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FATAL ARTERIOSCLEROTIC HEART DISEASE, WATER HARDNESS AT HOME, AND SOCIOECONOMIC CHARACTERISTICS[1]

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Comstock, G. W. (Training Center for Public Health Research, Johns Hopkins School of Hygiene and Public Health, Box 2067, Hagerstown, Md. 21740). Fatal arteriosclerotic heart disease, water hardness at home, and socioeconomic characteristics. *Amer J Epidem* 94: 1–10, 1971.—Several reports have indicated an inverse correlation between the hardness of community water supplies and deaths from arteriosclerotic and degenerative heart disease. An unusual opportunity to look at this association in more detail arose in Washington County, Maryland. Drinking water sources there vary markedly in hardness, and a private census in 1963 made it possible to match cases and controls from the same defined population and to study a number of socioeconomic characteristics. During the next three years, there were 189 deaths attributed to arteriosclerotic and degenerative heart disease among white males aged 45 to 64 who could be identified in the census. For each case, 2 controls were randomly selected from the census lists and matched for race, sex and year of birth. Water samples were collected from the residences of cases and controls and examined for total hardness. No significant association of arteriosclerotic and degenerative heart disease deaths could be found with water hardness. Deaths from these causes were more common among persons of lower socioeconomic status, among cigarette smokers, and among persons who attended church infrequently. Although water hardness is not likely to be a real risk factor for cardiovascular disease, the role of trace elements in home drinking water supplies should be investigated.

arteriosclerosis; coronary disease; epidemiology; heart diseases; religion; water

Abbreviations: ASDHD, arteriosclerotic and degenerative heart disease; ASHD, arteriosclerotic heart disease.

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From time immemorial, water has been credited with mystical powers, both therapeutic and prophylactic. Because few of these purportedly beneficial effects could be confirmed scientifically, it is not surprising that skepticism was the initial response to the idea that some component of drinking water might be related to arteriosclerotic cardiovascular disease.

Current interest in water as a potential risk factor for arteriosclerotic heart disease (ASHD) can be traced to two seemingly unrelated reports in the 1950's, one from the United States and the other from Japan (1, 2). In 1956, Enterline and Stewart called attention to the fact that there were marked differences between various regions of the U.S. with respect to age-adjusted death rates from coronary heart disease (1). This geographic association did not appear to be related to urbanization. A few years later, Sauer and Enterline showed that it was unlikely that differences in death rates resulted from regional diagnostic or reporting practices (3). Although it now seems certain that there is some important etiologic factor related to geography, its identification remains a major challenge to epidemiologists.

More directly related to the current interest in a "water factor" was the growing realization that some characteristic of drinking water might fit the observed geographic distribution of cardiovascular deaths. First suspicion of a water factor came in 1957, when Kobayashi, an agricultural chemist, noted a high correlation between acidity of river water and deaths from cerebrovascular disease in Japan (2). Schroeder, re-examining the raw data, found an even higher association with heart disease deaths (4). He next correlated death rates in the U.S. with water hardness, the only water supply characteristic readily available on a state-wide basis at that time (5). Using a weighted average for public water supplies and standardized death rates for each state, he found a variety of significant correlations. Most striking were the negative correlations between water hardness and deaths from hypertensive and arteriosclerotic heart diseases (6).

Confirmation of Schroeder's findings came first and most clearly from Great Britain where significantly negative correlations with water hardness were found for arteriosclerotic and hypertensive heart disease deaths. Even larger negative correlations were found with cerebrovascular disease and myocardial degeneration (7). In Sweden, water hardness showed a significant inverse relation to ASHD only among females over 65 years of age (8). Water hardness and ASHD deaths in Holland were significantly correlated for females but not for males (9). In Ontario, Canada, ASHD deaths, presumed to be sudden because the certificates were signed by coroners, were inversely correlated with hardness of municipal water supplies. Similar deaths not certified by coroners showed a slight positive association with water hardness (10). Somewhat similar findings were reported for the state of Washington, but only if Washington deaths classified as "sudden" regardless of certifier were compared with coroner-certified deaths in Ontario (11).

