SPECIAL ARTICLES

Variation in the Mineral Content of Commercially Available Bottled Waters: Implications for Health and Disease

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PURPOSE: Although the annual consumption of bottled water in North America is 12.7 gallons per capita, little is known about the potential health effects of these waters. We reviewed the amounts of major minerals found in commercially available bottled waters, the recommended daily allowances for these minerals, and their beneficial and harmful effects.

METHODS: We obtained the mineral content of various commercially available bottled waters in North America and Europe from *The Pocket Guide to Bottled Water*. We then conducted a Medline search to identify articles examining the beneficial and harmful effects of magnesium, sodium, and calcium.

RESULTS: Great variation exists in the mineral content of commercially available bottled waters. Among the bottled waters that we reviewed, the magnesium content ranges from 0 to 126 mg per liter, the sodium content ranges from 0 to 1,200 mg per liter, and the calcium content ranges from 0 to 546 mg per liter. Epidemiologic and clinical studies suggest that magnesium may reduce the frequency of sudden death, that sodium contributes to the occurrence of hypertension, and that calcium may help prevent osteoporosis.

CONCLUSION: The ideal bottled water should be rich in magnesium and calcium and have a low sodium content. Because there is great variation in the mineral content of commercially available bottled waters, the actual mineral content of bottled water should be considered when selecting one for consumption. **Am J Med. 1998;105:125–130.** ©1998 by Excerpta Medica, Inc.

Over the past decade, the popularity of bottled water has increased substantially in North America (1). Sales of bottled waters have increased by 400%, and 1 in 5 households now use bottled drinking water (2). Annual per capita consumption has risen from less than 8 gallons in 1991 (1,2) to 12.7 gallons in 1997 (Arthur von Wiesenberger, personal communication). Since bottled water is beginning to assume a prominent place in the North American diet, its health effects require evaluation. In this paper, we focus on the three most common minerals—magnesium, sodium, and calcium—in commercially available bottled waters. Many studies suggest that magnesium may protect against sudden death (3–8), that sodium contributes to the occurrence of hypertension (9–18), and that calcium may help reduce the incidence of osteoporosis (19,20). Because wide variations exist in the mineral content of commercially available bottled waters, understanding the potential beneficial and harmful effects of these minerals will provide valuable information about which bottled water to choose.

METHODS

We obtained the mineral content of various commercially available bottled waters in North America and Europe from *The Pocket Guide to Bottled Water* (21). This book describes the mineral content of commercially available bottled waters, most of which were verified via different Internet sites. We then reviewed the English language medical literature for the years 1990 to 1996 to identify articles examining the health benefits of the major minerals found in these waters, using the key terms of magnesium, sodium, calcium, heart, and bottled water. We also conducted an Internet search using the same key terms. Pertinent articles identified in the Medline and Internet searches were reviewed, and selected references from these articles were also examined.

Variation in Mineral Content of Bottled Waters

Substantial variations in the concentrations of the three major minerals were observed in the bottled waters studied. Magnesium content ranges from 0 to 126 mg per liter, sodium content ranges from 0 to 1,200 mg per liter,

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Supported by a research scholarship (MJE) from the Heart and Stroke Foundation of Canada.

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Manuscript submitted August 4, 1997 and accepted in revised form April 6, 1998.

0002-9343/98/$19.00
PII S0002-9343(98)00189-2

Table 1. Mineral Content of Commercially Available North American Bottled Waters

	Mineral Content in mg/L		
	Magnesium (350 mg)*	Sodium (2400 mg)†	Calcium (800 mg)*
A Santé	1	160	4
Adobe Springs	96	5	3
Arrowhead	5	3	20
Black Mountain	1	8	25
Calistoga	2	164	8
Canadian Glacier‡	0	1	1
Canadian Spring‡	3	2	11
Carolina Mountain	0	5	6
Clairval‡	7	13	20
Crystal Geyser Alpine Spring	6	13	27
Crystal Geyser Sparkling Mineral	1	30	2
Deer Park	1	1	1
Great Bear	1	3	1
La Croix	22	4	37
Lithia Springs	7	680	120
Mendocino	120	260	240
Monclair‡	12	475	8
Mountain Valley Spring	7	1	160
Naya‡	20	6	38
Ozarka	1	5	18
Poland Spring	1	4	1
Pure Hawaiian	0	0	0
Sierra	0	0	0
Sparkletts	5	15	5
Talawanda Spring	0	3	0
Talking Rain	2	0	2
Vichy Springs	48	1,095	157
Zephyrhills	7	4	52

