Duration of Diabetes and Risk of Ischemic Stroke
The Northern Manhattan Study

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Background and Purpose—Diabetes increases stroke risk, but whether diabetes status immediately before stroke improves prediction and whether duration is important are less clear. We hypothesized that diabetes duration independently predicts ischemic stroke.

Methods—Among 3298 stroke-free participants in the Northern Manhattan Study, baseline diabetes and age at diagnosis were determined. Incident diabetes was assessed annually (median, 9 years). Cox proportional hazard models were used to estimate hazard ratios (HR) and 95% CI for incident ischemic stroke using baseline diabetes, diabetes as a time-dependent covariate, and duration of diabetes as a time-varying covariate; models were adjusted for demographic and cardiovascular risk factors.

Results—Mean age was 69±10 years (52% Hispanic, 21% white, and 24% black); 22% had diabetes at baseline and 10% had development of diabetes. There were 244 ischemic strokes, and both baseline diabetes (HR, 2.5; 95% CI, 1.9–3.3) and diabetes considered as a time-dependent covariate (HR, 2.4; 95% CI, 1.8–3.2) were similarly associated with stroke risk. Duration of diabetes was associated with ischemic stroke (adjusted HR, 1.03 per year with diabetes; 95% CI, 1.02–1.04). Compared to nondiabetic participants, those with diabetes for 0 to 5 years (adjusted HR, 1.7; 95% CI, 1.1–2.7), 5 to 10 years (adjusted HR, 1.8; 95% CI, 1.1–3.0), and ≥10 years (adjusted HR, 3.2; 95% CI, 2.4–4.5) were at increased risk.

Conclusions—Duration of diabetes is independently associated with ischemic stroke risk adjusting for risk factors. The risk increases 3% each year, and triples with diabetes ≥10 years. (Stroke. 2012;43:00-00.)

Key Words: acute stroke ■ cerebral infarct ■ diabetes mellitus ■ epidemiology ■ risk factors

Diabetes mellitus is a major public health burden. In the United States, >23.6 million people have diabetes.1 Prevalence is increasing as the population ages and certain populations, such as minority groups, are more vulnerable. The number of people with diabetes diagnosed is estimated to increase 165% between 2000 and 2050.2 The independent association of diabetes with stroke is now well-documented.3–10 Notably, almost all prospective cohort studies have evaluated diabetes as an exposure at baseline, or the time of participant enrollment, and measured its effect on stroke outcomes during follow-up. In large cohorts with long periods of follow-up, a significant proportion of participants who did not have diabetes at baseline had development of diabetes over the period of follow-up.11 Taking this change in status into consideration may be expected to provide a more precise estimate of stroke risk.

Although some studies have assessed the relationship of duration of diabetes to risk of cardiovascular outcomes such as coronary heart disease, cardiovascular mortality, peripheral arterial disease, carotid wall thickness, and thin cap fibroatheroma,12–18 the association between duration of diabetes and stroke risk is less well-studied.

The Northern Manhattan Study prospective cohort, with its annual evaluation of diabetes diagnosis, provides an opportunity to investigate the utility of incorporating serial interval evaluations of diabetes into risk prediction estimates. We investigated the effect of updated diabetes status on stroke by incorporating diabetes as a time-dependent covariate. We further examined the effect of duration of diabetes on ischemic stroke risk.

Materials and Methods

Northern Manhattan Study is a prospective population-based cohort study designed to determine stroke incidence, risk factors, and prognosis in an urban multiethnic population. Northern Manhattan is defined as the area in New York City north of 145th Street, south of...
Selection of Prospective Cohort
The study has been previously described in detail. Briefly, community participants were eligible for enrollment if they: (1) had never had a stroke diagnosed; (2) were 40 years of age or older; and (3) resided for ≥3 months in a household with a telephone in northern Manhattan. Subjects were identified with random digit dialing using dual-frame sampling to identify both published and unpublished phone numbers. The protocol was approved by the Institutional Review Board at Columbia University Medical Center and the Miller School of Medicine, University of Miami, and participants provided informed consent.

Baseline Evaluation
Baseline data were collected via interviews by trained research assistants, medical record review, physical and neurological examination by study investigators, in-person measurements, and collection of fasting blood specimens for glucose and lipid measurements. A standardized questionnaire was adapted from the Behavioral Risk Factor Surveillance System developed by the Centers for Disease Control and Prevention regarding the following conditions: diabetes, hypertension, hypercholesterolemia, smoking, peripheral vascular disease, transient ischemic attack, and cardiac disease (including angina, myocardial infarction, coronary artery disease, atrial fibrillation, and valvular heart disease).

