Association Between Concurrent and Remote Blood Pressure and Disability in Older Adults

Ihab Hajjar, Daniel T. Lackland, L. Adrienne Cupples, Lewis A. Lipsitz

Abstract—The objective of this study was to investigate the association between blood pressure and disability in older adults. Stroke-free participants in the Charleston Heart Study (n=999, mean age=68.5±0.2 years SE, 57% women, and 39% African Americans) were followed between 1960 and 1993. Functional measures including Nagi’s Congruency in Medical and Self Assessment of Disability Scale, the Rosow-Breslaw Scale, and Katz’ Activities of Daily Living Scale, in addition to systolic and diastolic blood pressures, were collected in 1984–1985, 1987–1990, and 1990–1993. Additional systolic and diastolic blood pressures from 1960 to 1963 were also available. We defined remote blood pressure change as the change from 1960 to 1984 to 1985 and concurrent blood pressure change as the change from 1984 to 1985 to the follow-up periods. Hypertension was defined as blood pressure ≥140/90 mm Hg or receiving antihypertensive agents, and it was considered uncontrolled if subjects were receiving antihypertensive agents and blood pressure was ≥140/90 mm Hg. Greater increases in remote and concurrent systolic blood pressure increases but not diastolic blood pressure were associated with greater declines in all 3 of the functional measures. Participants with hypertension were also at an increased risk for developing new disability (hazard ratio: 1.28, 95% CI: 1.04 to 1.59 for Nagi scale; hazard ratio: 1.28, 95% CI: 1.02 to 1.59 for Rosow-Breslaw Scale; and hazard ratio: 1.3, 95% CI: 1.01 to 1.69 for Katz scale). Participants with uncontrolled hypertension were at greatest risk of disability compared with normotensive subjects. In stroke-free older adults, increases in remote and concurrent systolic blood pressure increases are associated with greater functional decline. Older adults with uncontrolled hypertension are at a particularly increased risk for disability. (Hypertension. 2007;50:1026-1032.)

Key Words: hypertension ■ disability ■ blood pressure ■ aged ■ Southeast

More than 50% of people ≥65 years of age in the United States have limitation in ≥1 functional activity. Previous longitudinal studies have suggested that stroke is associated with increased risk for disability and loss of independence in older individuals. For example, in the Framingham Disability Study, stroke was the strongest predictor of physical disability and explained 12% of the variance over the follow-up period in men. The independent relationship between blood pressure (BP) or hypertension and disability risk in stroke-free individuals is not known. This is especially important because >65% of older adults in the United States have hypertension. Furthermore, the Framingham population is predominantly white, whereas African American elderly individuals are more likely to report limitations in activities of daily living (ADL) and more likely to have hypertension. Therefore, investigating the relationship between BP and disability in a well-represented biracial population fills an important gap in our knowledge. Finally, the impact of BP on health takes a lengthy period of time. Therefore, it is important to consider BP years before individuals start showing evidence of functional decline and disability.

Controlling hypertension to <140/90 mm Hg is associated with reduced cardiovascular disease mortality and morbidity in older adults. Investigating the association between hypertension control status and disability has important clinical implications, because there are concerns that lowering BP may have a negative effect on function and quality of life in older adults.

Therefore, the primary objective of this study was to investigate the association of BP and hypertension with the rate of functional decline and the risk of disability in an aging biracial population. The second objective was to explore the relation between hypertension control status and these disability domains.

Methods

Sample
A primary rationale for selecting the Charleston Heart Study was its adequate representation of African Americans. Also, we were interested in a study that includes remote BP data before the functional measures. The Charleston Heart Study fits these criteria. Participants were recruited from the community of greater Charleston in 1960. For this analysis, we included data collected during 3...
measurement waves: 1984–1985, 1987–1990, and 1990–1993. We included participants who have available functional and BP data and excluded those with stroke at baseline and follow-up. Stroke data were collected using self-report. Of the 1040 participants evaluated in 1984–1985, 38 had stroke and 3 had missing data, leaving 998 available for this analysis. Of these, 978 (98%) were evaluated in 1987–1990 and 916 (92%) in 1990–1993. An additional 39 individuals developed stroke during the follow-up period (1984–1993) and were also excluded. In addition, BP and antihypertensive data 20 years before the 1984 wave were available on our selected sample. The institutional review board at Hebrew SeniorLife approved this analysis. All of the participants signed written consents.