Mineral content is based on *The Pocket Guide to Bottled Water* (21).

* Minimum daily intake recommended by the Committee on Dietary Allowances (55). To convert from mg/L to meq/L, multiply by 0.082 for magnesium, 0.044 for sodium, and 0.05 for calcium (56).

† Maximum daily intake recommended by the National Research Council (55).

‡ Canadian.

and calcium content ranges from 0 to 546 mg per liter. In general, waters bottled in North America (Table 1) had low mineral contents, while waters bottled in Europe (Table 2) had high mineral contents. For the North American bottled waters, the median concentration for magnesium was 2.5 mg per liter, for sodium it was 5 mg per liter, and for calcium it was 8 mg per liter. For the European bottled waters, the median concentration for magnesium was 23.5 mg per liter, for sodium it was 20 mg per liter, and for calcium it was 115 mg per liter.

When comparing the mineral contents of bottled water, it is important to know the variation of the mineral content from bottle to bottle. According to the technical director of the International Bottled Water Association, variation of mineral content is less than 5% (Arthur von Wiesenberger, personal communication) mainly due to different testing methods. We did not find any published studies that looked at the mineral content of tap water. However, from the limited information we were able to obtain, it appears that tap water in major North American cities contains relatively low levels of magnesium (<48 mg per liter), sodium (<195 mg per liter), and calcium (<85 mg per liter).

Recommended Dietary Allowances

The Recommended Dietary Allowances (RDA) are estimates of the required amount of nutrients needed for the average individual as determined by a scientific committee selected by the National Academy of Sciences and approved by the National Research Council (22). The committee on Dietary Allowances has proposed a minimum daily required intake for both magnesium (350 mg) and calcium (800 mg). For sodium, a maximum intake of 2,400 mg has been recommended.

Magnesium Physiology and Nutrition

Magnesium is the second most common intracellular cation, after potassium (23). It is responsible for several biologic processes that influence membrane and mito-

Table 2. Mineral Content of Commercially Available European Bottled Waters

	Mineral Content in mg/L		
	Magnesium (350 mg)*	Sodium (2400 mg)†	Calcium (800 mg)*
Apollinaris	126	572	95
Contrexéville	45	0	546
Evian	24	5	78
Ferrarelle	19	52	459
Gerolsteiner	112	134	368
Henniez	18	6	0
Levissima	1	2	17
Loka	4	139	4
Passugger	26	43	234
Pedras Salgadas	2	500	130
Perrier	5	15	143
Radenska	93	551	201
Ramlosa	0	0	0
San Pellegrino	57	47	204
Spa	1	3	4
Tipperary	23	25	37
Valser	55	10	436
Vichi Celestins	60	1,200	100
Vittel	38	4	181
Volvic	7	10	10

Mineral content is based on *The Pocket Guide to Bottled Water* (21).

* Minimum daily intake recommended by the Committee on Dietary Allowances (55). To convert from mg/L to meq/L, multiply by 0.082 for magnesium, 0.044 for sodium, and 0.05 for calcium (56).

† Maximum daily intake recommended by the National Research Council (55).

chondrial integrity, such as the proper functioning of adenosine triphosphatase (sodium-potassium ATPase) (3). In addition, magnesium is also essential for the synthesis and stability of nuclear DNA and for the mineralization of bone (24).

