

# Hypertension, Blood Pressure, and Heart Rate Variability

## The Atherosclerosis Risk in Communities (ARIC) Study

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**Abstract**—Dysregulation of the autonomic nervous system has been implicated in the development of hypertension. Heart rate variability is a noninvasive tool to quantitatively estimate cardiac autonomic activity and has been used to document decreased cardiac autonomic activity in hypertension. The ability of decreased heart rate variability to predict incident hypertension has not been well studied, and there are no studies of whether hypertension leads to changes in heart rate variability. We investigated the temporal sequence linking hypertension, blood pressure, and heart rate variability in a population-based cohort of 11 061 individuals aged 45 to 54 years at baseline. Individuals with hypertension had decreased heart rate variability at baseline, and this association was present across the full blood pressure range. Among 7099 individuals without hypertension at baseline, low heart rate variability predicted greater risk of incident hypertension over 9 years of follow-up. The hazard ratio (95% confidence interval [CI]) for the lowest compared with the highest quartile of the standard deviation of normal-to-normal R-R intervals was 1.24 (95% CI, 1.10–1.40), for the root mean square of successive differences in normal-to-normal R-R intervals was 1.36 (95% CI, 1.21–1.54), and for R-R interval was 1.44 (95% CI, 1.27–1.63). Over 9 years, there was no measurable difference in the rate of change in heart rate variability among those with and without hypertension, although the differences in heart rate variability at follow-up were smaller than those at baseline. These findings thus support the thesis that the autonomic nervous system is involved in the development of hypertension, yet suggest that differences in the autonomic profile of hypertensives and normotensives do not increase with time. (*Hypertension*. 2003;42:1106–1111.)

**Key Words:** autonomic nervous system ■ heart rate ■ heart rate variability ■ hypertension, detection and control ■ blood pressure

Although the pathogenesis of most hypertension is unclear, dysregulation of the autonomic nervous system has been implicated in its development. Heart rate variability (HRV) has emerged as a practical, noninvasive tool to quantitatively investigate cardiac autonomic dysregulation in hypertension. Studies have reported decreased HRV among hypertensives<sup>1–12</sup> and that the relation between blood pressure and HRV is present across a wide range of blood pressures.<sup>12,13</sup> Data from the Framingham cohort and a subset of the Atherosclerosis Risk in Communities (ARIC) cohort suggest that individuals with decreased HRV have an increased risk of developing hypertension, although results are inconsistent across measures of HRV<sup>1,2</sup> and sex.<sup>2</sup> It is also unknown to what degree hypertensives and normotensives experience similar declines in HRV. Thus, although the autonomic nervous system is involved in the regulation of blood pressure, the temporal sequence linking hypertension and HRV is unclear. This study was designed to investigate this temporal sequence over 9 years in the full ARIC cohort.

## Methods

### Study Population

The ARIC study is a prospective study of the natural history and etiology of atherosclerotic disease and of cardiovascular disease event rates, with the study population selected as a probability sample of 15 792 men and women aged 45 to 64 years from 4 US communities. The study objectives, design, sampling scheme, and cohort examination procedures have been described.<sup>14</sup> Eligible participants were interviewed at home and then invited to a baseline clinical examination between 1987 and 1989. Participants returned for 3 triennial follow-up clinical examinations. Before each examination, participants were asked to fast for 12 hours, to refrain from using tobacco, and not to participate in vigorous activities. HRV was measured at the baseline and third follow-up exams, whereas hypertension status was assessed at each examination.

The sample size for the baseline cross-sectional analysis was 11 061. After further exclusion of individuals with prevalent hypertension or without follow-up data, the sample size for the analysis of incident hypertension was 7009. The sample size for the analysis of the effect of baseline hypertension on the subsequent change in HRV was 6931. Detailed exclusion criteria can be found at <http://hyper.ahajournals.org>.

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## Heart Rate Variability

HRV was assessed by 2-minute and 6-minute beat-to-beat heart rate recordings approximately 9 years apart. We focused on 3 HRV measures: the mean normal-to-normal R-R interval length, the standard deviation of normal-to-normal R-R intervals (SDNN), and the root mean square of successive differences in normal-to-normal R-R intervals (rMSSD) (all in milliseconds). SDNN reflects total variability, and rMSSD estimates high-frequency variations in heart rate and primarily reflects the actions of the parasympathetic nervous system.<sup>15</sup> Whereas SDNN and rMSSD measure fluctuations in autonomic nervous system activity, the mean R-R interval measures the sum of the levels of parasympathetic and sympathetic influences.