Data Elements
Data collected included demographics, weight, height, and social elements (educational level, marital status, retirement status, access to health care, and alcohol and tobacco use). Self-reported comorbidity data were collected by an interview questionnaire, and a medication inventory was also performed. Cognitive function was assessed using the Short Portable Mini Mental Examination starting in the 1987–1990 wave. Mood was assessed using the Centre for Epidemiological Studies Depression Scale collected only in 1990–1993.

Two BP measurements were obtained using a mercury manometer at each visit by a trained observer. The observers underwent repeated audiometric examinations. The participant was in a seated position, and an appropriate size cuff was used. The cuff was placed at heart level, and each reading was rounded to the nearest 2 mm Hg. Systolic BP (SBP) was defined as the first Korotkoff sound (K1) and diastolic (DBP) as the fifth Korotkoff sound (K5). For this analysis, we used the mean of the 2 readings.

BP Predictors
Our main predictors were SBP and DBP, considered as continuous variables. Because BP changed over the study period, as well as between 1960 and 1984–1985, we designed our analysis to account for the change in BP. We defined 2 BP variables, as follows. Concurrent BP change is the variable reflected the change in SBP and DBP from the baseline measurement (1984–1985) to the follow-up periods (1987–1990 and 1990–1993). This was the concurrent change in BP measured at the same time as the outcome measures. Remote BP change is the variable that reflected the change in SBP and DBP from 1960 to the baseline measurements (1984–1985).

Because some participants were receiving antihypertensive agents during the period of BP measurement, these readings may not reflect the participants’ actual BP. To address this issue, we have used a method suggested by Cui et al and confirmed by Tobin et al of adding 10 mm Hg to SBP and 5 mm Hg to DBP in subjects receiving antihypertensive medications during each data collection visit for the BP analysis only. Please see http://hyper.ahajournals.org for an expanded Methods section and the Results section for the BP analysis without the treatment correction (Table S2).

Hypertension Predictors
We also defined hypertension status and control status at baseline (1984–1985) as predictor variables. We assigned each participant to 1 of 2 groups: normotensive if the mean BP was <140/90 mm Hg and the subject was not receiving antihypertensive medications or hypertensive if the mean BP was ≥140/90 mm Hg or if the subject was receiving antihypertensive medications. We further assigned hypertensive individuals to 2 groups: controlled hypertensive if the mean BP was <140/90 mm Hg with treatment and uncontrolled hypertensive if the mean BP was ≥140/90 mm Hg.

To study the association of hypertension status with disability, we compared normotensive subjects with hypertensive subjects. To study the association between control status and disability, we compared controlled and uncontrolled hypertensive subjects with normotensive and uncontrolled to controlled hypertensive subjects.

Functional (Outcome) Measures
Measures of disability and daily function were collected in 1984–1985, 1987–1990, and 1990–1999 using 3 standard scales: the Nagi’s Congruency in Medical and Self Assessment of Disability, the Rosow-Breslaw Scale and Katz’ ADL Scale. We considered these measures of disability in this analysis in 2 ways: as continuous variables to investigate the rate of change in functional abilities and as categorical variables to investigate the risk of developing new disability (a participant is disabled if the participant reported limitation in performing ≥1 activity on the corresponding scale).

Statistical Analysis
BP Analysis
We used linear mixed-effects models (PROC Mixed) for correlated data to investigate the association between SBP and DBP with disability. This procedure is less sensitive to missing data, allows us to model the change in predictors and covariates during the follow-up period, and calculates estimates of the functional measures at each visit adjusted for covariates. We first conducted univariate analyses by investigating the association between concurrent BP changes (independent variables) with functional measures as continuous variables (dependent variables). We then performed multivariate analyses by developing a mixed model for each outcome measure. The modeling process is provided in the online supplemental data. For these analyses, we present the rate of change in the specific disability scale for each 10-mm Hg BP increase obtained from the final models.

Hypertension Analysis
For the comparison between hypertensive and normotensive subjects and the comparison of the normotensive, controlled hypertensive, and uncontrolled hypertensive subjects, we also used linear mixed-effects models. We also conducted univariate and multivariate analyses as in the BP analysis with hypertension status or control status as the independent variables and the functional measures as the dependent variables included as continuous variables. We present the results including P values and least mean squares adjusted for the covariates from these models.

