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CHRONIC DISEASE EPIDEMIOLOGY AT THE THRESHOLD OF A NEW DECADE

Continued on Cover 2

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WATER HARDNESS AT HOME AND DEATHS FROM ARTERIOSCLEROTIC HEART DISEASE IN WASHINGTON COUNTY, MARYLAND[1]

GEORGE W. COMSTOCK,[2] GEORGE M. CAUTHEN AND KNUD J. HELSING

The relationships of drinking water characteristics to cardiovascular mortality have been thoroughly reviewed in recent years (1–6). Water hardness is the characteristic most often studied, and the usual outcome of interest is death from arteriosclerotic heart disease. Virtually all of these studies have been ecologic in nature, a method of investigation that may not properly account for individual risk factors nor for possible variations in water characteristics from time to time or from place to place within an area. To overcome some of these problems of ecologic studies, we used an approximation of a classical prospective epidemiologic design based on information gathered for Washington County, Maryland by the Training Center for Public Health Research. This center was established under the chairmanship and guidance of Philip E. Sartwell, and its continuing usefulness is due in great part to the subsequent support and encouragement by Abraham M. Lilienfeld, his successor as chairman of the Department of Epidemiology at The Johns Hopkins School of Hygiene and Public Health.

MATERIALS AND METHODS

Washington County is in western Maryland. Its southern boundary is the Potomac River, its eastern edge lies along the crest of the Blue Ridge Mountains, and its western tip extends into the Allegheny Mountains. Between the two mountain ranges is a broad valley shallowly underlain by limestone. Roughly a third of the population resides in the central city of Hagerstown, another third in the city suburbs, and the remaining third in small towns and rural areas.

Hagerstown obtains its drinking water from two sources—soft water from the Blue Ridge Mountains and moderately hard water from the Potomac River. The city supplies water to most of its suburbs and to small towns and individual residences along the main lines from the sources to the city. The remaining small towns have a variety of sources with water that ranges from soft to very hard. Most individual homes in the rural areas have deep wells whose water is soft in the mountains and very hard in the valley.

The study population was drawn from county residents aged 25 years or older in July 1963 who were identified in a private census estimated to have been more than 98 per cent complete (7). For the present study, only persons stating that their drinking water came from municipal supplies or deep wells (over 50 feet (15 meters) deep) have been included, thereby omitting a small proportion whose drinking water came from cisterns, springs or shallow wells. Residents of the small town of Sharpsburg were also excluded because of a recent major change in their water supply. The small number of nonwhites in the county were not included in the study population because of their different cardiovascular mortality experience (8) and their concentration in the city of Hagerstown.

[1] From the Department of Epidemiology, School of Hygiene and Public Health, The Johns Hopkins University, Baltimore, MD.
[2] Reprint requests to Dr. Comstock, Training Center for Public Health Research, Box 2067, Hagerstown, MD 21740.
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In 1971, a 5 per cent sample of the households in the 1963 census was selected and the residence status of each individual member was ascertained. This information has been used to estimate the midpoint population for the present study (9). The population was relatively stable in that very few persons over the age of 35 years had emigrated and few had changed residence within the county. In 1973, 359 participants in the 1963 census were interviewed in a mental health survey. Of those who were then between the ages of 30 and 50 years, 69 per cent still lived in the same house; 84 per cent of persons over the age of 50 were still at the address given 10 years earlier.

Death certificates for all county residents were matched against the private census records for the 12 years between July 16, 1963 and July 15, 1975. All diagnoses and the underlying cause of death were coded according to the Seventh Revision of the *International Classification of Diseases* (ICD). Durations of the immediate and underlying causes of death were also coded. Arteriosclerotic heart disease deaths for this study were defined as those with ICD codes 420–422. The rubric 422 was included because a few physicians in the community routinely referred to arteriosclerotic heart disease as arteriosclerotic cardiovascular disease. There were almost no deaths diagnosed as myocardial degeneration or coded 421.

A total of 1569 water samples have been collected from taps in private residences identified in the 1963 census. Collections were made in several different years and in all seasons. As a result of this extensive sampling, it is believed that the average hardness of drinking water supplied to any residence can be predicted if the geographic location is known and if the source is specified as municipal or individual deep well. Using this information, enumeration districts with only one type of drinking water source were assigned to one of six divisions of water hardness (table 1). Districts with more than one source were subdivided so that portions of a rural or suburban district with a municipal supply might be assigned to a different water hardness division than other areas of the same district which had individual deep wells.

