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Stimulus Response of Blood Pressure in Black and White Young Individuals Helps Explain Racial Divergence in Adult Cardiovascular Disease: The Bogalusa Heart Study

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Abstract

Blood pressure (BP) is a highly variable physiologic trait with short-term and long-term fluctuations within the same individual at different time points. The burden of BP on the cardiovascular (CV) system has been studied in terms of multiple cross-sectional BP measurements at rest, response of BP to stresses, as well as long-term longitudinal variability of BP. Observations from childhood are available extending into early middle age in the biracial (black-white) population of Bogalusa. Left ventricular mass index was used to illustrate damaging effects on the CV system by both resting BP levels and fluctuations. Long term BP variability reflecting intermittent and repeated variability was shown to have a greater effect in blacks. The childhood BP response to several stressors was found greater in blacks. These observations suggest, although at rest a greater vagal effect occurs in blacks, they show a greater response when reacting to a stimulus. This along with aspects like carbohydrate-insulin metabolism or other biochemical/physiological differences may account for the greater acceleration of CV atherosclerosis in blacks. The racial contrasts suggest, in part, lipoproteins effects may be greater in whites, while the effects of excess BP levels and variability of BP and Na⁺-K⁺ intake and diet as well as other environmental effects result in more CV damage in blacks. The strong association of hemodynamic measures with anatomic, metabolic and environmental factors emphasizes the need to begin prevention of risk factors, at an early age. Taken together, understanding racial (black-white) contrasts to stress contribute to both prevention and treatment of hypertension, especially for black males.

Keywords

blood pressure; hypertension; ethnicity; black/white contrasts; stimulus response; sympathetic activity

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Introduction

The etiology of essential hypertension is multifactorial in nature involving an interplay of genes and a host of other factors from lifestyle to environment. Despite decades of research, specific genetic and pathophysiologic mechanisms mediating the elevation of blood pressure (BP) are not completely understood (1).

BP is a highly variable physiologic trait which increases with age and body growth in childhood and has two aspects: 1) different levels among individuals at one time point (among-individual variability) and 2) short-term and long-term fluctuations within the same individual at different time points. (within-individual variability) (2,3). Studies have shown that wide variability of BP over a long-term period or 24 hours is associated with severity of end organ damage and an increase of subsequent cardiovascular (CV) and cerebrovascular events, even after adjusting for the mean BP levels (4,5).

Recently, long-term BP variability, as well as 24 hour monitoring, has received increasing attention because of its practical implications in the prevention and treatment of hypertension and related disorders (4–11). However, whether long-term BP variability, especially beginning in childhood, is a more powerful parameter than their levels per se in predicating cardiac/cerebral/renal diseases is unknown, particularly in blacks compared to whites. Further, studies in childhood among blacks and whites over time may provide clues to mechanisms of BP control with important implications for treatment and prevention.

Observations in Childhood

The within-individual variability has been studied in terms of 24 hours by ambulatory monitoring but also can be measured over seconds (beat to beat changes related to heart rate) (8). Children with higher casual levels of blood pressure, but not classified as hypertension, had a greater percentage of high levels persisting over 24 hours by ambulatory measurements comprising a greater BP load. Further, the decrease (nondipping) that occurs at night is less in blacks than in whites even in childhood (12–14). We found two series of casual measurements may misclassify a child as having hypertension and a series of 4–6 observations with replicate measurements are needed to establish hypertension in children. Importantly, a parental history of hypertension has an effect as expected (13). Observations of children in the top quintile show an increase in cardiac size by left ventricular wall thickness in systole, even adjusted for body surface area, ponderosity, race and sex (15). Echocardiographic observations also show racial differences in hemodynamic parameters in childhood, e.g., higher cardiac output in white males and higher peripheral resistance in blacks Fig 1(16).

