Hypertension

Trends in Blood Pressure and Hypertension Detection, Treatment, and Control 1980 to 2009

The Minnesota Heart Survey

Russell V. Luepker, MD, MS; Lyn M. Steffen, PhD; David R. Jacobs, Jr, PhD; Xia Zhou, MS; Henry Blackburn, MD

Background—Hypertension is common and treatable, but detection and control remain a major health challenge. This study sought to determine population trends in blood pressure and in the control of hypertension in the Minneapolis/St. Paul area (2010 population, 2.85 million) from 1980 to 2009.

Methods and Results—Surveys of risk factors were performed every 5 years among randomly selected adults aged 25 to 74 years. Data on hypertension knowledge and use of medications were collected by interview. Blood pressure was measured by standardized methods, with hypertension defined as blood pressure ≥140 mm Hg systolic and/or 90 mm Hg diastolic or controlled at <140 and/or 90 mm Hg with medications. Six surveys included 11,192 men and 12,795 women. Mean systolic blood pressure fell from 124.9 mm Hg in 1980 to 1982 to 121.1 mm Hg in 2007 to 2009 for men (P<0.0001) and from 120.1 to 114.7 mm Hg for women (P<0.0001). Similar trends for diastolic blood pressure were observed. The percentage of adults with uncontrolled blood pressure (≥140 and/or 90 mm Hg) with or without medication use fell from 20.3% to 5.8% (P<0.001) for men and from 13.1% to 2.7% (P<0.0001) for women. Antihypertensive medication use rose to 50% among all adults aged 55 to 74 years. Sixty-six percent of men and 72% of women with hypertension had their hypertension treated or controlled by 2007 to 2009. A majority of the decline in mean population blood pressure was the result of control with aggressive use of antihypertensive drugs. Stroke mortality in this population fell in parallel.

Conclusions—The rate of hypertension detection and control in this community is among the highest observed in a US population and already exceeds Healthy People 2020 goals. (Circulation. 2012;126:1852-1857.)

Key Words: hypertension ■ blood pressure ■ stroke ■ epidemiology

Hypertension is common in the United States, afflicting >76 million adults aged ≥20 years.1 It is more prevalent among certain age, sex, race, and ethnic groups but afflicts all population segments. Hypertension is associated with coronary heart disease, stroke, heart failure, kidney failure, and other chronic conditions.1,2 Treatments to control hypertension significantly reduce these diseases.2 As a result, guidelines for the detection, treatment, and control of hypertension have been advocated for more than 3 decades.3 The result is improved treatment and control associated with declining cardiovascular disease rates.4 Yet hypertension is undiagnosed, untreated, and uncontrolled in many instances. The most recent national recommendations in Healthy People 2020 continue to emphasize the need for enhanced prevention and hypertension control strategies.5

Clinical Perspective on p 1857

The Minnesota Heart Survey (MHS) is a population-based study of trends in cardiovascular risk factors, morbidity, and mortality in a large urban area.6 At regular intervals, cardiovascular risk factors, including blood pressure, are measured in a sample of adults randomly selected from the population. This report examines trends in population blood pressure and hypertension detection, treatment, and control from 1980 to 2009.

Methods

The MHS performed cross-sectional risk factor and health behavior surveys on noninstitutionalized resident adults aged 25 to 74 years in the 7-county Minneapolis/St Paul metropolitan area (2010 Census, 2.85 million). Surveys were conducted in 1980 to 1982, 1985 to 1987, 1990 to 1992, 1995 to 1997, 2000 to 2002, and 2007 to 2009. The Minneapolis/St. Paul population is predominantly white and has slightly higher levels of education and employment than the overall US population.

