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with Special Reference to Demineralized and Desalinated Water

Report on a Working Group

REGIONAL OFFICE FOR EUROPE
World Health Organization
COPENHAGEN

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WHO WORKING GROUP ON HEALTH SIGNIFICANCE OF CHEMICALS OCCURRING NATURALLY IN DRINKING-WATER

Brussels, 20–23 March 1978

1. INTRODUCTION

The WHO Regional Office for Europe, in collaboration with the Government of Belgium, convened a Working Group on Health Significance of Chemicals Occurring Naturally in Drinking-Water (project ICP/RCE 101(7)) in Brussels from 20 to 23 March 1978.

This meeting was one of a series of working groups concerned with different aspects of drinking-water, the results of which will serve as an input into the preparation of a new revision of the WHO standards for drinking-water (*1, 2*).

The membership of the subgroups and the list of participants are given in Annexes I and II, respectively.

The meeting was opened by Professor S. Halter, Secretary-General of the Belgian Ministry of Public Health and Family Welfare, who welcomed the participants and referred to the long history of collaboration between the Government of Belgium and WHO.

Dr M.J. Suess conveyed greetings from Dr Leo A. Kaprio, WHO Regional Director for Europe, and then referred to previous meetings in this series of activities and to the meeting on sodium, chlorides and conductivity which was to be held in May 1978 in The Hague.

Professor A. Lafontaine was elected Chairman, Professor J. Menczel Vice-Chairman, and Professor C.J. Roberts and Dr R.B. Dean Rapporteurs. Dr Suess acted as Secretary to the Working Group.

As part of an ongoing programme to revise the WHO standards for drinking-water, the European Regional Office organized an Evaluation Group on Intake by Man of Minute Contaminants from Water and Food, which met in Brussels in April 1976. That Group concluded, among other things, that "there was a need for further specialist consultations specifically devoted to a more thorough exploration of the various problems associated with the intake of minute amounts of micro-contaminants from water and food" (*3*).

The present Working Group concerned itself with the health significance of removing inorganic substances occurring naturally in drinking-water, an insufficiency of which might impair health. An important part of the discussion dealt with the relationship between mineral content and cardiovascular disease, and special reference was made to demineralized and desalinated water.

Some researchers believe that the presence or absence of a certain substance in drinking-water is directly associated with the differences in death rates from heart disease. Other researchers have suggested that water quality may be an indicator of other environmental conditions (for example, climatic) and that it may be these that have a direct effect on heart disease (*4, 5*). It should be recognized that some minerals might be absorbed more easily by the gastrointestinal tract when administered through drinking-water rather than through food. The total quantity of a mineral in food and water is not always available for absorption by the human body. For instance, some organic substances in food bind certain minerals. Such binding may, in turn, interfere with the absorption of the minerals in the gastrointestinal tract. The bioavailability factor, which is the fraction of a mineral constituent that is absorbed into the body from the alimentary tract, must always be taken into account.

When food is boiled in water, there can be sizeable extraction of minerals. It has been suggested that, in general, food should be cooked in the smallest possible quantity of water or that such water be reused for the preparation of soups and sauces. However, in certain cases, water can also extract from food soluble components that are undesirable, such as salt from preserved food and nitrates from some leafy vegetables. In such cases, serious consideration should be given to discarding the mineral-rich solution. These facts make it necessary to re-evaluate the loss to man of minerals, which may occur during cooking in water of variable quality, and to prepare new balance sheets for minerals that take into account local conditions of water and food availability and preparation.

2. WATER CONSTITUENTS AND SUPPLY

Water varies greatly in concentration of dissolved substances, both with geographical location and with the season of the year. It is not possible to define an average water constituency, for there is no agreement on its exact composition. Often, the concentration of ions in order of abundance is $Ca^{+2} > Na^{+} > Mg^{+2} > K^{+}$ for cations, and $HCO_3^{-} > SO_4^{-2} > Cl^{-}$ for anions. These ions are generally present in concentrations ranging from 1 to 250 mg/l. The remaining ions are present in lower concentrations, usually less than 1 mg/l, and many are found at concentrations even less than 1 μg/l (*6*).

Calcium and magnesium ions are the two major divalent cations, and collectively constitute some 95% of what is known as "hardness" in water. However, the other polyvalent cations can contribute to it. The results of many important epidemiological studies in the past have been expressed in terms of "hardness" rather than as concentrations of individual ions. For this reason the term "hard water", and its converse, "soft water", cannot be entirely discarded from being used in this report. However, preference should now be given to the measurement of the concentration of calcium and magnesium ions instead.

