Municipal Drinking Water and Cardiovascular Death Rates

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The association of the degree of softness of municipal water and death rates from hypertensive and arteriosclerotic heart diseases, demonstrated for 1949 to 1951 rates, persisted in 1960. Statistical analyses of death rates from 88 cities of the United States with levels of bulk and trace elements in municipal water supplies showed negative correlations for 12 major and 4 trace constituents. The purer the water in terms of dissolved elements, the higher was the death rate from this cause. No trace element of 19 measured was found highly correlated. One possible explanation of this phenomenon involves the corrosive quality of soft water for metal pipes in dwellings.

An association between death rates from hypertensive and arteriosclerotic heart diseases and degree of softness of municipal water in the United States was demonstrated on rates for 1949 to 1951.[1,2] This association was quickly confirmed in Great Britain by Morris and his colleagues.[3] No such relationship was found for other heart diseases or other major causes of death. Recently, Biörck and his colleagues showed highly significant negative correlations between calcium in drinking water and death rates from degenerative heart diseases in Swedish males.[4] Previously, Kobayashi[5] had pointed out an apparent geographical relation in Japan between death rates from cerebrovascular accidents and the sulfate: bicarbonate ratios of river water, suggesting a basis for examining variations in specific mortality according to geochemical patterns; his data were found significant.[6] Almost all river water in Japan is soft, with hardness less than 40 ppm,[7] compared with a mean hardness for raw municipal water in the United States of 139 ppm, for surface waters of 94 ppm, and for ground waters of 192 ppm.[8] In Sweden mean hardness was 65 ppm.[4]

None of these investigators was able to identify any single constituent of potable water as being closely associated with cardiovascular death rates, except perhaps calcium.[3] This element and the major anions inversely correlated fairly well with death rates from arteriosclerotic heart disease in 163 cities of the United States[1] and in 83 county boroughs of England and Wales.[3] On the other hand, only the cardiovascular diseases considered secondary to atherosclerosis and hypertension were related to the degree of softness of water.

Recently Durfor and Becker[9] published data on 18 bulk and 19 trace constituents in municipal waters from the 100 largest cities in the United States. Sauer had compiled death rates from arteriosclerotic heart disease in white males for most of these cities.[10] Therefore, the present study was made in an attempt to refine or exclude factors, both bulk and trace, in potable water which may or may not be related to death rates from these causes.

Materials and Methods

Death rates of white persons for 1960, age-adjusted, for 49 states and the District of Columbia, divided into the major cardiovascular diseases[11] were compared with weighted average hardness of municipal (finished) waters, by state, consumed by a majority of the population.[8] Data were confined to white persons, as the proportion of nonwhites to whites is increased in many of the states with water softer than average[2] and as the mortality from hypertensive heart disease of nonwhite persons is often several times greater than that of whites.[11]

Cities with published mortalities for arteriosclerotic (coronary) heart disease in white males aged 45 to 64 years[10] were compared with cities whose municipal supplies had been analyzed for the concentrations of major constituents and of trace elements in finished water.[9] Data both for death rates and for water were complete for 88 cities. Tap water from private dwellings was not analyzed.

The data were fed into a digital computer capable of calculating 625 coefficients of rank correlation (r) simultaneously. (1) Death rates from

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Table 1.—Coefficients of Correlation (r) of Death Rates in White Persons From Major Cardiovascular Diseases and Weighted Average Hardness of Municipal Waters by State, 1960

Disease*	r	P	Rate, 100,000 Population
Hypertensive heart disease (440-443)			
Male	−0.415	< 0.001	22.5
Female	−0.356	< 0.005	23.6
Vascular lesions of central nervous system (330-334)			
Male	−0.250	< 0.05	80.4
Female	−0.172	NS†	68.7
Arteriosclerotic heart disease (420)			
Male	−0.509	< 0.0005	305.3
Female	−0.364	< 0.005	137.8

*Numbers in parentheses refer to categories in the *International Statistical Classification of Diseases, Injuries and Causes of Death*, Seventh revision (1955), Geneva: World Health Organization, 1957, vol 1.