Other reports have been contradictory. A study of water hardness and fatal ASHD in Oklahoma counties showed a slight, insignificant, positive association (12). When the data were re-analyzed, using only counties where the majority of the population was served by public water supplies, the association became negative but not significantly different from zero (13). A similar study of the largest municipalities in the Republic of Ireland showed very little association of water hardness with ASHD. If deaths from myocardial degeneration were included, the correlation became positive (14). When the findings from the Republic of Ireland and North Ireland were combined, the correlation became negative but was still not significant (15). In the four regions of North Carolina, Brittain found that the association of water hardness with ASHD deaths among white males was nei-

ther negative nor linear. The highest death rates were found in the coastal plains region with water of intermediate hardness, while the highland region had the softest water and the lowest rates (16).

Pathologic studies have not clarified the situation. Data from 14 cities participating in the International Atherosclerosis Project showed generally negative correlations of atherosclerotic lesions with hard water. None of them were significant, however, and there were striking exceptions to the "soft water, hard arteries" aphorism (17). Crawford and Crawford compared the coronary arteries of men dying from accidents and from coronary heart disease in two British cities, one with very soft and one with hard water (18). Among the accident victims, coronary atherosclerosis was more marked among young men from the soft water area but was similar for older men from both areas. Old occlusions of the coronary arteries were more common in the soft water area. Low values for both calcium and magnesium were found in the arteries of young men from the soft water area; among older men, the values were similar in both areas. Consideration of all of the findings led the authors to speculate that something in the soft water area caused death at an earlier stage of the atherosclerotic process than in the hard water area.

In addition to these conflicting findings, further difficulties in accepting water hardness as an etiologic factor in ASHD are imposed by the nonspecificity of the correlations. This point was stressed by Winton and McCabe, who found significantly negative rank order correlations of water hardness in the United States with total deaths, diseases of the heart, malignant neoplasms, cirrhosis of the liver and ulcers of the stomach and duodenum. Significantly positive correlations were found with cerebrovascular diseases, accidents, congenital malformations, diseases of infancy, and gastritis. The values of these rank order correlations ranged from −.60 to −.68, and from +.60 to +.87. The authors wryly stated that "dissolved solids may be important to man but one would not expect them to be this important" (13).

The nonspecificity of the correlations raises the suspicion that both water hardness and death rates may be more directly related to some other cause or causes. Schroeder examined the association of a considerable number of water components with U.S. hypertensive and arteriosclerotic heart disease death rates. He found negative correlations for 12 major and four trace elements, and positive correlations for two elements. Hardness seemed to be one of the most consistent correlates (19). Voors, however, found the largest negative correlation for lithium, at least among whites (20). A wide variety of demographic and socioeconomic characteristics in Great Britain were looked at by Crawford, Gardner and Morris, who found no indication that water hardness was reflecting any other more important environmental variable (7, 21). In 116 metropolitan areas of the U.S., only climatic factors appeared to be more important correlates of ASHD mortality than water hardness and potassium content. Socioeconomic factors seemed to be relatively unimportant (22).

In spite of these contradictions and inconsistencies, the definite existence of large regional differences in ASHD death rates combines with the frequently sizable correlations of water hardness and this important cause of death to create a tantalizing situation. Water composition can easily be altered, and indeed is being altered constantly in all water treatment plants. If there is a water factor, its identification might quickly lead to important mass preventive measures.

Materials and methods

Washington County, in western Maryland, has a wide variety of sources of drinking water. Hardness values range from almost zero to 450 parts per million, calculated as calcium carbonate. Water from springs and wells in the Blue Ridge Moun-

tains on the county's eastern border and from the Allegheny Mountains on the west is usually soft. The limestone valley provides very hard water at unpredictable depths. As a consequence, many valley residents choose not to drill wells but to use cisterns which are filled by rain water or tank trucks. Hagerstown, the major city in the county, has two water sources—a soft water source in the Blue Ridge Mountains and a source of intermediate hardness, the Potomac River.