It is estimated that the body requires 220 to 410 mg of magnesium daily (3). The average magnesium intake in the United States ranges from 240 to 365 mg per day (23,25,26), but magnesium intake in several regions of the United States is often inadequate to meet daily requirements (26,27). Nuts, green leafy vegetables, cereals, and seafood have a high magnesium content (3). However, if these foods are boiled in soft water, they will tend to release their magnesium, whereas boiling these foods in hard water prevents loss of magnesium (26). Furthermore, due to differences in absorption, magnesium bioavailability may be greater from water than from food sources (3).

In some geographic areas, the magnesium content of drinking water may provide 20% to 40% of a person's daily magnesium requirement (28). For example, a liter of water with a magnesium content of 100 mg per liter contains 29% of the daily magnesium requirement of 350 mg per day (22). However, a liter of water that is low in magnesium (eg, <10 mg per liter) provides less than 3% of the daily requirement.

Magnesium Deficiency and Sudden Death

Cardiovascular disease rates may be inversely related to water hardness (3,5–8). Rates of cardiovascular mortality and sudden death are 10% to 30% greater in soft water areas (low in magnesium or calcium) than in hard water areas (high in magnesium or calcium) (3). Magnesium intake may have a cardioprotective effect, perhaps correlated with a reduction in rates of sudden death (29,30).

Animal and clinical studies also support an inverse relationship between magnesium intake and sudden death, for which two potential mechanisms have been proposed: arrhythmogenesis and coronary artery vasospasm. According to the arrhythmogenesis theory, magnesium deficiency promotes cardiac irritability, perhaps by causing malfunction of sodium-potassium ATPase (31). Clinical reports also suggest that magnesium deficiency lowers the threshold for digitalis-toxic arrhythmias, and that in certain cases, intravenous magnesium can reverse cardiac rhythm disturbances (3). A second theory proposes that magnesium deficiency promotes coronary artery vasospasm, leading to myocardial ischemia and sudden death. Several animal studies have provided evidence supporting this theory (32–34). In these studies, magnesium-deficient solutions induced vasospasm in aortic strips from rats that resolved with the addition of magnesium (32). Other studies have related magnesium deficiency with pathologic changes in the heart that have been linked to chronic myocardial ischemia (35,36).

Sodium Physiology and Nutrition

Sodium, the most abundant extracellular cation, maintains the osmolarity of extracellular fluid and is the main determinant of extracellular fluid volume (24). Acid-base balance and the transmission of nerve impulses are other important functions performed by sodium (37).

A great number of sodium-rich foods are found in the North American diet, including cheese, bread, cereals, and processed and preserved foods (22,24). For example, 1 ounce of cocktail peanuts contains 121 mg of sodium, a ¾ cup serving of cornflakes contains 211 mg of sodium, and a ½ cup serving of instant chocolate pudding contains 440 mg of sodium (22). Because the estimated minimum daily requirement of sodium for an adult (500 mg per day) (22) is easily achieved in most North American diets, no minimum recommended intake of sodium has been set by the Food and Drug Administration. However, the National Research Council has recommended limiting daily sodium intake to less than 2,400 mg (6 grams of salt), and the American Heart Association recommends limiting sodium intake to 3,000 mg per day (22). In contrast, the average sodium intake in North America has been estimated to be 4,000 to 6,000 mg per day (22). Drinking 1 liter of bottled water with a high sodium content (such as Vichy Springs—1,095 mg of sodium per liter) may provide an individual with 45% of the maximum recommended daily sodium intake. By choosing a bottled water low in sodium, such as Poland Spring (4 mg sodium per liter), sodium intake can be minimized.

Sodium Intake and Hypertension

In North America, hypertension affects 20% of the entire population (38). A persistent diastolic blood pressure increase of 5 mm Hg is associated with a 34% increase in the risk of stroke and a 21% increase in the risk of coronary heart disease (39). High salt intake is believed to be an important contributor to the occurrence of hypertension (38). Sodium is the major cation found in most salts, and it is believed to be the ion responsible for the hypertensive effects of a high salt intake.