Interval Evaluation
All participants were prospectively followed-up annually through telephone interviews, and mean duration of follow-up at time of analysis was 9.0±3.7 years. The yearly contact rate was 99%. Subjects were interviewed to determine changes in vital status, detect cardiac and neurological symptoms and events, and review any hospitalizations. The telephone assessment served as a screen for vascular events. The simple stroke question (“Since your last contact have you been diagnosed with a stroke?”) during telephone interview was 92% sensitive and 95% specific with in-person assessment, physician interviews, medical records, and neuroimaging data used as the gold standards. Participants with affirmative responses to neurological symptoms underwent examination and review by a study neurologist or had medical records reviewed. Hospital surveillance of admission and discharge were performed to provide data that may have been missed during the annual telephone follow-up.

Measure of Exposure
Diabetes at baseline was defined if a participant reported a history of medical diagnosis of diabetes mellitus or treatment with oral hypoglycemic agents or insulin. In addition, fasting blood glucose ≥126 mg/dL (6.5mmol/L) was used among those who did not self-report diabetes to adjudicate diabetic status and find “unaware” cases. Fasting blood glucose was measured using a Hitachi 747 automated spectrometer (Boehringer). Age at time of diagnosis was also recorded for those with self-report of diabetes at baseline, and diabetes duration was calculated. During follow-up evaluations among nondiabetic participants, the first follow-up contact at which there was self-report of new diagnosis of diabetes, treatment with oral hypoglycemic drugs, or insulin therapy was used to define conversion to diabetes during follow-up. Duration of diabetes was calculated from the onset of diabetes up to the date of ischemic stroke or censoring.

Validation of Diabetes Status Determined During Follow-Up
There were 74 instances in which a participant reported treatment with antidiabetic drugs or insulin without ever reporting the diagnosis of diabetes. Medical records were reviewed to validate these responses. The self-report of medications or insulin without report of the diagnosis of diabetes was consistent with a diagnosis of diabetes in 92% of cases. We reflected these changes in the analyses.

Similarly, there were 87 participants who self-reported the diagnosis of diabetes once but never reported any subsequent treatment. All these cases were confirmed to have diabetes on medical record review.

Measurement of Outcome
Stroke was defined during follow-up by the first symptomatic occurrence of any type of stroke including intracerebral hemorrhage, subarachnoid hemorrhage, and cerebral infarction, as previously described. Medical records were reviewed to verify details of suspected events. At least 2 neurologists reviewed data independently and classified strokes. Any disagreements were adjudicated by the principal investigators (R.L.S. and M.E.). We used only ischemic strokes for current analyses.

Statistical Analyses
All analyses were performed using SAS version 9.1 (SAS Institute). The distributions of diabetes at baseline were calculated, both overall and by subject characteristics, including demographics and risk factors. Cox proportional hazard regression models were fitted to calculate hazard ratios (HR) and 95% CI for ischemic stroke as the outcome. Main predictors were baseline diabetes, diabetes as time-varying covariate (incorporating new-onset diabetes during follow-up), and duration of diabetes as time-varying covariate. We used duration of diabetes as a continuous measure as well as categorized at 5 and 10 years to examine for threshold effects.

Models unadjusted and adjusted for demographic factors (age, sex, race–ethnicity, insurance status, and educational level) and behavioral and medical risk factors (hypertension, cardiac disease, high-density lipoprotein, low-density lipoprotein, current smoking, past smoking, alcohol consumption, waist circumference, and physical activity) were constructed. Assessment for 2-way interactions was conducted. We compared the Akaike Information Criterion among the baseline and the time-varying diabetes models.

Results
Baseline Characteristics
Baseline characteristics of the cohort are shown in Table 1. The mean age was 69±10 years; 62.8% of the cohort were women, 52.3% were Hispanic, 20.9% were non-Hispanic white, and 24.3% were non-Hispanic black.

At baseline, 574 participants (17.4%) self-reported diabetes and 142 subjects had fasting blood glucose >126 mg/dL, for a total of 716 (21.8%) with diabetes at baseline. Approximately 93% to 96% of participants visited their primary care physician at least once during the previous year for each year of follow-up. Among those who did not have diabetes at baseline (n=2582), 338 subjects (13.1%) reported new-onset diabetes during a mean 9.0 years of follow-up.