MHS sampling is designed to obtain a random sample of the target population; these methods have been described in detail elsewhere.7,8 In brief, a 2-stage cluster design was created from census maps. The 7-county metropolitan area was divided into 704 clusters of ~1000
households each. Forty clusters were selected randomly and used for each survey, with a sample of households randomly selected from within each cluster. The sampling fraction (5%–10%) varied by resources. The census maps were updated before each survey to account for new housing developments, and sampling was adjusted accordingly. In 1995, 4 clusters were added to represent new population growth, and in 2007, 3 more clusters were added for a total of 47. Once a house was selected, it was removed from sampling in future surveys. There were small differences in the sampling methodology between surveys, which have been described previously.8

After an introductory letter was sent, selected households were visited by a trained interviewer who performed a household enumeration, with those eligible selected for the survey. Data collection was performed in 2 stages. An initial home interview solicited information on history of hypertension, medication use for hypertension, and other health indicators. A visit to a survey center at a nearby clinic, public building, or university clinical center followed. At that site, further information was obtained, including direct measurement of the blood pressure, height, and weight. If an individual was unable or unwilling to come to the survey center, a second home visit could be scheduled for the additional measurements.

Blood pressure was measured with a random zero (RZ) sphygmomanometer (Hawksley) from 1980 to 1997 by technicians trained according to the method of Prineas9 and using an appropriate size cuff. After 5 minutes of seated rest, subjects had 2 blood pressure measurements taken 1 minute apart with their right arms at the level of the heart. The systolic blood pressure (SBP) and fifth phase diastolic blood pressure (DBP) were recorded, and the average of these 2 measures was used for these analyses. Room temperature, time of day, pulse rate, recent smoking, and other characteristics known to affect blood pressure were also recorded as potential adjustment factors. Quality of blood pressure measurements was evaluated with periodic calibration of the sphygmomanometer, observation of technician procedures, and the surveillance of blood pressure distribution values obtained by each technician.

During the 1995 to 1997 survey, a study comparing the RZ sphygmomanometer with the DINAMAP (GE Medical Systems Information Technologies) automated device was performed. All clinic subjects’ blood pressure levels were measured with both the RZ device and the DINAMAP monitor. The order of use of the device for each pair of measurements was random. In the 1995 to 1997 survey period (n = 4285 subjects), mean SBP was 118.70 ± 16.0 mm Hg with the RZ sphygmomanometer and 120.06 ± 18.3 mm Hg with the DINAMAP. DBP was 72.5 ± 10.23 mm Hg with the RZ sphygmomanometer, whereas it was 70.1 ± 10.10 mm Hg with the DINAMAP. In 2000, only the DINAMAP was used. To assess time trends in blood pressure, the calibration of the DINAMAP to the RZ sphygmomanometer was evaluated by regression of the average RZ measure on the average DINAMAP measure, which yielded the following equations:

\[ \text{Estimated RZ SBP} = 28.1240 + 0.7544 \times \text{DINAMAP SBP} \]
\[ \text{Estimated RZ DBP} = 21.7225 + 0.7246 \times \text{DINAMAP DBP} \]

The observed RZ SBP was lower than the DINAMAP SBP below a blood pressure of 115.5 mm Hg and higher above that value. Similarly, the observed RZ DBP was lower than the DINAMAP DBP below a blood pressure of 79.5 mm Hg and higher above that value. Reported values were adjusted on the basis of these findings.

The RZ device is known to read slightly but systematically lower than the standard sphygmomanometer. We previously published a comparability study,10 and the RZ values were adjusted to the standard sphygmomanometer for this presentation.

Participation rates for a fully completed survey ranged from 56% to 69% of the selected samples, with declining rates over time. More extensive data were available for the entire sample than for those who participated in the home interview only. Clinic respondents were slightly more likely than nonrespondents to be married, employed, better educated, and nonsmokers, but they did not differ at the home interview in reporting a history of hypertension.

Mortality trend data for stroke in the Minneapolis/St. Paul metropolitan area were accessed through the Minnesota Department of Health’s official records.12 These data were age adjusted to the 2000 Census data.

**Statistical Analysis**

All analyses were sex specific to illuminate the male/female differences in blood pressure level detection and treatment. General linear modeling techniques with SAS PROC GLIMMIX were used to estimate and test for differences among age-specific mean levels of SBP and DBP, as well as body mass index. The cluster design was included by the addition of the neighborhood clusters as a random effect. This allowed computation of an unbiased estimate of the variance of the sample means, which resulted in an inflation of the variance by ~5%. Age-adjusted prevalences of hypertension (with blood pressure cut points of ≥140 mm Hg systolic and/or ≥90 mm Hg diastolic and/or hypertension medication use) in the 6 surveys were analyzed by logistic regression with neighborhood cluster as a random effect, by use of SAS PROC GLIMMIX. Orthogonal polynomials were used to test linear functions simultaneously. Hypertensive patients at each survey were further classified into 4 mutually exclusive groups: Aware, treated, and controlled; aware, treated, and uncontrolled; aware, untreated, and uncontrolled; and unaware.

