Health Aspects of Calcium and Magnesium in Drinking Water

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NSF International and the International Life Sciences Institute assembled a diverse group of nutrition, medical, epidemiological and scientific experts in Baltimore, MD on April 24-26 for an International Symposium on Health Aspects of Calcium and Magnesium in Drinking Water. It was intended to examine in detail potential roles of magnesium and calcium in drinking water and their possible contributions to beneficial health consequences. The overarching issue addressed was whether consumption of drinking water containing a relatively small contribution to total daily dietary intake would provide positive health benefits particularly in people at higher risk because of deficient diets or other factors.

The meeting evolved from the process for developing guidelines in 2006 for health and environmental aspects of water desalination that was initiated by WHO's Eastern Mediterranean Regional Office in Cairo, Egypt. The information is also intended to contribute to the data bases for the *2008 WHO Guidelines for Drinking Water Quality* 4th edition, in respect to nutrients in drinking water and water hardness as they impact drinking water quality and health. The proximate lead in to the symposium was to expand upon the issues and recommendations of the report *Nutrients in Drinking Water* published by WHO in 2005.

The symposium opened with a list of questions and issues that were the challenges that introduced the subjects of discussion. Many of these were ultimately addressed in depth.

A fundamental question for this symposium: Could a small increment of daily mineral intake make a difference in population health status?

Health issues

- Does mechanistic biomedical evidence indicate benefits from incremental increases of daily mineral intake in deficient populations?
- Do controlled dietary and clinical studies support benefits?
- Do epidemiology studies provide support for benefits hypothesis?
- What is the strength of evidence for hard water/CVD hypothesis? (See below)
- Who are the high risk populations?
- If there are benefits, what is their approximate value?
- Can adverse effects be explained by corrosive water metals?
- Is there scientific support for other health benefits in respect to osteoporosis, hypertension, metabolic syndrome, etc.?
- Are there negative health impacts from increased consumption of calcium and magnesium?
- Are more definitive epidemiological, nutritional and biochemical studies possible?

Daily consumption

- Are the recommended daily allowances (RDA) for magnesium and calcium appropriate?
- What are worldwide dietary contributions of Mg/Ca and incremental water contributions?
- Uptake efficiency of food versus water sources?
- What is the optimal intake balance of calcium, magnesium and other ions?
- If there is a desirable water contribution, what should it be?
- Would it vary by region or lifestyle?
- How does the mineral composition of cooking water affect the mineral composition of cooked food?

Technological and economic issues

- Is 'soft' water different from 'softened' water?
- What is the technology and cost of mineralizing water?
- If it is desirable to consume 'hard' water, how would this affect municipal corrosion control, central softening or remineralization of desalinated water?
- How would it affect bottled water and beverages?
- How would it affect home water treatment?

The nutritional essentiality and benefits from sufficient dietary intakes of calcium and magnesium are well established but quantitatively imprecise. Most of the epidemiology studies conducted since the mid-1950s support the hypothesis that extra magnesium and/or calcium in drinking water can contribute to reduced cardiovascular disease (CVD) and other health benefits in populations. This is the so-called 'hard water cardiovascular disease benefits hypothesis'.

Calcium plays important roles in bone structure, muscle contraction, nerve impulses transmission, blood clotting and cell signaling; 99 percent of calcium is in bone and teeth and the remainder is in soft tissue. Low intake is associated with osteoporosis, rickets and hypertension. Consumption in drinking water also reduces the risk of kidney stones, probably by complexing with oxalates in the diet that compose some types of kidney stones. Magnesium is an essential cofactor for more than 350 enzyme systems and it is involved in energy metabolism,

nucleic acid synthesis, cellular balance, cardiovascular health and hormonal functions. Low magnesium intake has been associated with osteoporosis, increased calcium balance, insulin resistance, metabolic syndrome, increased oxidant stress and increased risk of cardiovascular disease. The adult human body contains about 24 grams of magnesium, about half in bone and the remainder in soft tissue; only about 0.3 percent is in serum. There is no simple, rapid and accurate test to assess a person's magnesium status.

Requirements for intake of dietary minerals

The diet is by far the principal source of minerals and nutrients. Diets vary widely by world region, age, economic level and individual preferences and unfortunately the trends seem to be moving toward lower mineral intakes regardless of affluence. There are circumstances where water could be a significant contributor to total daily intake of minerals.

