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Elevated Hypertension Risk for African-Origin Populations in Biracial Societies: Modeling the Epidemiologic Transition Study

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Abstract

Objectives—Blood pressures in persons of African descent exceed those of other racial/ethnic groups in the US. Whether this trait is attributable to genetic factors in African-origin populations, or a result of inadequately measured environmental exposures, such as racial discrimination, is not known. To study this question we conducted a multi-site comparative study of communities in the African diaspora, drawn from metropolitan Chicago, Kingston, Jamaica, rural Ghana, Cape Town, South Africa, and the Seychelles.

Methods—At each site 500 participants between the ages of 25 and 49, with approximately equal sex balance, were enrolled for a longitudinal study of energy expenditure and weight gain. In this report we describe the patterns of blood pressure and hypertension observed at baseline among the sites.

Results—Mean systolic and diastolic blood pressures were very similar in the US and South Africa in both men and women, although among women the prevalence of hypertension was higher in the US (24 vs. 17%, respectively). After adjustment for multiple covariates, relative to participants in the U.S., systolic blood pressure was significantly higher among South Africans by 9.7 mmHg ($p<0.05$) and significantly lower for each of the other sites: viz, Jamaica, −7.9 mmHg ($p=0.06$), Ghana, −12.8 mmHg ($p<0.01$), Seychelles, −11.1 mmHg ($p=0.01$).

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Author contributions RC, AL, TF, EVL, JPR, PB, RDA all conceived the idea and contributed equally to the manuscript. RDA, LRD, DAS, KG, LT, and GC all performed the analysis, tables and figures. All authors (RC, AL, TF, EVL, JPR, PB, RDA, LRD, DAS, KG, LT and GC) contributed equally to the interpretation of the data and writing of the manuscript.

Conclusion—These data are consistent with prior findings of a blood pressure gradient in societies of the African diaspora and confirm that African-origin populations with lower social status in multi-racial societies, such as the US and South Africa, experience more hypertension than anticipated based on anthropometric and measurable socioeconomic risk factors.

Keywords

blood pressure; African Diaspora; hypertension

Introduction

Beginning in the 1930's, epidemiologic research on cardiovascular risk factors in the US has given prominence to the disparity in hypertension risk among persons of African origin compared to those of European descent [1–3]. Relatively sparse data suggest that higher blood pressures are also observed among both Afro-Caribbean and African migrants to the UK [4, 5]. In the last decade a large number of surveys on blood pressure and hypertension has been carried out in Africa, however, these studies have invariably focused on specific communities or ethnic groups and have proven difficult to compare as a result of differing age distributions of the sampled participants, lack of age-standardization across studies and variation in the survey methodology used [6–14]. In studies where urban-rural comparisons were described, blood pressures were consistently lower in rural areas, and most sub-Saharan Africans still reside in rural communities [15]. In a large, internally standardized study comparing West Africans, Afro-Caribbeans and African Americans conducted in the 1990's we demonstrated a consistent east-to-west gradient in hypertension, closely paralleling the pattern of anthropometric and dietary risk factors [7]. In general, therefore, the current state of knowledge would suggest that in most of contemporary black Africa blood pressures are substantially lower than among African Americans.

Despite years of research, the cause of the black:white disparity in hypertension in the US is not well understood. A diet high in sodium and low in potassium is generally thought to be the *sine qua non* for age-related rise in blood pressure, while a low intake of fruits and vegetables together with obesity and lack of physical activity contribute additional risk [6, 16]. Nutritional and behavioral factors, however, do not fully explain the blood pressure gradient between US blacks and whites. Genetics and psycho-social stress have thus become the main competing hypotheses offered to explain racial patterns of hypertension in the US. A well-developed theoretical framework exists to support a role for chronic exposure to racial discrimination as a pathway to hypertension, although it remains difficult to confirm empirically [17–20]. Likewise, no convincing evidence yet supports the hypothesis that differential distribution of risk-conferring genetic polymorphisms can account for black:white patterns of blood pressure [7, 17, 21]. As result, the most informative data still come from comparisons of populations with similar ancestry in contrasting social contexts - under the assumption that the background of genetic factors is equivalent, geographic variation in blood pressure would offer support for a causal role of the social environment. Additional data is required, however, to confirm the role of psychosocial factors. Our prior study of the African diaspora demonstrates that environmental exposures are required to provoke the high rate occurrence of hypertension seen in US blacks [7], and data from

several multiracial countries in the Western Hemisphere other than the US have shown little evidence of a race gradient in blood pressure [22–26]. Surveys in additional African or Afro-origin populations could potentially shed further light on this long-standing debate.

We have undertaken a study of five community samples drawn from populations of African descent to examine differential risk of obesity, cardiovascular disease (CVD) and diabetes across differing levels of social and economic development [27]. In this report we assess a sub-set of the the measurable determinants of blood pressure and hypertension, such as body size, education attainment and employment type, and adjust comparisons for age and gender in the comparison of blood pressure across these communities.

Methods

Sampling Design and Participant Recruitment

Twenty-five hundred adults, ages 25–45, were enrolled in METS between January 2010 and December 2011. A detailed description of the study protocol has been previously published [27]. In brief, five hundred participants, approximately 50% of whom are female, were enrolled in each of five study sites: *viz*, rural Ghana, urban South Africa, the Seychelles, urban Jamaica and metropolitan Chicago. All participants were predominantly of African descent. The study sites were selected to represent a broad range of social and economic development as defined by the United Nations Human Development Index (HDI) 2010: i.e., Ghana as a low middle HDI country, South Africa as middle, Jamaica and the Seychelles as high, and the US as a very high HDI country.

Exclusion criteria included individuals with infectious diseases, including HIV-positive individuals, and pregnant or lactating women, as well as persons with conditions preventing normal physical activities, e.g. lower extremity disability. In Ghana, a simple random sample was generated for the age-range of the study from the population census for the rural town of Nkwantakese. In both Seychelles and South Africa sex- and age-stratified random samples were generated from their respective national censuses. In Kingston, Jamaica, districts were randomly sampled; beginning from a fixed point in each district (e.g., the north-west corner), and door-to-door recruitment was then carried out. Similarly, in Maywood, IL, USA, all city blocks in the community were randomized and door-to-door recruitment was conducted. The cohorts enrolled, therefore, were representative of their respective communities and are not to be viewed as nationally representative samples.