Risk of Developing Disability Analysis
Proportional hazard models were used to study the association between hypertension status and control status with the risk of developing disability. These models were developed using a stepwise model selection approach (forward/backward). For this analysis, the time variable was either the time to developing disability or the time to censorship for the participants who were lost to follow-up or who died. Proportional hazard model assumptions were met. We also calculated the cumulative incidence of disability for the follow-up period excluding those with disability at baseline (1984–1985) and the fraction of disability in the study population attributable to hypertension by calculating the population attributable risk percentage. Attributable risk percentage is calculated by dividing the attributable risk by the incidence of disability in the study population.

Covariates and Subgroup Interaction Analyses
For all of the analyses, covariates considered for model selection included age, gender, race, educational level, body mass index, baseline disability measures, alcohol, smoking status, and comorbidity (coronary artery disease, myocardial infarction, subsequent stroke, diabetes mellitus, peripheral vascular disease, and arthritis). Finally, we tested for relevant interaction by age, gender, race, body mass index (BMI), and comorbidities. All of the analyses were conducted using SAS Software.

Results
Sample
The mean age ± SE of the sample (n = 999) at baseline was 68.5 ± 0.2 years, 57% were women, and 39% were African American. The mean age at baseline (1984–1985) was 68.5 ± 0.2 years, 57% were women, and 39% were African American.
Among these, 699 (70%) were hypertensive and 413 (59%) of the hypertensive subjects were receiving antihypertensive medications. Only 146 (21%) were controlled to \(140/90\) mm Hg. The control rates remained constant through the study follow-up (20% in 1987–1990 and 21% in 1990–1993).

Table 1 describes baseline characteristics of our sample. Hypertensive participants were older, more likely to be African Americans, had higher BMI, reported fewer years of education, and had lower physical activity levels. Hypertensive subjects reported higher prevalence of diabetes mellitus and arthritis than normotensive subjects. There were no differences in cardiovascular disease or cognitive function between hypertensive and normotensive subjects (Table 1). At baseline in 1984–1985, hypertensive participants scored lower than normotensive participants on the Nagi scale. There was no difference in the scores on the Rosow-Breslaw and Katz ADL scales. We provide a similar comparison for the baseline characteristics among normotensive participants and controlled and uncontrolled hypertensive subjects in Table S1.

### BP Analysis

Table 2 describes the association between remote and concurrent BP change and the rate of functional measure change. Greater remote SBP increase was associated with greater decline rates in all 3 of the functional measures. Similarly, greater concurrent SBP increase was associated with greater decline rates in all 3 of the functional measures. This remained true in the multivariate models. In contrast, remote and concurrent DBP changes were not associated with any of the outcome measures (Table 2). These results did not change when we considered SBP and DBP without correction for the effect of antihypertensive subjects (please see the data supplement).

### Hypertension Analysis

Compared with normotensive participants, hypertensive participants demonstrated greater declines in all 3 of the functional measures. This remained true in the multivariate models after adjusting for potential confounders (Figure 1).
When we investigated the association between hypertension control status and functional measures, we found that uncontrolled hypertensive participants demonstrated greater declines in all of the measures compared with normotensive participants. However, they did not differ significantly from controlled hypertensive subjects (Figure 2).

**Risk of Disability Analysis**

Table 3 provides the results obtained from the Cox proportional hazards models. Compared with normotensive partici-
pants, hypertensive participants without baseline disability were at increased risk of developing a new disability during the follow-up period (Table 3). The attributable risk percentage of hypertension on disability was 15% for the Nagi scale, 36% for the Rosow-Breslaw Scale, and 22% for the Katz ADL scale.

Participants with uncontrolled hypertension were at increased risk of developing disability compared with normotensive participants. However, those with controlled hypertension, defined as BP <140/90 mm Hg with treatment, had no significant difference in disability risk compared with normotensive or uncontrolled hypertensive subjects (Table 3). This was true for all 3 of the functional measures. Attributable risk percentage for uncontrolled hypertensive participants compared with normotensive participants was 36% for the Nagi scale, 63% for the Rosow-Breslaw, and 25% for the Katz ADL.