SAS software was used for all analyses (SAS Institute Inc, version 8.2. SAS Institute).

This study was approved by the Institutional Review Board of the University of Minnesota, Human Subjects Code Number 9905M05621, and all participants signed an informed consent form.

Dr Luepker had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

**Results**

A total of 23 978 adults aged 25 to 74 years participated in the 6 surveys (11 192 men and 12 795 women). The average age of the population rose over time. As shown in Tables 1 and 2, there were significant trends in SBP and DBP over the 30 years of the study. SBP fell in men from an average 124.9 to 121.2 mm Hg and in women from an average 120.1 to 114.7 mm Hg, with significant linear downward trends (P < 0.0001). DBP also demonstrated a downward trend for both men and women between 1980 to 1982 and 2007 to 2009. Although the magnitude of the DBP fall was less, significant declines were also observed. Average body mass index, a measure of obesity, rose over time, and leveled off only in the last survey.

Most striking was the dramatic decline in individuals with recorded blood pressures ≥140 mm Hg systolic and/or 90 mm Hg diastolic with or without medications. The numbers trended steadily downward from 1980 to 1982 to 2007 to 2009, falling from 22.1% to 6.8% (P < 0.0001) for men and from 17.9% to 4.0% (P < 0.0001) for women. In addition, individuals with blood pressures ≥160 mm Hg systolic and/or 100 mm Hg diastolic were rare by the 2007 to 2009 survey (<0.2%; data not shown).

The details for treatment categories are shown in Figure 1. Using the standard categories of aware, treated, controlled, and unaware, we noted dramatic changes, particularly in the last 2 surveys. Those who were aware, were treated with medications, and had their blood pressure controlled according to a definition of <140 and <90 mm Hg increased dramatically and constituted 66% of men and 72% of women with reported hypertension in the 2007 to 2009 survey. At the same time, those who were aware, were treated, and had uncontrolled blood pressure or were unaware of their high blood pressure constituted shrinking proportions of the hypertensive population.
Tables 1 and 2 reveal the trends in SBP and DBP among normotensive subjects, treated hypertensive subjects, and untreated hypertensive subjects. These subcategories reveal the source of much of the decline in overall SBP in the population. Blood pressures in normotensive individuals have remained relatively stable over time, without evidence of trends; however, blood pressures in treated hypertensive subjects have improved dramatically over time, with a decline in mean SBP for hypertensive men from 135.6 mm Hg in 1980 to 1982 to 125.2 mm Hg in 2007 to 2009 (P<0.0001). For women, there were similar improvements in control for those with hypertension, with an average SBP level in 1980 to 1982 of 137.8 mm Hg and 123.5 mm Hg in 2007 to 2009. Untreated hypertensive subjects showed no trend in SBP, although they decreased substantially as a proportion of the population. DBP showed similar, although more modest trends, with treated hypertensive subjects playing the largest role in the decline in overall population blood pressure. It is clear from these data that hypertension was commonly detected and aggressively treated to recommended targets.

Table 3 describes antihypertensive drug use trends by age and sex. The use of antihypertensive medications rose steadily with age, and in the highest age categories (55–74 years), an average of 50% of all free-living adults were taking antihypertensive medication in the most recent period. Again, there was a steady increase from the 1980s. The effects of high levels of antihypertensive medication use, particularly in older adults aged 55 to 74 years, can be observed in the age-specific SBP trends (Figure 2). The trends in prevalence of treatment and more effective treatment were of a magnitude to affect the population’s SBP.