The protocol for METS was approved by the Institutional Review Board of Loyola University Chicago, IL, USA; the Committee on Human Research Publication and Ethics of Kwame Nkrumah University of Science and Technology, Kumasi, Ghana; the Research Ethics Committee of the University of Cape Town, South Africa; the Board for Ethics and Clinical Research of the University of Lausanne, Switzerland; the Ethics Committee of the University of the West Indies, Kingston, Jamaica; and the Health Sciences Institutional Review Board of the University of Wisconsin, Madison, WI, USA. Written informed consent was obtained from all participants.

Measurements

All measurements were made at outpatient clinics located in the communities. Weight (kg) and height (m) measurements were made on all participants while wearing light clothing and no shoes. Weight was measured to the nearest 0.1 kg using the same model standard calibrated balance at all 5 sites (Seca 770, Hamburg, Germany). Height was measured to the nearest 0.1 cm using a stadiometer (e.g. Invicta Stadiometer, Invicta, London, UK) with the participant's head held in the Frankfort plane. Waist circumference was measured to the nearest 0.1 cm at the umbilicus and hip at the point of maximum extension of the buttocks. Body mass index (BMI) was calculated as kg/m^2.

Body composition was estimated by bioelectrical impedance analysis (BIA) with the use of a single-frequency (50 kHz) impedance analyzer (model BIA 101Q; RJL Systems, Clinton Township, MI). A tetrapolar placement of electrodes was used on the right hand and foot. Fat-free mass (FFM) and fat mass (FM) were estimated from measured resistance by using an equation developed and validated in the METS cohorts [27].

Blood pressure was measured using the protocol of our ongoing international hypertension studies [7, 8, 28–30]. Systolic and diastolic blood pressure and pulse were measured using the Omron Automatic Digital Blood Pressure Monitor (model HEM-747Ic, Omron Healthcare, Bannockburn, IL, USA). With the antecubital fossa at heart level, three measurements were made at each of two time points separated by approximately 60 minutes for a total of six measurements. For the present analyses, the second, third, fifth and sixth measurements were averaged.

Questionnaires

Basic health history information, with a focus on cardiovascular conditions and diabetes, was collected, including age of first diagnosis where applicable. Fifty-four questions were included which covered general household characteristics, participant and significant other's occupation, parental education and household assets and amenities. These questions were based on the Core Welfare Indicators Questionnaire from the World Bank, originally designed to monitor social indicators in Africa [31].

Data management is centralized at the coordinating center at Loyola University Chicago. All data forms and questionnaires were scanned at each study site and, along with electronic Actical data files, were sent via secure FTP (Bitvise Tunnelier [32]) to the data manager at the coordinating center.

Statistical Analysis

Descriptive statistics were summarized using means+/−SD and proportions. Group differences were tested using Scheffe multiple comparison procedure, with the United States data as the reference [33]. Correlations were examined between blood pressure and anthropometric variables, and regression models developed to summarize multivariate relationships. In these analyses, data were stratified by site and sex as there were significant interactions between site and blood pressure, site and BMI, sex and blood pressure, and sex and BMI. All calculations were made using Stata (version 12, College Station, TX).

Results

The descriptive characteristics of the participants, by site, are presented in Table 1. Given the focus of the primary study on obesity, the full range of obesity rates in modern societies is included among the sampled participants, e.g., from approximately 50% in the US to 10% in Ghana, men and women combined. Among both men and women, Ghanaians were 6 cm shorter than the African Americans, likely reflecting lower nutrient intake before puberty. South African women and men were likewise 4–6 cm shorter than their US counterparts. A striking contrast in BMI was observed in South Africa, however, between men (mean BMI = 22) and women (mean BMI = 30); a similar, but considerably smaller, sexual dimorphism in obesity was seen in Jamaica.

The mean blood pressures observed in Ghana were the lowest, for both men and women, while the African Americans had the highest values. Findings among Jamaicans and participants from the Seychelles were intermediate. Among both sexes in South Africa, however, blood pressures were substantially higher than among Ghanaians, while for men at least the mean BMI and obesity prevalences were similar. The frequency distribution of both systolic and diastolic blood pressures demonstrates a substantial leftward skew in the South Africans (Figures 1a, b), and this variability is also reflected in the larger standard deviation around the mean. Any impact of treatment is captured in the definition of hypertension as current use of anti-hypertensive medications, and thus differential access to anti-hypertensive medication cannot explain the higher blood pressures in the South Africans.

Overall, the vast majority of participants were categorized as manual workers.. Because the sample frame for Ghana was rural, and in South Africa the study was carried out in an urban area, the types of employment were very different, with most South African men in the construction trades while in Ghana about a quarter of the men were engaged in subsistence agriculture. Only in the Seychelles and the United States did blood pressures differ between participants engaged in manual and non-manual labor ($p<0.001$); manual laborers' mean systolic blood pressure was 7 mmHg higher than among non-manual workers in the Seychelles (121.4 vs. 114.1 mmHg, respectively) and 8 mmHg higher in the United States (126.2 vs. 118.3 mmHg). Likewise, only in these two countries did blood pressures differ significantly among participants based on their primary occupations; in both the Seychelles and the United States, participants working in technical and craft occupations such as mechanics, plumbers or electricians, had mean systolic blood pressures significantly higher than the individuals reporting other primary occupations ($p<0.001$). In multivariate logistic analyses, controlling for age, sex, and BMI, we found no association between employment type, ie, manual labor vs. non-manual labor, either within site (p-values ranged from 0.10 to 0.91) or in the sample as a whole, after adjustment for site ($p=0.63$).

