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Body size and blood pressure: An analysis of Africans and the African diaspora

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Abstract

Background—Blood pressure is directly and causally associated with body mass index (BMI) in populations worldwide. However, the relationship may vary across BMI in populations of African origin.

Methods—We compared the relationship between blood pressure and BMI in populations of African origin, using thirteen samples from Africa, the Caribbean, UK and USA. We had access to data from individual participants for age, height, weight, blood pressure and treatment of hypertension. Analysis was restricted to 18,072 participants (age 35-64 years; 44% men). We carried out multivariate regression analysis to estimate the relationship between blood pressure and BMI by country and by sex. The use of anti-hypertensive treatment was taken into account by exclusion and by sensitivity analysis.

Results—There was a positive relationship between both systolic and diastolic blood pressure and BMI. In men the slopes for systolic blood pressure varied from 0.27 mm Hg per kg/m^2 (95% confidence interval = −0.01 to 0.56) in the US to 1.72 (0.92 to 2.53) in Ghana (Kumasi). In women, the slopes varied from 0.08 (−0.54 to 0.72) in South Africa to 1.32 (0.98 to 1.66) in the Republic of Congo. Similar variation in trends was seen for diastolic blood pressure. The higher the BMI, the shallower the slopes (−0.10 (−0.15 to −0.06) for systolic, −0−09 (−0.12 to −0.06) for

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diastolic). No differences were seen after excluding persons who were being treated for hypertension.

Conclusions—Blood pressure and BMI levels vary among populations of the African diaspora. The effect of BMI on blood pressure levels diminishes as BMI increases. These results suggest a complex relationship between excess body weight, adiposity and energy expenditure.

Hypertension affects more than a quarter of the world's adult population and this proportion is likely to reach 29% by 2025.[1] Most of this increase will occur in developing countries. Obesity is reaching epidemic proportions in the industrialized world[2] and contributes to morbidity and mortality.[3] Although obesity is less prevalent in developed countries, it is increasing with urbanization.[2]

There is a positive association between measures of obesity and blood pressure in both developed[4] and less developed countries.[5-6] In high-income countries, the prevalence of obesity and hypertension increase with increasing urbanization, Blood pressure is positively related to body mass index (BMI) in people of both European and African origin in developed countries. People of African origin living in developed countries have a higher mean BMI than their counterparts in Africa.[6-7] A number of studies from a wide range of environments in low, medium and high income countries indicate that the association between BMI and levels of blood pressure is constant. However, other study results suggest this relationship is not constant, but varies in populations at the extremes of the BMI distribution.

Combining studies from countries across Africa and the African Diaspora gives the opportunity to shed new light on this question. During the past decade, several population-based and community-based studies have been carried out in people of African origin living in Africa, the Caribbean, the United Kingdom and the United States. Where measurements are conducted similarly, these studies offer an opportunity to make international comparisons in populations with differing environmental exposures and differing levels of obesity.[6] The aim of this collaborative analysis of 13 studies was to study the relationship between blood pressure and BMI across a wide range of average levels of BMI, hypertension and obesity[8-11] in people of African origin living in rural and urban Africa, the Caribbean, UK and US.

METHODS

Study design

We identified 13 surveys conducted between 1988 and 2004 that collected standardized data on blood pressure, its treatment, and height and weight. Samples from Barbados, St Lucia, Jamaica, Cameroon and Nigeria were obtained from the International Collaborative Study on Hypertension.[7] Samples from Ghana were taken from two separate studies in Accra[12] and in Kumasi.[13] The sample from Congo was obtained from a population survey carried out within the framework of WHO STEPS (courtesy of Prof G Kimbally Kaki). The sample from Tanzania was obtained from a national study,[14] and the sample from South Africa was obtained from the SASPI 1 survey.[15] The Seychelles sample was obtained from the Seychelles Heart Study II, the UK sample from the Wandsworth Heart & Stroke Study[16] and the US sample from the National Health Examination and Nutrition Survey III (available for public use through the National Center for Health Statistics).[17] The studies were identified in 2004 at a meeting held in Lausanne.[7, 12-17] Soon afterwards, the principal investigators were invited to provide raw data on selected variables. Thirteen studies were included, and 3 investigators did not respond. We also exclude 5 studies published after 2004.[18-25] Each collaborator provided individual data on sex, age, systolic

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and diastolic blood pressure, height (in cm) and weight (in kg) (to calculate BMI [in kg/ m^2]),treatment of hypertension, and details on how blood pressure was measured.