Nearly all of the other metallic elements are associated, to a large degree, with other substances; the resulting chelates may exhibit positive, negative, or neutral ionic character (7). A significant fraction of heavy metals is adsorbed on particulate matter and much that has been reported as being in solution may be adsorbed on submicron particles that pass 0.45-μm pore filters. Aluminium, iron, and other polyvalent ions form polymeric hydroxides that can also adsorb lead, cadmium, and mercury. The alkali metals sodium, potassium, and lithium are usually freely dissolved and fully ionized in water. Alkaline earth elements, magnesium, calcium, strontium, and barium exist as simple ions as well as in complexes with anions and organic matter, and also in dispersion.

Most communities face a very limited choice of water supplies. If the original supply of a community should become inadequate as the population increases, arrangements may have to be made to introduce and add water from a distance. If the latter is a surface water of low mineral content and the former was a highly mineralized ground water, the composition of the mixture is likely to vary seasonally and between districts. In some areas water rich in calcium and magnesium ions is softened before distribution; in others the water may be softened in individual home units to different degrees. Some communities accept such water without attempting to change it. When water contains a high proportion of bicarbonate ions it can be softened with lime, which raises the pH and precipitates calcium carbonate; at higher pH, magnesium hydroxide is also precipitated. No ions are added to the water by this process and, in fact, the mineral content is reduced. If the principal anion is sulfate, the water may still be softened if the pH is raised with sodium carbonate, but the concentration of sodium ions is thereby increased. A third method employs sodium bound to an ion exchange resin, and replaces calcium and magnesium ions with twice as many sodium ions. Ion exchange units are the only form of domestic softener, and in some areas this method is also used for municipal water treatment.

A water supply is frequently blended to augment the quantity available. When water is softened by precipitation, it is usually most economical to remove nearly all of the calcium and magnesium from a portion of the water and then blend it with unsoftened water to produce an acceptable product. Likewise, desalinated water can be blended with an existing water supply to increase the volume, to add mineral ions and thereby improve the taste, and to reduce its aggressiveness. Sea water is unsuitable for blending with desalinated water, although on ships and on arid islands some addition of minerals may be necessary. A convenient method, which provides both magnesium and calcium in desirable proportions, is to pass the water over dolomitic limestone. Also, carbon dioxide may be added to provide sufficient buffer capacity in the water. Whenever chemicals are to be added to water, including sodium chloride used for regenerating water softeners, the quality of the additives should be of the highest possible purity, and comparable to the standards applicable to food additives and edible products.

Recently it has become possible to remove virtually all the salts from saline water and to prepare a product that meets current drinking-water standards. Distillation of sea water is practised in a number of arid areas to provide part or all of the drinking-water supply. Also, highly mineralized ground water may undergo treatment by distillation or membrane separation. The fact that pollution products such as ammonia, nitrites, and some volatile organic substances are not removed by distillation or membrane separation and may be concentrated in the water, means that water to be used for desalination should be free from gross pollution. Water softeners operated in the home may become breeding beds for bacteria. Yet so long as such softened water is used only after being boiled or effectively pasteurized, these bacteria are probably of no consequence. In this connexion a previous WHO working group has already recommended that water from the municipal supply be taken for drinking and food preparation before being softened in the home (*8*).

The increasing use of desalinated water raises two important issues: first, what are the adverse effects, if any, on health arising from the use of such water and second, which removed substances should be returned to make it a good water? Opinion in the Working Group differed about the addition of any minerals to natural water, even if it was very low in important minerals. Some members felt that magnesium and/or other minerals should be added only if the water had been artificially demineralized; there was also a feeling that such artificially demineralized water might be adverse to health unless its mineral composition had been "corrected" by returning certain ionic constituents. Others felt that the problem should perhaps be approached, for each element, in terms of its nutritional requirements and availability to the human body, regardless of the source of the water and whether the mineral-insufficient water was collected, for example, from a natural granite basin or from a desalination plant. In any event, either option should be based on a careful risk-benefit evaluation.

3. WATER REQUIREMENTS

The most urgent of all nutritional needs is the need for water. Under normal conditions in a moderate climate, the adult daily water requirement lies between 35 and 50 g of water per kg of body weight. In a tropical climate, or while working in hot areas, this need will be considerably higher. The daily requirement of an infant is 100–150 g of water per kg of body weight, i.e, some three times higher, weight for weight, than that of an adult (*9*). Water is consumed not only in the form of beverages, such as tea, coffee, soft drinks, juice, wine, and beer; about 1 litre is obtained from food daily. In this report, a quantity of 2 litres has been taken as the average amount of tap water consumed by a normal adult each day (*10, 11*). This includes its constitution by the consumer into drinks such as tea and squashes but not its consumption in the form of bottled drinks such as beer or "mineral water".

