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Stroke-Associated Deaths in Washington County,
Maryland, with Special Reference to Water Hardness

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K. J. HELSING, B.S., AND E. L. GOLDBERG, Sc.D.

SUMMARY Deaths associated with strokes from 1963 to 1975 among 36,860 adult residents of
Washington County, Maryland, were studied in relation to the hardness of drinking water at home, assessed
on the basis of 1,569 water samples taken during this period. There was no satisfactory evidence that water
hardness was related to stroke mortality. Age was a strongly related factor. There was little or no association
with sex, marital status, socio-economic status as reflected by education or housing, smoking history, or fre-
cuency of church attendance.

DEATH RATES from stroke have shown consid-
erable variation by state and by region of the
United States for the last 4 census years.1-4 The highest
rates have tended to occur in the South Atlantic or
East South Central regions, and the lowest in the Mid-
dle Atlantic or Mountain regions. Over this period,
the ratio of rates in the highest to lowest states has
been in the neighborhood of 2.0 and the ratio for
regions a little less than 1.5. A study of death certifica-
tion practices concluded that these differences in mor-
tality from stroke were largely real.6
Among the factors looked at as possible explana-
tions of these geographic differences has been hard-
ness of drinking water. In his pioneering study of
water characteristics and strokes, Kobayashi reported
a close relationship between death rates from
apoplexy in Japan and a measure of water acidity, the
ratio of sulfates to carbonates.6 Schroeder attempted
to confirm this finding in the United States, but found
only a slight correlation of the sulfate-bicarbonate
ratio with coronary heart disease. Total hardness,
however, showed significant associations with a
number of cardiovascular causes of death. In his first
paper, Schroeder merely mentioned that the correla-
tion of stroke deaths with water hardness was signifi-
cant for the age group 55-64.7 A later paper during the
same year reported a correlation of -0.33 between the
age-adjusted death rates from stroke in 1949-51 and
the weighted average of the hardness of finished water
by states.8 A slightly smaller negative correlation was
noted in 1960 for the 88 largest cities in the U.S.9
When Schroeder looked at the 1960 mortality data for
201 standard metropolitan statistical areas by race,
sex, and age, he found correlations of cerebral throm-
bosis death rates to be nonsignificant while those for
cerebral hemorrhage were significantly negative only

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This study was supported in part by Research Grant HL/ES
19073 and Career Research Award HL 21670 from the National
Heart, Lung, and Blood Institute; and Research Grant NS 06229
from the National Institute of Neurological Diseases and Stroke.
Reprint requests: Dr. G. W. Comstock, Training Center for
Public Health Research, Box 2067, Hagerstown, MD 21740.
for white and nonwhite males 45 to 64 years of age.19

An unfortunate feature of most studies in this field is the use of correlation coefficients to express the degree of association between mortality and water hardness. Although the sign of the coefficient does indicate the direction of the association, it is possible to have a high degree of correlation and yet have a change in risk from soft to hard water that is so slight as to be essentially meaningless. The regression coefficient is a much better indicator of the strength of an association, and has a number of other advantages over the correlation coefficient, as pointed out by Neri, Mandel and Hewitt.11 In the 2 studies in which a regression coefficient is available11,17 the estimated risks of stroke death associated with very soft water (0 ppm CaCO₃) were 1.15 and 1.03 times higher than the risks associated with very hard water (200 ppm CaCO₃).

Another major difficulty with previous studies on this topic is that the only individual characteristics that could be taken into account were race, sex, and age. The present study attempts to overcome this particular difficulty. It is prospective in nature, identifies a number of additional personal and socio-economic characteristics initially, and follows an identified group of subjects for a period of 12 years. It adds thereby to the general descriptive epidemiology of stroke, as well as providing a different look at the association of strokes with water hardness.

**Methods and Procedures**

Washington County is in western Maryland, lying largely in the broad valley between the Blue Ridge and the rest of the Appalachian Mountains to the west. Its southern boundary is the Potomac River. The mountain rocks are mostly of igneous origin, while those in the valley are mostly limestone.