The baseline resting, supine, 2-minute beat-to-beat R-R interval data were collected and analyzed according to standardized protocols and methods.<sup>16–18</sup> At the final follow-up examination, 6-minute records were collected under similar conditions.<sup>16</sup> Details of the processing of these HRV records can be found at <http://hyper.aha-journals.org>. Longer records were obtained at the final follow-up visit than the baseline visit to obtain more precise HRV estimates. These different lengths resulted in estimates that were not directly comparable. We therefore applied adjustment equations to the 6-minute records by using equations derived from a set of 271 6-minute records from the follow-up examination that were truncated at 2 minutes and reprocessed:

$$\begin{aligned}\ln(\text{RR}_{2\text{-minute}}) &= 0.01 + 1.00 \times \ln(\text{RR}_{6\text{-minute}}) \\ \ln(\text{SDNN}_{2\text{-minute}}) &= -0.09 + 0.98 \times \ln(\text{SDNN}_{6\text{-minute}}) \\ \ln(\text{rMSSD}_{2\text{-minute}}) &= 0.08 + 0.95 \times \ln(\text{rMSSD}_{6\text{-minute}})\end{aligned}$$

with correlation coefficients between observed 6-minute and 2-minute values of 0.99, 0.90, and 0.94, respectively. We did not examine frequency-domain measures because their performance in the adjustment equations was considered unacceptable.

## Other Measurements

Sitting blood pressure was measured 3 times with a random-zero mercury sphygmomanometer after a 5-minute rest; the average of the last 2 readings was used. Hypertension was defined as systolic blood pressure  $\geq 140$  mm Hg, diastolic blood pressure  $\geq 90$  mm Hg, or self-reported use of medications for high blood pressure during the 2 weeks preceding the clinic examination.

Participants also brought to the examination all medications they had taken in the preceding 2 weeks. Treated hypertensives were self-reported users of medications for high blood pressure and/or those who were taking medication from at least 1 of the following medication classes: angiotensin-converting enzyme (ACE) inhibitors,  $\beta$ -blockers, calcium channel blockers, diuretics, or other antihypertensive medication. Individuals without elevated blood pressure who were not self-reported users of medications for high blood pressure but who brought in 1 of the specific medications mentioned were classified as antihypertensive medication users but were also considered normotensive.

Trained interviewers administered questionnaires that assessed smoking history, physical activity, educational attainment, and medical history. Smoking status was characterized as current, former, or never. Education was classified as less than high school, high school, or greater than high school. Diabetes was defined as a fasting glucose level  $\geq 7.0$  mmol/L, a nonfasting level  $\geq 11.1$  mmol/L, a self-reported physician diagnosis, or pharmacologic hypoglycemic treatment.

## Statistical Analysis: Cross-Sectional

In this population, SDNN and rMSSD were positively skewed. In light of the robustness of our statistical models to departures from normality at large sample sizes, we elected not to logarithmically transform these measures for ease of interpretability of the change in HRV models. We first calculated adjusted means for the HRV measures by hypertension status. We also analyzed the association between blood pressure and HRV by pooling normotensives and hypertensives and using linear regression to determine the estimated

difference in HRV associated with a 10-mm Hg increment in blood pressure. Because of a strong effect modification by antihypertensive medication use, models included a term for medication use and a medication–blood pressure interaction term. To determine whether blood pressure and HRV were associated throughout the blood pressure range, we fit restricted quadratic splines stratified by medication use, with knots at the fifth, 25th, 50th, 75th, and 95th percentiles of the blood pressure distribution.<sup>19</sup> To compare the relative strengths of the HRV–blood pressure associations, we computed partial correlation coefficients, stratified by antihypertensive medication use, and adjusted for age, sex, race, study center, diabetes, smoking, education, and body mass index (BMI). When indicated, we investigated the effect of specific medication classes by using indicator variables.

## Statistical Analysis: Incident Hypertension

Incident hypertension was defined as systolic blood pressure  $\geq 140$  mm Hg, diastolic blood pressure  $\geq 90$  mm Hg, or self-reported use of antihypertensive medications at any of the 3 follow-up examinations among baseline normotensives. We used Weibull parametric models for interval censored data to estimate the hazard ratio of developing incident hypertension. The Weibull model is an accelerated-failure time model and a proportional-hazards model.<sup>20</sup> To determine whether the relation was monotonic, we specified the exposure by using indicator variables for the HRV quartiles, with lower cutpoints of 26.3, 34.8, and 45.9 ms for SDNN; 17.3, 24.6, and 34.9 ms for rMSSD; and 824.5, 904.4, and 988.8 ms for R-R interval. We also fit models with continuous HRV measures and report these results as the hazard ratio associated with a 1–interquartile range increment in the HRV measure. We examined potential effect modification by sex, diabetes, and BMI by using interaction terms.

