
The Minnesota Stroke Survey

Kamakshi Lakshminarayan, MD, PhD; Alan K. Berger, MD, MS; Candace C. Fuller, PhD, MPH; David R. Jacobs Jr, PhD; David C. Anderson, MD; Lyn M. Steffen, PhD; Arthur Sillah, MPH; Russell V. Luepker, MD, MS

Background and Purpose—We report on trends in poststroke survival, both in the early period after stroke and over the long term. We examine these trends by stroke subtype.

Methods—The Minnesota Stroke Survey is a study of all hospitalized patients with acute stroke aged 30 to 74 years in the Minneapolis–St Paul metropolis. Validated stroke events were sampled for survey years 1980, 1985, 1990, 1995, and 2000 and subtyped as ischemic or hemorrhagic by neuroimaging for survey years 1990, 1995, and 2000. Survival was obtained by linkage to vital statistics data through the year 2010.

Results—There were 3773 acute stroke events. Age-adjusted 10-year survival improved from 1980 to 2000 (men 29.5% and 46.5%; \( P < 0.0001 \); women 32.6% and 50.5%; \( P < 0.0001 \)). Ten-year ischemic stroke survival (n=1667) improved from 1990 to 2000 (men 35.3% and 50%; \( P = 0.0001 \); women 38% and 55.3%; \( P < 0.0001 \)). Ten-year hemorrhagic stroke survival showed a trend toward improvement, but this (n=489) did not reach statistical significance, perhaps because of their smaller number (men 29.7% and 45.8%; \( P = 0.06 \); women 39.2% and 49.6%; \( P = 0.2 \)). Markers of stroke severity including unconsciousness or major neurological deficits at admission declined from 1980 to 2000 while neuroimaging use increased.

Conclusions—These poststroke survival trends are likely because of multiple factors, including more sensitive case ascertainment shifting the case mix toward less severe strokes, improved stroke care and risk factor management, and overall improvements in population health and longevity. (Stroke. 2014;45:00-00.)

Key Words: epidemiology ■ stroke ■ survival

T here have been important advances in the acute and postacute care of patients with stroke in the last 3 decades, including risk factor–modifying therapies to prevent recurrent stroke events, thrombolytic treatments shown to limit postischemic stroke functional disability, and organized stroke unit care leading to fewer poststroke complications. Consequently, improved poststroke survival over this period is expected. In the United States, there are no nationwide surveillance systems tracking trends in stroke survival or other poststroke outcomes.\(^1\) The National Vital Statistics System reports annual stroke-related mortality. These statistics are an estimate of the population burden of stroke-related deaths for a given year coded by underlying cause of death rather than a measure of stroke outcomes. A recent statement from the American Heart Association/American Stroke Association describes a significant decline in stroke mortality in the 20th century in the United States with this trend continuing into the next decade (2001–2010).\(^2\) This decline was attributed to declining stroke incidence and recurrence rates as well as improved case fatality (early poststroke survival). The statement identified a need to examine these improvements in stroke outcomes by stroke subtype.

In this study, we use a multidecade hospitalized stroke surveillance database to examine sex-specific trends in both early and long-term poststroke survival and whether the observed survival trends are reflected across both ischemic and hemorrhagic stroke subtypes, as well as among clinically more severe strokes whose detection is unlikely to be affected by increasingly sensitive stroke diagnostic tools. Annual stroke mortality as reported by vital statistics data is a mix of case fatality, in-hospital and 30-day stroke-related deaths, and deaths that occurred subsequently that are attributed to stroke. Deaths that occur in the early poststroke period are more likely to be assigned stroke as the underlying cause of death.
on death certificates, and hence improvements in early poststroke survival can be expected to influence trends in stroke mortality. Improvements in long-term survival, especially ≥1 year poststroke will likely not have an effect on the reported stroke mortality. Herein, we parsed out survival across different poststroke time epochs.

The Minnesota Stroke Survey (MSS) is a multidecade, stroke surveillance system designed to examine trends in hospitalized stroke rates, poststroke survival, risk factors, and treatment in the Minneapolis–St Paul metropolitan area. Data collection started in 1970, taking place typically at 5-year intervals. Results examining trends in poststroke survival from the 1970, 1980, 1985, and 1990 surveys have been published previously. Herein, we report on 10-year poststroke survival outcomes pertaining to the 1995 and 2000 surveys and contrast them to poststroke survival from the 1980s and 1990s.