### Table 1. Age, Systolic Blood Pressure, and Body Mass Index Trends

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Men</td>
<td>n</td>
<td>Mean±SE</td>
<td>n</td>
<td>Mean±SE</td>
<td>n</td>
<td>Mean±SE</td>
</tr>
<tr>
<td>Age</td>
<td>1385</td>
<td>43.9±0.6</td>
<td>2417</td>
<td>44.8±0.5</td>
<td>2764</td>
<td>45.3±0.5</td>
</tr>
<tr>
<td>SBP</td>
<td>1385</td>
<td>120.1±0.5</td>
<td>2417</td>
<td>118.1±0.4</td>
<td>2764</td>
<td>117.3±0.4</td>
</tr>
<tr>
<td>Normotensive</td>
<td>1054</td>
<td>113.3±0.4</td>
<td>1926</td>
<td>112.3±0.3</td>
<td>2263</td>
<td>112.1±0.3</td>
</tr>
<tr>
<td>Treated HBP</td>
<td>177</td>
<td>137.8±1.3</td>
<td>306</td>
<td>135.0±1.0</td>
<td>243</td>
<td>132.3±1.1</td>
</tr>
<tr>
<td>Untreated HBP</td>
<td>154</td>
<td>147.5±1.2</td>
<td>185</td>
<td>148.0±1.1</td>
<td>258</td>
<td>143.3±0.9</td>
</tr>
<tr>
<td>BMI, kg/m²†</td>
<td>1385</td>
<td>24.9±0.3</td>
<td>2417</td>
<td>26.1±0.2</td>
<td>2764</td>
<td>26.6±0.2</td>
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</tbody>
</table>

*SBP indicates systolic blood pressure; HBP, high blood pressure (hypertension); and BMI, body mass index.

### Table 2. Diastolic Blood Pressure Trends

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>n</td>
<td>Mean±SE</td>
<td>n</td>
<td>Mean±SE</td>
<td>n</td>
<td>Mean±SE</td>
</tr>
<tr>
<td>SBP</td>
<td>1238</td>
<td>78.1±0.3</td>
<td>2212</td>
<td>76.7±0.3</td>
<td>2381</td>
<td>80.2±0.3</td>
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<tr>
<td>Normotensive</td>
<td>897</td>
<td>74.8±0.3</td>
<td>1677</td>
<td>73.8±0.2</td>
<td>1735</td>
<td>76.7±0.2</td>
</tr>
<tr>
<td>Treated HBP</td>
<td>144</td>
<td>83.7±0.9</td>
<td>215</td>
<td>82.7±0.8</td>
<td>232</td>
<td>83.6±0.7</td>
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<tr>
<td>Untreated HBP</td>
<td>197</td>
<td>88.2±0.7</td>
<td>320</td>
<td>87.7±0.6</td>
<td>414</td>
<td>91.7±0.6</td>
</tr>
<tr>
<td>Women</td>
<td>n</td>
<td>Mean±SE</td>
<td>n</td>
<td>Mean±SE</td>
<td>n</td>
<td>Mean±SE</td>
</tr>
<tr>
<td>SBP</td>
<td>1385</td>
<td>74.0±0.3</td>
<td>2417</td>
<td>72.9±0.3</td>
<td>2764</td>
<td>75.7±0.3</td>
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<tr>
<td>Normotensive</td>
<td>1054</td>
<td>70.9±0.3</td>
<td>1926</td>
<td>70.4±0.2</td>
<td>2263</td>
<td>73.4±0.2</td>
</tr>
<tr>
<td>Treated HBP</td>
<td>177</td>
<td>80.5±0.8</td>
<td>306</td>
<td>79.3±0.6</td>
<td>243</td>
<td>81.7±0.7</td>
</tr>
<tr>
<td>Untreated HBP</td>
<td>154</td>
<td>87.7±0.7</td>
<td>185</td>
<td>87.8±0.7</td>
<td>258</td>
<td>89.1±0.6</td>
</tr>
</tbody>
</table>

*DBP indicates diastolic blood pressure; HBP, high blood pressure (hypertension).