Some of the studies were based on a random probability sample of the whole nation, whereas others were a series of regional or local samples (Table 1). The age distribution of participants in the original surveys varied from 18 to 80 years; we restricted our analysis to those aged 35-64 years. Collectively, the studies enrolled 18,072 participants (44% men) aged 35-64 years, with the number of participants in individual studies varying from 249 to 3,703. The participation rate varied from 54% to greater than 90%. BMI was the only measure of body size consistently available across all populations. We defined obesity as a BMI of $30kg/m^2$ or greater.

Blood pressure measurement and definition of hypertension

A mercury sphygmomanometer was used for blood pressure measurements in the majority of studies, except in UK, Ghana (Kumasi), Tanzania, Seychelles and South Africa where automated devices were used (Table 1). Cuff sizes varied according to arm circumference, following standard protocols. All studies had at least two measurements, and the second (or the average of the last two measurements, if more than two were taken) was used to create the mean for the analyses. The rest period before blood pressure was taken was at least 5 minutes (Table 1). Standardization of blood pressure measurements with the mercury sphygmomanometer was carried out in the International Collaborative Study,26 Electronic devices used in other studies had been validated independently, thus enhancing the comparability of hypertension prevalence studies.27

A person was considered hypertensive if the systolic pressure was ≥140 mmHg, or the diastolic ≥90 mmHg, or the person reported current use of anti-hypertensive medication. The number of people on anti-hypertensive therapy was not known for Nigeria and Cameroon; the use of medication is very uncommon in these countries, and was therefore assumed to be zero.

Data analysis

We report results as means, with 95% confidence intervals (CI). We used linear regression to calculate age-adjusted mean systolic and diastolic blood pressure and BMI, within sex and country, using 45 years as the reference age. We used linear regression to estimate the age-adjusted relationship between blood pressure and BMI for each country and each sex. Quadratic terms were also modelled. We calculated age-adjusted prevalence of hypertension and obesity using direct standardization to the WHO population in 5-year age bands. We divided the data into age groups (35-44, 45-54, 55-64) to present data graphically. We plotted regression coefficients for blood pressure against mean BMI (adjusted for age and sex) weighting the points by the inverse of the variance. A random-effects model was used to estimate the relationship between the regression coefficients and mean BMI, weighting by the inverse of the variance. This procedure allows for different sample sizes to contribute unequally to the final estimate by giving more weight to larger studies. To estimate how much the treatment of high blood pressure would be likely to reduce the relationship between blood pressure and BMI, we carried out a sensitivity analysis adjusting the blood pressure of those on treatment by a random amount (10, 15, 20 and 25 mm Hg). It was assumed that the effect of treatment would be randomly distributed and the SD would be equal to 0.5 of the mean.

RESULTS

Characteristics of the populations

There was heterogeneity in age-adjusted levels of systolic and diastolic blood pressure among countries in both men (eTable 1a) and women (eTable 1b) (tables available with the online version of this article). Systolic blood pressure increased with age in all countries. This relationship could be seen in the African countries as well as in the Caribbean, US, and UK. The relationship of diastolic blood pressure with age followed a similar pattern. There was also heterogeneity in age-adjusted levels of BMI across countries (Table 2). There was no apparent relationship between BMI and age across countries. We found wide variation in the prevalence of high blood pressure, both across all the countries studied and within the African countries (Table 2). The proportion of patients using therapy for hypertension also varied (Table 2). The prevalence of obesity was lowest in African countries, (Table 2) with the leanest populations in Nigeria and Ghana (Kumasi). The prevalence of obesity was lower in men than women across the world.