Hagerstown, the central city, obtains its water from 2 sources: soft surface water from the Blue Ridge and moderately hard water from the Potomac River. Because water from the Blue Ridge is less expensive to treat and to circulate, it is used in preference to river water. Water supplied to the northeastern edge of Hagerstown and to homes along the distribution system on that side of the city is almost always soft Blue Ridge water. Hagerstown water to the southeast is almost always moderately hard river water, while the central city areas obtain water of intermediate hardness, varying with the availability of water from the Blue Ridge reservoir. There are 10 small towns in the county, with a variety of water supplies, ranging from soft to very hard. The other major sources in the county are deep wells for individual homes, providing hard to very hard water in the limestone areas and soft water in some of the mountain areas. Miscellaneous sources, such as cisterns, bottled water, shallow wells (less than 50 feet in depth), and springs, have been excluded from the study.

In the summer of 1963, a private census was conducted in Washington County which provided information on an estimated 98 per cent of the households.13 This information included race, sex, birthdate, marital status, years of schooling, smoking history, frequency of church attendance (a variable related to mortality apparently because it provided a measure of the ability to be mobile14), length of residence in the present domicile, and source of drinking water classified as city, deep well, shallow well, cistern, spring, and other. A housing index was constructed from the presence in the home of following 5 items: running water, complete bathroom, central heating, electricity or gas as cooking fuel, and a telephone. The presence of all 5 items, weighted equally, gave a score of 5; the absence of all five, a score of 0.

Water hardness in the county has been determined during 4 periods between 1963 and 1975. The first determinations were for a case-control study of arteriosclerotic heart disease deaths in males;15 the second, for a similar study among females;16 the third, for a study of depressed mood and lithium in the drinking water;17 and the fourth, for a representative sampling of municipal sources and individual deep wells.18 Hardness was determined by the Complexometric Hardness Titration method, using 0.02 normal solution of disodium dihydrogen ethylenediaminetetra-acetate, and reported as parts per million of calcium carbonate. The determinations were made without knowledge of the source of the individual specimens.

Because the 1,569 water samples from the 4 studies were collected over a period of several years, in all seasons, and in climatic conditions ranging from drought to excessive rainfall, it is believed that they reflect the long-term water hardness characteristics of the various areas in the county rather well. The geographic units selected for this analysis were the 91 enumeration districts of 1960 and 1963. Two were excluded: one, the town of Sharpsburg, because of a major change in its water supply, and the other because it is occupied solely by state penal institutions. Of the remaining 89, there were 42 that contained only study subjects who had municipally supplied drinking water at home, 22 with only subjects whose home drinking water came from deep wells, and 25 with some subjects who had municipal supplies and some with deep wells. The last group of 25 enumeration districts was treated as if each were composed of 2 subdistricts, one with municipal supplies and one with individual deep wells. This yielded a total of 114 geographic units, each of which was classified according to the median hardness of its drinking water supplies in the sample of 1,569 tested specimens. These units were then grouped into 6 water hardness divisions according to their median hardness values.

Death certificates for residents of Washington County dying during the 12-year period July 15, 1963, through July 14, 1975, have been coded by the staff of the Training Center for Public Health Research. Using the 7th Revision of the International Classification of Disease, all conditions mentioned on the death certificates were coded in addition to the underlying cause of death. Codes 331, 332, and 334 (cerebral hemorrhage, cerebral thrombosis and embolism, and
other and ill-defined vascular lesions affecting central nervous system, respectively) were classified as strokes for the purposes of this study.

In 1971, the current residence of a 5 percent sample of the 1963 census population was ascertained. This information has been used to estimate the probability that an enumerated person was living in the county at the mid-point of this study, namely July, 1969.

Because the distributions by age, marital status, years of schooling, housing index, smoking and church attendance all showed significant variations between the 6 water divisions, it was necessary to adjust the death rates for any effects of these dissimilar distributions. This was done by binary multiple regression, using a method described by Feldstein. In this method, each subclass of every variable is treated as a separate regressor with a value of 1 or 0, depending on whether the subject falls into a particular subclass or not. The method assumes that the effects of all variables are additive but requires no assumption that the relationships between independent and dependent variables are linear. Deviations from the average risk of dying can be readily calculated from the regression coefficients and these deviations are then converted into adjusted rates by adding them to the average risk of dying, paying attention to sign.