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Mortality trends for cerebrovascular disease (stroke) from 1990 to 2009 in the state of Minnesota paralleled these blood pressure changes (Figure 3). The overall trends for both men and women were downward; however, the effect has been particularly dramatic since the year 2000. From 1990 to 1999, the average decline in age-adjusted stroke mortality was 1.0% per year, whereas in 2000 to 2009, it was 3.5% per year.

**Discussion**

The improved detection, treatment, and control of hypertension are among the more important health achievements of the past 50 years. Substantial evidence from laboratory, epidemiological, and clinical trial data followed by vigorous public and professional education campaigns from the National High Blood Pressure Education Program, industry, and many voluntary organizations led to major changes in clinical practice. The Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure, now in its seventh edition, periodically summarizes the scientific data and makes public recommendations. Medications to treat hypertension are among the most commonly prescribed and sold. Despite all this progress, many cases are undetected and uncontrolled, with certain groups in the population lagging in their access to and use of successful treatments. Some authorities have even speculated that the attainment of a goal blood pressure of 140/90 mm Hg or less in 50% of hypertensive individuals may be “the best we can do.”

Data from the MHS provide population-based distributions of blood pressure and hypertension and their trends in a large urban population. Consistent sampling from a fixed geographic area and careful measurement methods allow valid comparisons over time. Blood pressure and hypertension control have been an area of particular interest in Minnesota, dating back to a 1973 to 1974 survey and more recently an evaluation of trends from 1980 to 2002.

Among the more interesting findings in the present study are the continuous decline of mean SBP and DBP in the population and an apparent source of those declines. Mean blood pressures among normotensive subjects, or those with blood pressure <140/90 mm Hg, have remained stable from the 1980 to 1982 survey to 2007 to 2009. Those with untreated hypertension also have stable mean blood pressures. However, large differences in mean SBP and DBP over time were found among treated hypertensive subjects. Their mean SBP fell, on average, 10 mm Hg in men and 14 mm Hg in women. Similar differences were observed for treated DBP, which fell 6 mm Hg for men and 8 mm Hg for women. This was coupled with an increasing proportion of hypertensive persons detected and under treatment. Effective treatment and the total number of treated hypertensive persons largely accounted for the observed fall in mean blood pressure in the population. Approximately 50% of the general population aged 55 to 74 years reported taking antihypertensive drugs.

The summation of these findings is reflected in the dramatic increases in the detection and treatment of hypertension over this period. Approximately 70% of hypertensive men and women in the present study population sample were aware, treated, and controlled for this condition in 2007 to 2009. Declining numbers of hypertensive persons were unaware, untreated, or inadequately treated. This trend, first noted in 2000 to 2002, has accelerated despite rising levels of overweight and obesity in this population.

The national picture can be seen from the National Health and Nutrition Examination Survey (NHANES) that examined hypertension trends from 1988 to 2008 among adults aged

![Figure 1. Trends in detection, treatment, and control of hypertension from 1980 to 1982 to 2007 to 2009 for men and women.](http://circ.ahajournals.org/)

### Table 3. Antihypertensive Drug Use Trends by Age and Sex (% Population), Age Adjusted

<table>
<thead>
<tr>
<th>Age, y</th>
<th>Men</th>
<th>Women</th>
<th>Men</th>
<th>Women</th>
<th>Men</th>
<th>Women</th>
<th>Men</th>
<th>Women</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>25–34</td>
<td>0.0</td>
<td>0.0</td>
<td>0.3</td>
<td>0.0</td>
<td>2.4</td>
<td>0.0</td>
<td>0.7</td>
<td>2.4</td>
<td>6.7</td>
<td>3.2</td>
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<tr>
<td>35–44</td>
<td>0.9</td>
<td>1.1</td>
<td>1.5</td>
<td>0.6</td>
<td>2.4</td>
<td>1.3</td>
<td>6.3</td>
<td>4.4</td>
<td>12.7</td>
<td>9.7</td>
</tr>
<tr>
<td>45–54</td>
<td>4.9</td>
<td>3.1</td>
<td>5.4</td>
<td>3.7</td>
<td>9.1</td>
<td>5.5</td>
<td>11.8</td>
<td>15.4</td>
<td>35.2</td>
<td>24.4</td>
</tr>
<tr>
<td>55–64</td>
<td>8.1</td>
<td>10.5</td>
<td>10.0</td>
<td>10.3</td>
<td>20.9</td>
<td>19.5</td>
<td>30.3</td>
<td>28.9</td>
<td>52.1</td>
<td>45.5</td>
</tr>
<tr>
<td>65–74</td>
<td>14.8</td>
<td>16.6</td>
<td>18.5</td>
<td>24.7</td>
<td>24.8</td>
<td>23.9</td>
<td>28.5</td>
<td>31.0</td>
<td>41.1</td>
<td>41.5</td>
</tr>
</tbody>
</table>
The age window does not directly overlap with MHS (age 25–74 years). Mean SBP in NHANES did not change significantly, whereas DBP fell in the general population over the 20 years of observation. Prevalence of hypertension increased from 1988 to 2000 but remained flat thereafter. Those with hypertension who were aware of, treated, and controlled for it rose from 27.3% in 1988 to 50.1% in 2007. Most of that change was in the second decade of observation. Mean SBP among hypertensive subjects both treated and untreated was 135.2 mm Hg in the national sample compared with 127.8 mm Hg in MHS for the most recent surveys.

