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Drinking Water Quality and Sudden Death: Observations from West and East Finland[1]

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Key Words. Water hardness · Coronary heart disease · Magnesium · Copper · Chromium

Abstract. Relationships of drinking water quality to CHD and sudden death were studied in two rural areas in western and eastern Finland. In the eastern area, drinking water is particularly soft and contains less magnesium and chromium but more copper than in the western area. A 15-year follow-up of resident males showed a higher death rate from CHD in the eastern area but no difference in the proportion of sudden deaths. The data suggest that CHD may be associated with low concentrations of magnesium and chromium in the drinking water, but no definite relationship was found between water quality and sudden death.

The mortality from coronary heart disease (CHD) varies widely between populations. According to one hypothesis, these differences are, in part, related to the degree of hardness of drinking water (9, 11, 21). Such a causal relationship, however, is unproven, and no agreement exists on the nature of the water factor and the biological mechanism through which water quality could operate (12, 15). It has also been suggested from mortality statistics that the higher death rates in soft water areas might be due to an excess of sudden deaths (1, 2, 4, 14).

Within Finland, there is a marked difference in the mortality from CHD between the eastern and the southwestern parts of the country (6, 13, 18). In a cohort study of two rural male populations, one from east Finland, the other

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from southwestern Finland carried over a 15-year period from 1959, the eastern cohort experienced a death rate from CHD about twice as high as the western cohort (7, 8). In 1970, we collected and analyzed samples of drinking water in the two regions. In both areas, drinking water is soft but much more so in the eastern area (16). The levels of the water constituents were also studied with reference to disease experience of the individuals in the cohorts over the 10-year period from 1959 to 1969 (16). The concentration of copper tended to be high and that of chromium tended to be low in the drinking water of men who had developed CHD or died from the disease. The findings on magnesium were equivocal.

For the present study, we used our 1970 data on the drinking water quality of the two regions but extended the observations on CHD to include 5 more years, 1969–1974. This gave us almost double the number of CHD deaths as compared with the previous study. An attempt was also made to examine the relationship of water quality to sudden death. Particular attention was paid to three elements: magnesium, copper and chromium.

Subjects and Methods

In two rural regions all resident men born between 1900 and 1919 were recruited in 1959 for a prospective investigation of CHD. The two cohorts were followed up yearly for mortality data and examined at 5-year intervals in 1964, 1969, and 1974 (7, 8).

In both areas, households draw drinking water from their own wells. In 1970, drinking water samples were collected from 93 wells in the western area and from 234 wells in the eastern area. The samples were analyzed for 22 water factors (16). The study areas were divided into sub-areas, 10 in the west and 33 in the east. Medians, representing the values for the drinking water in the sub-areas, were calculated for each of the water characteristics. All the subjects in a sub-area, including those who had died earlier, were assigned the values of the sub-area water (16). For this study on drinking water, however, only subjects whose residence had not changed since 1959 were included. The number of subjects who moved from their sub-area after 1970 was small and they were not excluded from the statistics. In the present study, data on magnesium, copper and chromium were analyzed for possible associations with the development of CHD and with the occurrence of sudden deaths in the two cohorts, during the period 1959–1974.

Deaths between 1959 and 1974 were classified by cause, using standard criteria (8). Copies of all death certificates were obtained. When death had occurred in a hospital, the hospital records were examined for the cause of death and for terminal events. For deaths occurring outside hospital, the certifying doctor, relatives of the deceased, or witnesses of death were interviewed or contacted somehow. Thus, in the majority of deaths ascribed to CHD, information additional to that on the death certificate was obtained. A standardized

classification was used for the length of the terminal episode prior to death caused by CHD. For the present purpose, sudden death was defined as unexpected on the day of death and occurring within an hour of the onset of acute symptoms.

The survivors were grouped according to their health status at the time of the 15-year re-examination in 1974. CHD was diagnosed when, in the absence of other heart disease, there was a history of angina on effort, typical attack of chest pain (20), heart failure, a resting ECG showing gross changes of QRS, ST or T waves, or atrial fibrillation (16). A small number of subjects were placed in the 'sick' categories although they had no definite symptoms or signs of heart disease in 1974. These were the men who upon the 10-year re-examination had fulfilled the above disease criteria, or showed an abnormal ECG response to an exercise test.

