of larger body mass have greater AC, and this biases BP readings. Average values of SBP and DBP in groups of underweight, normal, overweight, and obese people predicted by AC (sex, age, and BMI being statistically controlled) closely matched observed SBP and DBP averages in those groups. Out of 24 pairwise comparisons (3 samples from different populations × 4 groups of BMI × 2 pressure readings) of predicted and actual BP, only two produced statistically significant differences while 21 of the differences were 5 mm Hg or less. Correlations between BP and obesity found in epidemiological studies may be severely biased by effects of variation in AC. Sphygmomanometric measurements of BP should be corrected for continuous variation in AC.

In epidemiological studies, relationships between anthropometric indices of obesity and BP are accepted as proof that obesity is associated with cardiovascular problems (Alberti et al. 2009; WHO 1998). In epidemiological surveys, BP is commonly measured by sphygmomanometry. This involves

[1]UBVO, Institute of Social and Cultural Anthropology, University of Oxford, 51 Banbury Rd., Oxford OX2 6PE.

[2]Wood Jones Chair of Anthropological and Comparative Anatomy, School of Medical Sciences, University of Adelaide, Adelaide SA 5005, Australia.

*Correspondence to: Prof Maciej Henneberg, School of Medical Sciences, The University of Adelaide, SA 5005 Australia. E-mail: Maciej.Henneberg@adelaide.edu.au. Tel. +61-8-83035479, Fax +61-8-83034398.

Human Biology, August 2012, v. 84, no. 4, pp. 437–444.

inflating a cuff around the arm, pressure in the cuff closing arteries there, and the slow release of the pressure while listening in the cubital fossa for Korotkoff's sounds (Pickering et al. 2005) or detecting their equivalent electronically. Size of the cuff determines how easily cuff pressure is transmitted through the soft tissues of the arm to control the blood flow in the arteries. The soft tissues of the arm—skin, adipose tissue, and muscle—and the structure of the walls of the arteries themselves affect external pressures needed to close and open the arteries. In addition, the pressure in the arteries of the arm may depend on the hydrostatic pressure of the blood column in arteries above the level of the cuff. This is determined by gravity, stature, and body position. Thus, the pressure inside the cuff of the sphygmomanometer at the appearance and disappearance of Korotkoff's sounds is a function of the compressibility and bulk of the soft tissues of the arm, cuff size, body height above the heart, and the state of the cardiovascular system.

Measurement bias because of cuff size was recognized in 1901 (Booth 1977); current recommendations for accurate BP measurement include use of an appropriate cuff from one of four standard-sized cuffs, according to arm circumference (AC) (Marks and Groch 2000; Pickering et al. 2005). Use of separate cuffs may be a practical possibility in clinical settings where a number of cuffs can be conveniently stored and frequently changed from patient to patient, and where reading accuracy needed is 5−10 mm Hg. However, this method of adjusting for the technical bias in BP measurement is impracticable in broad epidemiological surveys where supposed random errors can be tolerated while efficiency of data collection is important. Even the use of a few standard cuff sizes does not remove the bias entirely because variation in AC is continuous. Influence of AC on BP readings from a sphygmomanometer is likely to be continuous, and existing categorical solutions to the problem of arm-size to cuff-size bias do not take this into account.

We test the hypothesis that arm soft-tissue size and stature influence BP readings in a gradual fashion. The extent of bias resulting from arm size and stature variation is examined, and the degree to which this may influence the results of epidemiological studies is discussed.

Materials and Methods

Samples of adults from three populations (total $n = 802$), diverse in socioeconomic and nutritional status, body size and BP, were used for this analysis (Table 1). These were chosen to represent a broad range of variation in body-size, shape, and BP. The populations, the samples derived from them, and the data collection methods are described elsewhere (Ulijaszek 1998; Ulijaszek and Koziel 2003). The two Papua New Guinea samples were obtained at Ok Tedi in 1999, and in the Purari delta in 1995−1997. The Cook Islander sample was obtained in 1996 on Rarotonga. Individuals taking anti-hypertension medication were excluded from analysis. In all cases, SBPs and DBPs were measured in a sitting position after 30 min rest by using a mercury sphygmomanometer with an adult cuff. The pressure at the fifth