### Results

A total of 36,860 persons over the age of 25 years in 1963 comprised the initial study population. All were white, there being too few nonwhites to yield meaningful results. Among these subjects in the ensuing 12 years, there were 1,089 deaths with stroke mentioned on the death certificate. Stroke was considered to be the underlying cause of death in 784 instances.

Deaths for which the diagnosis of stroke was mentioned are shown as average annual rates per 10,000 estimated mid-point population in Table 1 for several demographic and socio-economic characteristics, separately for males and females. For each sex, these rates have been adjusted for the effects of other

<table>
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<tr>
<th>Characteristic</th>
<th>Females</th>
<th></th>
<th></th>
<th>Males</th>
<th></th>
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<td>Mid-point pop</td>
<td>Crude</td>
<td>Adjusted*</td>
<td>Mid-point pop</td>
<td>Crude</td>
<td>Adjusted*</td>
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<td>31</td>
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<td>7,033</td>
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<td>45-64</td>
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<td>16</td>
<td>5,793</td>
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<td>24</td>
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<td>65-74</td>
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<td></td>
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<td>395</td>
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<td>85+</td>
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<td>338</td>
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<td>59</td>
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<td>28</td>
<td>12,921</td>
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<td>Separated, Divorced</td>
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<td>22</td>
<td>31</td>
<td>456</td>
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<td>37</td>
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<tr>
<td>Widowed</td>
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<td>110</td>
<td>36</td>
<td>509</td>
<td>121</td>
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<td>Years of schooling</td>
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<tr>
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<td>5,616</td>
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<td>9-11</td>
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<td>18</td>
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<td>3,015</td>
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<td>12</td>
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<td>756</td>
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<td>1,182</td>
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<td>0, 1 (Poor)</td>
<td>503</td>
<td>36</td>
<td>26</td>
<td>522</td>
<td>42</td>
<td>32</td>
</tr>
<tr>
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<td>502</td>
<td>42</td>
<td>41</td>
<td>482</td>
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<tr>
<td>3</td>
<td>801</td>
<td>37</td>
<td>37</td>
<td>817</td>
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<td>34</td>
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<tr>
<td>4</td>
<td>2,946</td>
<td>32</td>
<td>29</td>
<td>2,682</td>
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<td>26</td>
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<tr>
<td>5 (Good)</td>
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<td>29</td>
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<td>10,106</td>
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<td>28</td>
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<td>44</td>
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<td>2,327</td>
<td>34</td>
<td>27</td>
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<tr>
<td>Pipe, cigars only</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1,123</td>
<td>56</td>
<td>30</td>
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<tr>
<td>Ex-cigarettes</td>
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<td>15</td>
<td>30</td>
<td>2,861</td>
<td>33</td>
<td>29</td>
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<tr>
<td>Cigarettes</td>
<td>5,480</td>
<td>12</td>
<td>29</td>
<td>7,004</td>
<td>19</td>
<td>27</td>
</tr>
<tr>
<td>Unknown</td>
<td>1,414</td>
<td>43</td>
<td>32</td>
<td>344</td>
<td>51</td>
<td>34</td>
</tr>
</tbody>
</table>

| Church attendance | | | | | | |
| Once a week or more | 7,752 | 27 | 27 | 5,291 | 26 | 24 |
| Once a month | 2,001 | 22 | 28 | 1,528 | 25 | 27 |
| Twice a year | 3,018 | 28 | 33 | 2,800 | 25 | 26 |
| Less than twice a year | 1,108 | 26 | 30 | 1,543 | 22 | 26 |
| Never | 1,415 | 69 | 56 | 2,291 | 37 | 34 |
| Not stated | 1,030 | 32 | 25 | 1,076 | 36 | 30 |