Further studies conducted on children and adolescents selected at high, medium and low levels provided additional clues to mechanisms of BP control (17, 18). Based on diastolic BP (fourth phase), children aged 7–15 years were grouped into 5 strata: 1 (low BP) to 5 (high BP), representing all children of the extreme 2% for each strata 1 and 5; 70% random sampling fraction of the next 4% to 9% for strata 2 and 4; 3% to 8% random sampling fraction of the remaining children for stratum 3, for each race-sex specific group. Strata 1 and 2 were combined to form the low stratum; strata 3 the medium stratum; and strata 4 and 5 the high stratum. Black/white and gender contrasts were observed, as shown in table 1. Of particular interest are the higher BP levels and slower heart rate in black children; lower renin levels and less of a relation of BP levels to body weight and fatness in blacks. These observations also showed lower 24 hour urinary excretion of K^+ in blacks, implicated the renin-angiotensin system and dietary sodium intake as predictors of childhood BP levels and development of hypertension in blacks. The faster heart rates, a greater relation of BP to body fatness in white children, higher glucose and lower insulin levels suggested more

metabolic and adrenergic influences on BP levels in white versus black subjects; electrolyte exposure and state of renin-angiotensin system have more influence among black subjects.

The notion of a greater parasympathetic role in childhood BP in blacks with slower heart rate was challenged with observations from CARDIA on young adults showing faster heart rates in blacks (19). Further, observations from Oparil and co-workers (20) and Victor and co-workers (21) indicated increased sympathetic activity in black adults with hypertension by leg peroneal nerve impulse studies. Our heart rate variability studies earlier on children and adolescents in Bogalusa, indicated more sympathetic activity in whites. The observations in Bogalusa children and adolescents suggested more vagal control at rest in blacks and a greater sympathetic response occurring in young blacks with higher BP levels (22). Their findings in adults were in conflict with our observations in black children and adolescents.

The studies in Bogalusa subjects at rest were reminiscent of a strong vagal effect during diving reflex in seals, whales and other mammals (23,24). At rest the observations of slower heart rate and the heart rate variability studies implicated more parasympathetic control in blacks. Yet, with maturation into adulthood, there is increasing obesity, occurrence of metabolic syndrome and increasing BP levels indicating the need for longer observations, blood pressure and heart rate changing from childhood to adulthood. These were conducted as studies of the pressure-heart rate-product (double product) (25). Using long-term studies with repeated measures, the double product was found higher in white children but lower in black children (Fig 2). A “crossover” occurred around the 3rd decade of life, indicating racial (black-white) contrasts that implicated environmental as well as intrinsic factors.

Other studies of children were conducted in those stratified by BP levels, as above. BP responses (stimulus or stress responses) were examined to determine orthostatic changes, cold pressure effects and effect of hand grip isometric changes (26,27). These studies indicated a greater stimulus response of BP in blacks, especially black males. The opposite occurred for heart rate with a greater response in white children (Fig 3). The variations at rest and response by several stimuli indicated more complex control of BP involving baroreceptors and other mechanisms, eg endothelial function, which differs by race and sex. Heart rate may be more controlled by central cardiac control and a response to peripheral resistance.

Blood Pressure Variability Studies Over Long-Term

Aspects regarding blood pressure control was further explored by studying long-term observations from childhood extending into early middle age, using BP as a highly variable quantitative trait (28,29). Although BP measurements at one time point among individuals have provided important information on divergences in cardiac, renal and vascular diseases among individuals, as mentioned earlier, the variations or fluctuations within an individual over time could provide additional information with respect to mechanisms related to the development of hypertension and to disease of the CV system (30,31). Longitudinal data of the Bogalusa Heart Study children growing into adults was used to study trends of systolic BP changes from one individual to the next in terms of area under the curve (AUC), shown in figure 4. Data include adults, aged 24–48 years, mean age 38.4 years with 4 to 14 serial examinations from childhood with an average of 19.7 years of follow-up, 8515 total observations each representing six BP readings at each serial examination (32, 33). We noted, variability increased with age along with increasing levels of BP, especially in blacks.

The serial changes were evaluated by three methods: 1) BP variability as age related trends (variability I) (Fig 4) ; 2) deviations around age predicted values (variability II) (Fig 5) and 3) deviations from the mean (variability III) (Fig 6). Variability measures from childhood to

adulthood for each type of evaluation, as shown in table 2, indicate significant race and gender differences.

Standardized regression analysis of systolic BP variability for adult LVM index is shown in table 3 for the three models, adjusted for sex and adult age, TG/HDL-C, LDL-C and glucose. Strongest relations were shown for BMI and systolic BP variability in both races, while for diastolic BP significant relations were found for blacks and for BMI for both races (data not shown).