Relationship between blood pressure and BMI

There was marked heterogeneity both by sex and by country in the age-adjusted regression coefficients of change in blood pressure per unit change in BMI (Tables 3a and 3b). The slopes in men varied from 0.27 mmHg systolic blood pressure per unit of BMI in the US to 1.72 in Kumasi and in women from 0.08 in South Africa to 1.32 in the Republic of Congo. In most countries the relationship was direct, but with large variations (Table 3a and 3b). Roughly 5 to 20% of the variation in blood pressure was explained by BMI in different settings (Table 3a and 3b).

The relationship between blood pressure and BMI depended on the degree of overweight. The greater the mean BMI of the populations studied, the shallower the relationships between blood pressure and BMI (Figure 1). This was consistent for both systolic and diastolic blood pressure and was independent of the proportion of people being treated for high blood pressure (Table 4 and Figure 2). Quadratic terms did not add to the fit of the models in the majority of sites. Finally, sensitivity analysis indicates that if average treatment effect was as large as 25 mmHg, the results would persist but with an attenuation of the regression coefficient of up to 20% for systolic and 50% for diastolic blood pressure (Table 5).

DISCUSSION

We found a wide variation both in the prevalence of hypertension and in the relationship between blood pressure and BMI across populations of African origin living in different environments. As BMI increases, so the relationship between blood pressure and BMI weakens.

This is a pooled analysis of data from studies in diverse populations, including over 18,000 individuals of African descent living in Africa, the Caribbean, US and UK. Methods for measuring blood pressure were not fully comparable between studies. However, the adoption of more standardized protocols in recent years has improved the quality of epidemiologic studies of hypertension in populations of African descent, and we were able to identify a reasonable number of population-based studies that had used stringent standardized methods. Comparison of within-population parameters is less biased, and the data demonstrate a highly heterogeneous relationship between BMI and blood pressure with decreasing slope as the average BMI of the population increases.

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Blood pressure levels are the strongest predictors of stroke incidence within populations. In general, the stroke burden across the sampled countries is consistent with our hypertension prevalence estimates.28 Since there are no incidence data on stroke and only limited mortality data in sub-Saharan Africa, we were not able to validate the differences in blood pressure between countries by comparison with differences in stroke rates.

This analysis confirms previous suggestions of a wide variation in blood pressure levels,29 prevalence of hypertension,7 levels of BMI and prevalence of obesity30 in populations of black African origin. The evidence presented from African populations living in starkly contrasting environments argues for the influence of environment rather than genetic inheritance31 as the main determinant of variation in blood pressure and BMI.

A novel finding is the wide variation in the strength of the relationship between blood pressure and BMI among populations. BMI is an indirect measure of body composition. The percentage of body fat for a given BMI is higher in women than in men, and in those with sedentary compared with active lifestyles. It is possible that the differences we observed may be explained by the measure of fatness.32 Other measures such as waist circumference or waist-to-hip ratio are regarded as better estimates of abdominal adiposity. However, in prior studies of populations of African origin, the percentage of body fat as measured by bio-electrical impedance or by measurement of waist circumference was not a better predictor of blood pressure28 than BMI.29-30

Limitations

The study has several limitations. First, not all published African population samples are included. Some investigators declined to participate, and some studies became available too late to be included. While this may limit the representativeness and generalizability of prevalence rates, it is unlikely to affect the validity of the pooled or meta-regression analyses. Second, as stated earlier, heterogeneity in the methods for measuring blood pressure may have introduced possibly bias in the prevalence estimates. Howeve, it is unlikely this would have biased the ”within-population” estimates of the relationships between blood pressure and BMI. Furthermore, the large majority of studies underwent validations and all used standardized methods. Third, the studies are cross-sectional, hence inference on causality is not possible. Fourth, the studies were carried out over a more than 15 year time-span. From recent results within a population,36 it may be argued that the shallower relationships across populations may be due to the differences in time. In our study the regression coefficients did not vary by the time of the study.