†NS=not significant.

arteriosclerotic heart disease, hypertensive heart disease, and vascular lesions affecting the central nervous system were compared with water hardness by state; (2) death rates from arteriosclerotic heart disease in white males compared with 18 constituents of water in 88 cities; (3) death rates from arteriosclerotic heart disease in white males were compared with 23 qualities of water in the 25 cities with the highest and the 25 cities with the lowest rates; (4) constituents of water were compared with each other. The degree of significance of coefficients of correlation were obtained from standard tables. Differences in each constituent of water in the two groups of cities were determined by Student's *t*-test.

Analyses could not be made of death rates by city for diseases with much lesser incidences than that of arteriosclerotic heart disease, because of unreliability of the data. Those of the major cardiovascular diseases were reasonably accurate in larger, state-wise populations.[11]

Results

The inverse correlation of death rates from certain cardiovascular diseases by state and weighted average hardness of water was again present for 1960 rates (Table 1). The correlation coefficients were significant ($P < 0.005$) for hypertensive heart disease and for arteriosclerotic heart disease in both sexes. For vascular diseases of the central nervous system, a coefficient of doubtful significance appeared for white males, lower than previously found.[2] No relationships were evident between any of these variables and effective buying income per capita, a socioeconomic index.

Death rates from the three conditions considered were tested for relation to each other. There were good correlations between white persons dying of hypertensive heart disease and arteriosclerotic heart disease (males, r = 0.57; females, r = 0.43, $P < 0.005$) in the several states. Relationships between hypertensive or arteriosclerotic heart disease and vascular lesions affecting the central nervous system were not significant.

Significant relations of death rates from arteriosclerotic heart disease in white males aged 45 to 64 years and 23 constituents of water from 88 cities are given in Table 2. Those with potassium, specific conductance (total electrolytes), and hardness are especially evident, associated with most of the major constituents, all of which had negative coefficients. Of the trace substances, positive coefficients were found for copper and manganese. Death rates from all causes did not show significant correlations with any variable in water.

Significant differences in the bulk and trace constituents of water from the 25 cities with the highest and the 25 cities with the lowest death rates from arteriosclerotic heart disease are given in Table 3. The water associated with high death rates had less conductance, hardness, magnesium, sodium, potassium, sulfate, and barium and more copper ($P < 0.01$). It may have had significantly less solids, bicarbonate, chloride, silicon, lithium, strontium, and vanadium ($P < 0.05$). Although it also contained less calcium and aluminum, and more manganese and nickel, the differences were not significant. The means of the two groups of waters were quite similar in content of boron, chromium, fluorine, iron, molybdenum, lead, rubidium, and titanium and in pH.

Table 2.—Coefficients of Correlation (r) of Death Rates From Arteriosclerotic Heart Disease, White Males, Aged 45 to 64 Years, and Certain Major and Minor Constituents of Municipal Waters from 88 Cities*

	r	P
Deaths, all causes	+0.635	< 0.0005
Major Constituents		
Potassium	−0.475	< 0.0005
Specific conductance	−0.434	< 0.0005
Hardness	−0.411	< 0.0005
Magnesium	−0.398	< 0.0005
Silicon	−0.340	< 0.0005
Bicarbonate	−0.337	< 0.005
Dissolved solids	−0.302	< 0.005
Chloride	−0.281	< 0.005
Sodium	−0.268	< 0.01
Sulfate	−0.254	< 0.01
Calcium	−0.231	< 0.02
Minor Constituents		
Vanadium	−0.344	< 0.0005
Barium	−0.340	< 0.0005
Copper	+0.294	< 0.005
Strontium	−0.287	< 0.005
Lithium	−0.280	< 0.005
Manganese	+0.262	< 0.01
β-radioactivity	−0.211	< 0.025

*Only correlation coefficients greater than 0.178, $P = 0.05$, are included. Negative coefficients less than 0.178 were found for noncarbonate hardness, aluminum, boron. Coefficients were small for nickel and lead.