The prevalence of hypertension among men ranged from a low of about 5% in Ghana to over 30% in South Africa, and among women from 4% in Ghana to 24% in the US (Figure 2). Characteristics of those participants identified as hypertensive are presented in Table 2. While a similarly large proportion of hypertensive men in Ghana and South Africa were lean, high blood pressure was 6 times more common in South Africa. Among both Jamaican men and women there was a large discrepancy between the proportion that had been

previously told by a healthcare professional that they were hypertensive and the proportion currently taking medication for high blood pressure, suggesting either economic restrictions on purchasing the drugs or cultural biases against taking them. Except in Ghana, significant percentages of men currently smoked while among women smoking was relatively rare outside the United States. As anticipated, awareness of hypertension was low in Ghana and South Africa.

The single most significant epidemiologic risk factor for high blood pressure is elevated relative weight (Table 3). Correlations between BMI and systolic blood pressure among men in the various study samples ranged from 0.3 in the Seychelles to null in the US and South Africa (Figures 1.a and 1.b); among women, participants from the US had the weakest relationship between systolic blood pressure and BMI, and only the correlation observed in the Seychelles was significant, while South Africans again had the smallest point estimate.

The final multivariate regression model, controlling for age, sex, BMI, hypertension treatment, smoking status, years of education, employment type, site and the interactions between BMI and sex as well as BMI and site, illustrated that relative to the US systolic blood pressure was significantly higher among South Africans by 9.7 mmHg ($p<0.01$) and significantly lower for each of the other sites: viz, Jamaica, −7.9 mmHg ($p=0.06$), Ghana, −12.8 mmHg ($p<0.01$), Seychelles, −11.1 mmHg ($p=0.01$) (Table 4). In this model, other than the significant differences by site, age in years, treatment for hypertension and BMI were also statistically significant predictors of systolic blood pressure; 21.2% of the variance in systolic blood pressure was explained in the METS cohorts by this model.

Discussion

Using a standardized survey protocol we conducted a cardiovascular risk survey in five neighborhood cluster samples of populations of African origin. Hypertension prevalence was highest among the US participants when data for men and women were combined (~25%), although men in South Africa had comparable levels to US men (30%). Participants from the rural community in Ghana had relatively low blood pressures that increased little over the age-range surveyed here and hypertension prevalence was low (5%). Within each group an association with BMI was observed, although the magnitude of the correlation was lowest in the participants from populations with elevated blood pressures, namely the US and South Africa. The findings on BMI suggest that the South African population is fully integrated into the consumer lifestyle typical of Westernized societies, at least in respect to access to the quantity of calorie dense foods. After adjustment for body size, socioeconomic characteristics, smoking and treatment for hypertension, blood pressure was significantly higher among the participants from Khayelitsha, Cape Town, South Africa, than any of the other sites. In the multivariate statistical model controlling for measured risk factors, South Africans had 7.5 mmHg higher systolic blood pressure than did US participants, and this excess in blood pressure among South Africans was even more marked in comparison to the other cohort from Africa, resulting in a difference of 13.8 mmHg compared to Ghana.

Variation in the occurrence of disease in different geographic regions and among sub-populations, such as those categorized by race or ethnicity, has provided important clues to

etiologic factors and has contributed to the development of treatment and prevention strategies. As noted previously, the disparity in hypertension between blacks and whites in the US has been the focus of an enormous number of research studies and has served as the basis for the widely held view that genetic predisposition to high blood pressure varies between European and West African populations [18, 34]. However, as we have suggested elsewhere, this conclusion may reflect a myopic perspective that over-generalizes from the US data [8, 35]. In large regions of the world – particularly Eastern Europe and Russia – population surveys document much higher blood pressures than are found in US blacks, and stroke rates in Russia are almost 10 times higher than in the US [36]. In addition, studies with direct standardization of blood pressure measurement show a broad range of hypertension prevalences across the African diaspora, with consistently low rates observed in West Africa, and rates in the Caribbean similar to US whites [7].

In this report we further demonstrate that black South Africans have much higher blood pressures than West Africans; among men a 10 mmHg excess in age-adjusted systolic blood pressure is observed in the face of similar levels of at least one key risk factor – namely, obesity. Although political control was transferred to the majority black population in South Africa two decades ago, the enormous social and economic divisions between blacks and whites remain. In many respects, therefore, South Africa resembles the US more closely than any other country; both are biracial societies with marked residential segregation and economic inequality, two key measures of racial hierarchy. Other biracial societies in the Caribbean and South America, on the other hand, are characterized by far less racial polarization, although racialist attitudes remain prevalent and economic equality has not been achieved [22–26]. In Cuba, for example, a significant difference in blood pressure between blacks and whites is not observed, and narrow race gradients have also been documented in Trinidad and Brazil [22–26]. On the other hand, multiple surveys document higher blood pressures in blacks compared to whites in urban areas of South Africa [11, 37–39]. In Durban, South Africa, for example, prevalence of hypertension was 25% in blacks and 17% in whites in the 1980's [38]. A recent survey from the Cape Town area, conducted in close proximity to where our study was carried out, confirms very high levels of hypertension among black South Africans [40].

Information on risk factors for hypertension in our study was limited to BMI and variation in the strength of the BMI-blood pressure association by site was observed in our study. In a previous meta-analysis of 18,000 individuals of African origin we demonstrated a strong negative trend between the correlation of BMI with blood pressure and the prevalence of hypertension in a population [41], suggesting that the relative impact of relative weight declines as other factors came into play. This same finding is apparent in the data presented here, where relative weight seems to be playing a less important role in South Africa. This finding suggests that other environmental exposures assume a larger role in societies like the US and South Africa. We acknowledge, however, that given the relatively modest sample size this pattern could not be tested rigorously for statistical significance.