Implications

Attempts to relate body composition to blood pressure extend back the mid-20th century. Given the high correlation between lean and fat mass37 and the limited accuracy of methods available for field research, it remains unclear which component is more important in determining blood pressure. Recent evidence demonstrates an independent association of resting energy expenditure and blood pressure, unconfounded by BMI or adiposity.38 Since resting energy expenditure is primarily determined by lean mass,37-38 these findings suggest that increase in muscle mass, physiologically linked to increased body size, is the primary factor. Body composition changes linearly over the range of BMI, with higher percent body fat observed at the upper end of the distribution.37 Thus, increases in relative weight among the obese will reflect larger gains in adipose tissue relative to lean mass, compared with the lower end of the BMI distribution. The smaller increases in metabolically active fat-free body mass would therefore lead to smaller increments in blood pressure per unit change in BMI in obese groups, consistent with what we observed here. This effect is unlikely to be biased by changes in the pattern of energy expenditure itself since resting energy expenditure, corrected for lean mass, does not differ between rural Nigerians and US blacks.39 This mechanism would be sufficient to explain why the slopes of blood pressure on BMI flatten as BMI increases, since it is resting energy expenditure that is associated with blood pressure. More research is needed to clarify these metabolic mechanisms.

Several other models have been suggested to explain the association between adiposity and blood pressure, including neuroendocrine abnormalities and enhanced sympathetic nervous system activity. One model suggests that the increase in blood pressure seen with excess weight gain may be due to the release of angiotensinogen from adipocytes, leading to an increased production of angiotensin II, an increase in blood volume and blood pressure. Since people of black African ancestry tend to be low-renin individuals,40 with blunted responses to stimulations of the renin-angiotensin-aldosterone system, our results may be compatible with a blunting of this mechanism as BMI increases.

We have observed contrasts in the slope of the relationship between BMI and blood pressure in a range of populations from Africa and the African diaspora. Smaller increments in lean mass are observed in the obese per unit change in BMI, and this could be the underlying physiologic mechanism explaining our observation. As suggested in previous research,38 this interpretation would alter the standard view that increasing fat mass, per se, is the cause of increased hypertension risk in obese people of African descent.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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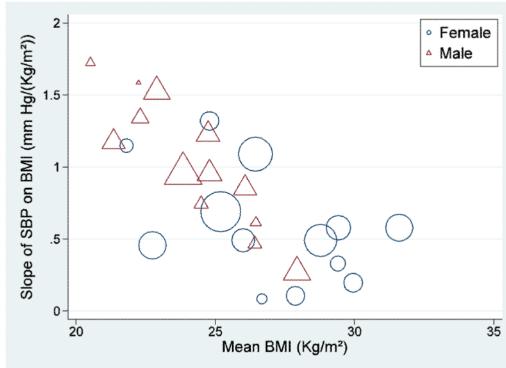

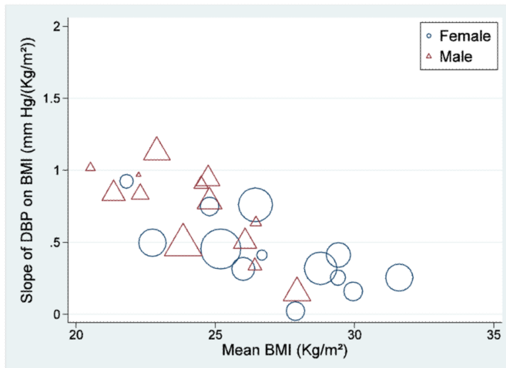

Fig. 1.

Relationship between the change in systolic (top) and diastolic (bottom) blood pressure with BMI and the average BMI in men (n=7,893; triangles) and women (n=10,179; circles) aged 35-64 years in populations of African descent across the world. Size of symbols proportional to sample size.