For many non-Western societies, hypertension is rare and the average blood pressure is low and does not increase with age (15,40,41). For example, the Yanomamo Indians of northern Brazil and southern Venezuela, who have low sodium diets, have blood pressures averaging less than 110/70 mm Hg (42). Genetically related populations with dissimilar diets were compared with these groups, and the population with the higher sodium intake had higher average blood pressures (16). In addition, when groups of people with low sodium diets had increased sodium intake, an increase in blood pressure was also observed (24). A highly significant relationship has been observed between average blood pressure and sodium intake in many populations around the world (Figure 1) (43). However, studies in industrialized popula-

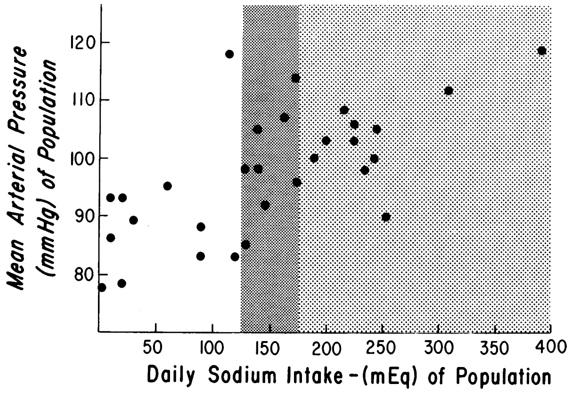

Figure 1. Mean arterial blood pressure and dietary sodium intake in 30 populations. The **shaded area** from 125 to 175 mEq of sodium per day (the average intake in an American diet) represents the range in which the mean arterial pressure shows no relationship with sodium intake. From McCarron DA et al (43), reproduced with permission.

tions have not found as close a relationship between sodium intake and hypertension (24), perhaps due to the sigmoidal shape of the curve linking salt intake and hypertension (Figure 2). Further rises in blood pressure are relatively minor after a sodium intake of 2,300 mg per day is achieved (44). The average daily sodium intake in Western societies ranges from 2,300 to 7,000 mg, making the relationship between salt intake and hypertension barely evident (24).

Animal studies have also demonstrated that hypertension can be induced or made more severe by increasing sodium intake, and that hypertension can often be prevented by sodium restriction (12,45–47). For example, experimental animals have been made hypertensive by

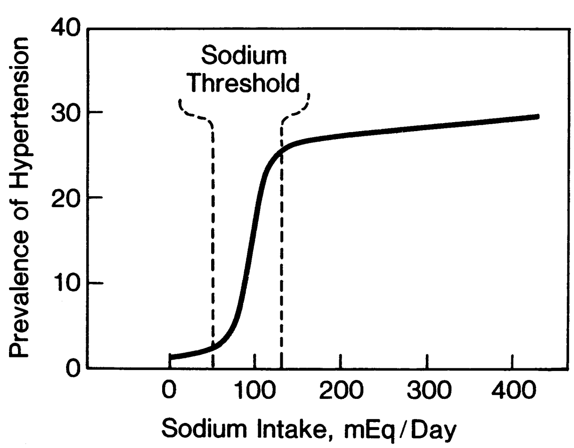

Figure 2. Sigmoidal curve representing the probable association between sodium intake and the prevalence of hypertension in large populations. From Kaplan NM (44), reproduced with permission.

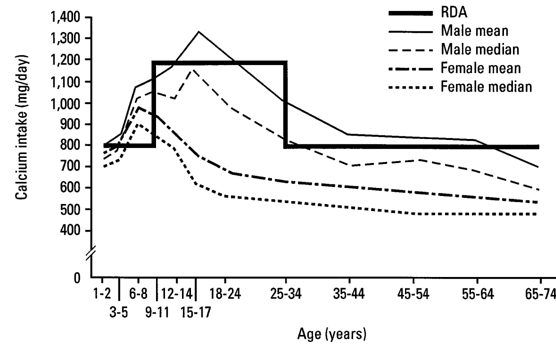

Figure 3. Calcium levels versus age for men and women in North America. Courtesy of the National Dairy Council. From Whitney EN et al (22), reproduced with permission.

providing them with 1% and 2% saline solutions for drinking water.

