Hardness of drinking-water and cardiovascular disease

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In the past 10 years or so evidence has been accumulating about an environmental factor which appears to be influencing mortality – in particular, cardiovascular mortality – and this is the hardness of the drinking-water. There is an inverse association between indices of water hardness and cardiovascular death rates; the softer the drinking-water the higher the death rates. This association has been found in several very different countries: in Japan (Kobayashi, 1957); in the USA (Schroeder, 1960*a*,*b*, 1966; Masironi, 1970); in the UK (Morris, Crawford & Heady, 1961; Crawford, Gardner & Morris, 1968); in Sweden (Biörck, Boström, Widström, 1965); in Ireland (Mulcahy, 1968); and in others. Although different components of cardiovascular mortality are more clearly involved in some of these countries than in others (e.g. cerebrovascular disease in Japan and myocardial degeneration in Sweden), the similarity of the findings in the largest studies, those in the USA and the UK, is remarkable.

The closest associations between death rates and water indices have been found in the UK (Crawford *et al.* 1968). In the sixty-one large county boroughs of England and Wales the correlation coefficients between cardiovascular death rates and water hardness are negative and highly significant; they are greatest with water calcium and the carbonate fraction; correlations with sodium are much lower and with magnesium, negligible. The main subgroups of cardiovascular disease – cerebrovascular, ischaemic heart, and 'other' heart disease, which includes hypertensive heart disease and the myocardial degeneration deaths – are all closely associated with water calcium (Table 1).

Bronchitis death rates show a lesser but still highly significant association with water hardness and calcium; this is of interest as many bronchitics die of cardiac complications. The rest of mortality is also negatively correlated but the coefficients are smaller. Findings at ages 65–74 years are similar. Fig. 1 shows the trend of cardiovascular death rates for men aged 45–64 in association with the calcium content of the drinking-water in these sixty-one county boroughs. The death rates in some of the soft-water towns are 1·5 times those in the very hard-water towns, indicating that a large number of deaths are involved in these differences.

These findings are not of course evidence of a direct 'causal' relationship between drinking-water and mortality; the correlations could be due to some confounding factor (or factors). In a comprehensive search for such, over a 100 indices of local

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Table 1. *Associations between water calcium and local death rates at ages 45–64 (1958–64) in the sixty-one county boroughs of England and Wales with a population of 80 000 or over in 1961*

Certified cause of death	Correlation (r) with water calcium (parts/10^6) ♂	♀
All cardiovascular disease:	−0·72	−0·71
cerebrovascular	−0·62	−0·54
coronary	−0·59	−0·62
other	−0·60	−0·60
Bronchitis	−0·55	−0·47
All other causes	−0·37	−0·44

Significance of correlation: $r > +0{\cdot}33$ or $r < -0{\cdot}33$; $P < 0{\cdot}01$.

social, economic, industrial, and other environmental conditions were correlated with water hardness (Crawford *et al.* (1968) give examples of these). There was no evidence that water hardness or calcium was merely reflecting other factors; rainfall was the only variable closely associated with these water components. This is as expected; the high-rainfall areas are mainly the soft-water areas and these areas have a high mortality from cardiovascular disease. A multiple regression study showed that, after allowing for other environmental and social factors, both water calcium and rainfall made significant contributions to the variance of cardiovascular death rates between the towns studied.