The Minnesota data demonstrate significantly better current levels of treatment and control, with lower average blood pressures among treated hypertensive subjects than in the national NHANES data. A systematic difference in measurement methods existed between NHANES and MHS. NHANES used the standard sphygmomanometer, with blood pressure measured by a health professional, and MHS used the RZ sphygmomanometer or an automated method adjusted to the standard sphygmomanometer. NHANES took 3 blood pressure measurements in most individuals and used the mean of the last 2 measures “when they [were] available.” MHS used the mean of the first and second measures. It is well recognized that the first measured blood pressure is usually the highest value, with declines in the second and subsequent measurements. With this difference in methods, one would anticipate that MHS values would be higher, because the first MHS measurement was always included in the mean. However, the values were actually lower, which suggests that Minnesota blood pressure levels, as well as treatment levels, were significantly better than the national data.

Minnesota has among the lowest cardiovascular disease rates in the United States. A previous comparison to NHANES suggests that this is in part because of lower mean risk factor levels, including smoking rates and rates of hypertension, high cholesterol, and obesity. The rates of stroke mortality in Minnesota are partially confirmatory of the greater level of control of hypertension, particularly true in the past decade.

The rates of hypertension detection and control observed in MHS exceed those proposed as goals in Healthy People 2020. The 2020 goal for the American population is 61.2% of the population aware of hypertension and treated and controlled. Despite the suggestion that it will be difficult to move the population to a figure >50% aware, treated, and controlled, this target appears very achievable on the basis of the Minnesota experience and has already attained in studies in Canada and northern Sweden.

The reasons for the quality of hypertension care are speculative. Minnesota has among the highest levels of health insurance coverage among its citizens and has a well-developed healthcare system. These factors, along with greater levels of high school and college education, higher family incomes, and fewer people in poverty than the national figure, may contribute to these positive health outcomes.

There are several limitations to the present study. Among them are the participation rates in a survey of the general population. Although similar to NHANES, it is possible that those who are nonresponders differ in important ways. The 2-stage nature of the MHS survey, a home interview followed by a clinic measurement, makes it possible to examine characteristics such as a history of hypertension. Clinic respondents were more likely to be married, employed, better educated, and nonsmokers; however, a history of hypertension did not differentiate clinic participation from the home interview. These factors also stayed constant, on average, over the years of the study.

Although Minnesota is increasingly diverse, the survey population is mainly white. In recent years, a larger number of Hispanics, southeast Asians, and east Africans became part of the Minneapolis/St. Paul metropolitan area and were sampled by MHS methods. In the most recent survey (2007–2009), 10% of participants aged 25 to 74 years were nonwhite.
Acknowledgments

The authors wish to acknowledge the participants in this study who gave of their time to ensure representative and quality data. We also wish to thank the MHS staff and those who led earlier surveys, including Donna Arnett, PhD, Aaron Folsom, MD, MPH, Richard F. Gillum, MD, MS, and J. Michael Sprafka, PhD.

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Disclosures

None.

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