There was little temporal variation in water hardness among deep wells in the rural areas or in supplies from small towns. The major variations with time occurred within the city limits of Hagerstown. The eastern areas of the city obtained water largely from the soft source in the mountains and the southwestern areas largely from the moderately hard Potomac River water. The other city areas obtained a mixture that varied with the availability of mountain water.

The range of water hardness from place to place was much more marked in the county outside of Hagerstown.

County residents supplied by the mountain source to the east of Hagerstown as the main passes their property or because they live in the eastern suburbs of the city have soft water. Two small municipal supplies in the eastern mountains are also soft. Moderately hard water is found in parts of the mountains to the east and west of Hagerstown, and along the main lines supplying Potomac River water to

TABLE 1

Estimated midpoint study population by water hardness division

Water hardness division	Water hardness as ppm $CaCO_3$		Estimated midpoint population
	Range of district medians	Mean of district medians	
A	0– 79	63	4,643
B	80–109	97	11,536
C	110–139	122	8,949
D	140–199	174	2,548
E	200–259	239	2,620
F	260–389	319	646
Total	0–389		30,942

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RESULTS

The estimated populat
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*Estimated midpoint stud
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Drinking water sources	To
Hagerstown	20,4
Small towns	5,3
Deep wells	4,7
Total	30,5

* 408 persons excluded from t
divisions within the above 12 s

the city. Residents in the limestone valley and a small town in the western tip of the county receive very hard water.

The characteristics of individual residents available from the 1963 census were sex, birthdate, marital status, years of schooling, smoking history, duration of residence in the household, and frequency of church attendance. This last characteristic is included because it has been found to be highly correlated with subsequent mortality, apparently because chronically ill persons did not attend church frequently (10). The effects of these characteristics on mortality were removed by binary multiple regression applied separately for each sex and for two durations of residence prior to 1963 (11, 12). Effects of urban-rural residence were largely controlled by analyzing each of the four sex and duration of residence groups separately for persons using water from the Hagerstown municipal supplies, persons using small town supplies, and persons with individual deep wells. There were thus 12 separate analyses for each outcome.

Results

The estimated populations at the midpoint of the 12-year study period are shown in table 2 for each of the 12 categories into which the population was divided. The total midpoint population is 30,942 persons, accounting for 371,304 person-years of experience.

During the study period, there were 6126 deaths of Washington County residents in the study population, of which 2406 or 39.3 per cent were coded as being due to arteriosclerotic heart disease (table 3). Deaths called "sudden" in this report, namely those in which the underlying cause had a duration of one hour or less, accounted for 976 or 40.6 per cent of the arteriosclerotic heart disease deaths. There were 503 deaths from arteriosclerotic heart disease in which the duration was recorded as instant, or 20.9 per cent of the total deaths from this cause (table 4).

The average annual death rates from arteriosclerotic heart disease are shown in figure 1 with separate panels for males and females with each of the three drinking water sources. In each panel, the solid line depicts the rates for persons who had lived in their homes for seven years or more prior to the 1963 census; the broken lines represent rates for persons with shorter durations of residence. Adjustments for the effects of other individual characteristics were made for each individual set of rates connected by the lines; they were not made between the 12 sets of rates. Long-term residents were older than shorter-term residents, and primarily for this reason, the death rates of the former are uniformly higher. Male rates are higher than corresponding female rates. Other than these, there are no consistent relationships, including that of ar-

Table 2

Estimated midpoint study populations supplied with water from Hagerstown, small town and deep well sources, by sex and duration of residence prior to the 1963 census

Drinking water sources	Total	Females		Males	
		7+ years	<7 years	7+ years	<7 years
Hagerstown	20,409	5535	5392	4458	5024
Small towns	5,365	1512	1280	1292	1281
Deep wells	4,760	1353	1036	1293	1078
Total	30,534*	8400	7708	7043	7383

* 408 persons excluded from this table and subsequent calculations because their water sources fell into divisions within the above 12 subgroups with fewer than 50 persons.

teriosclerotic heart disease deaths with water hardness.

In spite of the irregularities of the curves in figure 1, straight line relationships are not excluded by the data, and regression lines give a not unreasonable summary of the association of death rates with water hardness. The relative risks associated with soft water were expressed by dividing the calculated death rates at 0 ppm by the rates calculated for 200 ppm. These relative risks are shown in table 5. Only five of the 12 are greater than one. The findings suggest a harmful association with soft water for females and a protective association for males.