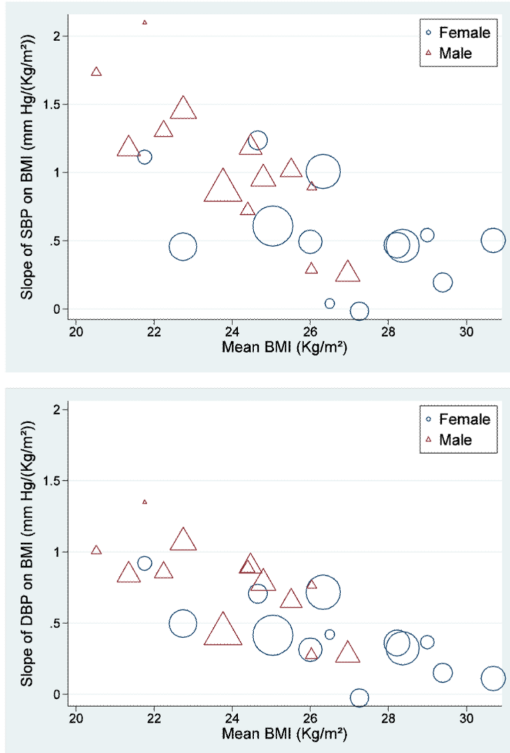

Fig 2.
Relationship between the change in systolic (top) and diastolic (bottom) blood pressure with BMI and the average BMI in untreated men (n=7,347; triangles) and untreated women (n=9,163; circles) aged 35-64 years in populations of African descent across the world. Size of symbols proportional to sample size.

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Table 1

Characteristics of population studies of people of African descent across the world.

						Blood pressure measurement		
Country	**Year of survey**	**Sample**	**Participation (%)**	**Age (y)**	**Sampling method**	**equipment**	**measures (n)**	**Rest before exam (min)**
Nigeria	1991-1993	Local	>90	25-74	Proportional stratified random population sample	Hg sphygm	3	10
Ghana (Kumasi)	2001-2002	Ashanti region	54	40-75	Stratified random sample from population census	Omron 705CP	3	5
Cameroon	1991-1994	Yaounde & villages	>90		Proportional stratified random population sample	Hg sphygm	3	10
Ghana (Accra)	1998	Greater Accra	75	25-102	Stratified two-stage cluster sampling	Hg sphygm	2	10
South Africa	2002	Agincourt sub-district	74	>35	Stratified random sample	Omron 705CP & M5-1	3	5
Tanzania	1998-1999	5 branches of Temeke District Dar es Salaam	62	25-64	Total population	Visomat® 2	3	
Seychelles	2004	National Census	80	25-64	Sex- and age-stratified random sample	Hg sphygm Automatic	3 3	30
Republic of Congo	2004	Brazzaville		25-64	Cluster sample	Tensoval®	3	
Jamaica	1993-1995	Spanish Town	65	25-74	Multistage, address	Hg sphygm	3	10
Barbados	1991-1994	Bridgetown	63		Proportional stratified random population sample	Hg sphygm	3	10
St Lucia	1991-1994	Vieux Forte	>90		Proportional stratified random population sample	Hg sphygm	3	10
US blacks	1988-1994	National	82	18-80+	Multistage population registry	Hg sphygm	6	5
UK blacks	1994-1996	SW London	64	40-59	Proportional stratified random population sample	Arteriosonde®	3	10

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Table 2

Age-adjusted prevalence of obesity, hypertension and its treatment in men (n=7,893) and women (n=10,179) age 35-64 years in populations of African descent across the world