Ingested water carries with it minerals and organic substances, the individual concentrations of which may be low. However, because the volume of water consumed may be large, the amount of desirable and undesirable substances contained in it may be significant. Therefore, the nutritional aspects, biological availability, and possible toxic levels of such substances must be considered. When studying the effects of individual substances, it must be appreciated that there may be interactions between the substances themselves, as well as interactions with other food components, which may reduce or enhance their availability and their effect on health.

Water requirements and consumption:

- vary considerably, depending on the consumers' age, diet, and work and on climatic conditions. Substances that may have no appreciable effect when normal quantities of water are consumed may become important when greater quantities are ingested;
- increase during pregnancy and breastfeeding; and
- are affected by pathological states, such as diabetes insipidus or diseases accompanied by profuse sweating. Population groups at high risk should be given special consideration from the toxicological and nutritional viewpoints.

3.1 Health significance of individual substances

The Working Group considered that the health significance of substances in drinking-water cannot be based only on adverse effects due to their presence and possible excess, but also on possible adverse effects due to their decreased concentration. Evidence that such a deficiency may impair health is based both on a consideration of its nutritional importance and on its acute and long-term effects on morbidity. Such evidence is derived from laboratory and animal studies and from epidemiological investigations of human populations. Judgements can only be made from evidence that is available at this time. The nature of health impairment is such that the existing pool of evidence will be continually supplemented as results become available from long-term surveillance of the health of populations, and as technical advances in the detection of morbidity occur. Judgements and recommendations will therefore need to be kept under regular review.

Adverse effects of pollutants in water are, on the whole, easier to demonstrate than beneficial effects of normal constituents, and this has tended to dominate the thinking of regulatory agencies and those who set standards. It has long been believed that some constituents of water can be beneficial to health. It has been observed, for instance, that people living in areas where the water supply contains relatively high levels of calcium and magnesium ("hard water") have lower death rates from heart disease than people living in areas with a low content of these minerals. The evidence for such a relationship has been well documented (*12*) and a number of theories have been proposed to account for it. Many assume that there is a substance present that is beneficial to health. However, it is not known whether this presumed "benefit" takes the form of protection against leaching of toxic metals from the plumbing, or arises from the presence of supplemental quantities of an important nutritional component. Another theory suggests that many "soft" waters contain an excess of ions, such as sodium, cadmium, and lead, that may exert a toxic effect.

With the recognition that water may contribute significantly to man's nutritional requirements, it is important to look at its constituents to see whether natural water is a significant nutritional source for some of them. Much of the evidence on the effect of water substances on medium- to long-term morbidity will result from epidemiological investigations, such as the search for the association between the distribution of a disease in a given population and the distribution of suspected chemicals or other factors in the water supply to which this population is exposed. An association by itself, however, does not establish a cause and effect. Often, this has to be ascertained by difficult and painstaking inquiries to determine the consistency of the association (from place to place, from population to population, and over time), its strength (i.e., the size of the risk of disease among those exposed compared with those not exposed), and its biological plausibility in laboratory and animal experiments.

The temporal relationship (i.e., the confidence with which exposure to the suspected cause can be judged to have antedated the onset of the disease) and, eventually, the search for a dose–response relationship (such as exists between fluoride and dental caries, or smoking and lung cancer) are essential prerequisites to the judgement that an association is likely to be a causal one. Modification, or even elimination of the suspected cause in non-causal associations, will have no effect on the frequency of the disease in question. For this reason, it is essential that good evidence of causality, such as that outlined above, be obtained before changes in the mineral content of drinking-water are recommended.

3.2 Identification of potentially important substances

The first task of the Working Group was to draw up a broad list of inorganic substances occurring naturally in drinking-water. This list was as follows: aluminium, antimony, arsenic, barium, beryllium, boron, bromine, cadmium, calcium, carbonates, chromium, cobalt, copper, fluorine, iodine, iron, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, nitrates, phosphates, potassium, selenium, silicon, silver, sodium, strontium, sulfates, thallium, tin, titanium, vanadium, and zinc. A number of additional minor elements and ions, which also occur in water in very small quantities, were not recognized as having any nutritional significance and were not further considered.

From the above list, the Working Group selected nine substances: calcium, chromium, fluorine, lithium, magnesium, potassium, selenium, sodium, and zinc, for discussion in greater detail because of evidence suggesting that these may be important to health in the context of drinking-water. These substances are usually added to demineralized or desalinated water by blending it with natural water in order to adjust the concentrations of calcium, magnesium, and bicarbonate ions. It was felt that such an addition should be acceptable. However, under no circumstances should the resulting blended water product depart from appropriate drinking-water standards.