Therefore, qualities of water associated with total electrolytes and the concentrations of the alkali metals and alkaline earths were related to death rates from coronary heart disease in such a way that the higher the death rate, the less were

Table 3.—Significant Differences in Constituents of Water in 25 Cities With Lowest and 25 Cities With Highest Death Rates From Arteriosclerotic Heart Disease, White Males, Aged 45 to 64 Years, Mean ± SE

	Lowest Death Rates	Highest Death Rates	Difference	t	P
		Death Rates			
Arteriosclerotic heart disease, per 100,000	476.2±10.9	669.2±11.6	+	18.0	<0.0001
All causes, per 100,000	1,514.5±36.2	1,757.6±33.2‡	+	4.9	<0.001
		Constituents			
Specific conductance, micromhos	432.1±50.8*	227.2±23.8	—	3.65	<0.001
Hardness, ppm	139.1±17.4†	79.8±10.9*	—	2.89	<0.005
Dissolved solids, ppm	248.3±30.3*	158.8±25.5	—	2.26	<0.025
Magnesium, ppm	16.5±4.0	5.1±0.9	—	2.75	<0.005
Bicarbonate (HCO$_3$), ppm	127.6±22.5†	76.0±12.1	—	2.01	<0.025
Sulfate (SO$_4$), ppm	53.5±8.7	25.1±3.3	—	3.06	<0.005
Sodium, ppm	34.5±7.7	14.9±3.7	—	2.49	<0.01
Potassium, ppm	35.0±6.4	16.0±2.9	—	2.69	<0.01
Chloride, ppm	34.2±8.8	16.1±2.6	—	2.05	<0.025
Silicon (SiO^2), ppm	15.4±3.0‡	8.5±1.5	—	2.04	<0.025
Barium, ppb	79.7±13.2	39.7±5.4	—	2.81	<0.005
Copper, ppb	7.1±1.8	42.0±12.8	+	2.69	<0.005
Lithium, ppb	16.8±4.4	5.3±3.8	—	1.98	<0.05
Strontium, ppb	244.1±44.3	126.0±27.3	—	2.27	<0.025
Vanadium, ppb	7.4±1.8‡	3.4±1.6	—	1.72	<0.05

Coefficients of correlation with death rates from arteriosclerotic heart disease within group (All coefficients were negative):

* ≥ 0.381, $P \leq 0.025$
† ≥ 0.445, $P \leq 0.01$
‡ ≥ 0.0597, $P \leq 0.0005$.

such constituents in water. Conversely, the higher the death rate, the greater were the concentrations of copper and possibly manganese in water.

In order to refine these differences, the concentrations of water constituents and death rates in each of the two groups of cities were correlated by rank. Death rates from coronary heart disease in the 25 cities with high rates were significantly related to water qualities as follows: inversely with lead ($P < 0.005$) and hardness ($P < 0.25$); directly with manganese ($P < 0.005$). In 25 cities with the lowest rates, deaths from coronary disease were significantly related as follows: inversely with silicon and vanadium ($P < 0.005$); bicarbonate and hardness ($P < 0.01$); specific conductance, solids, and boron ($P < 0.025$); and directly with no element. Therefore, no significant correlation with death rates appeared for any measured element or quality of water common to the two groups of cities, except hardness.

As expected, specific conductance was directly and highly related to the concentrations of the bulk elements, total solids, and hardness. Positive coefficients were also found for the trace elements barium, strontium, aluminum, molybdenum, lead, titanium, boron, vanadium, and lithium in varying degrees of significance. Negative correlations, when found, were low.

Comment

The relationship of death rates from hypertensive and arteriosclerotic heart disease in white persons by state and some factor of potable water associated with softness, previously demonstrated for 1950 rates, persisted in 1960. This phenomenon recurred in spite of a decline in the mortality of white males from hypertensive heart disease of 45.8% and a rise in mortality from arteriosclerotic heart disease of 10.8% during the decade.[11] That the known geographic variation of death rates from specific cardiovascular disorders can be linked to some quality in water in such different areas of the world as the United States,[1,2] Great Britain,[3] Japan,[5] and Sweden[4] suggests that the association is real. It was the purpose of this study to attempt to discover which constituents in water are so associated, in order to indicate further research on environmental factors influencing these diseases.

That the purity of water in terms of inorganic material is directly related to death rates from arteriosclerotic heart disease in white males deserves explanation. If this relationship is valid and a real influence exists, two hypotheses must be explored: (1) Some substance dissolved in water partly protects against or retards the disease or (2) some quality in pure water enhances the disease.