We hypothesize that advances in stroke care and secondary prevention during the last 3 decades (1980–2010) have led to improved long-term survival of patients hospitalized with stroke. Ischemic strokes form a larger proportion of all strokes worldwide and comprise 87% of all strokes in the United States. Many of the acute and postacute care treatment trials and secondary prevention trials have, therefore, focused on ischemic rather than hemorrhagic strokes. We hypothesize that there has been a differential improvement in survival between ischemic versus hemorrhagic strokes with hemorrhagic strokes showing less significant survival gains during the last 3 decades.

Methods

Survey Design

The MSS was approved by the University of Minnesota Institutional Review Board. Design of the MSS has been previously described in Lakshminarayan et al. and is summarized here. The target populations of the MSS were residents of the 7-county Minneapolis–St Paul metropolitan area aged 30 to 74 years who were hospitalized with stroke. Stroke cases were identified from lists of discharge diagnoses provided by all acute care hospitals serving this metropolitan area. The following acute cerebrovascular disease discharge codes from the International Classification of Diseases, Ninth Revision (ICD-9) were used to construct a sampling frame for each survey year: 431 (intracerebral hemorrhage), 432 (other and unspecified intracranial hemorrhage), 434 (occlusion of cerebral arteries), 436 (acute, but ill-defined cerebrovascular disease), and 437 (other and ill-defined cerebrovascular disease). Transient cerebral ischemia (transient ischemic attack; ICD-9 code 435) and subarachnoid hemorrhage (ICD-9 code 430) were not included. (Historical reasons for exclusion of transient ischemic attacks and subarachnoid hemorrhages are in the online-only Data Supplement.) For the 1980, 1985, 1990, and 1995 surveillance years, hospital records for 50% of the cases in the sampling frame were randomly selected for detailed abstraction. In 2000, hospital records for 100% of the cases in the sampling frame underwent detailed abstraction. A small percentage of patients (5–10%) had multiple stroke hospitalizations. We used the first event in each survey year for each person in our sampling frame.

Data Abstraction and Quality Control

Data were abstracted from hospital records by trained nurses using standardized data abstraction forms and a manual. The following were abstracted: demographic information, medical history including prior stroke, relevant clinical information on stroke signs and symptoms, diagnostic procedures, and autopsy reports. Reliability of data abstraction was examined by reabstraction of 5% of randomly selected charts by an experienced gold standard reference abstractor. An inter-rater reliability of >95% was achieved for key demographic and clinical variables used to calculate stroke rates. Photocopied neuroimaging reports were independently abstracted by a physician reviewer using a manual and standardized data collection forms.

Stroke Case Definitions

The MSS has traditionally used multiple diagnostic definitions to examine stroke rates. Some of these definitions are based solely on ICD-9 codes, whereas others use clinical features and neuroimaging findings in addition to ICD-9 codes. The reason for using multiple diagnostic definitions was to account for changes in case ascertainment sensitivity and specificity because of evolving technological (eg, neuroimaging) advances or coding policies.

To examine poststroke survival, we used the following 2 case definitions: (1) World Health Organization (WHO) definition: cases with at least 1 acute cerebrovascular disease ICD-9 code (431, 432, 434, 436, 437) listed among hospital discharge diagnoses and meeting the WHO criteria for acute stroke: a new neurologic deficit of presumed vascular origin lasting at least 24 hours or until death if death occurred within 24 hours with exclusion of nonstroke causes such as tumors and subdural hematomas; (2) neuroimaging definition: cases where at least 1 acute cerebrovascular disease ICD-9 code is listed among hospital discharge diagnoses and identified as experiencing definite, probable, or possible acute strokes by neuroimaging. Strokes identified by neuroimaging were subtyped into ischemic and hemorrhagic strokes to examine poststroke survival by subtype.

The WHO definition was applied to survey years 1980, 1985, 1990, 1995, and 2000. The neuroimaging definition was applied to survey years 1990, 1995, and 2000 when neuroimaging was used more frequently.

Poststroke Survival

Poststroke death and death date were identified for all cases by linkage of the MSS to the Minnesota Department of Health vital statistics data. Personal identifiers enabling this linkage were available for 100% of patients in survey years 1980, 1985, 1990, and 1995 and for 97% of patients in 2000. Cases were tracked for death through 2010. We had multidecade survival for the early survey years but less for more recent cohorts. That is, stroke cases hospitalized in 1980 were tracked for 30 years through 2010, whereas cases hospitalized in 2000 while also tracked through 2010 had only 10 years of poststroke survival data.