4. WATER AND CARDIOVASCULAR DISEASE

4.1 Health significance of calcium in drinking-water

Judgements about the importance of calcium to health hinge largely on the interpretation of epidemiological evidence. The volume of the evidence so far collected is now so great that it would not be possible for this report adequately to document the findings, let alone enter into a detailed account of their interpretation. The following discussion is based on what it is hoped is an impartial summary of the results of over 60 epidemiological investigations carried out over a period of 19 years, between 1957 and 1976. There is evidence from many properly designed epidemiological studies undertaken by independent investigators that "hardness" of drinking-water (and particularly the calcium content) in Canada, England and Wales, and the United States of America is inversely associated with cardiovascular mortality, and with adult mortality in general. The fact that some researchers have failed to find this association cannot negate the weight of evidence to the contrary. An association exists, but it is clearly not consistent.

Ever since 1957, when Kobayashi (*13*) observed an apparent association between the geographical distribution of the acidity of water in Japanese rivers and the distribution of apoplexy, then one of the major causes of mortality in Japan, an increasing number of investigators all over the world have worked to confirm and to establish the nature of the relationship between the quality of drinking-water and mortality, particularly from cardiovascular disease. The literature in this field is voluminous and the topic has seen several comprehensive reviews (*4, 12, 14*). Many different hypotheses have been advanced purporting to explain how the lack of calcium might play a role in the pathogenesis of cardiovascular disease. It has been suggested that certain types of cardiac disease may be aggravated by lack of calcium, because it is required for muscle contractions and has been shown to decrease serum lipid levels (*15, 16*). Crawford et al. (*17, 18*) attributed the increased mortality in "soft water" areas to an increased frequency of hypertension in the population, although initially the postulation was made of a protective effect of calcium against lead absorption. Later, a more complex mechanism was suggested, involving the ratio of magnesium and calcium to sodium (*19*). A similar theory was proposed by Joossens (*20*), who suggested that calcium acted as a protection against the harmful effects of sodium and, in 1968, Langford (*21*) proposed that a low calcium intake might aggravate the hypertensive effect of sodium. The relationship between "hardness" and infant mortality has not been studied so widely, and most reports of an inverse association came from well designed, large-scale investigations in England and Wales (*22, 23*). Although again there is some evidence to the contrary, an association between infant mortality and "hardness" of drinking-water has to be conceded. As before, an association exists but is not consistent.

The various dietary and water associations reported between calcium and other vascular and non-vascular diseases do not, in themselves, refute the hypothesis that calcium intake has a specific effect on mortality from ischaemic heart disease, and should not prevent the contemplation of prospective intervention studies. Indeed, the complexity of the situation suggests that prospective intervention may be the only means of settling the matter. As of this moment, however, a review of the existing epidemiological evidence suggests that the full picture may have an indirect explanation and have nothing at all to do with drinking-water. This must inevitably dampen the hope that mortality might be easily influenced either by dietary supplement with calcium or by manipulating the calcium content of the drinking-water supply.

4.2 Health significance of magnesium in drinking-water

At present, the implications of magnesium for public health hinge around two questions – are persons whose magnesium intake is optimal less likely to die of cardiovascular disease than those with lower intake (in testing this hypothesis, it is important to avoid cardiovascular symptomatology as a criterion of optimum magnesium intake), and does magnesium in drinking-water make an important contribution to the optimal level? The answers to both questions will be derived largely from epidemiological analysis; this in turn will depend on the availability of satisfactory health indices of suboptimal magnesium, so that their prevalence can be ascertained in populations with high and low intakes of magnesium from food and drinking-water.

Magnesium makes an interesting contrast with calcium. Evidence for an association of the latter with cardiovascular disease is very strong but the notion that the association is causal lacks support from animal and laboratory experiments, and also lacks biological plausibility. In contrast, the case for magnesium is biologically plausible but supporting epidemiological evidence is still rather weak. Nevertheless, the suggestion that variations in magnesium might be critical for hearts that are already damaged (coronary heart disease) or malfunctioning (arrhythmia) seems a very reasonable one.

The association between magnesium and sudden cardiovascular death (*24*) may be important, but not all investigators have found this association. Furthermore, it is not clear how legitimate it is to subdivide cardiovascular mortality in this way. Just how different, in terms of underlying pathogenesis, are subjects who die immediately from an infarct compared with those who survive, say 48 hours?

Much of the evidence showing an association between the magnesium content of drinking-water and heart disease comes from the same sources as that showing an association between heart disease and calcium (because the calcium and magnesium contents of drinking-water are highly interrelated). Consequently, many of the reservations that apply to the interpretation of evidence relating to calcium apply also to magnesium.