In a sense, our report completes a transition in the perspective toward hypertension in Africans that has been evolving for almost a century. Higher blood pressures in black Americans were recognized in the 1930's [1]. Among elderly blacks in rural Georgia mean

systolic blood pressures approaching 180 mmHg were recorded in the 1950's [1]. Unable to identify apparent causal factors in the environment, the prevailing view from the earliest discussions of this question posited that "…the frequency of hypertension in a given population … (is determined by)… the frequency in that population of a hypertensive gene" ([21], pg 183). Paul Dudley White, the preeminent American cardiologist of the first half of the 20th century, was particularly taken by the "high frequency with which hypertension has been found to exist among our American Negroes" ([21], pg 150). Looking past the dated language used in this commentary, White formulated an important insight into this question: "I used to ask my medical friends … about the situation in West Africa as to the prevalence of … hypertension in the jungle … " ([21], pg 150). But the evidence available at that time was fragmentary, based primarily on hospital cases from what was then Leopoldville in the Congo, and White concurred with the prevailing notion of "racial predisposition" ([21], pg151). The body of epidemiologic literature currently available instead points to etiologic forces inherent in the social context in which persons of African descent live as the most likely cause of racial differentials [42]. Research on the link between directly measured racial discrimination and blood pressure in US blacks has been inconsistent [17]. While the CARDIA cohort provided evidence of a "U"-shaped association, from lowest to highest levels of perceived discrimination, other studies have not replicated this finding [17]. Perceived discrimination is a difficult trait to study, however, and much of its impact may be mediated through mechanisms that are not consciously appreciated, or at least are difficult to quantify in survey research. In terms of the competing alternatives posed by the "nature-nurture" equation, emerging genetic studies do not support the hypothesis of excess heritable risk among blacks and known variants appear to have similar effects in all racial/ethnic groups studied to date [43]. Given the striking similarity in blood pressure distributions found in the US and South Africa, studies with direct standardization that attempted to account for dietary, psychosocial and genetic factors would help further clarify this long-standing etiologic conundrum.

There are several limitations to this study which should be recognized. First and foremost, the sample size by site is small, and the age range of participants does not include those at greatest risk of hypertension, namely the elderly. However, the young age range in our study, and as a consequence the small proportions of persons taking medications in all sites, has the advantage of limiting potential interference of treatment on blood pressure readings. Furthermore, by age 40 racial/ethnic trends in blood pressure are clearly apparent in the US, and the narrow age-range sampled in this study allows direct comparison across sites. As noted earlier, limited information was available on other hypertension risk factors and we were unable to identify significant contributors to the differences in blood pressure and hypertension risk across sites with our study's measured varaibles.. While the pattern of relationships between BMI and BP was similar to previous reports, none of the interaction comparisons (ie, cross-site BMI-BP correlations) were significant. Inferences about the contribution of racial marginalization in South Africa and the US must be based on the ecologic patterns described across Africa, the Caribbean and North America since no individual level measurements of discrimination were made. Additionally, the acknowledged impact of urban living on blood pressure and prevalence of hypertension cannot be ruled out as contributing to the high levels observed in the US and South Africa,

although all Jamaican participants were from Kingston, a large city with significant social stratification where we observed low mean blood pressure. Therefore the inference regarding the shared role of racial discrimination in the US and South Africa proposed here should be regarded as a hypothesis that requires further testing.

In conclusion, these data suggest that black South Africans in Cape Town have blood pressures that are disproportionately elevated relative to the level of obesity in the population, particularly among men, and thereby resemble closely the pattern seen in US blacks. Viewed within the context of geographic variation in blood pressure in the US, the Caribbean and other countries in Africa, one potential explanation of this finding could be the deleterious effect of racial discrimination that is a prominent feature of both US and South African society. A potential additive role for differences in dietary intake of sodium, potassium and fruits and vegetables cannot be excluded, however. Thus, we conclude that the primary finding from this study is the disproportionate elevation in blood pressure in the US and South African black population samples.

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References

1. Cooper R, et al. Trends and disparities in coronary heart disease, stroke, and other cardiovascular diseases in the United States: findings of the national conference on cardiovascular disease prevention. Circulation. 2000; 102(25):3137–47. [PubMed: 11120707]
2. Cooper R, Rotimi C. Hypertension in blacks. Am J Hypertens. 1997; 10(7 Pt 1):804–12. [PubMed: 9234837]
3. Egan BM, Zhao Y, Axon RN. US trends in prevalence, awareness, treatment, and control of hypertension, 1988–2008. JAMA. 303(20):2043–50. [PubMed: 20501926]
4. Cooper, RS. Hypertension Primer: The Essentials of High Blood Pressure. Izzo, LJ., editor. Council on High Blood Pressure Research, American Heart Association; 1998.
5. 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(8):523–34. [PubMed: 12874609]
6. Appel LJ, et al. A clinical trial of the effects of dietary patterns on blood pressure. DASH Collaborative Research Group. N Engl J Med. 1997; 336(16):1117–24. [PubMed: 9099655]
7. Cooper R, et al. The prevalence of hypertension in seven populations of west African origin. Am J Public Health. 1997; 87(2):160–8. [PubMed: 9103091]
8. Cooper RS, et al. An international comparative study of blood pressure in populations of European vs. African descent. BMC Med. 2005; 3:2. [PubMed: 15629061]
9. Amoah AG. Hypertension in Ghana: a cross-sectional community prevalence study in greater Accra. Ethn Dis. 2003; 13(3):310–5. [PubMed: 12894954]
10. Danaei G, et al. National, regional, and global trends in systolic blood pressure since 1980: systematic analysis of health examination surveys and epidemiological studies with 786 country-years and 5.4 million participants. Lancet. 377(9765):568–77. [PubMed: 21295844]
11. Hasumi T, Jacobsen KH. Hypertension in South African adults: results of a nationwide survey. J Hypertens. 30(11):2098–104. [PubMed: 22914543]
12. Dalal S, et al. Non-communicable diseases in sub-Saharan Africa: what we know now. Int J Epidemiol. 40(4):885–901. [PubMed: 21527446]