Statistical Analysis

Patient characteristics were tested for an overall trend across survey years. The Cochran–Armitage trend test was used for comparing categorical variables, and the generalized linear model (PROC GLM; SAS version 9.2; SAS Institute, Inc, Cary, NC) was used for comparing the means of continuous variables.

To compare survival across survey years, sex-specific, age-adjusted (to the year 2000 US Census), short-term (in-hospital, 30 days) and long-term (1, 5, 10 years) survival poststroke was calculated for each survey year for cases identified by the WHO definition and tested for an overall trend across the survey years. Survival trends after ischemic and hemorrhagic strokes identified by the neuroimaging definition were similarly examined.

To tease apart the effects of more sensitive case ascertainment leading to milder strokes in the case mix and hence apparent improved survival versus actual survival gains, we examined age-adjusted survival trends in subsets of patients who were admitted with severe strokes, that is, those who were unconscious or had a major neurological deficit at admission.

Results

A total of 6032 patients with stroke were sampled among the 5 survey cohorts (Table 1). Of all the acute strokes identified
with little improvement across subsequent survey years for men and women. Over the long term (Figure), there was little improvement in men at 1 year poststroke between 1980 and 1985 and then a clear improvement across subsequent survey years. For women, the pattern was not monotonic, but there were clear improvements in survival between 1980 and 1985, a slowing in 1990 and then a clear separation of survival curves in subsequent surveys. Ten-year survival improved in both men and women. The improved survival persisted after excluding patients who died in the first year poststroke.

Survival trends by stroke subtype—ischemic versus hemorrhagic—became available in 1990 because of advances in imaging technology. Early (30-day) ischemic stroke survival did not show significant improvement between 1990 and 2000 for men or women (Table 4). There was a significant increase in 1-year survival among women (74% versus 83%; P < 0.02); the increase in 1-year survival among men did not reach significance (78% versus 83%; P = 0.12). Long-term ischemic stroke survival for 10 years improved significantly in both men and women in 2000 compared with earlier surveys. In men, 10-year ischemic stroke survival was 35% in 1990 and 50% in 2000 (P = 0.0001). In women, the corresponding stroke survival was 38% in 1990 and 55% in 2000 (P < 0.0001). The improvement in 10-year survival persisted even when the observations were limited to those who survived their first poststroke year.

Hemorrhagic stroke survival was substantially worse than ischemic stroke survival (Table 4). Early deaths were considerable in 1990 (30-day survival was 61% in men and 63% in women) and remained substantial in 2000 (69% 30-day survival in men and women). Early hemorrhagic stroke mortality was >3× early ischemic stroke mortality. One-year survival after hemorrhagic stroke improved between 1990 and 2000 (47% and 63% in men and 53% and 65% in women) but was not statistically significant probably because of the small number of hemorrhagic strokes. Ten-year survival after hemorrhagic strokes improved from 29% in 1990 to 48% in 2000 (P = 0.06) in men, and from 39% in 1990 to 49% in 2000 (P = 0.1973) in women. Long-term hemorrhagic stroke survival showed a pattern of improvement similar to ischemic stroke although the numbers and power were small. To verify this, we examined age-adjusted hemorrhagic stroke survival trends after combining men and women (Table I in the online-only Data Supplement). In this combined analysis, 1-year survival improved from 50% in 1990 to 64% in 2000 (P = 0.02), and 10-year survival improved from 35% in 1990 to 48% in 2000 (P = 0.03), this improvement was largely because of improved 1-year survival.

Survival trends were examined separately in patients with severe strokes, that is, those admitted unconscious or with major neurological deficits (Table 5). Early survival did not improve for those admitted unconscious (30-day survival: 34% in 1980, 36% in 2000; P = 0.79). Long-term survival showed some gains, but we could not demonstrate significance, perhaps because of small sample size and consequent limited power (1-year survival: 21% in 1980, 29% in 2000; P = 0.14; 10-year survival: 9% in 1980, 16% in 2000; P = 0.12). For those admitted with major neurological deficits, both early survival (79% in 1980, 91% in 2000; P < 0.0001) and long-term survival (10-year survival: 33% in 1980, 51% in 2000; P < 0.0001) improved.
This large multidecade study of hospitalized stroke patients showed improved survival from 1980 to 2000. Early stroke survival improved between 1980 and 1985 with little improvement across subsequent survey years for men and women. Long-term survival for 1 year and 10 years after stroke improved in both men and women. The conditional rates of 1-year survival among 30-day survivors and 10-year survival among 1-year survivors indicate that the gains are because of improved long-term survival with a more limited contribution from improvements in early survival. When survey years were restricted to 1990 to 2000 and survival by subtype was examined, long-term survival improved significantly for ischemic strokes. Hemorrhagic stroke survival improved as well, but because of the smaller numbers of hemorrhagic stroke, the trends in improvement did not reach statistical significance. When men and women were analyzed together, 1-year and 10-year hemorrhagic stroke survival showed significant improvement between 1990 and 2000.