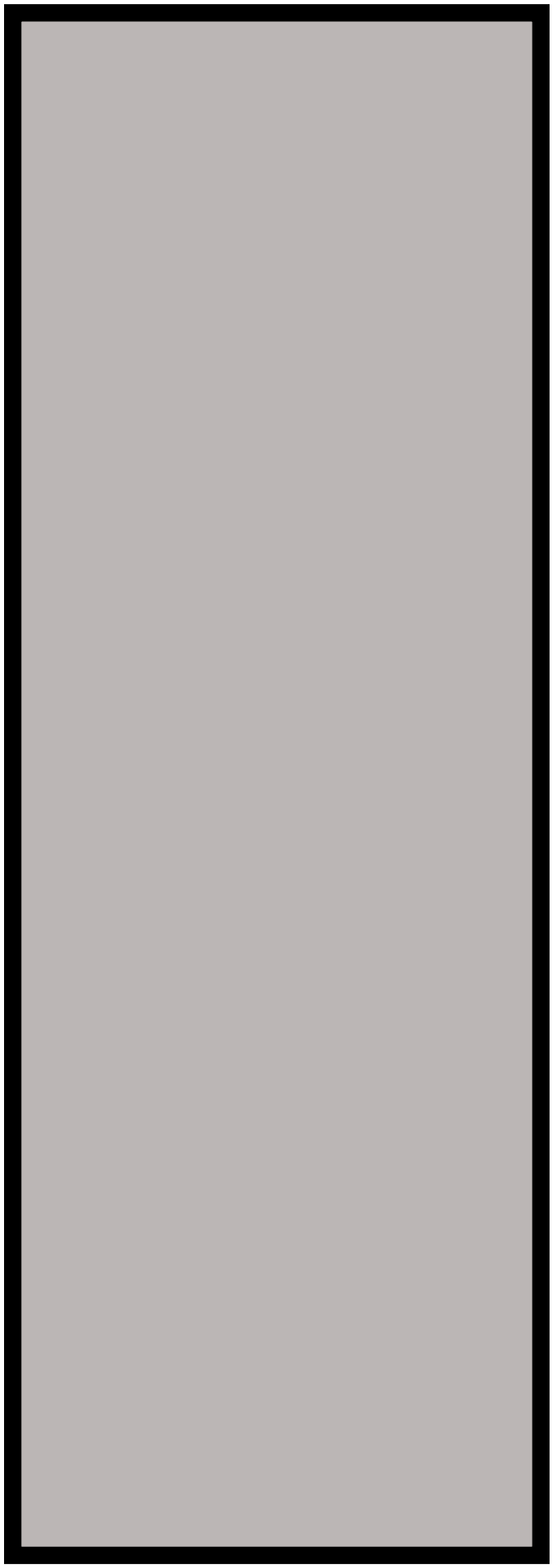
Drs. Stephanie Atkinson and Rebecca Costello noted that RDAs and recommended nutrient intakes (RNI) are approximate indicators of daily dietary needs to maintain good health. They vary by age, gender and body mass and the recommended values differ by country.

Although magnesium and calcium are recognized as essential nutrients, the quantitative needs for each have been difficult to precisely establish. In 2001 an expert consultation for the Food and Agricultural Organization/WHO set recommended intake (RNIs) for magnesium at 260 and 220 mg/day respectively for men and women 19-65 years old. The RNIs for calcium were set at 1,000 mg/day for men age 19-65 and women 19-50 years, and 1,300 mg/day for women 51-65 years. In 1997, the Food and Nutrition Board (FNB) of the National Academy of Sciences set RDAs for magnesium at 420-320 mg/day for men and women aged 31-70 years. It did not establish RDAs for calcium, but rather only adequate intakes (AIs) of 1,000 mg/day and 1,200 mg/day for adults aged 19-50 and 51-70 years.

Direct clinical signs of magnesium deficiency are not common, but have been reported when low magnesium intake is coupled with excessive losses due to prolonged diarrhea. Magnesium deficiency can be induced by some hypertension treatments. Dietary recommendations have been derived from a small number of balance studies in non-deficient individuals and they do not consider more chronic considerations, and have been challenged.