**Subgroup Interaction Analysis**

Table 4 provides the results of Cox proportional hazard models with an interaction term to test whether there was a different association between hypertension and disability by various subgroups. There was only a gender-based difference in the association between hypertension and disability. Women had a significantly increased risk of developing disability from hypertension compared with men based on the Rosow-Breslaw Scale and the Katz ADL scale but not the Nagi scale (Table 4). There were no consistent differences in the risk of developing disability from hypertension by age, race, obesity, or other comorbidities.

**Discussion**

This study suggests that, in a biracial elderly population, concurrent and remote SBP increases are associated with greater rates of decline in functional abilities. In contrast, neither remote nor concurrent DBP was associated with functional declines. In addition, those with hypertension at baseline have greater declines in functional abilities and are at increased risk of developing a new disability compared with normotensive individuals. Only those with uncontrolled hypertension have greater declines in functional abilities and are at increased disability risk.

Few previous studies have investigated the role of BP or hypertension in developing disability. Hubert and Fries identified hypertension as 1 risk of an array of factors for the development of disability over a period of 6 years in a group of 407 members of a runners club. In the Framingham Disability Study, hypertension was associated with an increased risk of disability. The populations in both studies were predominantly whites, and, hence, generalizability is limited. Our study extends these findings to a sample that, unlike the Framingham study, adequately represented African Americans. Moreover, none of the previous studies investigated the roles of SBP and DBP measured during the study period or remotely before the development of disability on the rate functional loss in an elderly population. Our analysis suggests that SBP plays a role in the loss of function, but DBP does not. This is in agreement with previous evidence suggesting that SBP is a better predictor of future cardiovascular and cerebrovascular disease in elderly individuals than...
Table 4. Exploring the Difference in the Association Between Hypertension at Baseline and the Risk of Disability by Age, Race, Gender, BMI, and Comorbidities

<table>
<thead>
<tr>
<th>Outcome (reference are those &lt;75 y)</th>
<th>Hazard Ratio*</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Katz ADL scale</td>
<td>0.73</td>
<td>0.46 to 1.14</td>
</tr>
<tr>
<td>Rosow-Breslaw Scale</td>
<td>0.67</td>
<td>0.43 to 1.02</td>
</tr>
<tr>
<td>Katz ADL scale</td>
<td>0.73</td>
<td>0.45 to 1.18</td>
</tr>
<tr>
<td><strong>Gender (men reference)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Katz ADL scale</td>
<td>1.28</td>
<td>0.87 to 1.88</td>
</tr>
<tr>
<td>Rosow-Breslaw Scale</td>
<td>1.80</td>
<td>1.22 to 2.66</td>
</tr>
<tr>
<td>Katz ADL scale</td>
<td>1.99</td>
<td>1.26 to 3.17</td>
</tr>
<tr>
<td><strong>Race (whites reference)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Katz ADL scale</td>
<td>1.28</td>
<td>0.86 to 1.93</td>
</tr>
<tr>
<td>Rosow-Breslaw Scale</td>
<td>1.08</td>
<td>0.72 to 1.62</td>
</tr>
<tr>
<td>Katz ADL scale</td>
<td>1.24</td>
<td>0.76 to 2.02</td>
</tr>
<tr>
<td><strong>Obesity (&lt;25 BMI as reference)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Katz ADL scale</td>
<td>0.49</td>
<td>0.17 to 1.42</td>
</tr>
<tr>
<td>Rosow-Breslaw Scale</td>
<td>0.19</td>
<td>0.07 to 0.52</td>
</tr>
<tr>
<td>Katz ADL scale</td>
<td>0.41</td>
<td>0.12 to 1.41</td>
</tr>
<tr>
<td><strong>CVD</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Katz ADL scale</td>
<td>0.81</td>
<td>0.50 to 1.32</td>
</tr>
<tr>
<td>Rosow-Breslaw Scale</td>
<td>0.87</td>
<td>0.54 to 1.42</td>
</tr>
<tr>
<td>Katz ADL scale</td>
<td>0.83</td>
<td>0.46 to 1.47</td>
</tr>
<tr>
<td><strong>Diabetes mellitus</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Katz ADL scale</td>
<td>1.25</td>
<td>0.77 to 2.03</td>
</tr>
<tr>
<td>Rosow-Breslaw Scale</td>
<td>1.37</td>
<td>0.83 to 2.28</td>
</tr>
<tr>
<td>Katz ADL scale</td>
<td>1.27</td>
<td>0.72 to 2.23</td>
</tr>
<tr>
<td><strong>Arthritis/pain</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Katz ADL scale</td>
<td>1.08</td>
<td>0.74 to 1.58</td>
</tr>
<tr>
<td>Rosow-Breslaw Scale</td>
<td>1.14</td>
<td>0.77 to 1.67</td>
</tr>
<tr>
<td>Katz ADL scale</td>
<td>1.21</td>
<td>0.77 to 1.90</td>
</tr>
</tbody>
</table>