We are aware of no regional studies that have monitored stroke mortality trends over the long term from 1980 to 2000. There are, however, reports of comparable trends in 30-day mortality from other regional studies. The Framingham cohort study9,10 reports a 30-day mortality of 20% and 21% in men and women for overall stroke during 1978 to 1989. The MSS mortality rate ranged between 17% to 22% for men and 15% to 21% for women during the 1980 and 1985 surveys, with lower mortality pertaining to the 1985 survey. For a later time period spanning 1990 to 2004, Framingham reported a 30-day mortality rate of 14% in men and 20% in women. The MSS mortality rate spanned 12% to 15% for men and 12% to 16% for women for 1990, 1995, and 2000 surveys. The Atherosclerosis Risk in Community (ARIC) study11 examined

### Table 2. Patient Population Characteristics for WHO Stroke Events Across Survey Years in Minneapolis–St Paul, Minnesota Metropolitan Area

<table>
<thead>
<tr>
<th>Variable</th>
<th>1980 (n=567)</th>
<th>1985 (n=602)</th>
<th>1990 (n=695)</th>
<th>1995 (n=660)</th>
<th>2000 (n=1249)</th>
<th>P Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female sex, %</td>
<td>44</td>
<td>46</td>
<td>47</td>
<td>45</td>
<td>47</td>
<td>0.36</td>
</tr>
<tr>
<td>Mean age, y</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>63</td>
<td>62</td>
<td>0.0002</td>
</tr>
<tr>
<td>Median age, y</td>
<td>66</td>
<td>66</td>
<td>67</td>
<td>66</td>
<td>65</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Race, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>87</td>
<td>92</td>
<td>91</td>
<td>82</td>
<td>74</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Black</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>9</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Hispanic</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Native American/other</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Missing</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Preadmission history, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>History of stroke</td>
<td>21</td>
<td>25</td>
<td>27</td>
<td>28</td>
<td>25</td>
<td>0.12</td>
</tr>
<tr>
<td>History of TIA</td>
<td>10</td>
<td>15</td>
<td>10</td>
<td>18</td>
<td>10</td>
<td>0.77</td>
</tr>
<tr>
<td>History of MI</td>
<td>...</td>
<td>20</td>
<td>19</td>
<td>16</td>
<td>16</td>
<td>0.006</td>
</tr>
<tr>
<td>History of atrial fibrillation</td>
<td>14</td>
<td>15</td>
<td>19</td>
<td>17</td>
<td>14</td>
<td>0.78</td>
</tr>
<tr>
<td>History of hypertension</td>
<td>53</td>
<td>58</td>
<td>63</td>
<td>67</td>
<td>68</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>History of diabetes mellitus</td>
<td>...</td>
<td>...</td>
<td>31</td>
<td>32</td>
<td>28</td>
<td>0.11</td>
</tr>
<tr>
<td>Clinical variables, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level of consciousness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unconscious</td>
<td>16</td>
<td>14</td>
<td>17</td>
<td>13</td>
<td>10</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Conscious</td>
<td>79</td>
<td>85</td>
<td>81</td>
<td>86</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Missing</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Neurological deficit, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major deficit (aphasia,* coma, visual field cut,* motor* or sensory* deficits in 2 of 3 body parts (face, arm, leg)</td>
<td>78</td>
<td>82</td>
<td>77</td>
<td>73</td>
<td>72</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Minor deficit* (slurred speech, apraxia, limited motor or sensory deficit, gait difficulties)</td>
<td>22</td>
<td>18</td>
<td>23</td>
<td>27</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Median LOS, d (IQR)</td>
<td>12 (19)</td>
<td>8 (8)</td>
<td>7 (7)</td>
<td>5 (5)</td>
<td>5 (5)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Neuroimaging present (CT or MRI), %</td>
<td>75</td>
<td>88</td>
<td>96</td>
<td>98</td>
<td>98</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>MRI present, %</td>
<td>18</td>
<td>30</td>
<td>30</td>
<td>60</td>
<td>60</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Diffusion-weighted imaging, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>35</td>
<td></td>
</tr>
</tbody>
</table>

Note: Age range 30 to 74 y. LOS excludes patients who died in-hospital (n=487). CT indicates computed tomography; IQR, interquartile range; LOS, length of stay; MI, myocardial infarction; TIA, transient ischemic attack; and WHO, World Health Organization.