13. Twagirumukiza M, et al. Current and projected prevalence of arterial hypertension in sub-Saharan Africa by sex, age and habitat: an estimate from population studies. J Hypertens. 29(7):1243–52. [PubMed: 21540748]
14. Kayima J, et al. Hypertension awareness, treatment and control in Africa: a systematic review. BMC Cardiovasc Disord. 2013; 13:54. [PubMed: 23915151]
15. Kaufman JS, et al. Determinants of hypertension in West Africa: contribution of anthropometric and dietary factors to urban-rural and socioeconomic gradients. Am J Epidemiol. 1996; 143(12): 1203–18. [PubMed: 8651219]
16. Adrogue HJ, Madias NE. Sodium and potassium in the pathogenesis of hypertension. N Engl J Med. 2007; 356(19):1966–78. [PubMed: 17494929]
17. Arriola KJR. Racial Discrimination and Blood Pressure among Black Adults: Understanding the Role of Repression. Phylon. 2002; 50(1):47–69.
18. Cooper RS, Rotimi CN, Ward R. The puzzle of hypertension in African-Americans. Sci Am. 1999; 280(2):56–63. [PubMed: 9924813]
19. Krieger N, Sidney S. Racial discrimination and blood pressure: the CARDIA Study of young black and white adults. Am J Public Health. 1996; 86(10):1370–8. [PubMed: 8876504]
20. Sellers SL, et al. The impact of goal-striving stress on physical health of white Americans, African Americans, and Caribbean blacks. Ethn Dis. 2012; 22(1):21–8. [PubMed: 22774305]
21. White, PD. Hypertension and atherosclerosis in the Congo and in the Gabon. In: Stamler, J.; Stamler, R.; Pullman, TN., editors. The Epidemiology of Hypertension. Grune and Stratton; New York: 1967. p. 150-154.
22. Hajjar I, Kotchen TA. Trends in prevalence, awareness, treatment, and control of hypertension in the United States, 1988–2000. JAMA. 2003; 290(2):199–206. [PubMed: 12851274]
23. Ordunez P, et al. Risk factors associated with uncontrolled hypertension: findings from the baseline CARMEN survey in Cienfuegos, Cuba. J Hypertens. 2008; 26(4):663–71. [PubMed: 18327074]
24. Ordunez P, et al. Ethnicity, education, and blood pressure in Cuba. Am J Epidemiol. 2005; 162(1): 49–56. [PubMed: 15961586]
25. Ordunez-Garcia PO, et al. Hypertension in Cuba: evidence of a narrow black-white difference. J Hum Hypertens. 1998; 12(2):111–6. [PubMed: 9580091]
26. Sichieri R, Oliveira MC, Pereira RA. High prevalence of hypertension among Black and Mulatto women in a Brazilian survey. Ethn Dis. 2001; 11(3):412–8. [PubMed: 11572407]
27. Luke A, et al. Protocol for the modeling the epidemiologic transition study: a longitudinal observational study of energy balance and change in body weight, diabetes and cardiovascular disease risk. BMC Public Health. 2012; 11:927. [PubMed: 22168992]
28. Cooper RS, et al. Heritability of angiotensin-converting enzyme and angiotensinogen: A comparison of US blacks and Nigerians. Hypertension. 2000; 35(5):1141–7. [PubMed: 10818078]
29. Luke A, et al. Association between blood pressure and resting energy expenditure independent of body size. Hypertension. 2004; 43(3):555–60. [PubMed: 14757780]
30. Luke A, et al. Relationship between blood pressure and physical activity assessed with stable isotopes. J Hum Hypertens. 2005; 19(2):127–32. [PubMed: 15385948]
31. African Region InfoBriefs. Ghana: Poverty Monitoring with the Core Welfare Indicators Questionnaire. The World Bank Group. 1999; 39
32. Bitvise Tunnelier. Jan 8. 2011 [cited 2011 30 March]; Version 4.40:[Available from: http://www.bitvise.com/tunnelier
33. Rosner, B. Fundamentals of Biostatistics. 5 th Edition. Duxbury; Pacific Grove, CA: 2000. p. 530-532.
34. Cooper RS, Kaufman JS. Race and hypertension: science and nescience. Hypertension. 1998; 32(5):813–6. [PubMed: 9822436]
35. Cooper RS, Kaufman JS, Ward R. Race and genomics. N Engl J Med. 2003; 348(12):1166–70. [PubMed: 12646675]

36. Redon J, et al. Stroke mortality and trends from 1990 to 2006 in 39 countries from Europe and Central Asia: implications for control of high blood pressure. Eur Heart J. 32(11):1424–31. [PubMed: 21487117]

37. Steyn K, et al. Hypertension in South African adults: results from the Demographic and Health Survey, 1998. J Hypertens. 2001; 19(10):1717–25. [PubMed: 11593090]

38. Seedat YK, Seedat MA, Hackland DB. Prevalence of hypertension in the urban and rural Zulu. J Epidemiol Community Health. 1982; 36(4):256–61. [PubMed: 7166680]

39. Lloyd-Sherlock, P., et al. Int J Epidemiol. 2014. Hypertension among older adults in low- and middle-income countries: prevalence, awareness and control.

40. Steyn K, et al. The global cardiovascular diseases risk pattern in a peri-urban working-class community in South Africa. The Mamre study. Ethn Dis. 2004; 14(2):233–42. [PubMed: 15132209]

41. Cappuccio FP, et al. Body size and blood pressure: an analysis of Africans and the African diaspora. Epidemiology. 2008; 19(1):38–46. [PubMed: 18091416]

42. Cooper RS. Race in biological and biomedical research. Cold Spring Harb Perspect Med. 2013; 3(11)

43. Franceschini N, et al. Genome-wide association analysis of blood-pressure traits in African-ancestry individuals reveals common associated genes in African and non-African populations. Am J Hum Genet. 2013; 93(3):545–54. [PubMed: 23972371]