* Rates have been adjusted for the effects of all other independent variables shown in this table as well as for the effects of water hardness as shown in Table 2.
variables in this table, as well as for the effects of water hardness. The rates of stroke-associated deaths rise steeply with age, more steeply for females than for males, a pattern somewhat different than that for the U.S. as a whole, where the increase with age in 1960 was almost identical for the two sexes.22 After adjustment, there is little evidence that the other factors in table 1 are related to the risk of stroke-associated death. One exception is that there is a decreased risk for persons who were classed as married in the 1963 census, but this achieves statistical significance only for females. The other exception is a negative association with frequency of church attendance, again among females, and largely the result of a high rate among women who did not go to church. As noted in earlier studies from this area, neither socio-economic status nor cigarette smoking is related to stroke-associated deaths.14, 23

Stroke-associated deaths also showed no significant relationship with the mean hardness of drinking water in the areas of residence (table 2). There was a slight suggestion, however, that the adjusted rates might be somewhat lower in the 3 water divisions with the hardest water than in the other 3 water divisions. There is also the probability that the associations with water divisions in table 2 might be confounded by the fact that residents of the city of Hagerstown and its suburbs make up the great majority of the population in water divisions B and C, and a substantial portion of the population in water division A.

In an effort to disentangle the effects of water hardness from urban-rural effects, the data were subdivided into 12 groups: 2 sexes, 3 water sources (Hagerstown; small towns; individual deep wells), and 2 durations of residence in the home prior to the 1963 census (less than 7 years; 7 years or more). Within each of these 12 groups, stroke-associated death rates were calculated by water divisions. The Hagerstown supply contributed to water divisions A, B and C; the small town supplies to divisions A through E; and the individual deep wells to divisions B through F. All of the rates were again adjusted for the effects of the variables in table 1.

The results of this more detailed analysis are shown in the figure as the adjusted rates of stroke-associated deaths by the mean water hardness of the relevant water divisions. The rates are consistently highest for persons who in 1963 had lived in the same house for 7 or more years. This does not necessarily reflect a hazard of residential stability but rather the fact that these populations were older than the people who had not lived that long in the same house. The adjustments were done within each of the 12 groups, not among them.

No statistically significant relationships of water hardness with stroke-associated deaths were demonstrated in any of these 12 groups. Of the 12 regression lines calculated to provide the best straight line fit for the observations plotted in the figure, 7 had a negative slope and 5 a positive slope. It should be noted, however, that all the slopes for the long-term residents were negative, one of the few facts consistent with the hypothesis that soft water in Washington County might be related to strokes.

Discussion

Virtually all reports of the association of mortality with water hardness have used as their study units large geographic entities, such as states, municipalities, or their component districts. Death rates for each area were compared with hardness of the finished water at the treatment plants. Usually, but unfortunately not always, the effects of factors most likely to cause confounding such as race, sex and age, were removed by using specific or adjusted rates. Much less often have the possible effects of socioeconomic or climatic factors been taken into account.

In the introduction, several U.S. studies were cited that pointed toward a negative correlation between drinking water hardness and stroke deaths.6-12 Some other studies in the United States have not confirmed the association of soft water with increased stroke deaths. For example, Winton and McCabe, using rank-order correlations for 135 central county areas with well-defined water sources, found strokes to be positively correlated with hardness.24 Stroke mortality in the 4 regions of North Carolina did not vary with water hardness26 nor did it in 2 studies which compared 2 different sets of 3 communities that seemed to be similar except for water hardness.28, 27 An intriguing finding by Morton was that an association of stroke mortality with soft water was found in

<table>
<thead>
<tr>
<th>Water division</th>
<th>Median hardness, ppm CaCO₃</th>
<th>Females</th>
<th></th>
<th></th>
<th>Males</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mid-point pop.</td>
<td>Crude</td>
<td>Adjusted*</td>
<td>Mid-point pop.</td>
<td>Crude</td>
</tr>
<tr>
<td>Total</td>
<td>--</td>
<td>16,333</td>
<td>31</td>
<td>31</td>
<td>14,600</td>
<td>28</td>
</tr>
<tr>
<td>A</td>
<td>49</td>
<td>2,459</td>
<td>38</td>
<td>38</td>
<td>2,184</td>
<td>26</td>
</tr>
<tr>
<td>B</td>
<td>101</td>
<td>6,176</td>
<td>28</td>
<td>29</td>
<td>5,360</td>
<td>28</td>
</tr>
<tr>
<td>C</td>
<td>118</td>
<td>4,724</td>
<td>34</td>
<td>31</td>
<td>4,225</td>
<td>31</td>
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<td>D</td>
<td>163</td>
<td>1,298</td>
<td>20</td>
<td>23</td>
<td>1,250</td>
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<td>E</td>
<td>272</td>
<td>1,351</td>
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<td>28</td>
<td>1,269</td>
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<tr>
<td>F</td>
<td>340</td>
<td>325</td>
<td>28</td>
<td>37</td>
<td>321</td>
<td>21</td>
</tr>
</tbody>
</table>