Table 1. Basic Characteristics of the Three Samples Studied

Men	*Purari* *Mean*	*n = 147* *SD*	*Ok Tedi* *Mean*	*n = 105* *SD*	*Cook Islands* *Mean*	*n = 96* *SD*
Age (years)	36.7	14.2	41.4	13.8	55.0	14.0
Stature (cm)	163.6	6.4	163.0	8.2	173.2	7.9
BMI (kg/m^2)	22.7	3.0	22.6	2.9	30.8	5.4
Skinfold: biceps	3.2	0.9	3.3	0.9	8.7	4.7
Triceps (mm)	5.4	2.2	6.0	2.0	15.2	6.8
Subscapular (mm)	9.8	3.8	11.2	4.8	26.6	10.6
Suprailiac (mm)	8.7	5.3	10.0	5.9	26.5	10.0
AC (cm)	26.0	2.5	27.3	2.8	33.6	4.2
LAC (cm)	24.6	2.4	25.8	2.6	29.9	3.3
SBP (mmHg)	122.0	16.2	123.0	13.9	142.1	19.0
DBP (mmHg)	79.9	13.8	71.8	12.0	91.1	14.7
Women	*Purari*	*n = 148*	*Ok Tedi*	*n = 169*	*Cook Islands*	*n = 163*
Age (years)	35.6	14.1	38.1	12.9	50.0	13.6
Stature (cm)	153.3	5.6	156.2	6.1	163.3	7.5
BMI (kg/m^2)	22.9	4.1	22.6	3.9	32.5	6.1
Skinfold: biceps	4.4	2.6	4.3	2.4	15.6	7.3
Triceps (mm)	9.0	4.2	9.9	5.0	25.9	7.3
Subscapular (mm)	15.1	8.2	15.4	9.4	35.0	6.7
Suprailiac (mm)	14.7	8.1	12.8	8.4	30.3	8.3
AC (cm)	23.7	3.0	25.3	3.5	33.7	4.3
LAC (cm)	21.6	2.4	23.0	2.7	27.2	2.7
SBP (mmHg)	117.9	16.4	122.2	14.2	134.5	19.6
DBP (mmHg)	78.3	13.2	70.3	11.8	86.6	13.8

BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; AC, arm circumference; LAC, lean arm circumference.

phase of Korotkoff sounds was recorded. The data used here are the average of two readings taken one minute apart. Data for each sample were analyzed separately, then as a combined metasample ("All").

Since adipose tissue and the muscles of the arm differ in their compressibility and elasticity, we calculated lean arm circumference (LAC) by subtracting averaged biceps and triceps skinfold thicknesses from AC:

$$\text{LAC} = \text{AC} - \mathbf{\Pi} * \text{AVGskinfold}.$$

where AC is arm circumference, Π is π value of 3.14159…, and AVGskinfold is the average of biceps and triceps skinfold thicknesses.

Besides separating the possible effect of muscle-tissue size on BP reading from its combination with adipose tissue in AC, this calculation removes the correlation between the amount of adipose tissue on the arm and in the rest of the body.

Statistical procedures included the calculation of descriptive statistics, partial correlations, regressions, and tests of significance by using SPSS version 11.0.4 for MacOSX.

Table 2. Partial Correlation Coefficients between Blood Pressure and Anthropometric Traits when Sex and Age Are Statistically Controlled[a]

Sample	*AC*	*Lean AC*	*Stature*	*BMI*	*Sum Skf*
Purari					
SBP	*0.34****	*O.31****	*0.13**	*0.29****	*0.26****
DBP	0.31***	0.32***	0.11	0.19**	0.14*
Ok Tedi					
SBP	*0.24****	*0.21***	*0.12*	*0.17***	*0.23****
DBP	0.21**	0.17**	0.10	0.11	0.20**
Cook Is.					
SBP	*0.26****	*0.26****	*0.07*	*0.27****	*0.23****
DBP	0.30***	0.28***	0.09	0.27***	0.29***
All					
SBP	*0.29****	*0.29****	*0.15**	*0.28****	*0.25****
DBP	0.38***	0.34***	0.20***	0.35***	0.34***

a. In the "All" sample, population of origin was also statistically controlled. Significance marked at *$P < 0.05$, **$P < 0.01$, and ***$P < 0.001$.

SBP, systolic blood pressure; DBP, diastolic blood pressure; AC, arm circumference; BMI, body mass index; SKF, skinfolds.

Results

Samples used here differ widely in average age, body height, BMI, skinfold thickness, AC, and BP (Table 1) covering a fair amount of the range commonly observed across population samples. AC and LAC correlate significantly with SBP and DBP when effects of age and sex are removed (Table 2). The amount of variation in BP explained by AC and LAC is similar to that explained by BMI or even slightly higher in most comparisons.