In the summer of 1963, a private census of Washington County was carried out by the Johns Hopkins School of Hygiene and Public Health, the National Cancer Institute, and the Washington County Health Department (23). Records were obtained from more than 98 per cent of the households in the county. Cases for the present study are all white males between the ages of 45 and 65 at the time of the census, who were classified as having died in the three-year postcensal period from arteriosclerotic and degenerative heart disease (rubrics 420–422 in the 7th revision of the International Classification of Disease) and whose death certificates could be matched to the 1963 census listings. For each case, two controls were selected from the census listings. With a separate random start for each selection, the next white male with the same birth year as the corresponding case was chosen. Controls are thus a probability sample of the white male census population, aged 45–64, stratified by year of birth.

Census information for cases and controls included enumeration district of residence, number of years lived in the county and in the present residence, relationship to head of household, marital history, years of school completed, number of persons per room, type of fuel used for cooking, number of complete bathrooms in the household, source of water supply, smoking history, and religious affiliation and attendance. Home visits were made in 1967 and 1968 to obtain a water sample and further details about the home water supply.

Water samples were tested for total hardness by the Complexometric Hardness Titration method, using 0.02 normal solution of disodium dihydrogen ethylene-diamine-tetra-acetate. Each titration was repeated without knowledge of the first test, and the average of two tests was recorded as parts per million of calcium carbonate. The tester did not know whether the sample came from the home of a case or a control. A few samples, for which the indicator failed to show a clear-cut color change, were tested with a standard soap solution by Dr. C. W. Kruse, Department of Environmental Health, Johns Hopkins School of Hygiene and Public Health.

Only one sample was collected from each residence. For most supplies, there is no reason to believe that water hardness fluctuated markedly on a seasonal basis. However, the city of Hagerstown and its environs, containing about one-half of the county population, has two water supplies. One from a reservoir in the Blue Ridge Mountains is quite soft with an official hardness rating of 12 to 36 ppm. The other supply comes from the Potomac River and is appreciably harder, ranging from 40 to 140 ppm. The gravity-fed mountain source is used as much as possible to save pumping water up from the river. For persons served by these two municipal supplies, the following procedure was used to assign a hardness value for their household water. In areas judged by the supervisor of the water department to be supplied at all times from only one source, persons using city water were assigned the average hardness value of all city sources tested in that area. Because testing was carried out over a period of months, this procedure tends to average out seasonal variations, although in fact these were not marked during the study period. For the parts of the city that receive water from both sources during the year, a line was drawn along the approximate points of equal probability of receiving either supply, thus dividing the area of mixed supply into two parts, one receiving most of its water

from the mountain reservoir, the other most of its water from the Potomac River. Residents of these two areas were assigned weighted averages of the mountain and river hardness values. The weighting factor for each area, 3 for the major source and 1 for the minor source, was thought to approximate the relative contributions of each source.

Results

During the three-year period after the census, there were 189 deaths from arteriosclerotic and degenerative heart disease (ASDHD) among white males aged 45–64 who were identified in the census population. Two were classified as chronic nonrheumatic endocarditis (rubric 421) and two as other myocardial degeneration (rubric 422). Of the 185 classified as ASHD, 169 specifically mentioned disease of the coronary arteries. Only seven of the cases had moved from their 1963 residences prior to death.

Cases and controls had virtually identical age distributions, with mean ages of 55.7 and 55.6 years, respectively. Cases had lived an average of 40 years in Washington County, and 14 years in their 1963 residences, compared with 39 years in the county and 17 years in the 1963 residences for controls. Water samples were tested for hardness for approximately 90 per cent of each group. For 13 cases and 23 controls, the currently available water supply did not represent the supply in 1963, and hence was not tested. For five cases and two controls, the 1963 residence was vacant or had been demolished, and for five cases and seven controls, the occupant refused to let the water be examined.

In spite of the tendency for water hardness to be associated with geography in this county, no significant differences in the distributions of cases and controls by political subdivisions could be found. A smaller proportion of cases than controls used rain water for drinking purposes. Spring water, which in this area is usually soft, was used by fewer cases than expected, and deep well water, usually hard, was used by the expected number of cases. Water softeners were used by only 10 cases in contrast with an expected number of 16.5 from the control experience.