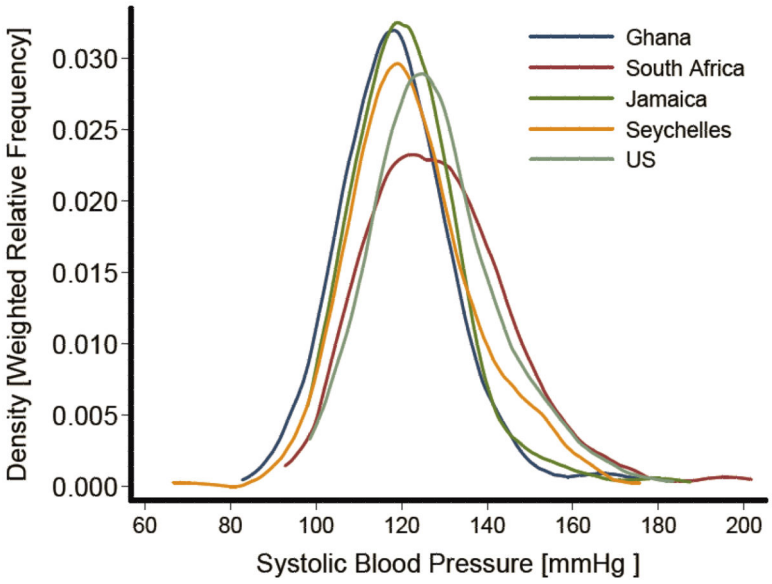

Figure 1a.
Frequency distribution of systolic blood pressures for men, by site, in METS

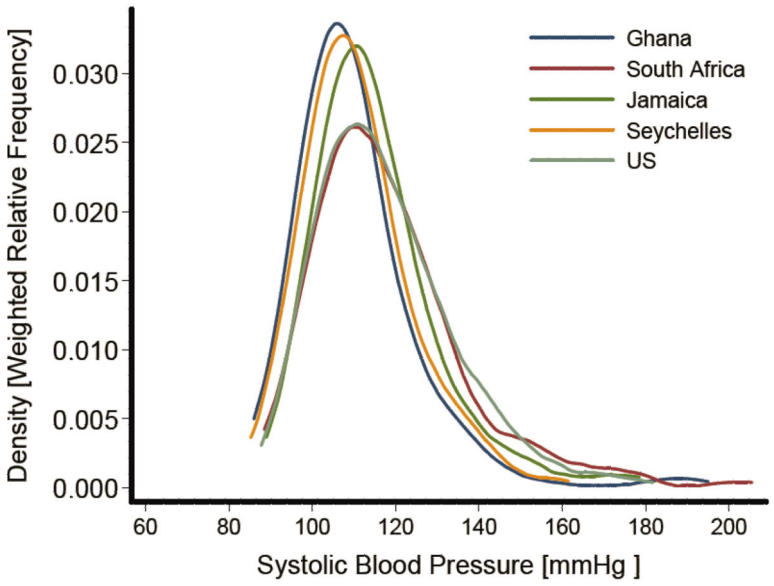

Figure 1b.
Frequency distribution of systolic blood pressures for women, by site, in METS

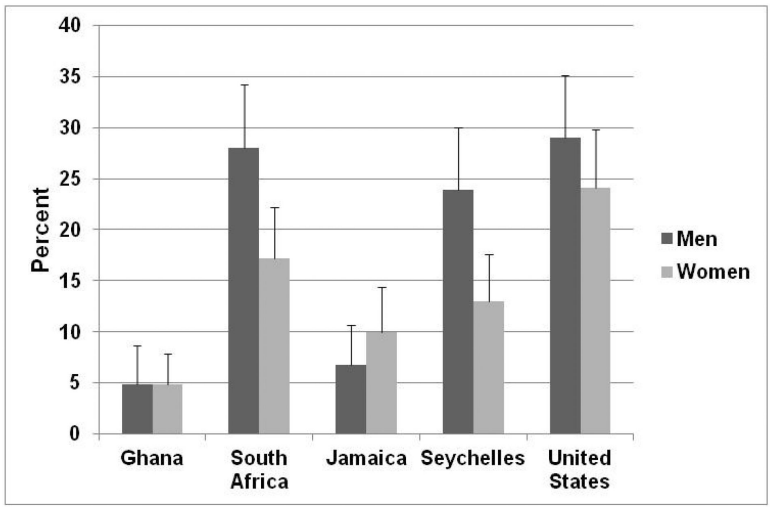

Figure 2a.
Prevalence of hypertension, by site and gender, in METS

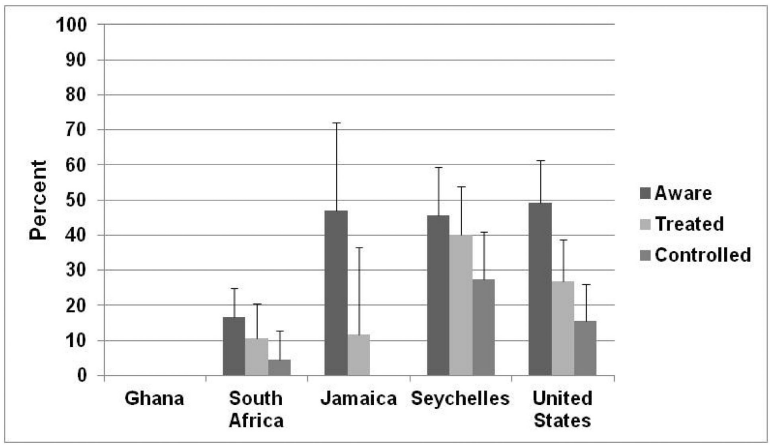

Figure 2b.