With regards to target organ changes, the impact of variability of systolic BP indicated significant increases of adult left ventricular mass (LVM) index in blacks. Similar effect was noted for diastolic BP (data not shown).

These results showed blacks vs whites and males vs females had greater BP variability. The impact on LVM index was greater in blacks, even after adjusting for average BP levels and other covariates. Further, BP variability, indicating a greater stimulus (stress) response, and responses in childhood all showed a greater burden of BP on the CV system over time (26,27). These observations are consistent with the greater vascular disease noted at autopsy in blacks, but more atherosclerosis of coronary vessels occurring earlier in white males (34,35).

Mechanism(s) and Clinical Implications

The BP measurements at rest and response to some stimulus producing variability show the complexity of BP control. Such observations implicate baroreceptor control of blood pressure as well as metabolic and hormonal influences governing BP changes moment to moment and over time. It is known that BP variability increases with age, increases with arterial vascular stiffness and with diabetes (4,5). The relatively recent development of non-invasive instruments that measure compliance, central aortic pressure, augmentation index, pulse wave velocity, integrity of vascular endothelium and intima-media thickness by Doppler studies provide an opportunity to note CV system effects by BP and potential target organ damage.

BP and heart rate have circadian patterns that are usually attributed to variations in autonomic tone and the renin-angiotensin-aldosterone system (RAAS). These are clearly important, and reflected by BP variability. However, the autonomic nervous system and the RAAS are primarily concerned with regulating flow to various vascular beds by altering vascular tone, heart rate and stroke volume. The determination of the need for variations in BP resides in the ability to accommodate increase or decrease in blood flow and that ability is dependent on the vascular endothelium responding to various shear stresses, which can be induced by various stimuli.

The regulation of vascular tone by the endothelium is governed primarily by endothelial-derived relaxing factor, i.e. nitric oxide (NO) and endothelial-derived hyperpolarizing factor. Interestingly, it has been found that black individuals produce more superoxide and less NO than white individuals (36) resulting in increased production of oxidant peroxynitrite. The endothelium is also responsible for modulating baroreceptor function. The differences in endothelial nitric oxide / superoxide / peroxynitrate metabolism underscore the potential predisposition to endothelial dysfunction and related disorders such as hypertension and diabetes mellitus in blacks (37). Further, excess adiposity results in endothelial dysfunction. Clearly, all of these mechanisms play a role in the variation of response seen between individuals, as well, by race-sex groups.

In our studies LVM index was used to illustrate damaging effects of both resting BP levels and fluctuations on the CV system. Long term BP variability reflecting intermittent and repeated variability was shown to have a greater effect in blacks (33). The childhood stimulus response to several BP challenges was found greater in blacks but an opposite effect by heart rate in whites (26,27). The observations suggest, although at rest a greater vagal effect occurs in blacks, they show a greater response, when reacting to a stimulus in blacks. Perhaps this along with aspects like carbohydrate-insulin metabolism or other biochemical/physiological differences may account for the greater acceleration of CV atherosclerosis of the abdominal aorta (34) and earlier vascular stiffness.

Even among youths and young adults there is more intimal surface involvement of coronary atherosclerosis with fibrous plaques in white males (35, 38), indicating earlier and greater coronary atherosclerotic disease in the white males. Yet, abdominal aorta intimal surface involvement with atherosclerotic lesions being greater in blacks may relate to variability of BP affecting a more distensible vascular area. Also, even though coronary calcification is greater in black males at high risk, less mortality from coronary atherosclerosis occurs in blacks than in whites (39). These racial contrasts suggest, in part, lipoproteins changes may be greater in whites, while the effects of higher and varying BP levels and dietary Na⁺-K⁺ and other environmental effects result in more overall CV damage in blacks. The occurrence of more diabetes mellitus in blacks also contributes to the complexity of mechanisms having an effect on the CV system (40,41). Such effects contribute to CV disease and an early age of death in black males.

Conclusion

The strong association of hemodynamic measures with anatomic, metabolic and environmental factors emphasizes the need to begin prevention of risk factors, at an early age. Taken together, the above studies showing racial (black-white) contrasts to stress underscore their importance for both prevention and treatment of hypertension, especially for black males. The observations also have implications for lifestyle and behavioral modifications, and choice of antihypertensive drugs which may have differences in effecting stimulus responses in black vs white subjects.