*Excludes events who were unconscious during the first examination (n=498).
30-day mortality for ischemic and hemorrhagic strokes hospitalized between 1987 and 1995, a period overlapping with our study, and found 30-day mortality rates of 7% to 8% for ischemic strokes and 30% to 35% for hemorrhagic strokes. Although ARIC and MSS hemorrhagic stroke mortality rates are comparable, ischemic stroke mortality rates were higher (range, 12% to 17%) in the MSS for some survey years. When comparing MSS and Greater Cincinnati Northern Kentucky Stroke Study (GCNKSS) hemorrhagic stroke death rates, MSS rates were somewhat lower (47–53% in 1990, 35–37% in 2000) than those reported by GCNKSS (59% in 1988, 53% in 1998–2003).12

Our data provide circumstantial evidence on factors that could underlie the observed trends in poststroke survival. The improvement in early survival could be because of the detection of less severe events or because of improved care. As we argued in an earlier report,6 several markers of stroke severity seem to have declined between 1980 and 2000 although some of this could be artifactual. For example, the median length of stay declined, with the steepest change between 1980 and 1985. The reliability of length of stay as a marker for severity, however, is reduced because it was coincident with the introduction of diagnosis-related group-based reimbursement in the early 1980s.13 The proportion of cases admitted with a major neurological deficit declined. The proportion of unconscious cases at admission declined as well, but this could be because of the influence of neuroimaging on discharge coding, that is, unconsciousness at admission is often not because of stroke, and the increased use of neuroimaging likely helped increase the specificity of discharge coding.6

It is also likely that the case mix has shifted toward less severe events because of the more sensitive case ascertainment facilitated by newer technology such as MRI and diffusion-weighted imaging. The recategorization of some transient ischemic attack as strokes based on neuroimaging evidence is also a factor in the shift toward less severe events as the use of imaging has increased. Supporting this, we note that the proportion of neuroimaging strokes that did not meet the WHO

Table 3. Age-Adjusted Survival Across Survey Years for Stroke Events Defined by the World Health Organization Stroke Definition Among Men and Women Aged 30 to 74 Years in Minneapolis–St Paul, Minnesota Metropolitan Area

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Men, n</td>
<td>318</td>
<td>325</td>
<td>368</td>
<td>361</td>
<td>637</td>
<td>0.0026</td>
</tr>
<tr>
<td>30 d</td>
<td>77.9</td>
<td>82.9</td>
<td>87.9</td>
<td>84.6</td>
<td>85.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>1 y</td>
<td>67.5</td>
<td>70.8</td>
<td>77.7</td>
<td>77.0</td>
<td>78.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>5 y</td>
<td>51.4</td>
<td>47.7</td>
<td>55.5</td>
<td>60.4</td>
<td>62.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>10 y</td>
<td>29.5</td>
<td>29.0</td>
<td>36.8</td>
<td>41.5</td>
<td>46.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>1 y among 30-d survivors</td>
<td>86.5</td>
<td>85.3</td>
<td>88.5</td>
<td>91.0</td>
<td>91.9</td>
<td>0.0022</td>
</tr>
<tr>
<td>10 y among 1-y survivors</td>
<td>43.1</td>
<td>40.4</td>
<td>47.6</td>
<td>54.3</td>
<td>59.0</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Women, n</td>
<td>249</td>
<td>277</td>
<td>327</td>
<td>299</td>
<td>576</td>
<td>0.0013</td>
</tr>
<tr>
<td>30 d</td>
<td>79.1</td>
<td>85.1</td>
<td>84.4</td>
<td>86.8</td>
<td>88.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>1 y</td>
<td>64.3</td>
<td>74.6</td>
<td>72.2</td>
<td>75.5</td>
<td>79.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>5 y</td>
<td>47.8</td>
<td>58.8</td>
<td>53.2</td>
<td>57.8</td>
<td>64.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>10 y</td>
<td>32.6</td>
<td>41.8</td>
<td>38.2</td>
<td>41.6</td>
<td>50.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>1 y among 30-d survivors</td>
<td>81.2</td>
<td>87.6</td>
<td>85.5</td>
<td>87.0</td>
<td>90.4</td>
<td>0.0049</td>
</tr>
<tr>
<td>10 y among 1-y survivors</td>
<td>50.1</td>
<td>55.8</td>
<td>53.1</td>
<td>54.6</td>
<td>63.8</td>
<td>0.0074</td>
</tr>
</tbody>
</table>
certain criteria of a focal deficit of presumed vascular origin lasting at least 24 hours increased from 13% in 1990 to 22% in 2000. While the preceding observations indicate a change in the case mix toward less severe events in later survey years, we note that survival has also improved in severe strokes especially in those admitted with major deficits (Table 5). Both early and long-term survival improved in those admitted with major deficits. Although there was a clear lack of improvement in early survival in those unconscious at admission, there was a trend toward improved long-term survival even in this subgroup.