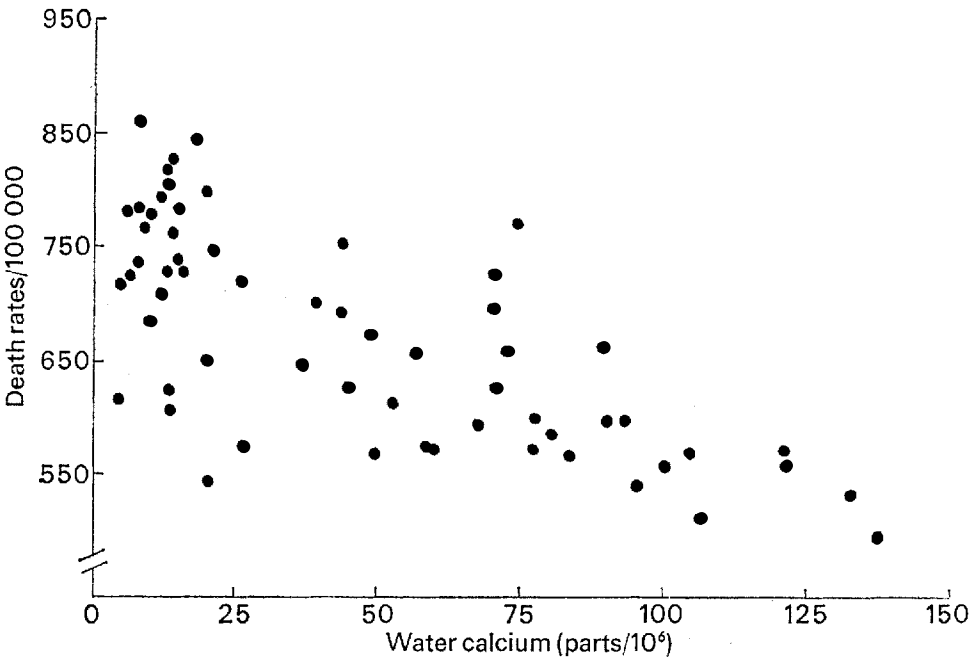

Fig. 1. Cardiovascular mortality (1958–64) in males aged 45–64 and water calcium in sixty-one large county boroughs in England and Wales.

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To investigate the association further, an attempt was made to study change in one variable in relation to change in the other. Death rates were studied in eleven large county boroughs of England and Wales where the hardness of the water had changed, opportunely and for a variety of reasons, by 50 parts/10^6 or more, during the past 30 or so years. A favourable effect on cardiovascular mortality was found where the drinking-water had become harder, compared with where it had become softer (Table 2). Non-cardiovascular death rates were unaffected (Crawford, Gardner & Morris, 1971).

Table 2. *Proportional changes in mortality at ages* 45–64 *between* 1948–54 *and* 1958–64 *related to changes in water hardness in the large county boroughs of England and Wales*

		% change in mortality		
Subjects	Cause of death	Water hardness increased (5 towns)	Water hardness unchanged (72 towns)	Water hardness decreased (6 towns)
♂	Cardiovascular disease	+ 8·5	+11·2	+20·2
	All other causes	−10·8	−13·0	−12·4
♀	Cardiovascular disease	−14·9	−11·8	− 9·0
	All other causes	−13·7	−10·9	−12·5

These findings, together with the unlikely chance that in several quite different countries the same local factors associated with cardiovascular mortality are producing indirect correlations with water hardness, suggest that there is a 'water factor' affecting cardiovascular disease. In this situation we have to consider the possibility that there is a direct cause and effect association between the drinking-water and cardiovascular disease—that some quality or component in the water is affecting some pathogenic process or mechanism in this disease.

Pathogenesis

The association could be with any of the main processes in cardiovascular disease, for example mural atheroma, intravascular thrombosis, hypertension, and even with non-specific mechanisms in cardiac failure. In a pathological study, Crawford & Crawford (1967) compared the prevalence of cardiac lesions in a soft-water town with those in a hard-water town, and the findings pointed to a factor affecting the myocardium rather than arterial disease. This suggests that sudden deaths, due to fibrillation and disturbance of myocardial electrophysiology, might be more frequent in soft-water areas.

It appears from the mortality studies that all the main subgroups of cardiovascular disease are involved; although ischaemic heart disease is the largest fraction of all cardiovascular mortality it is neither the most closely nor the most consistently associated. Hypertension would seem to be the most likely common factor.

There are then two main suggestions arising from the evidence at present: (a) that a factor directly affecting myocardial function possibly through electrolyte imbalance is involved; and (b) that hypertension may be more prevalent in soft-water areas.