More pertinent evidence is shown in table 1, which summarizes the distributions of cases and controls by the hardness of their home water supplies. The mean hardness value for cases is 124 ppm and for controls, 114 ppm. The entire distribution for cases is shifted slightly to the right, the difference being most marked for the hardest waters.

The relative risk of dying from ASDHD is shown in table 2 for selected attributes; the details for the matched pair analyses

Table 1

Distribution of cases and controls by hardness of home water supply*

Percentile	Hardness of home water supply	
	Cases	Controls
	ppm	*ppm*
10th	45	40
25th	68	65
50th	104	103
75th	109	107
90th	262	224
Mean hardness	124	114

* Parts per million of calcium carbonate.

Table 2

Relative risk of dying from arteriosclerotic or degenerative heart disease associated with specified attributes

Attribute	Relative risk
Mean water hardness, 0–99 ppm	0.78
Mean water hardness, 150+ ppm	1.35
Cooking fuel not electricity	1.24
Home without complete bathroom	1.30*
Fewer than 9 years of schooling	1.46
Never smoked cigars	1.48
Smoked cigarettes in 1963	1.51*
Attended church less than once weekly	2.02†

* $p < .05$ when trend is taken into account.
† $p < .01$.

TABLE 3

Distribution of cases and matching controls by selected attributes

Attribute	Total persons with usable information		Complete trios*				Complete pairs*		
	Controls	Cases	Controls		Cases +	Cases −	Controls	Cases +	Cases −
Water hardness (0–99 ppm)	346	166	+	+	5	12	+	6	5
			+	−	20	43	−	5	13
			−	−	15	41			
Water hardness (150+ ppm)	346	166	+	+	1	3	+	1	5
			+	−	8	30	−	4	19
			−	−	23	71			
Cooking fuel not electricity	378	189	+	+	18	15	+		
			+	−	47	53	−		
			−	−	28	28			
Home without complete bathroom	378	189	+	+	1	3	+		
			+	−	9	47	−		
			−	−	30	99			
Fewer than 9 years of schooling	378	189	+	+	41	14	+		
			+	−	52	38	−		
			−	−	22	22			
Never smoked cigars	378	189	+	+	56	19	+		
			+	−	56	27	−		
			−	−	20	11			
Smoked cigarettes in 1963	378	189	+	+	27	23	+		
			+	−	58	28	−		
			−	−	27	26			
Attended church less than once weekly	378	189	+	+	63	15	+		
			+	−	59	21	−		
			−	−	22	9			

* +, signifies that case or control has the attribute; −, signifies that case or control does not have the attribute.

are shown in table 3. Water hardness values were determined for 136 complete trios, each consisting of a case and two matching controls. In 29 instances, water hardness was known only for the case and one matching control. Water samples were obtained for one case but not for either of his controls, and for 16 controls but not for the cases to which they had been matched. Complete matching trios were available for the other attributes.

The risk associated with water hardness is in the opposite direction from that reported in the original studies. Fewer persons with soft water at home and more persons with hard water at home died from ASDHD than would be expected from the distribution of controls. However, this trend is not significantly different from zero. The observed direct association of ASDHD with water hardness persisted when the study group was stratified by length of residence in their 1963 home. Furthermore, it was most markedly positive for sudden deaths.

Cases and controls also differed with respect to a number of socioeconomic and personal characteristics. On the 1963 census records, 10.7 per cent of the cases but only 4.2 per cent of the controls were listed as not being heads of the households in which they were living. Although living in someone else's household might be related to pre-existing illness, deaths among persons not heads of households were not concentrated early in the study period, nor were their terminal illnesses longer, as might be expected if their household status were solely the result of disability. Marital histories of cases did not differ significantly from those of controls.

Over one-half of the study population used electricity for cooking, one-sixth used gas piped in from a central system, one-quarter used bottled gas, and a few used other fuels. The use of fuels other than electricity for cooking was considered to be more common in inadequate than in adequate housing. As shown in table 2, this indicator is slightly but not significantly associated with fatal ASDHD. Another useful index of housing adequacy in Washington County is the number of complete bathrooms for the exclusive use of the household. Significantly more cases than expected lived in houses lacking a complete bathroom and fewer cases than expected had more than one complete bath. Crowding, expressed as persons per room, did not appear to be a risk factor. A socioeconomic indicator not related to housing, namely education, did appear to be related to ASDHD, although not significantly. On the average, cases had completed 8.6 grades of school and controls 9.5 grades. The difference was most marked with respect to post-graduate education: one case and 15 controls had had more than 16 years of schooling.