*Adjusted for effects of all independent variables in table 1.
Colorado in 1949-51 when the counties were grouped by river basin but not by altitude; in 1959-61, on the other hand, the stroke-soft water association was demonstrable by the altitude but not by the river basin grouping. 

Studies in other countries, excluding those in which no sex and age standardization was done, generally agree in finding negative associations of stroke mortality with water hardness. Only 2 discordant findings have been reported. One study in England, using proportionate mortality, found a slight curvilinear relationship, with the lowest mortality in areas with the softest and the hardest waters. In Hannover, Germany, a city served by 5 water supplies, there was no discernible correlation, but all 5 sources had hard to very hard waters.

Crawford and her co-workers looked for other evidence bearing on this association. They identified 5 county boroughs in England that had increased and 6 that had decreased the hardness of their drinking water during the previous 30 years. Among those with increased water hardness, stroke mortality decreased by 6% for males and 22% for females. When the water hardness was decreased, male stroke mortality was unchanged while female mortality decreased by 16%. These changes, however, caused few shifts from one water hardness category to another. Of the towns with increases in hardness, only one changed from soft to moderately hard water, one changed from moderately hard to hard, and the others remained in the hard or very hard category. Of those with decreases in hardness, one changed from hard to moderately hard; the others all remained in the very hard category. Clearly, these "natural" experiments did not adequately test the effects of changing from soft to hard water or vice versa.

While the use of relatively large geographic entities has advantages both with respect to accessibility of data and to the increased probability that individuals have the same drinking water at home and elsewhere, misleading findings might result from the ecological fallacy, as pointed out by Susser. For example, if the estimates of the Water Quality Association are correct, a very high proportion of persons in some U.S. communities may be drinking softened water although they would be classified as residents of hard water areas by the usual method of analysis.

An alternative is to study individuals and the hardness of drinking water as it is supplied to their homes. This approach removes any possibility of the ecological fallacy and, more importantly, allows adjustment for the effects of a number of personal variables that cannot be assessed from community statistics. The drawback to this approach is that the number of subjects is perfecly limited, and allowances for hardness of drinking water away from home cannot be made.

A compromise taken in the present study was to

![Figure. Average annual deaths per 10,000 with stroke mentioned on the death certificate, adjusted for the effects of age, marital status, education, housing, smoking, and frequency of church attendance, Washington County, MD, 16 July 1963 to 15 July 1975.](http://stroke.ahajournals.org/)

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**FEMALES**

**HAGERSTOWN**

- In same house in 1963--
  - 7+ years
  - < 7 years

**SMAK TOWNS**

**DEEP WELLS**

**MALES**

**WATER HARDNESS (ppm CaCO₃)**

---

**FIGURE.** Average annual deaths per 10,000 with stroke mentioned on the death certificate, adjusted for the effects of age, marital status, education, housing, smoking, and frequency of church attendance, Washington County, MD, 16 July 1963 to 15 July 1975.
sample home drinking water supplies over a long period of time and to use these results to classify the hardness of drinking water for all persons living in each small enumeration district of the county who have one of 2 specific water sources, municipal supplies or individual deep wells. Any effect of the ecological fallacy is decreased because homes with water softeners were sampled in proportion to their local and temporal frequency, and their hardness values were averaged with others in each district. Although as many as a quarter of the homes in one enumeration district had water softeners in 1975, their use in most hard water areas of this county has not been common.

The problem of exposure to drinking water away from home was approached by examining the mortality of men and women separately. In a random sample of 2,691 adult residents of Washington County between 1971 and 1974, only 39 percent of the women were employed compared to 80 percent of the men. Presumably, therefore, women in this area are appreciably more exposed to drinking water at home than are the men, and any differences attributable to drinking water ought to be more marked among women.