Table 3. Partial Correlation Coefficients between Blood Pressure and Anthropometric Traits when Body Mass Index, Sex, and Age Are Statistically Controlled[a]

Sample	*AC*	*Lean AC*	*Stature*	*Sum Skf*
Purari				
SBP	*0.21****	*0.18***	*0.12**	*0.09*
DBP	0.26***	0.26***	0.10	0.01
Ok Tedi				
SBP	*0.18***	*0.13**	*0.11*	*0.16***
DBP	0.20**	0.14*	0.09	0.10**
Cook Is.				
SBP	*0.08*	*0.10*	*0.15**	*0.05*
DBP	0.14*	0.12*	0.16**	0.14*
All				
SBP	*0.12***	*0.14****	*0.14****	*0.08**
DBP	0.18***	0.14***	0.19***	0.14***

a. In the "All" sample, population of origin was also statistically controlled. Significance marked at *$P < 0.05$, **$P < 0.01$, and ***$P < 0.001$.

AC, arm circumference; DBP, diastolic blood pressure; SBP, systolic blood pressure; SKF, skinfolds.

Table 4. Partial Correlation Coefficients between Blood Pressure and Arm Circumference (AC), Stature and Body Mass Index (BMI) when Sum of Skinfolds, Sex, and Age Are Statistically Controlled[a]

Sample	*AC*	*Lean AC*	*Stature*	*BMI*
Purari				
SBP	*0.25****	*0.25****	*0.11*	*0.16***
DBP	0.28***	0.29***	0.10	0.16**
Ok Tedi				
SBP	*011*	*0.10*	*0.05*	*−0.01*
DBP	0.09	0.08	0.04	−0.07
Cook Is.				
SBP	*0.13**	*0.16***	*0.06*	*0.15**
DBP	0.12	0.15*	0.08	0.09
All				
SBP	*0.17****	*0.18****	*0.08**	*0.14****
DBP	0.20***	0.19***	0.12**	0.15***

a. In the “All” sample, population of origin was also statistically controlled.
SBP, systolic blood pressure; DBP, diastolic blood pressure.

Stature, used as a proxy of the height above the heart, also correlates with BP in some of the samples tested. This correlation is increased when the effects of BMI are removed, but the amount of variance in BP explained by stature is small (Table 3). The correlations between AC and LAC and BP remain largely significant after the effects of BMI (Table 3) and skinfold thickness (Table 4) are removed. When the effects of AC are removed, no significant association between BMI and BP remains, while associations between sex and BP are practically nonexistent (Table 5).

Regressions of BP on AC (Table 6) accurately predict average SBP and DBP values in normal, overweight, and obese groups (Table 7), indicating

Table 5. Partial Correlation Coefficients between Blood Pressure and Stature, Sum of Skinfolds, Body Mass Index (BMI), and Sex when Arm Circumference (AC) and Age Are Statistically Controlled[a]

Sample	*Sex*	*Lean AC*	*Stature*	*BMI*	*Sum Skf*
Purari					
SBP	*0.02*	*−0.06*	*0.01*	*0.06*	*0.08*
DBP	0.08	0.01	−0.03	−0.02	0.01
Ok Tedi					
SBP	*0.05*	*−0.11*	*0.02*	*−0.02*	*0.10*
DBP	0.00	−0.08	0.03	−0.09	0.06
Cook Is.					
SBP	*−0.15**	*0.14**	*0.12**	*0.06*	*−0.07*
DBP	−0.11	0.09	0.12	0.02	−0.02
All					
SBP	*−0.05*	*0.06*	*0.08**	*0.05*	*0.02*
DBP	−0.00	−0.03	0.08*	0.06	0.09*

a. In the “All” sample, population of origin was also statistically controlled.
SBP, systolic blood pressure; DBP, diastolic blood pressure; SKF, skinfolds.

Table 6. Regression Equations to Predict Blood Pressure from Arm Circumference when Age, Sex and Body Mass Index Are Statistically Controlled

Purari:	*SBP = AC * 1.14 + 91.60;*	DBP = AC * 1.18 + 49.78
Ok Tedi:	*SBP = AC * 0.75 + 102.99;*	DBP = AC * 0.55 + 56.64
Cook Islands:	*SBP = AC * 0.36 + 125.06*;	DBP = AC * 0.47 + 72.50
All:	*SBP = AC * 0.41 + 114.62;*	DBP = AC * 0.51 + 64.98

SBP, systolic blood pressure; DBP, diastolic blood pressure; AC, arm circumference.

that differences in BP averages between BMI groups may reflect measurement biases resulting from continuous variation in AC rather than the actual differences in the state of cardiovascular systems.