The observed improvement in long-term survival is likely a reflection of increased use of secondary preventive therapies and especially improved hypertension awareness and treatment. This improved awareness and management of hypertension is true for our Minnesota population as well as nationwide. We note that the history of hypertension in patients with stroke (Table 2) has increased. The Minnesota Heart Survey, a parallel study to the MSS, found declining rates of hypertension in the general Minneapolis–St Paul population but an increase in the proportion of patients who were aware of their diagnosis of hypertension. The National Health and Nutrition Examination Survey also found increased awareness, detection, and treatment of hypertension at a national level in the United States. Hence, we argue that there is likely improved hypertension management that has contributed to fewer recurrent vascular events and improved survival. There is also greater evidence for secondary preventive therapies in stroke, including trials of antithrombotic agents such as anticoagulation for patients with atrial fibrillation with stroke, which have also driven down stroke recurrence rates and presumably improved survival. There is some indication that the overall patient population is trending toward a healthier profile. The lower prevalence of a history of myocardial infarction in subsequent survey years supports this.

Finally, we note that the overall life expectancy in the general population has increased for the time period of the study. Hence, this could also contribute to improved stroke survival in synergy with specific improvements in poststroke treatments and care. For example, the median life expectancy in the 7-county metro area covered by the MSS increased 6.0 years in men (72.3 years in 1980 versus 78.3 years in 2005) and 2.3 years in women (80 years in 1980 versus 82.3 years in 2005) during the period of our study. Based on the above observations, we think that the improvement in poststroke survival is likely due to multiple trends, including shifts in the case mix toward less severe strokes mediated by more sensitive case ascertainment and reclassification of transient ischemic attack as strokes in later surveys, improved acute and postacute treatments (eg, stroke unit care) as evidenced by improved early survival even in those with severe strokes, improved evidence for and increased use of secondary preventive therapies and treatment of risk factors such as hypertension that have driven down recurrence of stroke and other

### Table 4. Age-Adjusted Survival Across Survey Years for Ischemic and Hemorrhagic Stroke Events Defined by Neuroimaging Definition Among Men and Women Aged 30 to 74 Years in Minneapolis–St Paul, Minnesota Metropolitan Area