## Statistical Analysis: Change in HRV

We defined the mean annual change between baseline and follow-up as follow-up HRV minus baseline HRV, all divided by the number of years between baseline and follow-up. We present the mean annual change in HRV, both with and without adjustment for baseline HRV.

Analyses that adjusted for baseline HRV were corrected for measurement error in baseline HRV measures, blood pressure, and continuous risk factors, after assuming random intraindividual plus measurement process variations in these variables. Following a previously described procedure,<sup>21,22</sup> we used a regression calibration method to correct for multivariate measurement error.<sup>23</sup> Measurement errors for all baseline independent variables were assumed to be statistically independent, as well as those between HRV measurements taken at baseline and follow-up.

Reliability coefficients are available from repeated measurements 1 to 2 weeks apart on 63 individuals using the ARIC protocol for R-R interval (0.92), SDNN (0.86), and rMSSD (0.91). On the basis of reliability coefficients of 0.99 for weight and height, we used an estimate of 0.95 for BMI. Unpublished results from 190 ARIC participants with repeated measurements 1 to 2 weeks apart during the second follow-up examination period gave reliability coefficients of 0.75 for systolic blood pressure and 0.62 for diastolic blood pressure. Statistical analyses were performed with SAS version 8 (SAS Institute, Inc).

## Results

### Cross-Sectional Findings

Of the 3577 hypertensives at baseline, 72% were treated with antihypertensive medication. Further details of the study population can be found in the online-only data supplement (available at <http://www.hypertensionaha.org>).

Crude SDNN, rMSSD, and R-R interval were lower among hypertensives compared with normotensives, and this difference persisted after adjustment for age, sex, race, study center, diabetes, smoking, education, and BMI (Table 1).

**TABLE 1. Adjusted\* Means (95% CIs) for Baseline HRV Measures by Prevalent Hypertension Status: ARIC Study**

HRV Measure, ms	Normotensives	Hypertensives		
	n=7484	All (n=3577)	Treated (n=2562)	Untreated (n=1015)
SDNN	37.3 (37.0, 37.7)	35.1 (34.5, 35.6)†	35.0 (34.4, 35.7)†	35.2 (34.2, 36.2)†
rMSSD	28.6 (28.2, 29.0)	27.4 (26.8, 28.0)†	28.1 (27.4, 28.8)	25.8 (24.7, 26.8)†
R-R interval	908.7 (905.7, 911.8)	897.1 (892.6, 901.6)†	912.3 (907.0, 917.6)	860.5 (852.4, 868.5)†

HRV indicates heart rate variability; SDNN, standard deviation of R-R intervals; rMSSD, root mean square of successive differences in R-R intervals.

\*Adjusted for age, sex, race, study center, diabetes, smoking, education, and BMI.

† $P<0.05$ , compared with normotensives.

Treated hypertensives had a higher rMSSD and longer R-R interval than did untreated hypertensives, with no difference for SDNN. Treated hypertensives and normotensives had a similar rMSSD and R-R interval. Because of the large number of medication combinations and possible confounding by indication, it was difficult to determine the effects of different medications on HRV. In general, those using  $\beta$ -blockers had HRV equal to or greater than that in untreated hypertensives, whereas those using diuretics or ACE inhibitors had a lower HRV (data not shown).

Higher blood pressure was associated with markedly lower HRV in the entire cohort (data not shown). There was considerable effect modification by antihypertensive medication use, with stronger associations among individuals not using antihypertensive medications (Table 2). The associations tended to be stronger for diastolic than for systolic blood pressure, as measured by partial correlation coefficients (data not shown). Splines supported the use of a single linear term in the models and revealed that, if anything, the slope of the HRV–blood pressure association was steeper at lower blood pressures. Similarly, the associations were even greater when the analysis was restricted to normotensives (data not shown).