Fortunately, mobility has not been a major problem in this county. Losses from emigration and deaths have been accounted for by using a mid-point study population calculated from the results of an investigation in 1971 of the whereabouts of a 5 percent sample of the 1963 census population. Residents who remain in the county also tend to remain in the same house. In a sample of 349 adults interviewed in 1973, 70 percent of them between the ages of 30 and 50 were still living at their 1963 address; the comparable figures for persons between 50 and 70 and persons over 70 years of age are 85 and 82 percent respectively.

Of all the factors examined in this study, only age has an important relationship to stroke mortality. There is no satisfactory evidence that drinking water hardness at home is related to the prevalence of stroke at death, nor to deaths allocated to stroke as the underlying cause, which showed an essentially similar pattern.

On the basis of current evidence, it seems unlikely that strokes are related in any important way to water hardness. Reports of various studies give inconsistent results, some showing negative and some positive associations. The "dose-response" curves in this study (figure) are highly irregular. There is no experimental evidence or biological explanation to make such an unsystematic association plausible. Fear of strokes should not deter anyone from drinking soft water.

Unfortunately, it is exceedingly difficult to prove or disprove the reality of very low relative risks, say on the order of 1.2. Sampling errors, study defects, and confounding factors can easily obscure or magnify such weak associations. And yet it seems worthwhile to keep on trying. So many people are exposed to soft drinking water, and water treatment is so simple that removal of even a risk as weak as this could prevent much disability and death in the aggregate if a risk could be unequivocally demonstrated. Conversely, much concern could be alleviated if no risk could be found. It is to be hoped, however, that future studies will be much more sophisticated than almost all of their predecessors.

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SUMMARY Studies based on hospital populations reported from negro communities in several countries in Africa suggest that cerebrovascular disease (CBVD) shows increasing mortality and morbidity in Africans although 2 decades ago CBVD was believed to be uncommon. We report the first study in the African to determine the incidence of stroke in an urban area, Ibadan, Nigeria.

Stroke Vol 10, No 2, 1979

Incidence of Stroke in an African City: Results from the Stroke Registry at Ibadan, Nigeria, 1973–1975

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A STROKE REGISTER (which included subarachnoid hemorrhage (SAH) intracerebral hemorrhage (CH), cerebral infarction (CI), but excluded transient ischemic attacks, (TIA) and subdural hematoma) was operated for Ibadan, Nigeria, from April 1, 1973 to March 30, 1975 as part of the international multicentric program of the Cardiovascular Diseases Unit of the World Health Organization. Its purpose was to study the incidence of stroke in several communities. Total coverage of Ibadan was obtained by notification to hospitals, general practitioners, private nursing homes, coroner's office (for cases of sudden death), and the office of the Medical Officer of Health for the city. Case finding of stroke patients was carried out by a Nursing Sister who visited various health institutions in Ibadan at least once a week. The register included only those resident for at least one year in Ibadan. Neurological and clinical evaluation, where possible, was done by 2 neurologists (B.O.O. and O.B.) In others, the diagnosis was based on the case histories and results of available investigations. Follow up after discharge from the hospitals was difficult, for in addition to shortage of personnel, incorrect addresses given by patients made tracing an uphill task and many patients did not return to the clinics for evaluation. The population data for Ibadan, provided by the Ministry of Economic Planning, Western State of Nigeria, were based on projection of the 1963 census.

Results

During the 2 year period, 318 patients were registered and this number almost certainly represented the minimum for most of the patients were seen in hospitals and nursing homes.

Table 1 shows that the male to female ratio is 5 to 2 compared with a male to female ratio of 1.3 to 1 in the population. The peak age-specific incidence in the male is in the eighth decade and in the female in the 7th decade, with higher incidence rates in males than in females in almost all age groups and generally low incidence rates in those below the age of 40 years. The apparently low incidence rates in 8th and 9th decades

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Stroke-associated deaths in Washington county, Maryland, with special reference to water hardness.

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*Stroke*. 1979;10:199-205
doi: 10.1161/01.STR.10.2.199

*Stroke* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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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/10/2/199

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