Are Two Really Better Than One?  
Empirical Examination of Repeat Blood Pressure Measurements and Stroke Risk in the Renfrew/Paisley and Collaborative Studies

Carole L. Hart, MA; David J. Hole, MSc; George Davey Smith, MD

Background and Purpose—Blood pressure measured on 2 occasions in 2 large prospective cohort studies in Scotland was related to stroke, defined as stroke mortality or hospital admission for stroke. The purpose was to investigate whether 2 blood pressure readings gave a more accurate estimate of stroke risk over a long follow-up period than 1 reading.

Methods—In the 1970s, the Renfrew/Paisley general population study investigated 3060 men and 3502 women and the Collaborative study investigated 2683 employed men on 2 occasions. The mean years between screening were 4 and 5, respectively. Blood pressure measured on the 2 occasions was related to stroke risk in 17-year and 21-year follow-up periods after the second screening, respectively.

Results—For both systolic and diastolic blood pressure, the mean of the measures on the 2 occasions, the maximum of the 2 measures and the measure corrected for regression dilution was more strongly related to stroke over the follow-up periods than either single measure.

Conclusions—Two blood pressure measurements seem better than 1 for indicating stroke risk. Underestimation using single measures will lead to both misclassification of the risk of disease for individuals and also the population-attributable risk of disease associated with elevated blood pressure. (Stroke. 2001;32:2697-2699.)

Key Words: blood pressure ■ epidemiology ■ prospective studies ■ stroke prevention

A single measure of a risk factor may underestimate the underlying risk factor–disease associations. Statistical corrections have been made for this, but they are based on a number of assumptions, which may or may not hold. It is important to empirically examine this issue in studies with repeat measurements. We have investigated the relationship between blood pressure measured on 2 occasions and stroke in 2 large, prospective cohort studies in Scotland.

Methods
The Renfrew/Paisley study was carried out between 1972 and 1976 on 15 406 residents aged 45 to 64 years from the towns of Renfrew and Paisley. Between 1977 and 1979, 8532 residents attended for rescreening. On each occasion, blood pressure was recorded as the mean of 2 measurements taken with the subject seated, using a London School of Hygiene sphygmomanometer and a cuff of 12 × 22 cm. Diastolic pressure was recorded at the disappearance of the fifth Korotkoff sound. After the exclusion of participants with missing blood pressure readings on either occasion and those reporting previously detected high blood pressure or treatment for it, the cohort comprised 3060 men and 3502 women. The Collaborative study similarly screened 5766 working men aged 35 to 64 years between 1970 and 1973 and rescreened 2686 in 1977. After exclusion of participants with missing blood pressure measurements, there were 2683 men (because there was no relevant question, we were unable to exclude men with previously recorded high blood pressure). A computerized linkage with the Scottish Morbidity Records (SMR) system provided records of all acute inpatient discharges with main diagnoses of stroke occurring after the second screening. Participants were flagged by the NHS Central Register in Scotland, which provided information on deaths. Stroke was defined as either having a hospital discharge record with a main diagnosis of stroke or dying of stroke in the follow-up period after the second screening. Stroke was defined as International Classification of Diseases, 8th Revision (ICD-8), or ICD-9 codes 430 to 438, and ICD-10 codes I60 to I69 and G45. Follow-up periods were 17 years for the Renfrew/Paisley study and 21 years for the Collaborative study. The mean years between screening were 4 and 5, respectively.

Each individual’s average diastolic blood pressure and average systolic blood pressure were calculated from the measures on the 2 occasions. The maximum of the 2 diastolic and the 2 systolic blood pressure measurements were also calculated. The Cox proportional hazards models were used to calculate the relative rates associated with a 10-mm Hg increase in blood pressure for each individual measure, for the averages, and for the maximum measures. Additionally, the regression dilution method was used to find the corrected associations. This method attempts to obtain a more accurate estimate of usual blood pressure than a single measure. Single measures are subject to both measurement errors and real deviations from usual blood pressure, resulting in the underestimation of the relationship between blood pressure and disease. This is because the lowest category of blood pressure contains proportionally more people whose blood pressure reading is lower than their usual, and the highest category contains proportionally more people with a higher-than-usual blood pressure reading. The second measure of blood pressure was used to correct for this underestimation.

Received February 14, 2001; final revision received August 13, 2001; accepted August 15, 2001.
From the West of Scotland Cancer Surveillance Unit (D.J.H.), Department of Public Health (C.L.H.), University of Glasgow, Glasgow, UK, and the Department of Social Medicine (G.D.S.), University of Bristol, Bristol, UK.
Correspondence to Carole Hart, Department of Public Health, University of Glasgow, 1 Lilybank Gardens, Glasgow G12 8RZ, UK. E-mail c.l.hart@udcf.gla.ac.uk
© 2001 American Heart Association, Inc.

Stroke is available at http://www.strokeaha.org
with the following method. The baseline measures were divided into quintiles, and the mean measure for each fifth was calculated for both the first and second measures by using the baseline quintiles. The range was taken as the difference between the top and bottom fifths. The regression dilution ratio was calculated as the ratio of the range for the second measure to the first measure (Table 1). These ratios were similar to those from other studies.1,2 The corrected association was estimated by multiplying the uncorrected regression coefficient from the baseline measure by the inverse of the regression dilution ratio.