Analyses were also carried out using two definitions of sudden death, namely deaths with a duration of the terminal episode of less than one hour, and a subset in which death was reported to be instantaneous. Because the associations of the two with water hardness were virtually the same, only the findings for deaths in which the terminal episode lasted less than one hour are reported. The rates of sudden deaths adjusted for sex, water source, and duration of residence are shown in figure 2, which is set up similarly to figure 1 except for the scale on the ordinate. There is no consistent pattern of sudden deaths with water hardness.

Relative risks of sudden death associated with drinking soft water (0 ppm) are shown in table 6. In this instance, seven of the 12 relative risks are greater than unity. Overall, the risks are slightly greater for females than for males and also for persons using deep wells than for those with municipal drinking water sources at home.

Finally, death rates from noncardiovascular causes were examined. The relative risks of dying from a condition other than a cardiovascular cause associated with soft drinking water (0 ppm vs. 200 ppm hardness) are shown in table 7. Six of the 12 relative risks are greater than one. The relationships with soft water are inconsistent but are generally as great as those for arteriosclerotic heart disease.

Discussion

The present study was ecologic only insofar as it was necessary to assign the median water hardness for a district to each of its residents. This method of classifying hardness of drinking water at home is defensible for most of the population, who lived in areas with few or no water softeners. In some districts, however, the use of water softeners increased from very few in 1963 to a figure of 27 per cent for one area in 1975. The use of a median water hardness level for each district is not a completely

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Table 3

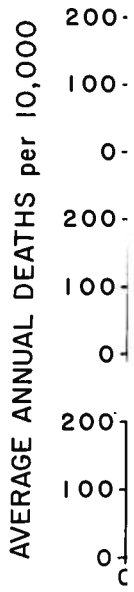
Percentage of total deaths due to arteriosclerotic heart disease, by sex

Cause of death	Females		Males	
	No.	%	No.	%
Arteriosclerotic heart disease	940	34.0	1466	43.6
Other	1826	66.0	1894	56.4
Total	2766	100.0	3360	100.0

Table 4

Percentage distribution of arteriosclerotic heart disease deaths by sex and duration of terminal episode

Time from onset to death	Females		Males	
	No.	%	No.	%
Instant	159	16.9	344	23.5
<1 hour but not instant	166	17.7	307	20.9
>1 hour	615	65.4	815	55.6
Total	940	100.0	1466	100.0



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Small towns	(
Deep wells	1
Total	1

* $p < 0.05$ (subtotals and to

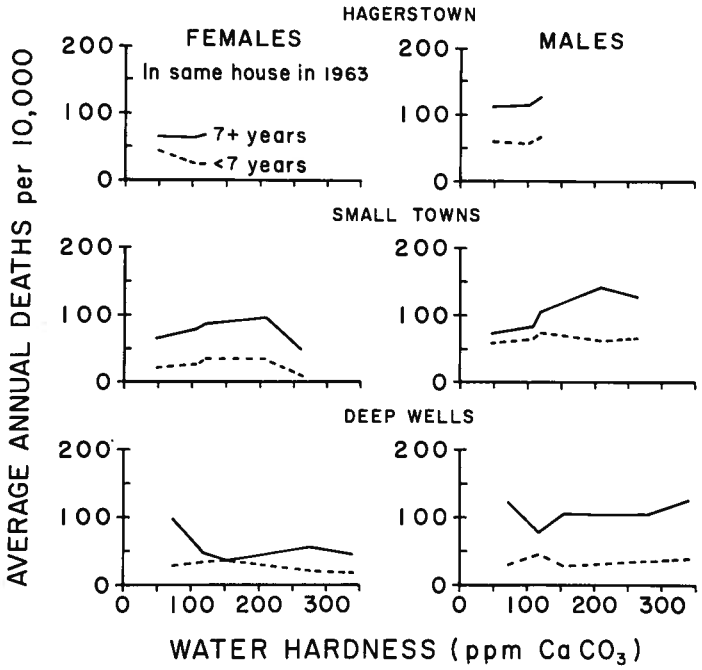

FIGURE 1. Adjusted average annual deaths from arteriosclerotic heart disease per 10,000 population by sex, sources of drinking water, and duration of residence in home prior to 1963, Washington County, MD, 1963–1975.