Country	Sex	Sample size No.	% Obesity Mean (95% CI)	% Hypertensive Mean (95% CI)	% receiving Treatment for Hypertension Mean (95% CI)
			AFRICA		
Nigeria	Men	1306	0 (0 to 1)	12 (10 to 14)	0
	Women	1611	4 (3 to 5)	13 (11 to 15)	0
Ghana (Kumasi)	Men	298	1 (0 to 2)	22 (18 to 27)	1 (0 to 3)
	Women	481	5 (3 to 7)	19 (16 to 23)	2 (1 to 3)
Cameroon	Men	779	8 (6 to 10)	23 (20 to 26)	0
	Women	797	18 (15 to 20)	22 (19 to 25)	0
Ghana (Accra)	Men	1080	6 (5 to 8)	32 (29 to 35)	6 (4 to 7)
	Women	1644	26 (24 to 28)	36 (34 to 38)	6 (5 to 8)
South Africa	Men	54	2 (0 to 6)	36 (23 to 50)	7 (1 to 14)
	Women	195	27 (20 to 33)	35 (28 to 41)	8 (5 to 12)
Tanzania	Men	1665	7 (6 to 8)	32 (30 to 35)	3 (2 to 3)
	Women	2048	18 (16 to 20)	36 (34 to 38)	5 (4 to 6)
Seychelles	Men	442	18 (14 to 21)	53 (49 to 58)	29 (25 to 33)
	Women	538	41 (37 to 45)	48 (44 to 52)	35 (31 to 39)
Republic of Congo	Men	542	3 (1 to 4)	47 (43 to 51)	5 (3 to 7)
	Women	494	17 (14 to 20)	48 (43 to 52)	6 (4 to 8)
			CARRIBEAN		
Jamaica	Men	612	13 (10 to 16)	24 (21 to 28)	10 (8 to 12)
	Women	962	40 (37 to 43)	29 (27 to 32)	18 (16 to 20)
Barbados	Men	196	16 (11 to 21)	35 (28 to 42)	16 (11 to 21)
	Women	289	41 (35 to 47)	35 (30 to 41)	23 (18 to 28)
St Lucia	Men	293	8 (5 to 11)	32 (26 to 37)	4 (2 to 6)
	Women	335	33 (28 to 38)	39 (34 to 44)	17 (13 to 21)
			US/UK		
US blacks	Men	418	29 (24 to 33)	44 (38 to 48)	26 (22 to 30)

Country	Sex	Sample size No.	% Obesity Mean (95% CI)	% Hypertensive Mean (95% CI)	% receiving Treatment for Hypertension Mean (95% CI)
	Women	446	50 (46 to 55)	48 (44 to 53)	34 (29 to 39)
UK blacks	Men	208	14 (10 to 19)	55 (48 to 61)	23 (17 to 29)
	Women	339	34 (29 to 39)	43 (37 to 48)	24 (20 to 29)

Age-adjusted using direct standardization to WHO population in 5-year age band. Hypertension defined as blood pressure ≥140 and/or 90 mmHg or being on anti-hypertensive medication

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Table 3a

Relationships between blood pressure and body mass index in untreated men (n=7,347), age 35-64 years, in populations of African descent across the world.