In the 1963 census, persons were asked if they had ever smoked pipes, cigars or cigarettes. The proportion of cases and controls who had ever smoked pipes was almost the same. Considerably fewer cases than expected had smoked cigars at some time. The decreased risk of ASDHD associated with cigar smoking was not related to cigarette smoking, since both smokers and non-smokers of cigarettes had lower risks if they had ever smoked cigars. Unfortunately, information on amount and duration of cigar smoking was not obtained. The risk of ASDHD for persons who smoked cigarettes at the time of the 1963 census was greater than for ex-smokers. The risk for cigarette smokers was dose-related, being most marked for persons with a usual consumption of more than two packs daily.

Of the 567 cases and controls in this study, only 27 stated that they were Catholics, and 6 that they were Jewish. Twenty-four said they had no religion, and 65 did not care to answer this question. The remaining 445 men were Protestants. Affiliation with a particular religious sect was not associated with fatal ASDHD. Frequency of attendance at religious services, on the other hand, was highly associated with ASDHD, the risk for persons attending church infrequently being nearly twice that for persons who attended once a week or more often. A similar association was noted for deaths occurring in each of the three years following the 1963 census, making it unlikely that this association was entirely the result of sick men not being able to attend church frequently.

The relationship of water hardness to ASDHD would be much easier to determine if water hardness were not also associated with other characteristics. Indices of inadequate education and housing were least common and cigar smoking was most common among men with water of intermediate hardness. Men with soft water at home were most likely to smoke cigarettes and to attend church infrequently. To estimate the magnitude of each of these risk factors independently of the effects of the others, the findings were adjusted by the multiple regression method described by Feldstein (24). Age adjustment had already been accomplished by the use of age-matched controls. The results are shown in figure 1. Adjustment reduced the magnitude of the relative risks slightly but made no difference in the relative importance of any of the selected characteristics.

Discussion

A by-product of the current interest in a possible water factor has been the confirmation of sizable geographic differences in cardiovascular mortality rates within several countries. In at least two, the United States and Great Britain, these differences have persisted for some time (19, 25). Unfortunately, the responsible factor has yet to be identified. A review of all of the studies on water hardness shows that its correlations with cardiovascular disease are not often similar with respect to magnitude, to sex or age groups affected, or to the type of disease involved. These inconsistencies, taken together with the considerable number of heterogeneous noncardiovascular causes of death that are also related to water hardness, make it difficult to accept water hardness per se as anything but a spurious risk factor.

This impression is reinforced by the results of the present study, done on individuals and their home water supplies rather than on large population groups and public supplies. The study is further strengthened because both cases and controls are probability samples from the same identified population, conditions rarely met in case-control studies. Its principal weakness is that water hardness was determined for drinking water only at the subjects' homes.

A possible way out of the morass of conflicting and inconsistent findings comes from the suggestion that some characteristic of water as it is consumed might be the pertinent factor (5, 21). While water hardness may not be expected to vary greatly