TABLE 5

Relative risks of dying from arteriosclerotic heart disease associated with water hardness of 0 ppm compared to water hardness of 200 ppm, by sex, duration of residence prior to 1963, and drinking water source

Drinking water source	Total	Females		Males	
		7+ years	<7 years	7+ years	<7 years
Hagerstown	1.07	0.90	2.61*	0.72	0.77
Small towns	0.95	1.23	1.33	0.54*	0.93
Deep wells	1.04	1.07	1.49	0.83	0.88
Total	1.02	1.06	1.73	0.69	0.86

* $p < 0.05$ (subtotals and total not tested).

trict is not a completely satisfactory solution to this problem, though it is probably better than taking no account of the frequency of softeners. Other than this, the method of categorization of water hardness in this study appears to reflect temporal changes in a reasonable way. With respect to a number of other potentially important individual characteristics, notably smoking, socioeconomic status and duration of residence, the present study has the classical design of a prospective epidemiologic study.

The association of soft water with arteriosclerotic heart disease deaths was examined separately for each sex because there is evidence that women in Washington County are more likely to be exposed to drinking water at home than men. In a random sample of 2691 adults interviewed between 1971 and 1973, 80 per cent of the men but only 39 per cent of the women were employed and presumably out of the home for much of the day. The fact that more positive associations of soft water with arteriosclerotic heart dis-

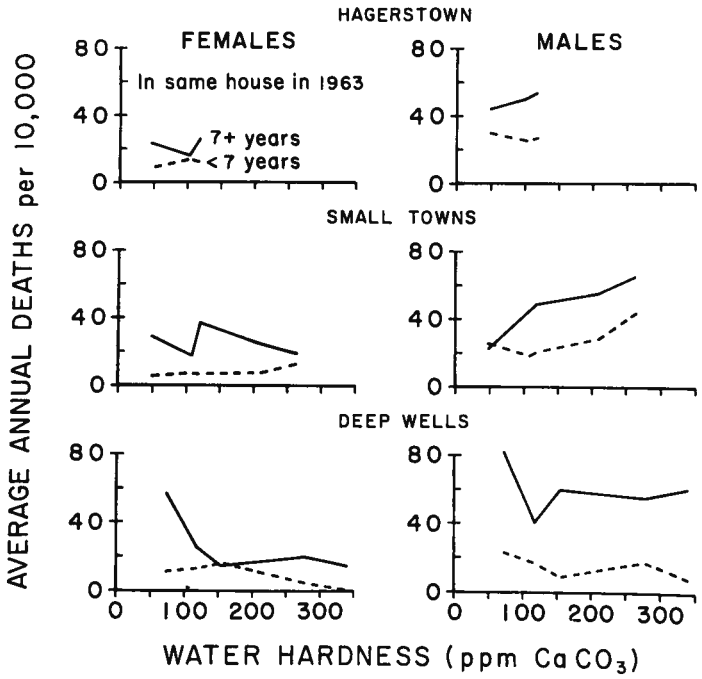

FIGURE 2. Adjusted average annual deaths per 10,000 population from arteriosclerotic heart disease with a duration of terminal episode less than one hour by sex, sources of drinking water, and duration of residence in home prior to 1963, Washington County, MD, 1963–1975.

TABLE 6

Relative risks of sudden death due to arteriosclerotic heart disease associated with water hardness of 0 ppm compared to water hardness of 200 ppm, by sex, duration of residence prior to 1963, and drinking water source

Drinking water source	Total	Females		Males	
		7+ years	<7 years	7+ years	<7 years
Hagerstown	0.83	1.06	0.46	0.64	1.50
Small towns	0.60	1.44	0.40	0.42*	0.53
Deep wells	1.42	1.46	2.33	1.02	1.17
Total	0.89	1.31	0.75	0.65	0.98

* $p < 0.05$ (subtotals and total not tested).

TABLE 7

Relative risks of dying from noncardiovascular causes associated with water hardness of 0 ppm compared to water hardness of 200 ppm by sex, duration of residence prior to 1963, and drinking water source

Drinking water source	Total	Females		Males	
		7+ years	<7 years	7+ years	<7 years
Hagerstown	1.61	1.52	1.20	0.97	3.81*
Small towns	0.73	0.99	0.60	0.86	0.55*
Deep wells	1.21	1.65*	0.97	1.06	1.28
Total	1.13	1.35	0.89	0.96	1.39

* $p < 0.05$ (subtotals and total not tested).