### Incident Hypertension

After adjustment for age, sex, race, study center, smoking, education, and BMI, we observed an inverse monotonic relation between HRV at baseline and development of hypertension (Table 3). In models with continuous HRV measures,

**TABLE 2. Estimated Differences\* (95% CIs) in HRV Measures for Each 10-mm Hg Increment in Blood Pressure by Antihypertensive Medication Use: ARIC Study**

Blood Pressure, mm Hg	HRV Measure, ms	Medication Use	
		No	Yes
Systolic	SDNN	−0.71 (−0.93, −0.50)	−0.23 (−0.52, 0.06)†
	rMSSD	−1.06 (−1.30, −0.84)	−0.17 (−0.48, 0.15)†
	R-R	−14.42 (−16.13, −12.72)	−5.72 (−8.06, −3.37)†
Diastolic	SDNN	−1.72 (−2.07, −1.37)	−1.38 (−1.90, −0.86)
	rMSSD	−2.44 (−2.81, −2.06)	−1.73 (−2.29, −1.17)†
	R-R	−32.02 (−34.81, −29.24)	−27.58 (−31.68, −23.47)

\*Adjusted for age, sex, race, study center, diabetes, smoking, education, BMI, antihypertensive medication use, and a blood pressure–medication use interaction term.

† $P<0.05$ , for blood pressure–medication use interaction term.

we found a hazard ratio (95% confidence interval [CI]) for a 1–interquartile range decrement (20 ms for SDNN, 18 for rMSSD, and 174 ms for R-R interval) of 1.11 (95% CI, 1.05–1.18) for SDNN, 1.12 (95% CI, 1.06–1.17) for rMSSD, and 1.18 (95% CI, 1.12–1.26) for R-R interval. We did not observe any appreciable interaction with age, sex, or obesity, although slightly stronger associations were observed among diabetics than nondiabetics (data not shown).

### Change in HRV

Compared with the baseline cross-sectional sample, individuals who had HRV data at the third follow-up examination tended to be slightly younger and were less likely to be black or male, more likely to be never-smokers, or more highly educated, less likely to be diabetic, and to have slightly higher baseline SDNN and R-R interval (please see <http://hyper.ahajournals.org>).

SDNN and rMSSD decreased over the 9 years of follow-up while R-R interval increased (Table 4). The differences in HRV by baseline hypertensive status had decreased considerably by the follow-up examination. The differences in the rate of change of HRV between normotensives and all hypertensives were not statistically significant, however, with or without adjustment for baseline HRV. Treated hypertensives and normotensives had very similar mean annual changes. Whereas untreated hypertensives had different rates of change compared with normotensives, the direction was not consistent across HRV measures.

### Discussion

Not only was prevalent hypertension associated with decreased HRV but also the association between HRV and blood pressure was present across the full blood pressure range. Individuals with low HRV at baseline were at an increased risk of developing hypertension over 9 years of follow-up, thus indicating that decreased HRV often precedes the development of hypertension. Although there were no measurable differences in the rate of change in HRV among those with and without hypertension over 9 years, the differences in HRV at follow-up were smaller than those at baseline.

### Cross-Sectional Findings

As the largest such study to date, our findings concerning HRV and prevalent hypertension are in agreement with previous large, population-based<sup>1–3,12</sup> and case-control<sup>4–9</sup> studies. Although there is disagreement about the association

**TABLE 3. Adjusted\* Hazard Ratios (95% CIs) of Incident Hypertension From Weibull Models Over 9 Years of Follow-Up, by Quartiles of Baseline HRV: ARIC Study**

HRV Measure, ms	HRV Quartile			
	4	3	2	1
SDNN	1.00	1.03 (0.91, 1.17)	1.20 (1.06, 1.36)	1.24 (1.10, 1.40)
rMSSD	1.00	1.08 (0.95, 1.22)	1.17 (1.04, 1.33)	1.36 (1.21, 1.54)
R-R interval	1.00	1.07 (0.94, 1.22)	1.20 (1.06, 1.36)	1.44 (1.27, 1.63)

\*Adjusted for age, sex, race, study center, diabetes, smoking, education, and BMI.

between normalized low-frequency power and hypertension, these studies agree that individuals with prevalent hypertension have lower SDNN, lower high-frequency power and low-frequency power in absolute units, and decreased R-R interval. Most of these studies focused on frequency-domain measures, with fewer reporting on rMSSD<sup>2</sup> or SDNN.<sup>1–3,6</sup> We found equal or higher HRV among users of  $\beta$ -blockers and decreased HRV among users of ACE inhibitors and diuretics. This differs from the findings of the Hoorn and the Framingham studies, which found lower HRV among users of  $\beta$ -blockers (Framingham and Hoorn) and diuretics (Hoorn).<sup>3,24</sup>