Results

Differences between the Two Areas

Table I shows the number of deaths grouped into three broad categories for the two cohorts, for the entire period 1959–1974. Total mortality was higher in the eastern population, and the number of deaths caused by CHD was nearly twice as high in the eastern cohort (14.7%) as in the western one (8.7%, $p < 0.001$).

Table II describes the length of the terminal episode in deaths caused by CHD. There was no significant difference between the two cohorts in the proportion of men who died within an hour of the onset of terminal symptoms, but the percentage of deaths classified as caused by chronic heart failure was higher in the east than in the west. The proportion of deaths with insufficient information on the terminal episode was almost twice as high in the west as in the east.

Table III presents the data for the concentrations of magnesium, copper and chromium in the drinking water in the two areas. In the east, where the

Table I. Deaths between 1959 and 1974. Men aged 40–59 in 1959

	West Finland	East Finland
Number of men identified in 1959	888	823
Total number of deaths between 1959 and 1974	235 (26.5%)	251 (30.5%)
Coronary deaths	77 (8.7%)	121 (14.7%)
Other cardiac causes	12 (1.4%)	18 (2.2%)
Other causes	146 (16.4%)	112 (13.6%)

mortality from CHD is high, the average concentrations of magnesium and chromium are lower, but the concentration of copper is higher than in the west. Note that the concentrations shown in table III are sub-area medians and as such are lower than the average concentrations because the original levels were positively skewed (16). The concentrations in individual wells also had greater ranges than those presented here. For example, the maximum concentrations of magnesium were: west, 108 mg/l; east, 23 mg/l.

Table II. Length of terminal episode in CHD deaths

Length of terminal episode	Number of men	
	West Finland	East Finland
1 h or less	30 (52%)	45 (43%)
>1 h	27 (47%)	50 (48%)
Chronic heart failure (CHD)	1 (2%)	10 (10%)
Total classified	58 (100%)	105 (100%)
Insufficient data	19	16
Total	77	121

Table III. Concentrations ($\bar{x} \pm$ SEM) of magnesium, copper and chromium in the drinking water in the two study areas in 1970

	West Finland 93 water samples 10 sub-areas			East Finland 240 water samples 33 sub-areas		
	sub-area medians			sub-area medians		
	min.	max.	$\bar{x}$	min.	max.	$\bar{x}$
Mg, mg/l	6.9	27.8	13.1 ± 2.0	0.6	7.3	3.1 ± 0.3** (−)
Cu, µg/l	8.5	27.3	19.0 ± 1.6	0.0	101.8	34.8 ± 5.1* (+)
Cr, µg/l	4.4	16.1	8.1 ± 1.1	0.0	7.6	2.4 ± 0.4** (−)

− = Lower; + = higher than in the west.
*$p < 0.01$; **$p < 0.001$.

Table IV. Concentrations ($\bar{x} \pm SEM$) of magnesium, copper and chromium in the drinking water of men who died between 1959 and 1974 compared with that of men who were alive in 1974

		Alive	Deaths		
			all	CHD	other cause
West Finland	n	366	138	49	89
Mg, mg/l	$\bar{x}$	13.6 ± 0.4	13.7 ± 0.5	12.7 ± 0.7	14.2 ± 0.7
Cu, µg/l	$\bar{x}$	20.2 ± 0.3	21.0 ± 0.4	21.1 ± 0.7	20.9 ± 0.5
Cr, µg/l	$\bar{x}$	8.8 ± 0.2	8.4 ± 0.3	7.5* (--) ± 0.4	8.9 ± 0.4
East Finland	n	427	195	95	100
Mg, mg/l	$\bar{x}$	3.6 ± 0.1	3.3* (--) ± 0.1	3.3 ± 0.1	3.2* (--) ± 0.2
Cu, µg/l	$\bar{x}$	38.8 ± 1.5	37.6 ± 2.1	40.7 ± 3.0	34.6 ± 2.8
Cr, µg/l	$\bar{x}$	2.6 ± 0.1	2.4 ± 0.2	2.4 ± 0.3	2.4 ± 0.2

-- = Lower than in the 'alive' group.
*$p < 0.05$.