Much stress is currently being placed on evidence relating to the magnesium content of heart and other muscles. Lower levels have been found in male residents of "soft water" areas who die from accidents compared with their counterparts from "hard water" areas (*25–27*). In studies on persons killed in accidents, Anderson (*27*) found the myocardial magnesium level to be 7% lower in 54 persons from water areas low in magnesium than in 29 persons from water areas high in magnesium. However, the statistical significance of this difference is quite small and hence of questionable biological importance.

The magnesium concentration in the myocardium of subjects dying of ischaemic heart disease was found to be 24% lower than that of subjects dying from accidents (*27*). It is difficult to judge whether the apparently lower magnesium content of a damaged heart is a result or a cause of that damage.

In summary, it must be admitted that the evidence in support of a causal relationship between the magnesium content of drinking-water and heart disease is still rather weak. In fact, it is not as substantial as that already available in support of an association between the calcium content of water and heart disease. However, the magnesium hypothesis has an important feature which the calcium one does not possess, namely, a strong biological plausibility which is well substantiated by animal and laboratory experiments.

4.3 Health significance of sodium in drinking-water

As described in section 2, the process of removing calcium, magnesium, and other ions, using ion exchange resins, may result in the addition of sodium to drinking-water. For this reason, the possible effects of an increased intake of sodium on health are important, and are discussed in this section.

Several investigators have reported that in certain primitive populations, who used no salt in their diets, the usual increase of blood pressure with age was not observed (*20, 28–30*). Shaper et al. (*31*) reported rapid rises in the blood pressure of young Samburis, who normally ate food without salt, when they were given 15 g of salt per day during their military service. Sakaki (*32*) reported a progressive decline in the blood pressure of Japanese children whose table salt intake during school meals was reduced.

While the harmful effects of a diet rich in sodium appear to have been confirmed, the effects, if any, of the consumption of drinking-water rich in sodium are less certain. In 1975, Steinbech et al. (*33*) reported the prevalence of hypertension among the villagers of Juilovka, Romania, to be one of the highest in the world. The concentration of sodium in their drinking-water was found to be 26 times higher than in Bucharest and in a neighbouring village in the Gurghu Valley. To date, epidemiological studies have not been able to show normal concentrations of sodium in drinking-water to be a hazard to health. However, concern has been expressed about the possible harmful effects of softened drinking-water containing an excess of sodium ions. A previous WHO working group (*8*) proposed that water softened in this way should not be used for drinking and for the preparation of food because the use of home deionized water not only adds sodium but also alters the proportion of sodium to potassium, sodium to calcium and sodium to magnesium. Such alterations may be important in the pathogenesis of hypertension (*34*).

There is substantial evidence that patients with high blood pressure benefit from a low-sodium diet.[a] It has been reported that, under normal conditions, the sodium content of drinking-water in Europe comprises 2–6% of the daily intake of sodium (*4*). It would seem that most people can eliminate the large quantities of sodium present in the average diet without apparent ill effects. In the United States it was recently suggested that at least 40% of the total population would benefit if total sodium intake were maintained at no more than 2 g per day (*11*).

5. ELEMENTS SELECTED FOR DETAILED DISCUSSION

Having identified the potentially important substances, the Working Group went on to examine for each substance the relation between the recommended daily dietary intake and the likely daily intake from food and from drinking-water.

The decision to recommend the supplementation of drinking-water with a particular substance ultimately depends on:

(*a*) the inherent value of the substance to human health;

(*b*) the amount that would normally be supplied from sources other than drinking-water;

(*c*) local circumstances such as climate, dietary customs, and the availability of drinking-water; and

(*d*) whether drinking-water is a suitable vehicle for the respective substance.

In this section, these issues are examined briefly in respect of calcium, magnesium, sodium, potassium, zinc, chromium, fluorine, silicon, and lithium.

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[a] The implications of this in relation to the sodium content of drinking-water were examined in detail by the WHO Working Group on Sodium, Chlorides and Conductivity of Drinking-water held in The Hague in May 1978 (*35*). This Working Group recommended that patients with hypertension and/or congestive heart failure requiring a daily sodium intake of not more than 500 mg should be supplied with water containing a maximum of 20 mg of sodium per litre. This is because it is not possible to provide food with less than 460 mg of sodium per day and the patient will require 2 litres of drinking-water daily. The Working Group also recommended that if the sodium content of the water supply exceeds 20 mg/l the health authorities should be informed of the actual concentration, and that the sodium content of all drinking-water should be monitored.