Acknowledgments

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Endocardiographically Measured Left Ventricular Output and Peripheral Resistance on Boys and Young Men across Age Groups and by Race

Soto, et al. Am J Med Sci 1989. The Bogalusa Heart Study (16)

Figure 1.

Echocardiographic studies show greater cardiac output in white boys and greater peripheral resistance in black boys.

Berenson, et al. J Am Soc Hypertens. 2008. The Bogalusa Heart Study. (25)

Figure 2.

Observations of heart rate show rates decrease with age from childhood to middle age with higher levels in white children while heart rate $\times$ systolic BP (double product) was greater in white children and greater in black adults with a “crossover” around 25 years of age. (25)

Adapted from Voors et al. Hypertension. 1980. The Bogalusa Heart Study. (26)

Figure 3.

Stimulus response to various stressors shown by resting-supine and maximal-stressed systolic BP as measured by the Whittaker Sphygmostat, by race, sex, and BP stratum. Black boys showed most significant ($p < 0.005$) positive trends over the BP strata for a variety of stresses. In contrast whites show increase of heart rate. Adapted from Voors et al. Hypertension. (26)

Variability I = age-related trend (a); Long-term burden = a + b

Chen W, et al. J Biomed Biotechnol. 2010. The Bogalusa Heart Study. (32)

Figure 4.

Area under the curve for systolic BP for two different individuals at various examinations. The first trace is for all individuals showing BP from childhood extending into adulthood. (32)

Variability II = Deviations around age-predicted values

Chen W, et al. American College of Cardiology 59th Annual Scientific Session 2010.

The Bogalusa Heart Study. (33)

Figure 5.
 Systolic BP variability deviation from age predicted value. (33)

Variability III = Deviations from mean values

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The Bogalusa Heart Study. (33)

Figure 6.

Systolic BP at serial measurements showing deviation from mean levels. (33)

Table 1

Contrasts Regarding Correlates of Blood Pressure Levels in Black and White Children	
White > Blacks	Blacks > Whites
<u>All blood pressure strata</u>	
Percentage body fat	Blood pressure (BP)
Plasma renin activity	Lower urine K ⁺ excretion
Dopamine β hydroxylase (D β H)	
Fasting plasma glucose	
<u>High blood pressure strata</u>	
Resting heart rate	Peripheral resistance
Cardiac output	Correlation of 24-h urine Na ⁺ with BP
Renin activity and D β H	(males only)
1-h postprandial plasma glucose	Inverse correlation of plasma renin with BP

Berenson, et al. Metabolism. 1979. The Bogalusa Heart Study. (18)

Table 2

Variability Measures of Blood Pressure from childhood to Adulthood

	White		Black		Race Difference	
	Male n=317	Female n=401	Male n=125	Female n=210	Male	Female
SBP (mmHg)						
Variability I	13.1	8.1**	17.0	13.2**	<0.001	<0.001
Variability II	4.2	3.9**	4.7	4.5	<0.001	<0.001
Variability III	7.6	6.1**	10.3	8.5**	<0.001	<0.001
DBP (mmHg)						
Variability I	11.7	8.7**	12.4	10.9**	0.100	<0.001
Variability II	4.0	4.0	4.4	4.5	0.017	<0.001
Variability III	7.5	5.9**	8.9	7.4**	<0.001	<0.001

Variability I = age related trend; Variability II = deviations around age-predicted values; Variability III = deviations from overall mean

Sex difference within racial group:

* p<0.05;

** P<0.01

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Table 3

Standardized Regression Coefficients of Systolic BP Variability Measures on Adulthood LVM Index (g/m^2), Adjusting for Sex, Adulthood Age, TG/HDL-C, LDL-C and Glucose

	Whites	Blacks
	β	β
Model I		
BMI	0.42**	0.45**
First childhood BP	0.07	0.16**
BP Variability I	0.11**	0.29**
Model II		
BMI	0.42**	0.46**
Average BP	0.10**	0.24**
BP Variability II	0.01	0.01
Model III		
BMI	0.42**	0.45**
Average BP	0.10**	0.11
BP variability III	0.02	0.23**

p<0.01

Chen W, et al. American College of Cardiology 59th Annual Scientific Session 2010. The Bogalusa Heart Study. (33)