Hardness of water depends upon the formation of insoluble calcium and magnesium soaps, and not upon sodium or potassium. Hardness was the only available measurement of water on a state-wide basis with which to correlate specific death rates.[1] Of the 50 cities with high and low death rates, 11 provided softened municipal waters. Four of those with high rates reduced hardness to 82 ppm ± 3.36 (standard error of the mean [SE]); seven with

Table 4.—Approximate Daily Human Intakes of Several Elements From Food and Water. Values for Cities With Lowest Death Rates*

Elements	Water	Food	% From Water
	Major Elements, Mg		
Calcium†	45	800	5.6
Magnesium†	33	270	12.2
Sodium†	69	4,400	1.5
Potassium†	70	3,000	2.3
Silicon†	14	>35	<40.0
	Trace Elements, μg		
Aluminum‡	540	36,000	1.5
Boron†	130	15,000	0.9
Barium†	160	1,400	11.4
Cadmium‡	<4	25	<16.0
Chromium	3	75	4.0
Copper†	14	2,500	0.6
Lithium†	34	....	....
Manganese†	28	3,000	0.9
Molybdenum	6	1,000	0.6
Lead†‡	7	300	2.3
Strontium†	480	2,700	17.8
Titanium‡	4	300	1.3
Vanadium†	15	2,000	0.8

*Values for water from Table 3 and Durfor and Becker,[9] assuming 2 liters intake per day; for food from Underwood,[12] Altman and Dittmer,[13] and Schroeder.[14] Elements believed essential for man are in italics.

†Correlation with death rates from arteriosclerotic heart disease in one or more analysis.

‡Accumulates in man.[13]

Table 5.—Trace Elements in Water Pipes and Tap Waters Standing Therein*

	Copper	Cadmium	Nickel	Tin	Lead	Antimony
Copper pipe, HNO_3 extracted, %	....	0.16	10.3	1.18	0.11	0.005
Soft water, spring, dwelling, stale, µg/liter	1,400	1.1	ND†	ND	ND	....
Same, fresh, µg/liter	190	ND	ND	ND	ND	....
Hard water, well, dwelling, stale, µg/liter	40	....	....	....	....	....
Soft water, municipal, lake, hospital, stale, µg/liter	730	0.64	ND	....	2.3	....
Same, fresh, µg/liter	170	0.06	....	....	....	....
Same, hot, µg/liter	440	ND	....	....	4.5	....
Galvanized iron pipe, HNO_3 extracted, %	....	2.3	0.35	0.49	0.05	0.001
Soft water, municipal, lake, dwelling, stale, µg/liter	....	0.25	ND	....	ND	....
Same, fresh, µg/liter	....	0.10	....	....	....	....

*Short sections of used pipe were extracted with 1 N HNO_3 for 24 hours. Stale water from tap after standing overnight; fresh water after running 15 minutes or more. Spring water had 18 ppm hardness; municipal water, 20 ppm. Spring water standing in laboratory dissolved from a section of copper pipe 153 µg of copper per 100 sq cm surface per day at pH 7.0.

†ND = not detected.

low rates to 129 ppm ± 9.65 (SE), ($P < 0.005$). Thirty of the 100 cities reported softened their supplies.[9]

In softer waters, specific conductance and hardness were directly related to the bulk elements and to aluminum, barium, chromium, molybdenum, lead, strontium, fluorine, and titanium. In harder waters, they correlated significantly with the bulk elements and barium, strontium, lithium, vanadium, and boron. In no case was the amount of one of these substances in water a substantial increment of the amount normally present in food,[12-14] except perhaps that of silicon (Table 4). From what is known of these elements at this time, none (with the possible exception of lead) can be implicated in the pathogenesis of either hypertensive or coronary heart disease, nor does the data implicate any single element, major or trace, in water as possibly retarding the disease.

Cumulative trace elements have been suspected of influencing cardiovascular disorders, especially cadium in hypertension.[15] Chromium deficiency in rats is associated with aortic plaques.[16] Cadmium was not detected in municipal water by the method used,[9] although it was found frequently in tap water in the United States[17] and in river water in Japan[18] by other methods. Chromium did not differ in the waters of the two groups of cities. According to these statistics, six trace elements in water correlated inversely with death rates and two essential micronutrients correlated directly. Insofar as is known, none of these accumulates in man, except lead[14] (Table 4), which had a negative coefficient. If a toxic trace element is influencing the disease adversely, it is probably not among those measured.