Much of the evidence concerning the bodily requirement of individual elements derives from balance studies in which the recommended daily intake is calculated as the amount required to replace the natural body loss. Calculation of the benefit or debit to health that might result from modest changes in the recommended daily intake must, however, await the development of more sophisticated methods of measuring individual health. Also, more needs to be known about the different absorption of substances taken in with water as compared with their ingestion with food.

5.1 Calcium

Calcium is essential for man. It is a main structural skeletal element and is necessary for blood clotting and for the normal functioning of, *inter alia*, nerve tissues. The evidence for the suggestion that water containing a high concentration of calcium could protect against cardiovascular disease is discussed in section 4.1.

Calcium, along with magnesium, accounts for most of the "hardness" of water and, because "hard" water is not as corrosive as "soft" water, it is less likely to leach potentially harmful metals such as lead, copper, and cadmium from water pipes. The calcium content of water plays an important role in this protective effect. The proportion of dietary calcium supplied by drinking-water depends on its concentration in the water. Assuming an intake of 2 litres per day, the proportion of dietary calcium provided by the water of 21 major European cities was found to be 17%, with a range of 2–28% (*6*).

Because of the close relationship between calcium and magnesium ions in water, and because of the importance of achieving a proper balance of added substances, the decision to add calcium to reconstituted water should, ideally, be made in joint consideration with the need to add magnesium. The need to buffer a water against corrosiveness and to achieve, where applicable, a proper balance between calcium and other essential elements and minerals that may also have to be added, should also be taken into account (*8*).

5.2 Magnesium

Magnesium is an important, mainly intracellular, bivalent cation in all body tissues and, *inter alia*, maintains the functional and structural integrity of the myocardium. Experimental magnesium deficiency induces cardiac necrosis (see also previous discussions in section 4.2).

Important sources of magnesium in food are nuts, cereals, seafoods, meats, and vegetables (*36*). The recommended total intake is at present about 300 mg per day (*37*), while average intake in a western diet is reported to be about 250 mg per day (*6*). In Canada, Neri & Johansen (*14*) found that drinking-water from water areas with a high magnesium concentration may contribute up to 20% of the total daily intake, compared with around 1% in water areas with a low magnesium concentration. These researchers calculated that residents in Canada where the "hardness" of the drinking-water is greater than 150 mg/l as $CaCO_3$ receive an average of 50 mg of magnesium more than people living in "soft water" areas, given a similar dietary intake for each. They suggest that this amount may be important under circumstances where requirements might be raised by stressful situations such as an episode of arrythmia.

Zoeteman & Brinkmann (*6*) found that the average concentration of magnesium in European drinking-water supplies, being about 12 mg/l, is relatively low and constitutes about 10% of the daily intake. The same authors report that bottled "mineral water", which is quite widely used in some European countries, might contribute an average of 40% of the total daily intake of magnesium.

When magnesium ions are removed as a result of demineralization, the reconstitution of the resultant water to its original magnesium ion content should be considered. In other situations and where the likelihood has been shown that a local population would benefit from the addition of magnesium to the diet, it will be necessary first to consider the safety and effectiveness of such action. Ideally, cost-benefit comparisons of alternative ways of producing the same degree of benefit (e.g., by adding the mineral to the diet instead) should be undertaken to ensure that the use of water as the vehicle is the most economical one.

5.3 Sodium

Evidence that sodium ions are causally associated with hypertension is examined in section 4.3. Because sodium is the ion that is usually added in the ion-exchange process, it is considered important to discuss its sources and consumption in some detail.

Daily consumption of sodium varies widely. Some primitive societies have survived for generations on diets providing less than 1 g per day. Patients on low-sodium diets can be maintained on a diet containing as little as 0.2 g per day, while intakes of up to 9.6 per day have been reported for working adult males in New York City (*11, 38*). It is difficult to select foods for a nutritionally acceptable diet that contain less than 200 mg per day of sodium. Almost all the excess sodium in a diet, beyond that naturally present in raw foods, has been added in the form of common table salt. The only other significant contribution is from drinking-water. In Europe, the sodium content has been reported to range from 4 to 125 mg/l (*6*). Values up to 1.9 g/l were reported in a survey of 2100 water supplies in the USA, but the median value in this survey was less than 20 mg/l and less than 8% of the supplies contained more than 100 mg/l (*39*). High sodium concentrations are found in surface water in arid areas, and in ground water that comes in contact with salt deposits or infiltrating sea water. Many coastal water supplies have a high salt content from ocean spray. Sodium may be added to water in substantial amounts by water softening, particularly if ion exchange or soda/lime processes are employed.