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ischemic strokes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men, n</td>
<td>229</td>
<td>201</td>
<td>480</td>
<td></td>
</tr>
<tr>
<td>30 d</td>
<td>88.3</td>
<td>83.3</td>
<td>89.8</td>
<td>0.56</td>
</tr>
<tr>
<td>1 y</td>
<td>77.6</td>
<td>77.2</td>
<td>82.6</td>
<td>0.12</td>
</tr>
<tr>
<td>5 y</td>
<td>51.2</td>
<td>60.7</td>
<td>66.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>10 y</td>
<td>35.3</td>
<td>41.3</td>
<td>50.0</td>
<td>0.0001</td>
</tr>
<tr>
<td>1 y among 30-d survivors</td>
<td>87.8</td>
<td>92.4</td>
<td>91.9</td>
<td>0.09</td>
</tr>
<tr>
<td>10 y among 1-y survivors</td>
<td>45.1</td>
<td>53.2</td>
<td>60.9</td>
<td>0.0002</td>
</tr>
<tr>
<td>Hemorrhagic strokes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men, n</td>
<td>168</td>
<td>159</td>
<td>401</td>
<td></td>
</tr>
<tr>
<td>30 d</td>
<td>86.6</td>
<td>85.1</td>
<td>91.6</td>
<td>0.08</td>
</tr>
<tr>
<td>1 y</td>
<td>73.6</td>
<td>75.7</td>
<td>82.5</td>
<td>0.02</td>
</tr>
<tr>
<td>5 y</td>
<td>51.9</td>
<td>59.0</td>
<td>69.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>10 y</td>
<td>38.0</td>
<td>39.1</td>
<td>53.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>1 y among 30-d survivors</td>
<td>84.9</td>
<td>88.9</td>
<td>90.2</td>
<td>0.09</td>
</tr>
<tr>
<td>10 y among 1-y survivors</td>
<td>51.3</td>
<td>51.2</td>
<td>67.3</td>
<td>0.0011</td>
</tr>
<tr>
<td>Women, n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 d</td>
<td>61.4</td>
<td>66.7</td>
<td>68.7</td>
<td>0.39</td>
</tr>
<tr>
<td>1 y</td>
<td>47.1</td>
<td>53.7</td>
<td>62.9</td>
<td>0.08</td>
</tr>
<tr>
<td>5 y</td>
<td>41.2</td>
<td>46.2</td>
<td>53.4</td>
<td>0.17</td>
</tr>
<tr>
<td>10 y</td>
<td>29.7</td>
<td>33.3</td>
<td>45.8</td>
<td>0.06</td>
</tr>
<tr>
<td>1 y among 30-d survivors</td>
<td>76.5</td>
<td>80.5</td>
<td>91.5</td>
<td>0.06</td>
</tr>
<tr>
<td>10 y among 1-y survivors</td>
<td>59.0</td>
<td>62.6</td>
<td>73.6</td>
<td>0.18</td>
</tr>
</tbody>
</table>

### Table 5. Age-Adjusted Survival Across Survey Years for Stroke Events Defined by the World Health Organization Stroke Definition Among Men and Women (Combined) Aged 30 to 74 Years Hospitalized in Minneapolis–St Paul, Minnesota Metropolitan Area

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Unconscious, n</td>
<td>90</td>
<td>85</td>
<td>115</td>
<td>85</td>
</tr>
<tr>
<td>30 d</td>
<td>33.7</td>
<td>35.4</td>
<td>36.3</td>
<td>35.3</td>
</tr>
<tr>
<td>1 y</td>
<td>21.4</td>
<td>23.5</td>
<td>24.0</td>
<td>28.3</td>
</tr>
<tr>
<td>5 y</td>
<td>17.0</td>
<td>14.2</td>
<td>16.3</td>
<td>18.8</td>
</tr>
<tr>
<td>10 y</td>
<td>9.2</td>
<td>9.5</td>
<td>9.3</td>
<td>11.7</td>
</tr>
<tr>
<td>Major deficit, n</td>
<td>440</td>
<td>491</td>
<td>535</td>
<td>479</td>
</tr>
<tr>
<td>30 d</td>
<td>79.2</td>
<td>81.1</td>
<td>84.2</td>
<td>89.7</td>
</tr>
<tr>
<td>1 y</td>
<td>66.2</td>
<td>69.9</td>
<td>72.3</td>
<td>80.1</td>
</tr>
<tr>
<td>5 y</td>
<td>49.8</td>
<td>51.0</td>
<td>53.8</td>
<td>62.9</td>
</tr>
<tr>
<td>10 y</td>
<td>32.7</td>
<td>33.3</td>
<td>37.9</td>
<td>43.2</td>
</tr>
</tbody>
</table>

Survival shown for patients who were unconscious or with major neurological deficits at admission. Table 2 defines major neurological deficits.
vascular events, and finally a shift in the patient population toward a healthier profile and increased longevity in the general population as a whole.