Discussion

Since arm skinfolds and LAC are correlated with BMI (Henneberg and Veitch 2005), the technical bias in BP measurement resulting from the use of

Table 7. Average Systolic and Diastolic Actual Blood Pressure in Categories of Body Mass Index (BMI) Compared to Blood Pressure Predicted from Arm Circumference[a]

BMI	*n*	*Actual*	*SBP* *Pred.*	*Diff.*	*Actual*	*DBP* *Pred.*	*Diff.*
Purari							
<18.5	23	114	115	−1	75	74	1
18.5−25	205	119	120	−1	78	79	−1
25−30	56	123	123	0	81	82	−1
>30	9	144	124	20**	92	83	9*
Ok Tedi							
<18.5	25	119	118	1	67	68	1
18.5−25	189	122	122	0	71	71	0
25−30	47	123	124	−1	70	72	2
>30	12	134	127	7	77	74	−3
Cook Islands							
<18.5	2	128	133	−5	79	83	−4
18.5−25	28	135	135	0	83	85	−2
25−30	77	134	136	−2	87	87	0
>30	151	140	138	2	90	90	0
All							
<18.5	51	118	121	−3	72	71	1
18.5−25	422	121	125	−4**	75	75	0
25−30	180	128	129	1	81	79	2
>30	173	139	135	4**	89	85	4**

a. Differences significant at $P < 0.05$ and $P < 0.01$ level of paired *t*-test marked * and **. No Bonferroni correction to the levels of significance applied. If Bonferroni corrections were applied, no difference would remain significant.

SBP, systolic blood pressure; DBP, diastolic blood pressure.

the same adult-cuff size on individuals with different arm sizes is responsible for a substantial, and certainly significant, amount of BP difference between normal and overweight or obese people. To illustrate, we show here BPs predicted from ACs for thin (BMI <18.5 kg/m^2), normal (BMI 18.5$-$25 kg/m^2), overweight ($>25-30$ kg/m^2), and obese (>30 kg/m^2) people (Table 7). As can be seen in most BMI categories, in most samples, differences between SBP and DBP predicted solely from AC and those actually observed are trivial and, in most cases, insignificant. If a consideration is made of multiple comparisons and the Bonferroni correction to the levels of significance applied, no difference remains significant.

There is little doubt that in cases of serious obesity the risk of cardiovascular disease increases (Alberti et al. 2009; WHO 1998), but a simple routine sphygmomanometric measurement of BP may not provide an appropriate assessment of this risk because of a mechanical bias inherent in its measurement in arms of increased size. It may be that metabolic processes producing obesity in some individuals also affect their cardiovascular systems, especially the elasticity of arterial walls, and yet there may not be a universal and direct link between obesity and actual pressure in arteries, were this latter measured directly and not via compression of the arm by the cuff of a sphygmomanometer.

Acknowledgments The collection of the data was funded by the Japanese Ministry of Education, Science and Culture (Cook Island samples), the University of Cambridge, United Kingdom (Purari samples), and the University of Oxford, United Kingdom (Ok Tedi samples).

Received 15 May 2012; revision accepted for publication 31 July 2012.

Literature Cited

Alberti, K. G., R. H. Eckel, S. M. Grundy et al. 2009. Joint Scientific Statement: Harmonizing the Metabolic Syndrome: A Joint Interim Statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. *Circulation* 120:1640−1645.

Booth, J. 1977. A short history of blood pressure measurement. *Proceedings of the Royal Society of Medicine* 70(11):793–799.

Henneberg, M., and D. Veitch. 2005. Is obesity as measured by body mass index and waist circumference in adult Australian women 2002 just a result of the lifestyle? *Human Ecology Special lssue* 13:85– 89.

Marks, L. A., and A. Groch. 2000. Optimizing cuff width for non-invasive measurement of blood pressure. *Blood Pressure Monit.* 5:153–158.

Pickering, T. G., J. E. Hall, L. J. Appel et al. 2005. Recommendations for blood pressure measurement in humans and experimental animals. American Heart Association Scientific Statement. *Circulation* 111:697–716.

Ulijaszek, S. J. 1998. Hypertension among adults of the Purari delta of the Gulf Province, Papua New Guinea population. *Papua New Guinea Medical Journal* 41:65–71.

Ulijaszek, S. J., and S. Koziel, S. 2003. Associations between blood pressure and economic modernization among adults on Rarotonga, the Cook Islands. *Anthropological Review* 66:65–75.

World Health Organization. 1998. *Obesity: Preventing and Managing the Global Epidemic*. Report on a WHO Consultation on Obesity, Geneva, 3−5 June 1997 WHO/NUT/NCD/98. Geneva: World Health Organization.