CVD indicates cardiovascular disease (myocardial infarction, angina, stroke, or peripheral vascular disease).

*These hazard ratios are testing the hypothesis that there is a difference in the association between hypertension and disability risk by the corresponding subgroup. It calculates the additional risk in that subgroup compared with the reference group. For example, the risk of disability based on the Rosow-Breslaw Scale associated with hypertension in women is 1.8 times that in men.

DBP.

Nevertheless, hypertensive subjects as a group are at increased risk of both functional decline and developing a new disability.

This analysis suggests that those with uncontrolled hypertension had an increased risk of incident disability, whereas those with controlled hypertension had a similar incident disability as those without hypertension. The lack of association between controlled hypertension and disability risk suggests that adequate control of hypertension may prevent functional decline. However, this could also be related to the small sample size of those with controlled hypertension. These findings should be interpreted cautiously and need to be replicated in other studies with larger samples.

Women are more likely to develop disability compared with men. In this study we found that, compared with men, women are particularly at an increased risk of developing disability from hypertension. Because hypertension is more prevalent in women, this may provide a possible explanation for the increased predisposition to disability in women.

The development of disability with aging is a complex process and involves interactions between the individual’s abilities and the surrounding environment. Contrary to previous thought that disability was because of disabling medical illnesses, recent literature emphasizes a conceptual difference between comorbidity and disability. We found an association between hypertension and measures of disability, which was robust to adjustment for self-reported relevant comorbidities including diabetes mellitus, cardiovascular disease, and arthritis. The mechanisms by which hypertension may produce disability are not known. It is possible that hypertension may lead to disability through its effect on white matter hyperintensities in the brain, cerebrovascular function, overall lean muscle mass, inflammation, or changes in the renin angiotensin system. It could also be mediated through the effect of hypertension on cognitive function not assessed in the Charleston Heart Study, such as executive function or fluid intellectual functioning. Further studies to explore these possible mechanisms are needed.

An advantage of our study population is the low rate of hypertension control, which enabled us to assess the association between uncontrolled hypertension and disability. Also, the sample had close to 40% Southeastern African Americans, who were underrepresented in previous studies.

A limitation of our study is that our sample was not disability free at baseline. We conducted 2 analyses: 1 investigating the rate of functional decline and the second investigating the risk of developing a new disability in those without disability at baseline. Both approaches lead to similar results. Another limitation is that all of the functional measures were self-reported. These measures have been widely used for assessing disability in the general population. Furthermore, comorbidity assessment was conducted using self-report via an interview. In particular, there was no further objective confirmation for the diagnosis of stroke. Although this method has been validated for stroke diagnosis, our results should be interpreted cautiously. Also, measures of cognitive function and mood were not conducted except in the later period of the study. Because BP and disability are related to both, interpretation of our results should take this into consideration.

Higher concurrent and 20 years’ previous SBP increases are associated with an increased rate of functional decline in older adults. In addition, those with hypertension, particularly uncontrolled hypertension, have a significant increase in disability risk independent of other risk factors or comorbidities.

**Perspectives**

This study suggests an association between elevated SBP and hypertension with disability in older adults. Considering that 65% of the elderly population has hypertension and that 71% of them have uncontrolled hypertension, it is contributing significantly to disability and to healthcare expenditure in the
United States. Further investigation on the underlying mechanism of this association and clinical trials to test the effect of controlling hypertension on disability are essential future research areas.

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Disclosures
D.T.L. is on the Speakers’ Bureau for Novartis, Bristol-Myers Squibb, Merck, and Pfizer and has received research support from Novartis. The remaining authors report no conflicts.

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