The data from the United States,[1,2] Great Britain,[3] Sweden,[4] and Japan[5] suggest that some quality of water associated with but other than those measured may influence cardiovascular death rates. The waters associated with the highest death rates in all four areas were of a nature considered corrosive to metal pipes.[19] The ability of water to dissolve metals from pipes depends directly upon the degree of softness and the concentrations of carbonic acid, alkaline bicarbonates, chlorides, and sulfates. Soft waters tend to contain carbon dioxide and bicarbonate. Soft waters high in sulfate, as in Japan, are especially corrosive. Hard waters do not ordinarily attack pipes unless they have been softened, in which case sodium bicarbonate, replacing calcium bicarbonate, induces corrosion. When this water is heated, free carbon dioxide is formed, making hot water more corrosive than cold water.

This investigation concerns water in municipal supplies and not water consumed from the tap, which has stood in and circulated through mains and pipes in buildings. Therefore, trace metals cannot be completely excluded as affecting cardiovascular mortality. Soft water may absorb considerable metal from pipes. In Table 5 are the results of analyses of used water pipes and water from two private dwellings and two hospitals. Some values for copper exceeded the maximum found in 100 municipal waters, 250 ppb.[9]

The corrosiveness of soft water is a constant problem in municipal water works and private dwellings.[19] In water works, brass fittings may contain the alloying metals, nickel, aluminum, arsenic, antimony, and tin. In older private houses, copper pipes and fixtures may contain tin, arsenic, and cadmium. The modern copper tubing widely used in the United States, however, has only contaminants of other metals, aside from lead and tin in solders. Galvanized iron pipes expose water to cadmium, a contaminant of zinc.[17] As lead, tin, and cadmium accumulate in man,[14] these and perhaps other metals require investigation as to their influence upon atherosclerosis or hypertension.

The association of water and death rates from two common cardiovascular diseases has been declared "spurious" by Dingle et al,[20] who pointed out that states having a seacoast showed higher death rates than states without. They used "cardiovascular disease" (*International Causes of Death*, sixth revision, No. 330-334 and 400-418[21]), however, as a single factor, whereas it was composed of ten.[11] Such statistical pitfalls are all too common. In fact, coefficients of correlation of hardness of water and death rates from hypertensive heart disease in white persons aged 55 to 64 years were −0.501 in coastal and −0.518 in interior states ($P < 0.005$), hardly a spurious association. This relationship, however, is not evident in smaller geographical areas with lesser populations. Neither in Ireland,[22] where water is often soft, nor in Oklahoma,[23] where water is generally hard, and death rates from these causes below average, was it demonstrable. If corrosion is a factor, these negative results might be expected in hard-water areas or where pipes in dwellings are dissimilar to the type used in the United States.

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FREUDIANISM AND SYMBOLISM.—A special kind of thinking about sex became prominent in the twentieth century owing to the extensive use of metaphor and simile in Freudian psychology. The exclusive Freudian preoccupation with the allegorical role of orifices, and of objects that by a stretch of the imagination might fill them, creates the impression that sex life must be extremely dull for adults and is enlivened only by the effects of the Freudians' apparent confusion about whether the male and female parts are the same or different and whether they can be distinguished from countless inanimate objects.

Myriads of metaphorical symbols are ordinarily used to enrich experience and enliven communication in everyday life; these symbols are infinite in number, variety, and interest. A number of them involve reference to sexual phenomena, but most do not. Many Freudians, however, find sexual significance in a ludicrous variety of everyday words and objects. Moreover, Freudism is oddly confusing in its persistent disregard of the differences between fertility and sexuality—a difference commonly acknowledged by others. (For example, when Lowell referred to Emerson's "masculine faculty of fecundating other minds" he quite probably did not visualize Emerson as an oversized phallus.) Finally, Freudism, instead of enriching thinking and expression, stultifies them by limiting the usable symbols to a small number—i.e., two.—Altschule, M.D.: *Roots of Modern Psychiatry: Essays in the History of Psychiatry*, New York and London: Grune & Stratton, Inc., 1965, p 109.