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Water components

If a direct relationship is postulated between the mortality and the drinking-water, there are several possible mechanisms. Thus, trace elements could be involved; soft waters could be carrying toxic elements from pipes or soil into supply; hard waters could be protective due to their mineral content.

There is a considerable literature on the effects of trace elements (including those metals which may be absorbed from pipes) on some processes known to be involved in cardiovascular disease. Some elements, for example vanadium, manganese, chromium, and lithium, may have a protective effect—mainly by influencing lipid metabolism and arterial disease; others, such as lead, cadmium and cobalt, are known to be harmful (Masironi, 1969). Studies comparing trace element concentrations between soft and hard waters, in the USA (Schroeder, 1966; Masironi, 1970), in Sweden (Boström & Wester, 1967), and in the UK (Crawford *et al.* 1968) have not, however, produced any consistent picture. Table 3 lists the elements found to be at higher concentrations in either soft or hard waters in the various studies. However, it is difficult to make comparisons between the studies because of differences in sampling.

Table 3. *Differences in the distribution of trace elements in soft and hard waters*

		Trace elements		
Country	Study	Higher concentration in areas with soft water and high death rates	Higher concentration in areas with hard water and low death rates	Type of water tested
USA	Schroeder (1966)	Manganese, nickel, copper	Potassium, barium, silicon, lithium, strontium, vanadium	Treated 'municipal' water
Sweden	Boström & Wester (1967)	Cobalt, mercury, lanthanum	Molybdenum, selenium, barium, gold, tungsten	'Raw' and 'tap'-water
England and Wales	Crawford *et al.* (1968)	Manganese, aluminium	Boron, iodine, fluorine, silicon	'Tap'-water
USA	Masironi (1970)		Chromium, zinc, manganese, iron, cadmium	'Raw' water

In none of these studies was any element found to be present in a concentration which could be considered toxic, but in the UK, where plumbosolvency from soft and acid water has caused trouble in the past, there is evidence that the pick-up of lead from pipes may still be a problem. A few years ago high concentrations of lead were found in water lying in pipes overnight or longer, particularly in some soft-water towns (Table 4) (Crawford & Morris, 1967). Furthermore, the lead content of ribs (from cases in the Glasgow–London pathological study mentioned earlier) was considerably higher in the former—a mean value of 93 parts/10^6 compared with 54 parts/10^6 in the latter hard-water area (Crawford & Crawford, 1969). Measures have now been taken to counteract the plumbosolvent character of the

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Table 4. *Distribution of lead in overnight water of inhabited houses in county boroughs of England and Wales in* 1967

Type of water	No. of towns	Average hardness as $CaCO_3$ (parts/10^6)	No. of samples	Lead (parts/10^6)			
				<0·1	0·10–0·19	0·20–0·29	0·30 and over
Soft	9	40	50	34	5	3	8
Hard	8	264	45	30	14	0	1

waters in several of the towns and, in recent sampling, high concentrations of lead, that is >0·3 parts/10^6, were not found. However, seven out of thirty-nine hard and seven out of forty-four soft-water samples had lead concentrations over 0·05 parts/10^6, the accepted upper safety limit (WHO, 1963).

It has been shown by Schroeder (1965) that the absorption by the body of trace elements, such as lead, cadmium, zinc and chromium, is inversely related to the concentration of calcium in the medium; so lead in hard waters is probably harmless as it is unlikely to be absorbed. The importance of calcium in protecting against lead is well known, and milk is given in large quantities to workers in lead factories to prevent absorption. A concentration of lead which may be harmless in a hard water could be dangerous in a soft water, and this may be relevant to the present problem. There is a general awareness now regarding many trace elements, including lead, that concentrations which had been considered safe in the past may not in fact be safe, and that long exposure to small concentrations may be harmful and render people less able to survive other stresses. It is clear, however, that lead contamination cannot be the whole explanation of the 'water story'; it could, however, be a contributory factor and might explain the much clearer picture and the higher correlations in the UK than in the USA.