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ease were found among women is consistent with their greater exposure. The net effect of employment on the sources of drinking water in this county would be a greater exposure to moderately hard water. While this should reduce any real association with soft water for men, it is hard to see how this type of misclassification could cause a reversal of their relative risks to less than unity.

If soft water exerts its postulated harmful effect by favoring the development of arteriosclerosis, one might expect the difference between persons exposed to soft and to hard water to be most marked among those with the longer exposures. That this was not so is a point against this mechanism of causation.

If, on the other hand, hard water should be beneficial by supplying magnesium to marginally deficient diets, thereby protecting the heart against abnormal electrical impulses, this effect should be most clearly manifest by differences in sudden deaths (13). The duration of exposure should not be particularly important for an element as potentially soluble as magnesium. Furthermore, since the magnesium content of the diet appears to be related to the magnesium content of the water in which food is cooked (14), the differences in exposures of males and females should be less than when drinking water is the only means of ingestion. The findings in this study, however, give little or no support to the beneficial effects of magnesium. The two supplies with the greatest variation in magnesium content, small town and deep wells, show opposite associations of sudden death and hardness and hence with magnesium content.

Finally, in addition to the inconsistent relationships of water hardness with heart disease, there is evidence against the specificity of this effect. In the Washington County population, noncardiovascular deaths were as likely to be associated with soft water as were deaths from arteriosclerotic disease.

A water factor in the pathogenesis of arteriosclerotic heart disease remains a tantalizing possibility. Even though all available evidence indicates that its effect must be slight at best, the fact remains that even the removal of a low attributable risk would save a large number of lives. Furthermore, the ease with which the composition of drinking water can be changed adds to the incentive to search for a water factor. But the search needs to become much more sharply focussed than it has been. There is almost no excuse for any more ecologic studies. Future work needs to deal with individuals and with elementary facts such as the amount of water consumed by American adults, its sources, the effects of water on other foods, and the effects of additives such as coffee, tea and soft drink syrups on water. While the odds that there is really a water factor do not seem great, the rewards for its identification warrant at least a modest investment in sound scientific studies.

References

1. Punsar S: Cardiovascular mortality and quality of drinking water. An evaluation of the literature from an epidemiological point of view. Work-Environ-Health 10:107–125, 1973
2. Neri LC, Hewitt D, Schreiber GB: Can epidemiology elucidate the water story? Am J Epidemiol 99:75–88, 1974
3. Sharrett AR, Feinleib M: Water constituents and trace elements in relation to cardiovascular disease. Prev Med 4:20–36, 1975
4. Epstein FH, Schuler G: Umwelfactoren und kardiovaskuläre Krankheiten. Soz Praeventivmed 20:84–88, 1975
5. Heyden S: The hard facts behind the hard-water theory and ischemic heart disease. J Chronic Dis 29:149–157, 1976
6. Comstock GW: Water hardness and cardiovascular diseases. Am J Epidemiol 110:375–400, 1979
7. Comstock GW, Abbey H, Lundin FE Jr: The nonofficial census as a basic tool for epidemiologic observations in Washington County, Maryland. *In* Kessler II, Levin ML, editors: The Community as an Epidemiologic Laboratory. Baltimore, The Johns Hopkins Press, 1970, pp 73–97
8. Moriyama I, Krueger DE, Stamler J: Cardiovas-

cular Diseases in the United States. Cambridge, Harvard University Press, 1971
9. Comstock GW, Cauthen GM, Helsing KJ, et al: Stroke-associated deaths in Washington County, Maryland, with special reference to water hardness. Stroke 10:199–205, 1979
10. Comstock GW, Tonascia JA: Education and mortality in Washington County, Maryland. J Health Soc Behav 18:54–61, 1977
11. Feldstein MS: A binary variable multiple regression method of analyzing factors affecting perinatal mortality and other outcomes of pregnancy. J Roy Stat Soc 129 (Series A, Part I): 61–73, 1966
12. Shah FK, Abbey H: Effects of some factors on neonatal and postneonatal mortality. Analysis by a binary variable multiple regression method. Milbank Mem Fund Q 49:33–57, 1971
13. Anderson TW, Neri LC, Schreiber GB, et al: Ischemic heart disease, water hardness, and myocardial magnesium. Can Med Assoc J 113:199–203, 1975
14. Robertson JS: Minerals and mortality. Am Water Works Assoc 71:408–413, 1979

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