Only 2 studies have examined the association of HRV with blood pressure throughout the blood pressure range on a continuous or interval scale. One examined systolic and diastolic pressure and also found slightly stronger associations for diastolic than systolic blood pressure.<sup>12</sup> In the other study, the association between systolic blood pressure and SDNN was greatly attenuated by adjustment for age.<sup>13</sup> Another study, small and limited to hypertensives, found only weak associations between blood pressure and HRV.<sup>11</sup> Our data show that the HRV–blood pressure association extends

to low blood pressures and is stronger among lower blood pressures than among blood pressures in the hypertensive range. This finding is significant, because it shows that the association between blood pressure and HRV is continuous, without a marked threshold and with important effects even at relatively low blood pressures.

### Incident Hypertension

To our knowledge, only 2 studies have examined the relation between HRV and incident hypertension. The Framingham study reported the 4-year cumulative incidence of hypertension based on 2-hour HRV records and found an association between logarithmically transformed low-frequency power among men only and no association for SDNN and high-frequency power in either sex. Odds ratios adjusted for baseline blood pressure were presented, which might be an overadjustment, because blood pressure is on the causal pathway between HRV and hypertension.<sup>2</sup> In a subset of ARIC records with slightly different data processing, Liao et al<sup>1</sup> reported an increased 3-year cumulative incidence of hypertension by quartile of high-frequency power and SDNN, with no association for low-frequency power. Our association

**TABLE 4. Adjusted\* Means (95% CIs) and Annual Mean Changes (95% CIs) of HRV by Baseline Hypertensive Status: ARIC Study**

HRV Measure	Normotensives	Hypertensives		
	(n=4959)	All (n=1972)	Treated Hypertensives (n=1442)	Untreated Hypertensives (n=530)
<b>SDNN</b>				
Baseline, ms	37.8 (37.4, 38.3)	35.7 (35.0, 36.5)†	35.7 (34.8, 36.5)†	35.9 (34.6, 37.3)†
Follow-up, ms	31.5 (31.1, 31.9)	30.2 (29.5, 30.8)†	30.3 (29.5, 31.0)†	29.8 (28.7, 31.0)†
Mean annual decrease, ms/y	0.71 (0.66, 0.77)	0.63 (0.54, 0.72)	0.60 (0.50, 0.71)	0.68 (0.52, 0.85)
Mean annual decrease, adjusted for baseline, ms/y‡	0.67 (0.62, 0.71)	0.74 (0.67, 0.81)	0.73 (0.65, 0.80)	0.78 (0.66, 0.91)
<b>rMSSD</b>				
Baseline, ms	28.6 (28.1, 29.1)	27.2 (26.5, 28.0)†	28.0 (27.1, 28.9)	25.2 (23.8, 26.6)†
Follow-up, ms	24.9 (24.4, 25.3)	24.3 (23.5, 25.0)	24.6 (23.7, 25.4)	23.5 (22.1, 24.8)
Mean annual decrease, ms/y	0.42 (0.36, 0.48)	0.33 (0.23, 0.43)	0.39 (0.27, 0.50)	0.19 (0.01, 0.37)†
Mean annual decrease, adjusted for baseline, ms/y‡	0.39 (0.34, 0.44)	0.40 (0.33, 0.48)	0.40 (0.31, 0.49)	0.42 (0.27, 0.56)
<b>R-R interval</b>				
Baseline, ms	911.5 (908.0, 915.0)	906.8 (901.1, 912.6)	922.2 (915.5, 928.9)†	866.8 (856.1, 877.4)†
Follow-up, ms	964.3 (960.4, 968.1)	966.4 (960.1, 972.6)	975.3 (968.0, 982.5)†	943.1 (931.5, 954.7)†
Mean annual increase, ms/y	5.92 (5.53, 6.31)	6.65 (6.01, 7.28)	5.93 (5.19, 6.67)	8.53 (7.36, 9.70)†
Mean annual increase, adjusted for baseline, ms/y‡	5.97 (5.62, 6.33)	6.52 (5.94, 7.10)	6.37 (5.70, 7.05)	6.91 (5.83, 8.00)

\*Adjusted for age, sex, race, study center, diabetes, smoking, education, and BMI.

† $P < 0.05$ , compared with normotensives.