For most of the people most of the time, the sodium ion concentration in drinking-water does not pose a health hazard, but attention should always be paid to the existence of high-risk groups, such as persons on restricted sodium diets, people living in hot climates whose fluid intake may be very high, and those whose drinking-water has a very high content of natural sodium. While it may not be cost-effective to reduce the sodium content of drinking-water to satisfy the needs of patients with heart diseases who are trying to maintain a low-salt diet, it certainly would be possible to reduce intentional additions of sodium to water.

5.4 Potassium

Potassium is the principal monovalent intracellular cation. It is important as a skeletal element and, particularly, in the functioning of the cardiac muscle. As an essential element, it is usually considered that potassium is adequately supplied by food.

The average daily requirement for potassium is thought to be around 2.5 g. It has been observed that, in Europe, the average concentration of potassium in municipal water supplies ranges from 0.5 to 18 mg/l (*6*). Therefore, under normal circumstances, the intake of potasssium from drinking-water does not appear to make a significant contribution to the daily intake of this substance. Both potassium and sodium do, however, give a taste to drinking-water.

5.5 Zinc

Zinc forms an important part of many enzymatic systems and has been shown to be essential (*37*). Zinc deficiency in man has been shown to be associated with poor growth, delayed sexual development, impaired wound healing, and loss of the senses of taste and smell (*40*).

Foodstuffs of mammalian origin, and also fish and other seafoods, are important sources of zinc (*37*). The composition of the diet, and the availability to the human body of the element, influence the amount of dietary zinc needed to meet the requirement. It has been calculated that 22 mg per day would be needed to meet the adult requirement if the availability of zinc was 10%. Young children and pregnant and lactating women will need more (*37*). Zinc deficiency has been reported both from developing and developed countries (*37*). Present drinking-water standards allow an intake of up to 10 mg per day from drinking-water, which is about half of the adult dietary requirement. Available data, however, suggest that the actual amounts in drinking-water are far lower than this (*1, 2*). It is possible, however, that zinc uptake from drinking-water might be higher than that from food, but further investigations are needed to test this possibility.

As far as is known, there are no naturally occurring sources of drinking-water that contain sufficiently high levels of zinc to suggest a need for the supplementation of demineralized or desalinated water. A problem could arise if it was proposed to demineralize a water with a high natural zinc content. If this were to arise, it would need careful evaluation from the viewpoint of the nutritional status of the population.

5.6 Chromium

Trivalent chromium is an essential element (*37*). It plays a vital role in glucose metabolism through its influence on glucose tolerance. In contrast to trivalent chromium, the hexavalent form is of concern because of its adverse effects. In water, chromium can be present in both the hexavalent and trivalent forms; the former is more soluble than the latter. In the trivalent form, chromium will form insoluble compounds at the natural pH of water, unless protected by complex formation.

Hexavalent chromium, when administered to animals in food or water, is absorbed at approximately 5% of the dose. Food contains chromium also in trivalent form, which is absorbed at only 0.5–1% of the total daily intake. However, under certain conditions this figure may be higher (*37*). Hexavalent chromium is easily reduced by the body to the trivalent state with consequent loss of toxicity and gain in nutritional importance. This conversion is practically irreversible.

Trivalent chromium is the the active ingredient of the glucose tolerance factor (*37*). Studies from several countries have reported an association between low chromium intake and impaired glucose tolerance which has been improved following the administration of chromium salts. In the United States, reports of abnormal glucose tolerance tests in middle age and the association of repeated pregnancies and diabetes with decreased tissue chromium levels, suggest that the population may be in a state of marginal chromium deficiency (*40*). A similar situation may exist in other parts of the world (*37*). A study in Jordan suggests a relationship between chromium deficiency in drinking-water and health (*41*): an impaired glucose tolerance was found among children drinking water containing 0.5 μg/l. Glucose removal rates improved following the administration of 250 μg chromium chloride. In Finland, an association between cardiovascular disease and the chromium content of drinking-water has been reported (*42*).

The dietary requirement of chromium needed to compensate urinary loss is thought to be 22–500 μg, depending on the chemical nature of chromium in individual food (*37, 43*). Food is an important source of chromium but occasionally, because of poor absorption, the dietary contribution may be inadequate. Chromium intakes in the United States vary from 5 to over 100 μg per day (*37*). In Europe, tap water usually contains about 2 μg/l (*6*), and in the United States the range is from "not detected" to 35 μg/l (*11*). In the USSR, surface water with levels of up to 100–200 μg/l have been reported. (*44*).

Because of reports associating low chromium levels in water with human pathology, the nutritional status of the population with respect to chromium should be considered in situations where water treatment could result in a significant decrease in the chromium content of drinking-water. The possible broader significance of drinking-water as a nutritional source of chromium deserves further investigation.