Daily intakes versus needs

Dr. Choon Nam Ong (National University of Singapore) and other presenters noted that calcium and magnesium intakes for many people do not meet needs, even considering national differences in RDAs and RNIs. In developing countries, calcium intakes are less than needed by most children and almost all adults; mean intakes in developed countries are less than needed by most adults. Extreme calcium and magnesium undernutrition in children leads to rickets and the onset of osteoporosis in adults, especially females. Intake levels of calcium are lowest in developing nations in the Middle East, Latin America and especially in parts of Asia East. In the U.S., more than 75 percent of men and 90 percent of women may consume less than the AI of calcium. Magnesium and calcium deficiencies may increase as populations age, due to poorer diets, less consumption and poorer uptake efficiencies. Regardless of the standard of the magnesium intake reference, large numbers of people do not meet their needs. In the U.S. more than 75 percent of men and 50 percent of women consume less than the RDA.



Dr. Ong and Dr. Joyce Donohue of U.S. EPA noted that the mineral content of drinking waters varies widely throughout the world as well as within countries. Some examples ranged from about two mg/L to 89 mg/L for calcium, and from zero to 48 mg/L for magnesium. Bottled waters ranged from nil up to several hundred mg/L in some mineral waters.

Dr. Ann Grandjean focused on variables and benefits associated with total water consumption as well on the contributions of calcium and magnesium to the RDA or ADI that can be achieved from some drinking waters.

Intake versus uptake

Several of the nutrition experts including Dr. Connie Weaver (Purdue University), presented information that indicated that the availability of minerals after ingestion varies by the type of food source. Most magnesium in food is complexed with other dietary components. The presence of phytates and oxalates found in many vegetables inhibits the uptake of numerous minerals. Bioavailabilities of calcium and magnesium may range from less than 25 percent in vegetable products to greater than 50 percent in milk and water, but even these reported values differ in the studies depending upon the measurement methodology.

Epidemiology

Dr. Rebecca Calderon (U.S. EPA) and Dr. Paul Hunter (University of East Anglia) reported that perhaps hundreds of studies of varying quality have been performed over the last 50 years relating drinking water calcium or magnesium or water hardness and health end points. In particular, indications of CVD benefits, but also osteoporosis, bone fracture and other affects, have been noted. Most of these studies were of the ecological type and suffer from similar methodological weaknesses. Dr. Frantisek Kozisek from the Czech Republic reviewed the literature from Eastern Europe and Russia and concluded that those studies were consistent with others that suggested beneficial effects. Most of the ecological studies reported inverse associations between CVD mortality and water hardness, specifically calcium or magnesium levels. However, results were not always consistent. A report on the *British Heart Study* by Dr. Richard Morris (University College London) did not find benefits from hard water consumption in a group of soft and hard water communities when CVD confounders like blood pressure, smoking, physical activity and socioeconomic status were removed.

The strongest epidemiological argument in favor of a water magnesium effect was provided by Dr. Paul Hunter based upon analytical studies in Taiwan (by Dr. Chun-Yuh Yang, who also spoke at the meeting) and Sweden (Rubenowitz) that reported a reduction of CVD mortality risk with increasing magnesium levels in drinking water, but there were no strong associations with water hardness or calcium levels. The magnesium benefits seemed to level off at about 10 mg/L in the five analytical studies that were reviewed. There are other larger CVD risk factors, however. There was a consistent finding of reduced rates of CVD associated with consumption of drinking water with increasing levels of magnesium. Even a small percentage benefit, if real, would have a very significant impact on death rates and public health.

Biological plausibility of CVD benefits from magnesium

Presentations by Dr. William Weglicki (George Washington University Medical School cardiologist) and Dr. Rhian Touyz (hypertension chair at the

Ottawa Health Research Institute) and others provided information on mechanisms at the cellular and vascular levels that demonstrate important roles for magnesium in heart function and vascular health. Intravenous magnesium infusion is commonly used as an early treatment in many hospitalized CVD patients who present with low magnesium serum levels and supplements are frequently prescribed posttreatment after discharge. Rodent studies using dietary restrictions of magnesium result in acute inflammatory responses associated with increased free radical formation, pro-inflammatory cytokines and neuropeptides. Neurocardiac pathways implicate sensory C fibers in the perivascular distribution of inflammation and the appearance of myocarditis in the animals. Antioxidant drugs and nutrients provide protection against oxidant damage. Dr. Earl Ford of the Centers for Disease Control and Prevention in Atlanta, Ga., reported that decreased metabolic syndrome correlated well with increased dietary magnesium.