‡Corrected for measurement error in baseline covariates.



for SDNN is smaller than that reported by Liao et al, which might be caused by random sampling error, slight differences in data processing, or different follow-up periods.

To assess the possible impact of regression to the mean, we repeated these analyses with a lower baseline hypertension cutpoint (blood pressure  $\geq 130/85$ ) or a higher incident hypertension cutpoint (blood pressure  $\geq 160/90$ ); this did not appreciably change the results.

Our findings with regard to HRV and incident hypertension suggest that autonomic nervous system dysregulation precedes the development of clinical hypertension. This interpretation is supported by the work of Reaven et al,<sup>25</sup> Palatini and Julius,<sup>26</sup> and Julius and Nesbitt,<sup>27</sup> which posits that dysregulation of the autonomic nervous system is involved in the development of clinical hypertension. Reaven et al emphasized the increased sympathetic activity, whereas Julius and coworkers described both sympathetic overactivity and parasympathetic withdrawal. In fact, sympathetic overactivity could explain many components of the multiple metabolic syndrome, of which hypertension is just one component.

### Change in HRV

Julius and colleagues<sup>27,28</sup> further suggest that, as part of the "blood pressure seeking property" of the central nervous system, sympathetic tone will tend to decrease after the development of hypertension. Observing that many individuals with mild or borderline hypertension have increased cardiac output, normal vascular resistance, and an increased heart rate, Julius and colleagues hypothesized that prolonged blood pressure elevation, increased sympathetic activity, and decreased parasympathetic activity lead to a normalization of cardiac output, an increase in vascular resistance and parasympathetic tone, and a decrease in sympathetic tone. This theory therefore suggests that the HRV of hypertensives and normotensives would tend to converge with time. In general, this is what we observed in our cohort, although we did not detect any substantial differences between hypertensives and normotensives in the rate of change in HRV.

We present our findings for the change in HRV both unadjusted and adjusted for baseline HRV values because there is controversy concerning adjustment for baseline values. When adjusting a change for the baseline value, one must adjust for measurement error, or else the resulting estimates will be biased.<sup>22</sup> The unadjusted values compare the change in HRV while ignoring the effect of baseline HRV, whereas the adjusted values compare the change in HRV conditional on baseline HRV. Given the correlation between baseline HRV and the change in HRV, some estimates are affected by adjustment for baseline HRV. Our overall conclusions, however, are not.

This study used a large, biracial, population-based cohort with 9 years of follow-up to examine the relation between HRV and hypertension from many temporal viewpoints. To highlight some weaknesses in our results, we were limited by the different recording lengths at baseline and follow-up. Although our conversion equations were extremely reliable for time-domain measures, they were inadequate for frequency-domain measures. HRV measurements were avail-

able at only 2 time points, which limited the types of analyses that we could perform. Furthermore, whereas both HRV recordings were taken during the morning, the mean recording time at the follow-up examination was approximately 1 hour earlier than the mean recording time at baseline, so HRV circadian rhythms affected our estimates. Although there was a sizable amount of missing HRV information, the differences in cardiovascular risk factors between those with HRV information and the full cohort were small. In addition, 2633 individuals did not attend the third follow-up examination. Complex treatment regimens and the possibility of indication bias made exploring the differences between treated and untreated hypertensives difficult. Although we had excellent data on hypertension incidence, the duration of prevalent hypertension at baseline was unknown.

### Perspectives

Our findings suggest that there is a decline in HRV relatively early in the development of hypertension, although we did not detect any substantial differences in the rate of change in HRV between hypertensives and normotensives over 9 years. Our prospective results also indicate that decreases in autonomic nervous function precede the development of clinical hypertension. These findings are thus consistent with the hypotheses of Julius and colleagues concerning the "blood pressure seeking property" of the central nervous system.<sup>27,28</sup> However, autonomic regulation of heart rate is the result of the complex interplay of several factors. By using short-term, time-domain HRV measures, we have only partially captured cardiac autonomic nervous system function. Thus, there are aspects of normal and abnormal autonomic regulation that are not reflected in our results. Furthermore, given that blood pressure is a complex trait determined by the interaction of multiple genetic, environmental, and demographic factors and that involves numerous autoregulatory responses, it is difficult to determine to what degree decreases in autonomic nervous function are a cause or a consequence of hypertension. Further studies are needed to isolate the various contributions of sympathetic overactivity versus parasympathetic withdrawal, as well as the role of various antihypertensive treatments, on changes in HRV.

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