Diabetes at Baseline and as a Time-Dependent Covariate
There were 244 incident ischemic strokes. Baseline diabetes was associated with risk of stroke (unadjusted HR, 2.6; 95%
Diabetes at baseline was associated with a higher risk of ischemic stroke (adjusted HR, 2.4; 95% CI, 1.8–3.2). In the fully adjusted model, including demographic and other cardiovascular risk factors including smoking, alcohol consumption, low-density lipoprotein, high-density lipoprotein, blood pressure, waist circumference, history of cardiac disease, and physical activity, the association was unchanged (adjusted HR, 2.5; 95% CI, 1.9–3.3; Table 2). When new-onset diabetes was taken into account as a time-varying covariate, diabetes was still associated with an increased risk of stroke (adjusted HR per year, 1.03; 95% CI, 1.02–1.04).

Duration of Diabetes

The mean duration of diabetes among people who self-reported diabetes at baseline was 17.3±11.6 years (median, 13.7 years). Among the 338 subjects with diabetes diagnosed during follow-up, mean duration was 4.5±3.2 years (median, 4.2 years). With each year of diabetes, stroke risk increased by 3% (adjusted HR per year, 1.03; 95% CI, 1.02–1.04).

Duration was also categorized as <5 years, 5 to 10 years, and ≥10 years, with nondiabetic participants as a reference group. Without assuming linearity, the trichotomized duration of diabetes variable was fitted adjusting for other risk factors. The null hypothesis that all 3 groups had the same risk of stroke was rejected (χ² test with 2 degrees of freedom, P=0.01). Compared to those without diabetes, those with diabetes, and new diabetes, the risk of stroke was increased (Table 2).

Table 1. Baseline Sociodemographic and Cardiovascular Risk Factors in the Northern Manhattan Study

<table>
<thead>
<tr>
<th>Sociodemographic and Cardiovascular Risk Factors, N (%) or Mean ± SD</th>
<th>Total</th>
<th>Diabetes at Enrollment</th>
<th>No Diabetes at Enrollment</th>
<th>Persistently Without Diabetes</th>
<th>New Diabetes During Follow-Up</th>
<th>P*</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>3298</td>
<td>716 (21.7%)</td>
<td>2582 (78.2%)</td>
<td>2244 (68.0%)</td>
<td>338 (10.2%)</td>
<td></td>
</tr>
<tr>
<td>Age (y)</td>
<td>69±10</td>
<td>69±8</td>
<td>69±11</td>
<td>70±11</td>
<td>66±9</td>
<td>0.43</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>2071</td>
<td>438 (61.2%)</td>
<td>1633 (63.2%)</td>
<td>1425 (63.5%)</td>
<td>208 (61.5%)</td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>1227</td>
<td>278 (38.8%)</td>
<td>949 (36.8%)</td>
<td>819 (36.5%)</td>
<td>130 (38.5%)</td>
<td>0.31</td>
</tr>
<tr>
<td>Race/ethnicity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>690</td>
<td>100 (14.0%)</td>
<td>590 (22.9%)</td>
<td>556 (24.8%)</td>
<td>34 (10.1%)</td>
<td>Reference</td>
</tr>
<tr>
<td>Black</td>
<td>803</td>
<td>196 (27.4%)</td>
<td>607 (23.5%)</td>
<td>552 (24.6%)</td>
<td>55 (16.3%)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Hispanic</td>
<td>176</td>
<td>408 (57.0%)</td>
<td>1318 (51.0%)</td>
<td>1076 (48.0%)</td>
<td>242 (71.6%)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Completed high school education</td>
<td>1511</td>
<td>282 (39.4%)</td>
<td>1229 (47.6%)</td>
<td>1107 (49.3%)</td>
<td>122 (36.1%)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Insurance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medicaid/no insurance</td>
<td>1435</td>
<td>375 (52.4%)</td>
<td>1060 (41.1%)</td>
<td>870 (38.8%)</td>
<td>190 (56.2%)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Medicare/private insurance</td>
<td>1841</td>
<td>335 (46.8%)</td>
<td>1506 (58.3%)</td>
<td>1358 (60.5%)</td>
<td>148 (43.8%)</td>
<td>Reference</td>
</tr>
<tr>
<td>Smoking status</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>1548</td>
<td>317 (44.3%)</td>
<td>1231 (47.7%)</td>
<td>1076 (48.0%)</td>
<td>155 (45.9%)</td>
<td>Reference</td>
</tr>
<tr>
<td>Past</td>
<td>1179</td>
<td>273 (38.1%)</td>
<td>906 (35.1%)</td>
<td>787 (35.1%)</td>
<td>119 (35.2%)</td>
<td>0.09</td>
</tr>
<tr>
<td>Current</td>
<td>569</td>
<td>126 (17.6%)</td>
<td>443 (17.2%)</td>
<td>379 (16.9%)</td>
<td>64 (18.9%)</td>
<td>0.42</td>
</tr>
<tr>
<td>Moderate alcohol consumption</td>
<td>1075</td>
<td>181 (25.3%)</td>
<td>894 (34.6%)</td>
<td>796 (35.5%)</td>
<td>98 (29.0%)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Any physical activity</td>
<td>1909</td>
<td>380 (53.1%)</td>
<td>1529 (59.2%)</td>
<td>1352 (60.2%)</td>
<td>177 (52.4%)</td>
<td>0.0027</td>
</tr>
<tr>
<td>Cardiac disease</td>
<td>792</td>
<td>210 (29.3%)</td>
<td>582 (22.5%)</td>
<td>500 (22.3%)</td>
<td>82 (24.3%)</td>
<td>0.0002</td>
</tr>
<tr>
<td>Waist circumference (in)</td>
<td>36.8±5.0</td>
<td>38.4±5.0</td>
<td>36.3±4.9</td>
<td>36.5±0.0</td>
<td>38.4±4.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>High-density lipoprotein (mg/dL)</td>
<td>46.8±14.6</td>
<td>43.7±14.0</td>
<td>47.6±14.6</td>
<td>48.4±14.7</td>
<td>42.7±13.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Low-density lipoprotein (mg/dL)</td>
<td>129.1±36.1</td>
<td>126.3±39.1</td>
<td>130.0±35.3</td>
<td>129.8±35.3</td>
<td>130.8±35.0</td>
<td>0.02</td>
</tr>
<tr>
<td>Systolic blood pressure (mm Hg)</td>
<td>143.7±21.0</td>
<td>146.7±20.0</td>
<td>142.9±21.3</td>
<td>142.7±21.2</td>
<td>144.2±22.0</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