There have been suggestions that other trace elements may be important. Schroeder (1969) speculated that cadmium, dissolved from galvanized pipes, could be causing hypertension and might be the 'water factor'. Voors (1969) considered that hard waters might be protective due to their higher lithium content. Häsänen (1970) found that the best correlation with diseases of the circulatory system in Finland was with the iodine content of the drinking-water. It seems unlikely however that any one element could explain the various findings in different areas, and the possibility that the hard waters may be protective due to their whole mineral content must be considered.

Calcium, magnesium and sodium are the main cations in drinking-water, and of these, calcium is the most closely associated with mortality in several studies. However, as the intake of magnesium and sodium is overwhelmingly from food, the lack of correlation between their concentrations in drinking-water and cardiovascular disease is to be expected, although they may be involved through interrelationships with calcium.

Water calcium could be important in two ways. First, it may act by inhibiting the absorption of toxic elements from pipes and soil as indicated above. In drinking-

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water, therefore, calcium may be protective against several trace elements and it may be more meaningful to look at the concentration of trace elements relative to that of calcium rather than absolute values.

Second, water calcium might constitute an effective addition to dietary calcium, although there is controversy concerning the contribution that water calcium makes to total intake. It has been shown in several studies (Widdowson & McCance, 1943; Murray & Wilson, 1945; Widdowson, 1954) that in the UK hard drinking-water may provide a meaningful amount of calcium in the diet. The difference in intake between hard- and soft-water areas could amount to 200 mg daily. It is estimated that less than 30% of the ingested calcium is absorbed; and, if factors affecting absorption are taken into account, the importance of water as a source of calcium may be greater than has been realized. Dauncey & Widdowson (1972) studied single specimens of urine from 157 men living in hard-water areas, and 196 men living in soft-water areas, and found that the amounts of calcium, magnesium, and potassium excreted were similar in the two areas. However, others have found that random samples of urine give a poor estimate of 24-h excretion (Watson & Langford, 1970) and, therefore, it is doubtful if conclusions regarding calcium intake can be drawn from this study. Further *ad hoc* studies are needed to assess the contribution of water calcium to calcium absorption.

At low levels of calcium intake, magnesium metabolism is altered and this may be important. Three studies have shown differences in tissue concentrations of calcium and magnesium ions between soft- and hard-water areas (Crawford & Crawford, 1967; Bierenbaum, Fleischman, Dunn, Belk & Storter, 1969; Kamiyama, Yamada, Kobayashi & Takahashi, 1969).

It is the interrelationship of ions which must be emphasized; the relationship of calcium and sodium may be of importance in the 'water story'. Calcium and sodium ions are excreted by the kidneys in a fairly constant ratio (Walser, 1961; Nordin, Hodgkinson & Peacock, 1967), and one can speculate that sodium retention could develop more readily when the serum calcium concentration is low and less is excreted.

Douglas & Langford (1969) found that more rats became hypertensive when the calcium: sodium ratio in the diet was reduced; and there are suggestions from studies on human populations in Japan (Kamiyama, Kobayashi, Takahashi, Wakamatsu & Kurashina, 1968), and from animal experiments (Schroeder, Nason & Balassa, 1967), that a low-calcium diet is associated with greater prevalence of hypertension, particularly in females. High prevalence of hypertension has also been reported in populations living in areas with very high concentrations of sodium (600 parts/10^6) in the drinking-water (Fatula, 1967).

In most drinking-waters the concentration of sodium is low (50 parts/10^6 or less) but artificial softening can result in very high values (Garrison & Ader, 1966). A common method of softening is by base exchange, substituting sodium for calcium ions, which may be particularly detrimental to health and might contribute to the findings in the study reported above (Crawford *et al.* 1971).

These observations and speculations can be summed up in the hypothesis that

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the concentrations and interrelationships of the 'bulk' ions – calcium, magnesium and sodium – are of fundamental importance in the association of cardiovascular disease with drinking-water; harmful trace elements, particularly metal contaminants from pipes, for example lead, may also be involved, but their effect may depend on interrelationships with calcium.

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