Proportion of male hypertensive participants aware of condition, taking medications for hypertension and having their hypertension controlled in METS. Number of hypertensive participants by site: Ghana (n=10), South Africa (n=66), Jamaica (n=17), Seychelles (n=55), United States (n=71)

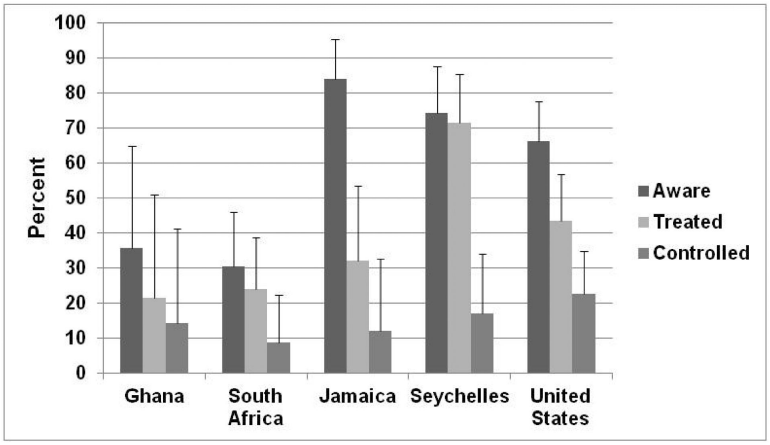

Figure 2c.

Proportion of female hypertensive participants aware of condition, taking medication for hypertension and having their hypertension controlled in METS. Number of hypertensive participants by site: Ghana (n=14), South Africa (n=46), Jamaica (n=25), Seychelles (n=35), United States (n=62)

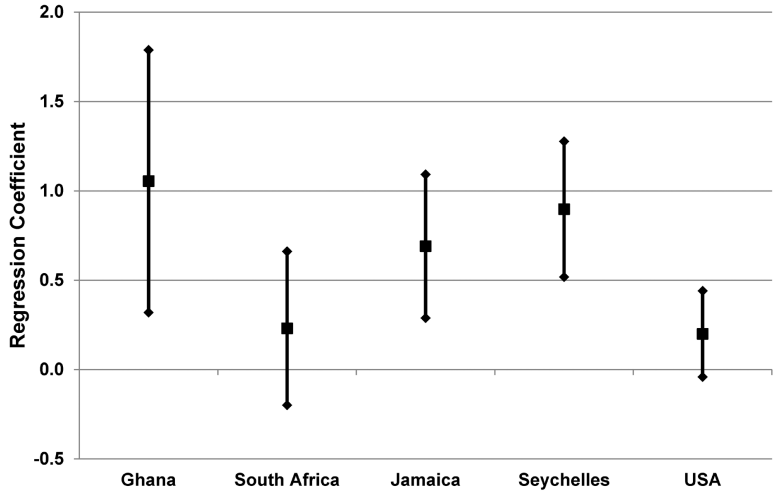

Figure 3a.

Regression coefficients (95% confidence intervals) for relationship between systolic blood pressure and BMI by site and sex among men in the Modeling the Epidemiologic Transition Study (METS), adjusted for age. Regression coefficients differ across sites (likelihood ratio test $p<0.05$).

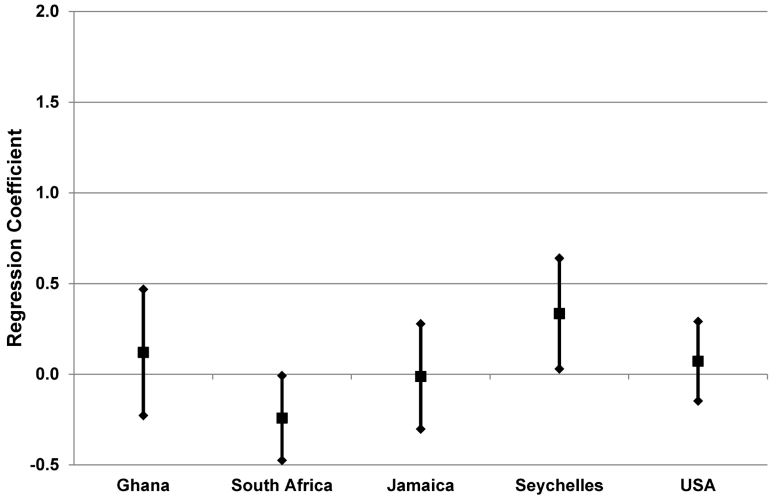

Figure 3.b.

Regression coefficients (95% confidence intervals) for relationship between systolic blood pressure and BMI by site among women in the Modeling the Epidemiologic Transition Study (METS), adjusted for age. Regresiion coefficients differ across sites (likelihood ratio test $p<0.05$).

Table 1

Participant Characteristics by Site and Sex – mean ± SD.

	Ghana	South Africa	Jamaica	Seychelles	United States
			Men		
Sample size	207	232	249	230	243
Age (y)	34.6 ± 6.7*	33.7 ± 5.6*	34.0 ± 5.9	36.5 ± 5.1	35.5 ± 6.2
Weight (kg)	63.6 ± 9.1**	65.5 ± 13.6**	73.1 ± 15.0**	80.1 ± 16.0**	92.7 ± 24.9
Height (cm)	169.0 ± 6.6**	170.8 ± 6.3**	176.0 ± 6.7	173.9 ± 6.2**	176.6 ± 6.6
Body Mass Index (kg/m^2)	22.2 ± 2.7**	22.4 ± 4.3**	23.6 ± 4.5**	26.5 ± 4.9**	29.7 ± 7.6
Waist Circumference (cm)	77.1 ± 10.5**	80.9 ± 11.5**	80.3 ± 12.1**	89.4 ± 11.8**	97.2 ± 21.6
Body Fat (%)	19.4 ± 6.8**	27.6 ± 7.3**	22.5 ± 7.9**	27.5 ± 7.8**	32.5 ± 10.1
Systolic Blood Pressure (mmHg)	118.9 ± 13.1**	129.0 ± 17.1	121.5 ± 12.8**	122.7 ± 14.6*	127.9 ± 14.5
Diastolic Blood pressure (mmHg)	68.5 ± 11.4**	79.6 ± 13.2	71.2 ± 11.1**	75.0 ± 11.4**	81.0 ± 12.1
			Women		
Sample size	293	268	251	270	257
Age (y)	34.0 ± 6.6	33.1 ± 6.0*	34.7 ± 6.2	35.8 6.0	35.0 ± 6.3
Weight (kg)	63.6 ± 13.1**	82.0 ± 22.2**	78.5 ± 18.6**	72.1 ± 17.3**	91.7 ± 24.4
Height (cm)	158.0 ± 5.7**	160.1 ± 6.3**	163.2 ± 6.6**	161.4 ± 6.5**	164.0 ± 6.2
Body Mass Index (kg/m^2)	25.5 ± 5.2**	31.9 ± 8.2*	29.5 ± 6.7**	27.6 ± 6.2**	34.1 ± 8.8
Waist Circumference (cm)	84.2 ± 12.5**	96.9 ± 16.6*	92.0 ± 13.8**	87.9 ± 12.4**	101.9 ± 19.6
Body Fat (%)	34.6 ± 7.3**	44.9 ± 7.7	39.5 ± 7.2**	37.8 ± 7.5**	45.5 ± 7.7**
Systolic Blood Pressure (mmHg)	110.5 ± 15.2**	118.2 ± 18.6	115.2 ± 14.7	110.8 ± 12.8*	117.5 ± 16.1
Diastolic Blood Pressure (mmHg)	66.2 ± 11.4*8	76.3 ± 11.8*	72.1 ± 11.4**	71.2 ± 9.9**	79.6 ± 13.2