Strengths of our study include our use of algorithmic clinical and neuroimaging-based stroke definitions across survey years rather than pure ICD-9–based stroke metrics. These clinical and neuroimaging-based algorithms enable consistent case definitions and allow for comparison of outcomes across multiple surveys. Also, a unique aspect of the MSS is the availability of multidecade survival data. One weakness is that because the MSS is by design a study of hospitalized strokes, it cannot be used to examine nonhospitalized strokes. Data from other studies such as the Northern Manhattan Study\(^17\) suggest that between 6% and 7% of strokes are missed by hospital surveillance alone. Although we include all metro area hospitals in our surveillance, a small proportion of strokes, including nursing home strokes and strokes that did not come to medical attention, could have been missed by our surveillance system. The population under surveillance is the Minneapolis–St Paul metro area, and we excluded patients residing in zip codes outside the metro area. Minneapolis–St Paul residents hospitalized outside the metro area were also missed; however, we think this number may be small because most of the large hospitals are within the metro area. Therefore, the MSS is close to a population sample of strokes. The age range of our hospitalized patients with stroke is limited to 30 to 74 years. Hence, we are unable to comment on the survival of those aged <30 years or >75 years. The Global Burden of Disease study\(^16\) found that in high-income countries (which would be comparable to the MSS setting), stroke mortality has declined in all age groups, including the very young (<20 years), young and middle-aged (21–64 years), older (65–74 years), and in the very old (>75 years) for both ischemic and hemorrhagic strokes. While stroke mortality as obtained from the death certificate data reflects poststroke survival, it is incomplete because, as strokes become more remote in time from death, the likelihood that they will be documented as contributing cause of death declines. The current study, based on prospective case identification, prolonged observation, and complete ascertainment of mortality status, supports the Global Burden of Disease study results. By extrapolation, it is likely that the findings of improvement in mortality in the young and the very old by the Global Burden of Disease study is valid as well.

In conclusion, 10-year poststroke survival has shown significant gains between 1980 and 2000. Most of the survival gains seem to be because of improved long-term survival with a more limited contribution from short-term improvement. The observed improvements in poststroke survival is likely multifactorial and due to more sensitive case ascertainment identifying less severe strokes, overall improvements in population health and longevity, and better secondary preventive therapies after stroke.

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This research was supported by the National Institute of Neurological Disorders and Stroke (NINDS)/National Institutes of Health (NIH) grant R01NS39028). K. Lakshminarayan was supported by an NINDS/NIH career development award (grant K23NS051377).

Disclosures

None.

References

Kamakshi Lakshminarayan, Alan K. Berger, Candace C. Fuller, David R. Jacobs, Jr, David C. Anderson, Lyn M. Steffen, Arthur Sillah and Russell V. Luepker

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SUPPLEMENTAL MATERIAL


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METHODS

TIAs were not included historically in the MSS due to problems with diagnostic accuracy. TIA diagnoses are based on patient’s subjective reports which are less precise than those of patients with stroke whose longer lasting signs and symptoms can be reliably assessed by physicians. Furthermore, TIA are heterogeneous and each TIA symptom has its own sensitivity and specificity and this also poses a problem in uniform diagnostic accuracy. Similarly, sub-arachnoid hemorrhages were considered to be due to berry aneurysms and other congenital vascular malformations. The original intent of the Minnesota Stroke Survey (and the Minnesota Heart Survey) was to understand cardiovascular disease (CVD) and stroke and the impact of the traditional vascular risk factors including hypertension, hyperlipidemia, diabetes and tobacco smoking on stroke and CVD. Hence, sub-arachnoid hemorrhages were not included in the surveillance.

ONLINE TABLE I. Age Adjusted Survival Across Survey Years for Hemorrhagic Stroke Events Defined by Neuroimaging Definition for Men and Women (Combined) Aged 30-74 Years in Minneapolis-St. Paul, Minnesota Metropolitan Area.

<table>
<thead>
<tr>
<th>Age Adjusted Survival, %</th>
<th>1990</th>
<th>1995</th>
<th>2000</th>
<th>P-trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men &amp; Women Combined, n</td>
<td>92</td>
<td>97</td>
<td>296</td>
<td></td>
</tr>
<tr>
<td>30-day</td>
<td>62.0</td>
<td>68.2</td>
<td>69.2</td>
<td>0.21</td>
</tr>
<tr>
<td>1-year</td>
<td>50.4</td>
<td>59.0</td>
<td>64.3</td>
<td>0.02</td>
</tr>
<tr>
<td>5-years</td>
<td>46.3</td>
<td>52.0</td>
<td>55.7</td>
<td>0.11</td>
</tr>
<tr>
<td>10-years</td>
<td>35.1</td>
<td>41.9</td>
<td>48.0</td>
<td>0.03</td>
</tr>
<tr>
<td>1-year among 30-day survivors</td>
<td>81.1</td>
<td>86.5</td>
<td>93.0</td>
<td>0.01</td>
</tr>
<tr>
<td>10-years among 1 year survivors</td>
<td>68.8</td>
<td>71.3</td>
<td>74.7</td>
<td>0.40</td>
</tr>
</tbody>
</table>

REFERENCES