Results

In the follow-up periods, 224 men and 237 women from the Renfrew/Paisley study and 194 men from the Collaborative study had a hospital discharge for, or died of, stroke. Higher blood pressure was associated with higher relative rates of stroke (Table 2). For men in the Renfrew/Paisley study, the relative rate of stroke was stronger for the mean diastolic blood pressure, the maximum diastolic blood pressure, and the corrected diastolic blood pressure measurements than for either the first or the second diastolic blood pressure measurements individually. The same effect was seen for systolic blood pressure. Similar results were seen for the Renfrew/Paisley women, although the relative rates for systolic blood pressure appeared stronger than for the Renfrew/Paisley men. For the Renfrew/Paisley women, the same relative rates were seen for the mean, maximum, and corrected systolic blood pressures. The relative rates for the Collaborative men followed the same pattern, and for this cohort the same relative rates were seen for the mean, maximum, and corrected diastolic blood pressures. The relative rates were higher than for the Renfrew/Paisley study, but this could have resulted from the longer follow-up period or the exclusion of participants with high blood pressure from the Renfrew/Paisley study. For each cohort, the relative rates corrected for regression dilution were stronger than, or the same as, the relative rates for mean and maximum diastolic or systolic blood pressure, with the exception of the maximum diastolic blood pressure for the Renfrew/Paisley women.

Discussion

Previous studies have used models to suggest that there is underestimation of the strength of associations of disease with blood pressure and have suggested that repeat measurements be made.1,2 We have shown that in all cases investigated, the average, the maximum, or the corrected measure had a stronger relationship with stroke than a single measure. The degree to which single measures underestimate the underlying strength of association seems to be similar to that predicted from models. This underestimation will lead to both misclassification of the risk of disease for individuals—of importance, given the increasing use of risk-based guidelines for treatment of elevated blood pressure—and also the population attributable risk of disease associated with elevated

---

### TABLE 1. Regression Dilution Ratios

<table>
<thead>
<tr>
<th></th>
<th>Renfrew/Paisley</th>
<th>Collaborative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td>Systolic blood pressure</td>
<td>0.56</td>
<td>0.55</td>
</tr>
<tr>
<td>Diastolic blood pressure</td>
<td>0.56</td>
<td>0.56</td>
</tr>
</tbody>
</table>

### TABLE 2. Age-Adjusted Relative Rates of Stroke Associated With 10-mm Hg Increase in Blood Pressure Measured on 2 Occasions in Men and Women (45–64 y) from the Renfrew/Paisley Study and Men (35–64 y) From the Collaborative Study

<table>
<thead>
<tr>
<th></th>
<th>Renfrew/Paisley*</th>
<th>Collaborative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td>No. of strokes</td>
<td>224</td>
<td>237</td>
</tr>
<tr>
<td>Diastolic blood pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First</td>
<td>1.12 (0.99–1.26)</td>
<td>1.11 (0.98–1.25)</td>
</tr>
<tr>
<td>Second</td>
<td>1.14 (1.02–1.27)</td>
<td>1.15 (1.03–1.28)</td>
</tr>
<tr>
<td>Mean</td>
<td>1.18 (1.03–1.35)</td>
<td>1.18 (1.03–1.35)</td>
</tr>
<tr>
<td>Maximum</td>
<td>1.16 (1.02–1.31)</td>
<td>1.21 (1.08–1.36)</td>
</tr>
<tr>
<td>Corrected‡</td>
<td>1.22 (0.99–1.51)</td>
<td>1.20 (0.97–1.49)</td>
</tr>
<tr>
<td>Systolic blood pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First</td>
<td>1.08 (1.01–1.16)</td>
<td>1.08 (1.02–1.15)</td>
</tr>
<tr>
<td>Second</td>
<td>1.08 (1.01–1.15)</td>
<td>1.15 (1.08–1.21)</td>
</tr>
<tr>
<td>Mean</td>
<td>1.11 (1.03–1.20)</td>
<td>1.16 (1.08–1.24)</td>
</tr>
<tr>
<td>Maximum</td>
<td>1.12 (1.04–1.19)</td>
<td>1.16 (1.10–1.23)</td>
</tr>
<tr>
<td>Corrected‡</td>
<td>1.15 (1.02–1.30)</td>
<td>1.16 (1.04–1.29)</td>
</tr>
</tbody>
</table>

*17 years of follow-up after second screening.
‡21 years of follow-up after second screening.
§With the method of MacMahon et al.1
blood pressure and the potential for reducing this through programs aimed at lowering the mean blood pressure of the population.

**Acknowledgments**

Funding was provided by grants from Chest, Heart and Stroke Scotland and the Stroke Association. The authors acknowledge the contribution of Pauline MacKinnon in maintaining the databases.

**References**


Are Two Really Better Than One?: Empirical Examination of Repeat Blood Pressure Measurements and Stroke Risk in the Renfrew/Paisley and Collaborative Studies
Carole L. Hart, David J. Hole and George Davey Smith

Stroke. 2001;32:2697-2699
doi: 10.1161/hs1101.098637
Stroke is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2001 American Heart Association, Inc. All rights reserved.
Print ISSN: 0039-2499. Online ISSN: 1524-4628

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://stroke.ahajournals.org/content/32/11/2697

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Stroke can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Stroke is online at:
http://stroke.ahajournals.org//subscriptions/