*Significantly different from United States, p<0.05

**Significantly different from United States, p<0.001

Table 2

Characteristics of Participants Identified as Hypertensive* (%)

	Ghana	South Africa	Jamaica	Seychelles	United States
			Men		
% Hypertensive (N)¥	4.8 (10)	28.0 (66)	6.8 (17)	23.9 (55)	29.0 (71)
Awareness¥	0	16.7**	47.1	45.5	49.3
Currently Taking BP Meds	0	10.6	11.8	40.0*	26.8
BMI < 25.0	80.0**	75.8**	52.9*	20.0*	12.7
BMI 25.0 – 29.9	20.0	15.2*	5.9*	41.8	33.8
BMI ≥ 30.0	0	9.1**	41.2	38.2	53.5
Current Smoker	16.7	58.9	35.7	29.5*	51.5
			Women		
% Hypertensive (N)¥	4.8 (14)	17.2 (46)	10.0 (25)	13.0 (35)	24.1 (62)
Aware¥	37.5*	30.4**	84.0	74.3	66.1
Currently Taking BP Meds	21.4	23.9*	32.0	71.4*	43.6
BMI < 25.0	35.7*	15.2	20.0	17.1	6.5
BMI 25.0 – 29.9	42.9*	30.4*	32.0*	25.7	12.9
BMI ≥ 30.0	21.4**	54.4*	48.0*	57.1*	80.7
Current Smoker	0	7.7*	12.0*	4.8*	37.1

¥Hypertension defined as systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥90 mmHg, or taking hypertension medications; Awareness defined as having been told previously by physician they had high blood pressure

*Significantly different from United States, $p<0.05$

**Significantly different from United States, $p<0.01$

Table 3

Pearson Correlation Coefficients for Systolic Blood Pressure or Diastohc Blood Pressure and Age and Measures of Adiposity Among Participants Untreated for Hypertension[£*] (r)

	Systolic Blood Pressure					Diastolic Blood Pressure				
	Ghana	**South Africa**	**Jamaica**	**Seychelles**	**United States**	**Ghana**	**South Africa**	**Jamaica**	**Seychelles**	**United States**
					Men					
Age	−0.01	0.14	0.07	0.20	0.18	0.16	0.19	0.15	0.30	0.17
BMI	0.24	0.08	0.22	0.27	0.10	0.23	0.10	0.30	0.46	0.27
Waist	0.14	0.10	0.23	0.22	0.13	0.15	0.15	0.33	0.42	0.28
%Fat	0.09	0.11	0.16	0.15	0.02	0.17	0.18	0.26	0.34	0.16
					Women					
Age	0.16	0.34	0.33	0.28	0.20	0.17	0.35	0.28	0.22	0.18
BMI	0.04	−0.15	0.04	0.14	0.02	0.22	0.05	0.30	0.26	0.25
Waist	0.10	−0.10	0.09	0.16	0.07	0.23	0.07	0.32	0.29	0.27
%Fat	−0.02	−0.16	0.003	0.005	−0.01	0.16	0.08	0.23	0.15	0.17

£Sample sizes for men: Ghana (n=207), South Africa (n=229), Jamaica (n=247), Seychelles (n=208), United States (n=226); sample sizes for women: Ghana (n=290), South Africa (n=268), Jamaica (n=243), Seychelles (n=245), United States (n=230)

*A11 correlation coefficients (r) ≥ 0.14 are statistically significant at $p<0.05$

Table 4

Multiple Regression Model Describing Systolic Blood Pressure in the METS Cohorts*

	B Coefficient	95% Confidence	Interval	p-value
Age (y)	0.45	0.34	0.55	<0.001
Sex**	1.40	−3.92	6.71	0.61
BMI (kg/m^2)	0.34	0.14	0.55	0.001
Treatment for hypertension	12.8	9.83	15.85	<0.001
Current smoker	1.16	−0.49	2.80	0.17
Manual labor	−0.49	−2.00	1.02	0.52
Education (y)	−0.18	−0.42	0.06	0.15
Sites				
South Africa	9.66	2.53	16.79	<0.01
Ghana	−12.76	−21.85	−3.68	<0.01
Jamaica	−7.88	−16.05	0.28	0.06
Seychelles	−11.11	−19.86	−2.36	0.01
Interaction terms				
BMI X Sex	−0.41	−0.60	−0.22	<0.001
BMI X South Africa	−0.22	−0.45	0.01	0.06
BMI X Ghana	0.29	−0.05	0.62	0.10
BMI X Jamaica	0.22	−0.06	0.50	0.12
BMI X Seychelles	0.21	−0.08	0.51	0.16
Intercept	101.8	90.1	113.5	<0.001

*21.2% of variance in systolic blood pressure in METS cohorts explained by this model (r^2 =0.212)

**Variable coding: men = 1, women = 2; self-reported treatment for hypertension = 1, no treatment = 0; current smoker = 1, non-smoker = 0; manual labor job = 1, non-manual labor job = 0