SD indicates standard deviation.

*Diabetes at baseline vs no diabetes at baseline.

CI, 2.0–3.3). In the fully adjusted model, adjusted for demographic and other cardiovascular risk factors including smoking, alcohol consumption, low-density lipoprotein, high-density lipoprotein, blood pressure, waist circumference, history of cardiac disease, and physical activity, the association was unchanged (adjusted HR, 2.5; 95% CI, 1.9–3.3; Table 2). When new-onset diabetes was taken into account as a time-varying covariate, diabetes was still associated with risk of ischemic stroke (adjusted HR, 2.4; 95% CI, 1.8–3.2). The Akaike Information Criteria for the models were similar (3333.1 for the model using baseline diabetes and 3335.2 in the model using diabetes as a time-dependent covariate). There were no interactions between diabetes and age, race—ethnicity, or sex.

Table 2. Risk of Ischemic Stroke Associated With Baseline Diabetes and Diabetes as Time-Dependent Covariate

<table>
<thead>
<tr>
<th>Models</th>
<th>Hazard Ratio</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline diabetes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unadjusted (diabetes only)</td>
<td>2.6</td>
<td>2.0–3.3</td>
</tr>
<tr>
<td>Adjusted for demographic variables*</td>
<td>2.7</td>
<td>2.1–3.5</td>
</tr>
<tr>
<td>Adjusted for demographic variables and cardiovascular risk factors†</td>
<td>2.5</td>
<td>1.9–3.3</td>
</tr>
<tr>
<td>Diabetes as time-dependent covariate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unadjusted (diabetes only)</td>
<td>2.5</td>
<td>1.9–3.2</td>
</tr>
<tr>
<td>Adjusted for demographic variables*</td>
<td>2.6</td>
<td>2.0–3.4</td>
</tr>
<tr>
<td>Adjusted for demographic variables and cardiovascular risk factors†</td>
<td>2.4</td>
<td>1.8–3.2</td>
</tr>
</tbody>
</table>

*Age, sex, education, race—ethnicity, and insurance.
†Age, sex, education, race—ethnicity, insurance, waist circumference, alcohol consumption, smoking status, physical activity, high-density lipoprotein, low-density lipoprotein, history of cardiac disease, and systolic blood pressure.
follow-up does not confer added information. Second, subjects with newly diagnosed diabetes may be more compliant with treatment, which has been shown to be beneficial for primary stroke prevention in our cohort. Third, the median duration of follow-up for those with diabetes at baseline in our cohort was 13.7 years, but it was only 4.2 years for those with development of diabetes after baseline, which may not be sufficient to manifest cerebrovascular events. Last, we used both self-report and laboratory results to identify diabetes at baseline. However, self-report alone was used to define diabetes during telephone follow-up, which may have led us to miss cases, because nearly one-third of diabetes cases may be undiagnosed.