Small changes in magnesium levels have significant effects on vascular tone, contractility, reactivity and growth. Thus magnesium may be important in physiological regulation of blood pressure and perturbations in vascular homeostasis could play a role in processes underlying blood pressure elevation.

Drs. Gerald Combs and Forrest Nielsen of the USDA Human Nutrition Laboratory in Grand Forks, N.D. reported that carefully controlled human dietary consumption studies involving magnesium showed that within a few months, a managed low magnesium diet caused individual heart arrythmias (arterial flutter and fibrillation and increased ventricular premature discharges) in postmenopausal women and decreased energy efficiency characterized by increased peak oxygen and peak heart rates during exercise tests, biochemical changes, calcium retention, increased phosphorus and decreased potassium urinary excretion. The adverse effects were reversed when magnesium was increased to normal levels in the diets.

Consumption of low TDS water

Dr. Shailendra Vajpeyee (Surat, Gujarat, India) and John Fawell (U.K.) attempted to address the question of whether consumption of very low total dissolved solids (TDS) water could *per se* have adverse health effects over the long term. Some animal studies have indicated adverse consequences and some human reports from eastern Europe are also suggestive. It was concluded that more controlled studies were needed, with defined fixed diets and careful biochemical measurements, to resolve the question.

Water treatment and bottled water

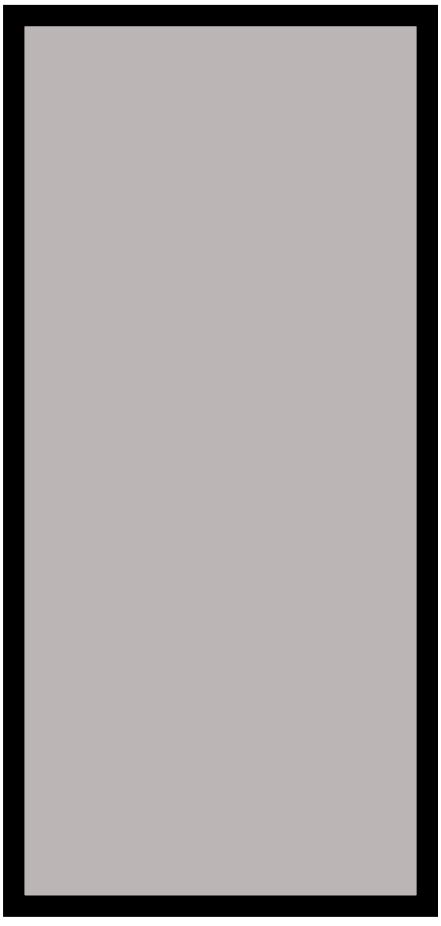
Several presenters including Drs. Margreet Mons and Jan Peter van der Hoek of The Netherlands reported on the benefits of softening on water quality and the ability to control corrosion in water systems in the Netherlands. Joe Harrison of WQA addressed the distinct differences between naturally soft and softened waters. Josep Molas Pages of the Coca-Cola Company discussed technical and cost elements of the addition of minerals to bottled water and beverages. He noted that addition is technically feasible at low cost and that calcium-fortified orange juice is widely available and a good medium for mineral fortification. On the other hand, consumer taste preferences are an important limiting factor, especially for water.

Desalinated and many other waters must be remineralized to control corrosivity to pipes. Dr. Maarten Nederlof described options for remineralization of nanofiltration and reverse osmosis per-

meates. Calcite/marble filtration or lime addition are the most common approaches. Costs were on the order of 2.5 cents per cubic meter (1,000 liters) per 10 milligrams of magnesium. In the Netherlands a minimum hardness of 1.0 mmole/L is prescribed. Dr. Regu Regunathan discussed perspectives in the point of use and point of entry water treatment industries and positive opportunities and negative aspects of possible recommendations to maintain or increase minerals in drinking water. He noted that several companies were already providing options for adding minerals to softened or distilled water.