5.7 Fluorine

It is now generally agreed that fluoride in drinking-water, at a concentration of about 1 mg/l, is effective in reducing the incidence of dental caries. WHO has for many years recommended the addition of fluoride to drinking-water for this purpose (*1, 2, 45–47*). Recently, fluoride has been recognized as an essential element for animals (*48*).

Fish and tea are important sources of fluoride (*45*). When fluoride is added to drinking-water, the latter usually becomes the principal source of fluoride in the diet (*46*).

5.8 Silicon

Silicon has been shown to be an essential element for animals (*37*). It is associated with mucopolysaccharide synthesis in the formation of bone and connective tissue and skeletal development (*49*). In the rat, rabbit, pig, and chicken there is an inverse relationship between the silicon content and aging of certain tissues. In the arterial wall, the level of silicon has been found to decrease with the development of atherosclerosis. Silicon deficiency has not been identified in man.

However, on the basis of laboratory and animal studies it has been suggested that a lack of silicon might be involved in the pathogenesis of atherosclerosis (*50*). It was also suggested that the apparently beneficial effects of bran and other high-fibre diets in reducing the risk of ischaemic heart disease might also be due to the high silicon content of these substances (*51*).

Drinking-water provides only a fraction of the daily intake (*6*). At present, no recommendations can be made concerning the optimal concentration of silicon in drinking-water. Further research is encouraged.

5.9 Lithium

There is no evidence that lithium is an essential nutrient for man. It is a substance that is used successfully in the treatment of depression. In one part of the USA an association has been reported between the lithium content of drinking-water and certain parameters of mental health, such as admission rates to mental hospitals (*52*). However, at present, there seems to be no justification for suggesting the addition of lithium to drinking-water.

6. GENERAL CONCLUSIONS AND RECOMMENDATIONS

The conclusions of the Working Group regarding the health significance of certain substances in water are general and apply to all potable water. The recommendations regarding additions refer specifically to water such as is produced by desalination and certain demineralization techniques. The desirability of adding substances to natural water must be evaluated with due regard to local conditions.

6.1 Conclusions

(1) Present knowledge suggests that water could be an important source of certain essential substances, especially magnesium and calcium. This applies particularly in circumstances where the mineral intake from diet alone may be deficient.

(2) Increased corrosion of pipes should be taken into account when proposals for the use of demineralized drinking-water are examined.

(3) The decision to add fluoride to drinking-water to control dental caries is based on epidemiological studies of the effectiveness of this substance. This decision has been reached by observing, over long periods of time, the effect on large numbers of people drinking water containing various levels of fluoride. Any future use of water to convey further beneficial pharmacological effects through the addition of other substances should be preceded by similar evaluations of safety and effectiveness. Ideally, cost-benefit comparisons of alternative ways of producing the same degree of benefit (e.g., the possibility of adding the substance to food instead) should also be undertaken to ensure that the use of water as the vehicle is the most economical one.

6.2 Recommendations

(1) Further studies should be conducted to measure the absorption of trace elements consumed with water and to determine the various factors that influence their absorption and bioavailability. Information is also required on the speciation of trace elements.

(2) Much-needed information should be sought about changes in the mineral and other nutrient content of foods during their preparation and cooking, especially when boiled in waters of different mineral content.

(3) Information is needed on the total mineral intake of local populations, particularly when changes in the mineral content of their drinking-water are contemplated. In judging the safety and effectiveness of individual minerals, particular attention should be paid to the identification of population groups that may be at particular risk, for example, infants, pregnant women, nursing mothers, persons with renal disease, and those who are aged or ailing.

(4) A better understanding is required of the true nature of the association between cardiovascular mortality and the concentration of calcium and magnesium ions (and other components of "hardness") in drinking-water, which may only be achieved by prospective intervention studies involving changes in the concentration of these ions in water. Should the relationship eventually prove to be a causal one, the benefits that could be derived from modifying the mineral content of drinking-water would be so considerable that no opportunity should be missed to establish such studies as soon as possible.

(5) Research should be conducted to ascertain the possible harmful effects to high-risk groups of an excess of sodium artificially introduced into water during the process of demineralization.

(6) The use of demineralized and/or desalinated water in a given area should be approached cautiously, and preferably only after a careful study has been made of the total mineral intake of the local inhabitants.

(7) The effects of water demineralization on health should be measured. Ideally, epidemiological studies should be conducted whenever conditions are appropriate, and the World Health Organization is requested to take a special interest in promoting and assisting such investigations.

(8) A critical review should be undertaken of all original epidemiological studies conducted so far on the relationship between the mineral composition of drinking-water and health, and the World Health Organization is requested to promote such a review using the best accepted criteria for the evaluation of scientific evidence.

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