Among those with diabetes ≥10 years, risk of ischemic stroke is 3-times the risk among those without diabetes. Our study provides evidence that the risk of ischemic stroke increased continuously with duration of diabetes mellitus. The increase is not as much during the second half of the first decade, but it increases steeply as the disease enters its second decade. This must, however, be interpreted keeping in mind that true onset of diabetes may be 4 to 7 years earlier than clinical diagnosis.

This is the first prospective cohort study to address the association of diabetes duration and ischemic stroke among both men and women. The Nurses’ Health study reported an association between diabetes duration and various stroke subtypes among women, in which the risk of ischemic stroke increased from 1.5 (0–4 years) to 4.1 (≥20 years). The maximum increase in the risk was seen at the 10-year mark, similar to our findings. Our cohort has men and women 40 years of age or older and representation by Hispanic, white, and black participants, as compared to the Nurses’ Health study cohort, comprising predominantly white women ages 30 to 55 years at the time of enrollment.

Several potential mechanisms could explain the association of diabetes duration and stroke in our study. There is evidence of association between diabetes duration and atherosclerotic lesions, including intimal medial thickness and thin cap fibroatheromas. Carotid plaque thickness has been shown to predict ischemic stroke in our cohort. In addition, hypertension is twice as prevalent among those with diabetes as in people without diabetes, and long-term hypertension causes accelerated microvascular and macrovascular complications among those with diabetes. The risk of microalbuminuria has been shown to increase with increasing duration of diabetes and microalbuminuria has been reported as a strong and independent risk factor of stroke among patients with diabetes. Other potential mediators may be endothelial dysfunction and abnormalities in fibrinogen and clotting mechanisms.

Our study has public health implications. Although stroke rates have been declining among those with diabetes, the rapid increase in diabetes incidence over the same period is leading to a higher overall stroke burden. In recent decades, the age of onset of type 2 diabetes has decreased, paralleling the obesity epidemic in young adults. As the population ages and the elderly live longer, more and more people will live with longer duration of the disease. It is thus important to better understand the dynamics between diabetes, time, and...
stroke, and to emphasize the importance of interventions to prevent early diabetes. Minimizing the number of years a patient has diabetes would help combat the increase in stroke risk with each year of the disease.

Our study has several strengths. Northern Manhattan Study is designed to focus on risk factors for stroke in whites, blacks, and Hispanics living in the same community. The study has a large sample size, long duration of follow-up, minimal loss to follow-up, and detailed information on potential confounding factors. Our study design also allowed us to use diabetes as a time-dependent covariate to model risk of stroke and to study the relationship between diabetes duration and ischemic stroke among both men and women.

However, this study is not without limitations. First, because we were limited to using self-report to determine diabetes during follow-up, we may have misclassified “unaware” individuals with diabetes as not having diabetes, leading to a bias toward the null. Use of quantifiable measures of glycemic status such as fasting blood glucose or hemoglobin A1c as time-dependent covariates may have added additional prognostic information. However, our cohort may be atypical in that there was a high degree of follow-up with primary physicians (93%–96% annually), which may have led to a higher likelihood of diagnosis with diabetes. However, although we do have data collected during the annual follow-up interview on visits to primary care doctors, we do not have data on whether diabetes screening occurred during those visits. Second, the duration of follow-up may not have been long enough to bring out the difference between baseline and time-dependent models. Third, duration of diabetes at baseline was calculated based on participants’ self-reported age of onset, which is vulnerable to inaccuracy, because there is a lag time between onset and diagnosis. The apparent threshold of 10 years identified in this study, therefore, may be an underestimate. The analysis of duration and stroke are complicated by the fact that longer duration is associated with older age, and residual confounding cannot be ruled out. We did not have sufficient numbers to detect interaction by sex, age, and race/ethnicity, and thus cannot comment on the differential effect of diabetes or its duration in segments of the cohort. However, our findings are in agreement with other large population-based cohorts.

In conclusion, use of diabetes as a time-dependent covariate adds little incremental value to using diabetes at baseline as a risk factor for stroke. Duration of diabetes, however, increases the risk of ischemic stroke, independent of coexisting risk factors. As more people have development of diabetes earlier and live longer, this relationship assumes public health importance and warrants steps to institute long-standing and sustainable lifestyle changes for primary prevention and appropriate long-term management after diagnosis.

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Disclosures
None.

References
among individuals without diabetes mellitus (from the Northern Manhattan Study). 

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