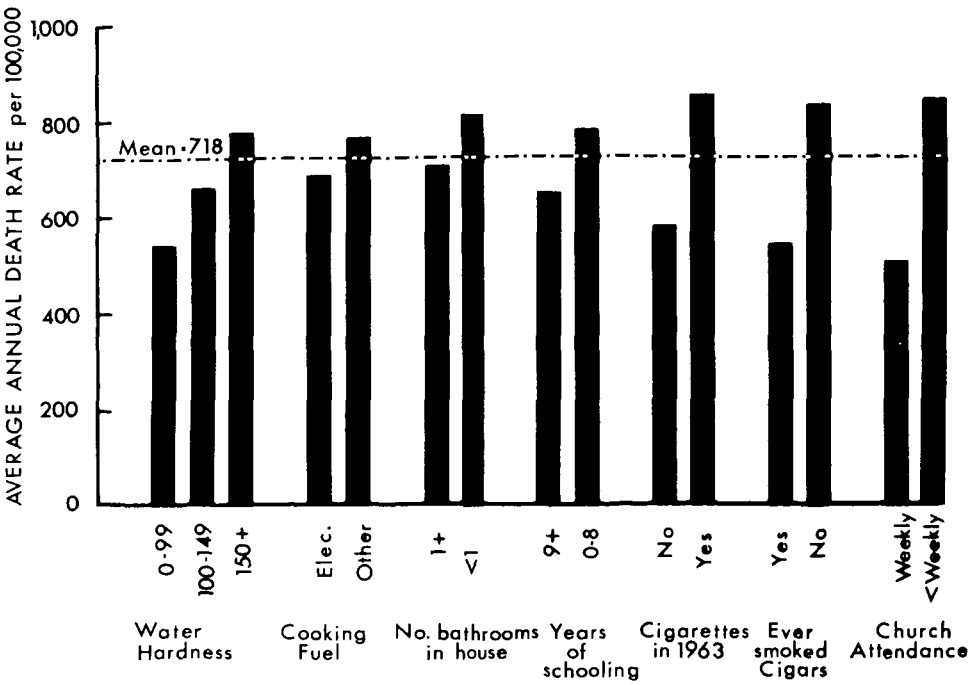

FIGURE 1. Average annual death rates from ASDHD for white males, 45-64 years, Washington County, Maryland, by hardness of home drinking water and selected socioeconomic and personal characteristics. (Each rate adjusted for all other selected characteristics and for age.)

from producer to consumer unless a home water softener is used, other changes in water composition can easily occur within the distribution system. These changes are most likely to occur if the water is corrosive, a characteristic often but not exclusively associated with softness.

Corrosive waters can dissolve metallic substances from the pipes, particularly after standing for some time. Schroeder has suggested cadmium from galvanized pipes as a likely cause of hypertension, which in turn might cause coronary or cerebral vascular disease (5). Crawford and Morris have shown that water can pick up considerable amounts of lead from pipes laid down before this use of lead was prohibited (26). Copper, as many persons can attest from the blue stains left by a dripping faucet, can also be dissolved from copper pipes by some waters.

If the proper elements were looked for in the consumers' home water supplies, the present confused picture with respect to water characteristics and cardiovascular disease might clear up quickly. Such studies, by definition, will have to concern individuals rather than large political or economic subdivisions of the population. It may also be desirable to restrict studies to housewives, or to study the water supply both at home and at work, although a major effect of home water supply should not be completely hidden by outside sources. Case-control studies offer the most efficient and feasible experimental design. They would have the greatest chance of arriving at a conclusive answer if conducted in communities like Washington County, Maryland with marked variation in water supplies within an otherwise relatively homogeneous community.

In any event, it is likely that both cardiovascular disease and water hardness will be associated with personal and socioeconomic characteristics. In the present study,

it was possible to allow for the effects of several such characteristics, although financial considerations required the omission of two common socioeconomic indicators, occupation and income. However, it does not seem likely that the addition of these two factors would have changed the results in an important way.

A surprising finding was the strong negative association of frequency of religious attendance with fatal arteriosclerotic heart disease. It is premature to speculate on the meaning of this association other than to note that it is obvious that regular church attenders differ in many ways from those who rarely or never go to church. It is also possible that church attendance may produce a favorable psychic or emotional response. Because frequency of attendance is an aspect of religious experience that is very easily determined, it is hoped that future investigations will include information on church attendance to confirm or deny its importance as a risk factor for arteriosclerotic heart disease. If confirmed, the implications of this finding raise intriguing questions for future research.

The implications of identifying a water factor in the causation of arteriosclerotic cardiovascular disease are quite different. If some component of drinking water is causing disease, it can almost certainly be reduced or removed. If the water factor is a deficiency of some kind, this can be remedied. In either case, preventive treatment could quickly benefit large segments of the population. It is this possibility of an effective mass attack on a major health problem that makes further exploration for a water factor a matter of high priority.

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