The observations presented in tables I–III show that the two areas differ both in mortality caused by CHD and in the concentrations of magnesium, copper and chromium in the drinking water. On the other hand, the proportion of deaths which were sudden was similar in the two populations. This would suggest that if there is a relationship here between water quality and CHD, it is not caused by an excess of sudden deaths in the eastern area.

Differences within the Two Areas

The relationships between the concentrations of the three elements in the drinking water and CHD or sudden deaths within the two areas are presented in tables IV and V – the numbers are smaller than those in the previous tables because water data were not available for all subjects (16).

Table V. Concentrations ($\bar{x}$ ± SEM) of magnesium, copper and chromium in the drinking water of men who died from CHD and of those who were alive in 1974

		Alive			CHD deaths			
		no HD	CHD	other HD	all	≤1 h	>1 h	insufficient data
West Finland	n	182	146	38	49	20	18[1]	11
Mg, mg/l	$\bar{x}$	13.5 ± 0.5	13.6 ± 0.6	13.8 ± 1.2	12.7 ± 0.7	11.9 ± 0.9	14.7 ± 1.4	10.7 ± 1.1
Cu, µg/l	$\bar{x}$	20.0 ± 0.4	20.3 ± 0.4	20.7 ± 0.9	21.1 ± 0.7	21.4 ± 0.9	21.3 ± 1.0	20.4 ± 1.9
Cr, µg/l	$\bar{x}$	8.4 ± 0.3	9.3** ± 0.3	8.4 ± 0.6	7.5 ± 0.4	7.5 ± 0.5	7.9 ± 0.8	6.7 ± 0.7
East Finland	n	179	195	53	95	33	49[2]	13
Mg, mg/l	$\bar{x}$	3.6 ± 0.1	3.6 ± 0.1	3.5 ± 0.2	3.3 ± 0.1	3.3 ± 0.2	3.3 ± 0.2	3.2 ± 0.4
Cu, µg/l	$\bar{x}$	37.4 ± 2.3	39.1 ± 2.2	42.4 ± 4.0	40.7 ± 3.0	39.3 ± 5.2	40.1 ± 4.1	46.5 ± 9.1
Cr, µg/l	$\bar{x}$	3.2 ± 0.2	2.3**- ± 0.2	2.2*- ± 0.3	2.4*- ± 0.3	2.3 ± 0.5	2.5 ± 0.3	2.1 ± 0.6

Men grouped according to the length of the terminal episode or heart disease status in 1974. Comparison with the 'no heart disease' group.
+ = Higher; – = lower than in the 'no HD' group.
*$p < 0.05$; **$p < 0.01$.
[1] Includes 1 death from chronic heart failure.
[2] Includes 8 deaths from chronic heart failure.

In the western area, the only statistically significant finding was a low concentration of chromium in the drinking water of the men who had died from CHD by 1974 (table IV). In the eastern cohort, the concentration of magnesium was statistically lower in the drinking water of the men who had died from CHD, as compared with the 'alive' category. Within each region, the pattern of concentration of magnesium, copper and chromium confirmed the observations

reached by comparing one region to the other but most of the differences were not statistically significant.

In table V the 'alive' group is broken down into three categories on the basis of the cardiac status in 1974, whereas the group of deaths caused by CHD is divided into clusters according to the length of the terminal episode. For statistical purposes, the 'no heart disease' category was used here as a reference. The differences between the two CHD death categories with known length of terminal episode (≤ 1 or >1 h) were also tested for significance.

In the west, the water concentrations of chromium in all subgroups of CHD death were low compared to the 'no HD' group but the differences were not statistically significant (cf table IV). The group of subjects alive with clinical signs of CHD had a high water concentration of chromium. No significant associations were found between any of the elements and the suddenness of death. In the east, death from CHD, and survival with clinical signs of CHD or other cardiac diseases were associated with low concentrations of chromium in the drinking water. Again, none of the element concentrations were associated with the suddenness of death.