My conclusions

The symposium presented a wide range of nutrition, health, epidemiological, medical, clinical, dietary and technological expert perspectives regarding the value of providing drinking water with a small amount of magnesium. It was not designed to reach a conclusion but to provide a diverse body of scientific information for use by technical decision makers and policy makers. It is clear that large portions of the world's population are deficient in daily magnesium and calcium intake relative to recommended values and the deficiencies may increase with age.



My reading was that the epidemiological case for benefits was consistent with benefits from magnesium but also somewhat mixed, which is the nature of ecological studies that have not taken into consideration sufficient consumption variables and confounders. However, the results from the analytical studies with the best designs (from Taiwan and Sweden) were consistent and quite strong and led to values of about 10 mg/L magnesium as beneficial for CVD mortality in the study populations. The controlled human dietary studies in postmenopausal women were clearly positive and indicated arrythmias that were induced in a few weeks on low magnesium intake were reversed when the dietary magnesium levels were restored to more typical levels. Mechanistic biochemical and medical studies gave strong support for the beneficial value of adequate intakes of magnesium and calcium in providing protection from oxidative stress and for vascular health. Adverse effects are not indicated from increased calcium and magnesium intakes beyond typical diets with a large margin of safety except for individuals with significant renal pathology.

Water manufactured by desalination or reuse should be stabilized/remineralized prior to entry into the water distribution system to increase alkalinity and to control its corrosivity toward piping. Water treatment processes can readily add minerals at low cost and softening processes in the central treatment plant and the home can be adjusted to obtain desirable levels of minerals in the drinking water. Remineralization methods that include addition of calcium and magnesium are more desirable than other techniques because they also contribute nutrient minerals to water that will be drunk or used in food preparation. One approach used in some desalination processes including seawater is to blend some of the source water with the finished water. This can add back significant amounts of minerals at essentially no cost.

The larger public health question that should be addressed is: what are the most desirable and effective methods to assure that the world public has sufficient magnesium and calcium in their total daily diets?

There are several non-exclusive opportunities to improve the total dietary intake of nutrient minerals. The choice is a matter of success potential, cost effectiveness, widespread impact across the population, public health policy and law. The preferable approach is probably via improved diet; e.g., by greater consumption of vegetables and dairy products. However, diets are consumer choices that cannot be imposed and trends for dietary consumption have been in the opposite direction. Many developed as well as developing countries and societies have chronically deficient diets. The addition of nutrients to foods is commonly practiced and includes fortified milk and juices and vitamin and mineral additives to breads and cereals.

Many nations/communities permit or require addition of fluoride to drinking water. There are examples of mandated addition of iodide to drinking water/bottled water (parts of Russia), and chelated iron to water (parts of Brazil). Some bottled water and beverages can be fortified to provide supplemental nutrients. This is a particularly efficient approach since bottled water is growing in popularity in many world regions, all of the water is consumed and the incremental unit costs are negligible.

Dietary mineral supplements are available over the counter at low cost. Their use would also be a matter of consumer choice.

In general, a combination of these approaches, tailored to each society, would probably achieve the most success. The medical and public health communities as well as the general public need to be educated about nutritional needs and benefits and to know the composition of foods, water and beverages that they consume so that they can make informed choices; but care must be exercised to protect against over nutrition for some individuals and in some circumstances.

About the author

♦ *Dr. Joseph Cotruvo is President of Joseph Cotruvo & Associates, Environmental and Public Health Consultants, Washington, D.C. USA. His Ph.D. is in physical organic chemistry. He was Director of the Drinking Water Standards Division and the Toxic Substances Risk Assessment Division during his almost 25 years of service with U.S. EPA. He currently works extensively on drinking water quality, desalination, water reuse and water delivery systems and health science issues. Cotruvo also serves on several World Health Organization panels and on research panels with the National Water Research Institute and the WaterReuse Foundation. He is a member of the Agua Latinoamerica Comité Consultivo de Asesores Technicos and Vice President of AIDIS USA. He may be contacted by phone/fax: (202) 362-3076 or email: joseph.cotruvo@verizon.net.*