		Systolic blood pressure (mm Hg per unit of BMI)		Diastolic blood pressure (mm Hg per unit of BMI)	
Country	**No.**	**ß (95% C I)**	**R^2**	**ß (95% C I)**	**R^2**
		AFRICA			
Nigeria *	1306	1.17 (0.84 to 1.51)	0.05	0.84 (0.63 to 1.04)	0.05
Ghana (Kumasi)	298	1.72 (0.92 to 2.53)	0.09	1.02 (0.51 to 1.52)	0.06
	293	1.73 (0.93 to 2.54)	0.09	1.01 (0.50 to 1.51)	0.05
Cameroon *	779	0.95 (0.64 to 1.27)	0.08	0.78 (0.54 to 1.02)	0.06
Ghana (Accra)	1080	1.52 (1.23 to 1.82)	0.15	1.12 (0.94 to 1.31)	0.14
	1018	1.45 (1.15 to 1.76)	0.14	1.07 (0.88 to 1.26)	0.12
South Africa	54	1.58 (−0.09 to 3.26)	0.07	0.97 (0.04 to 1.90)	0.09
	49	2.10 (0.08 to 4.11)	0.12	1.35 (0.30 to 2.40)	0.14
Tanzania	1665	0.95 (0.75 to 1.16)	0.14	0.48 (0.34 to 0.62)	0.07
	1631	0.87 (0.66 to 1.08)	0.12	0.43 (0.28 to 0.57)	0.06
Seychelles	442	0.85 (0.52 to 1.19)	0.16	0.50 (0.29 to 0.72)	0.09
	301	1.01 (0.65 to 1.38)	0.14	0.66 (0.42 to 0.90)	0.11
Republic of Congo	542	1.34 (0.90 to 1.78)	0.18	0.83 (0.53 to 1.14)	0.08
	519	1.30 (0.87 to 1.73)	0.17	0.86 (0.56 to 1.15)	0.09
		CARIBBEAN			
Jamaica	612	1.23 (0.90 to 1.55)	0.20	0.94 (0.69 to 1.19)	0.13
	550	1.18 (0.84 to 1.53)	0.17	0.90 (0.65 to 1.15)	0.12
Barbados	196	0.47 (−0.11 to 1.04)	0.11	0.34 (−0.03 to 0.71)	0.05
	166	0.29 (−0.37 to 0.94)	0.07	0.28 (−0.13 to 0.69)	0.04
St Lucia	293	0.74 (0.19 to 1.30)	0.07	0.90 (0.50 to 1.30)	0.08
	281	0.72 (0.16 to 1.28)	0.07	0.89 (0.48 to 1.30)	0.08
		US/UK			
US blacks	418	0.27 (−0.01 to 0.56)	0.07	0.15 (−0.06 to 0.36)	0.01
	305	0.26 (−0.07 to 0.58)	0.05	0.28 (0.03 to 0.52)	0.02
UK blacks	208	0.61 (−0.10 to 1.32)	0.06	0.64 (0.27 to 1.00)	0.07

Country	No.	Systolic blood pressure (mm Hg per unit of BMI) ß (95% C I)	R^2	Diastolic blood pressure (mm Hg per unit of BMI) ß (95% C I)	R^2
	149	0.89 (0.06 to 1.73)	0.05	0.76 (0.31 to 1.21)	0.08

All adjusted for age and calculated for each country separately;

* all untreated

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Table 3b

Relationships between blood pressure and body mass index in untreated women (n=9,163) age 35-64 years, in populations of African descent across the world.

Country	No.	Systolic blood pressure (mm Hg per unit of BMI) ß (95% C I)	R^2	Diastolic blood (mm Hg per unit of BMI) ß (95% C I)	R^2
AFRICA					
Nigeria *	1611	0.46 (0.22 to 0.69)	0.10	0.50 (0.36 to 0.63)	0.06
Ghana (Kumasi)	481	1.15 (0.68 to 1.61)	0.14	0.92 (0.68 to 1.16)	0.15
	467	1.23 (0.92 to 1.54)	0.14	0.92 (0.68 to 1.16)	0.15
Cameroon *	797	0.49 (0.22 to 0.77)	0.11	0.31 (0.13 to 0.50)	0.04
Ghana (Accra)	1644	1.09 (0.90 to 1.28)	0.19	0.76 (0.66 to 0.86)	0.15
	1546	1.01 (0.82 to 1.20)	0.18	0.72 (0.61 to 0.82)	0.13
South Africa	195	0.08 (−0.55 to 0.72)	0.06	0.41 (0.05 to 0.78)	0.03
	183	0.04 (−0.64 to 0.72)	0.07	0.42 (0.03 to 0.81)	0.03
Tanzania	2048	0.69 (0.53 to 0.85)	0.16	0.45 (0.35 to 0.56)	0.08
	1966	0.61 (0.45 to 0.77)	0.15	0.42 (0.31 to 0.52)	0.07
Seychelles	538	0.58 (0.32 to 0.84)	0.18	0.41 (0.25 to 0.57)	0.08
	332	0.47 (0.22 to 0.72)	0.15	0.36 (0.19 to 0.53)	0.07
Republic of Congo	494	1.32 (0.98 to 1.66)	0.25	0.75 (0.53 to 0.97)	0.15
	470	1.24 (0.90 to 1.57)	0.23	0.71 (0.48 to 0.93)	0.13
CARIBBEAN					
Jamaica	962	0.49 (0.29 to 0.69)	0.15	0.32 (0.19 to 0.45)	0.04
	787	0.46 (0.27 to 0.66)	0.15	0.32 (0.18 to 0.46)	0.04
Barbados	289	0.20 (−0.14 to 0.54)	0.16	0.16 (−0.05 to 0.37)	0.05
	216	0.19 (−0.14 to 0.53)	0.12	0.15 (−0.09 to 0.39)	0.03
St Lucia	335	0.11 (−0.24 to 0.45)	0.13	0.02 (−0.21 to 0.25)	0.03
	281	−0.02 (−0.37 to 0.34)	0.12	−0.02 (−0.28 to 0.23)	0.03
US/UK					
US blacks	446	0.58 (0.35 to 0.81)	0.17	0.26 (0.11 to 0.40)	0.03
	280	0.51 (0.24 to 0.77)	0.17	0.11 (−0.07 to 0.30)	0.01
UK blacks	339	0.33 (−0.09 to 0.75)	0.11	0.25 (0.03 to 0.48)	0.04