Discussion

All three drinking water elements studied here have been implicated as water factors (3, 5, 16). Along with calcium, magnesium is the principal element affecting water hardness. In the eastern area, where the mortality from CHD is high, the drinking water is particularly soft and has low concentrations of magnesium and chromium, elements which are considered to be protective (3, 22, 23, 25). On the other hand, the concentration of copper, which is thought to be harmful, is high (5). Other drinking water constituents also occur in markedly different concentrations in the two areas. In the east the levels of NO_3, K, Co, Ni and Ba are higher and those of Ca, Na, F (16) and of Si (24) lower than in the west. Unpublished data show that the mean concentration of Cd is higher in the west than in the east though the difference is not statistically significant. Several of these water constituents have also been suspected as water factors (15, 22, 24). In our previous study, magnesium, chromium and copper had showed some associations with CHD within the two study areas (16). With 5 more years of follow-up, the results were similar except that the associations for copper were not statistically significant.

Mortality statistics have suggested an increased proportion of sudden deaths

in soft water areas (1, 2, 4, 14). The results of the present work on individual men do not indicate such an association, nor was any of the three elements definitely related to the suddenness of death. There are, however, several possible sources of error in such data. Misclassification of causes of death cannot entirely be avoided. The autopsy rate was less than 20% in the east, and about 25% in the west. However, evidence from other sources indicates that the difference in the CHD death rates between the two areas is real (6, 13, 18). The definition of sudden death poses a more difficult problem. Witnesses are not always available and their descriptions of the event are notoriously inaccurate. In stressful characteristics, the two populations are traditionally believed to react quite differently, and this may cause a bias in the proportion of sudden deaths in the two populations. However, it is unlikely that such bias would affect the relationships within a population.

A problem of prime importance in all water studies is the part played by drinking water in the supply of the incriminated elements (15). There are indications that under some circumstances magnesium and chromium may occur in drinking water in amounts that are large enough, compared to those present in food, to be of nutritional importance (22, 25). Whether this is the case in Finland remains an open question. Nonetheless, our two populations seem to be ideally suitable for a water study since the men lead a similar rural life, each probably getting most of his drinking water from his own well. For the present study, sub-area median concentrations, instead of concentrations in the individual wells, were used as water data. Whether such median values reflect the individual's exposure to the elements studied more truly than the individual well concentration remains a matter of conjecture (16). The use of medians decreases the differences between the categories and between the two areas and attenuates the relationships under study. In both areas, the median concentrations of magnesium in the drinking water were on the low side and the ranges were narrow, particularly in the east. Yet there were indications that magnesium, along with chromium and possibly copper, might be involved in the genesis of CHD.

A further basic element for a study on drinking water is the constancy of concentrations, which has received scant attention (15). We had an opportunity to investigate this aspect of the problem when, in 1974, 4 years after the collection of the samples for the present study, the two cohorts were re-examined and new drinking water samples were obtained. Unfortunately, those 2 years represented two extremes as regards rainfall during the periods immediately preceding water collection, particularly in the eastern area. In 1974 the

amount of rainfall in the three preceding months was about $2^1/_2$ times that in 1970 in the east, and in both areas large differences were present in water table levels between the 2 years (10, 26). From the 1974 samples several water constituents were analyzed and concentrations in wells included on both occasions (west, n = 22; east, n = 46) were compared to those of 1970. In spite of these complicating factors the concentrations of bulk elements (Na, K, Ca, Mg) were remarkably similar, and the correlations between the values of the 2 study years were quite good. For magnesium, the correlation coefficients (r) were 0.89 ($p < 0.001$) in the west and 0.58 ($p < 0.001$) in the east. However, concentrations of chromium were low in 1974 as compared to 1970, and the correlation coefficients were not significant. Methodological difficulties involved in the determination of chromium (19) may to some extent account for the difference.

However, the concentrations of fluorine were also lower in 1974 than in 1970 with correlation coefficients being non-significant, whereas excellent agreement was found with previous values when samples stored from 1970 were re-analyzed. No information is available on copper since copper was not included in the later study. Obviously, the analytical difficulties associated with chromium would obscure, rather than clarify, any relationships with CHD. It may also be noted that another study of the men of the two regions showed that they have a particularly low excretion of chromium in their urine, compared with values found elsewhere (17).

In conclusion, our data support the hypothesis that the quality of drinking water plays a part in the difference in mortality from CHD between the two study areas. However, the findings do not support the hypothesis that the alleged water factors operate through an increase in the frequency of sudden death.

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