Country	No.	Systolic blood pressure (mm Hg per unit of BMI)		Diastolic blood (mm Hg per unit of BMI)	
		ß (95% C I)	R^2	ß (95% C I)	R^2
	227	0.54 (0.06 to 1.02)	0.14	0.37 (0.11 to 0.63)	0.06

All adjusted for age and calculated for each country separately;

* all untreated

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Table 4

Meta-regression of slope of blood pressure on body mass index in each country by sex against mean body mass index for sex and country.

	Systolic blood pressure β (95% CI)	Diastolic blood pressure β (95% CI)
Both sexes (n=17,972)	−0.10 (−0.15 to −0.06)	−0.09 (−0.12 to −0.06)
Untreated only ((n=16,510)	−0.11 (−0.16 to −0.06)	−0.08 (−0.11 to −0.05)
Men (n=7,893)	−0.17 (−0.26 to −0.08)	−0.10 (−0.16 to −0.04)
Untreated only (n=7,347)	−0.18 (−0.28 to −0.08)	−0.09 (−0.16 to −0.03)
Women (n=10,179)	−0.06 (−0.11 to −0.00)	−0.06 (−0.10 to −0.02)
Untreated only (n=9,163)	−0.06 (−0.13 to 0)	−0.07 (−0.11 to −0.03)

Interaction between sexes p=0.042 (systolic blood pressure) p=0.17 (diastolic blood pressure) without adjustment for anti-hypertensive therapy. Interaction between sexes p=0.054 (SBP) p=0.52 (DBP) in untreated only.

Model 1: blood pressure = $\beta_0 + \beta_1 \text{age} + \beta_2 \text{BMI}$ within country and sex strata.

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Table 5

Sensitivity analysis for effect of anti-hypertensive treatment. Meta-regression of slope of blood pressure on body mass index in each country by sex against mean body mass index for sex and country (7,893 men and 10,179 women).

	Systolic blood pressure	Diastolic blood pressure
No adjustment	−0.10 (−0.15 to −0.06)	−0.09 (−0.12 to −0.06)
10 mm Hg	−0.09 (−0.14 to −0.04)	−0.07 (−0.10 to −0.04)
15 mm Hg	−0.09 (−0.14 to −0.04)	−0.06 (−0.10 to −0.03)
20 mm Hg	−0.08 (−0.13 to −0.03)	−0.06 (−0.09 to −0.02)
25 mm Hg	−0.08 (−0.13 to −0.03)	−0.05 (−0.09 to −0.02)

Patients on anti-hypertensive therapy have blood pressure adjusted by random amount from a normal distribution with mean 10, 15, 20 and 25 mm Hg and SD equal to 0.5 × mean.