Since the seminal study of Kempner et al (48), many investigators have looked at the effects of salt restriction on blood pressure. Cutler et al (49) performed a meta-analysis of these studies and concluded that a reduction of sodium intake to 1,500 to 1,700 mg per day would result in a decrease of 4 to 6 mm Hg in systolic blood and of 2.3 mm Hg in diastolic blood pressure.

Calcium Physiology and Nutrition

Calcium is the most abundant mineral in the body. The bone contains 99% of the body's calcium, while the blood contains only 1% (24). Calcium helps regulate muscle contraction, helps transmit nerve impulses, and regulates ion exchange across cell membranes. It also helps in the secretion of hormones, digestive enzymes, and neurotransmitters (22,24).

Naturally bioavailable calcium is found almost exclusively in milk, milk products, and water. Because the intake of these products is often low, many foods are now fortified with calcium (eg, orange juice). Calcium can also be found in small amounts in several vegetables, many of which contain binders that impede its absorption (22). Among the few vegetables that contain bioavailable calcium are mustard greens, parsley, broccoli, and kale (22).

The recommended dietary allowance for calcium after 24 years of age for both men and women is 800 mg per day (22); the need is higher during childhood, fetal growth, pregnancy, and lactation. However, nutritional surveys indicate that the calcium intake of more than 50% of the North American population is well below the National Research Council's daily recommendation (Figure 3) (22). This imbalance is especially true for adult women, who have an average consumption of 600 mg of calcium per day (22). Thus, the average North American woman needs an extra 200 mg of calcium per day.

The bioavailability of calcium in water is believed to be at least as high as that of milk and milk products (50,51).

Therefore, selecting a bottled water with a high calcium content may help achieve the daily recommended intake. For example, a liter of Contrexeville bottled water contains 546 mg of calcium, about 68% of the recommended daily allowance.

On the other hand, ingesting too much calcium may lead to the formation of kidney stones. As a low calcium diet (400 to 600 mg daily) has been suggested as a preventive treatment for patients with type 2 idiopathic hypercalciuria (52), people with a history of kidney stone formation might benefit from avoiding bottled waters with a high calcium content.

Calcium Deficiency and Osteoporosis

Over 24 million people in North America are at risk for osteoporosis (53), which may be prevented by increasing peak bone mass (22,24). A population-based study observed a reduced rate of age-related bone loss and hip fractures in a community receiving a high calcium diet in comparison with an adjacent community on a low calcium diet (54). In another study, an inverse relationship between calcium intake and osteoporotic vertebral fracture frequency was seen. For example, Finnish women, with the highest daily calcium intakes (1,300 mg per day), had the lowest frequency of fractures. In comparison, Japanese women, with the lowest daily calcium intake (400 mg per day), had the greatest frequency of fractures (20,54).

When animals are fed calcium deficient diets, their bones become susceptible to fractures (54). A low calcium diet resulted in a loss of trabecular bone in adult cats, a generalized thinning of bone in dogs, and a decreased bone mass in young growing rats (20). The bones of experimental animals become weak, soft, and lack density when their diets lack calcium, phosphorus, and vitamin D.

Other Minerals

Bottled waters contain other minerals as well as trace elements that have important functions in the body. For example, chromium may reduce fatty acids and cholesterol levels in the blood, while copper may play a role in the formation of hemoglobin. Zinc may help in the proper functioning of the immune system, enzymes, taste, and smell; it may also help in the healing process of body tissues. However, the content of trace elements in most bottled waters is low and their daily requirements are usually met with normal dietary intake.

CONCLUSION

Consumption of bottled water in North America has been increasing for the past 2 decades. In 1997, per capita consumption was 12.7 gallons per year in the United States as a whole (Arthur von Wiesenberger, personal communication) and over 20 gallons per year on the West Coast (1,2). A wide variation exists in the mineral content of bottled waters that are commercially available in North America and Europe: magnesium content ranges from 0 to 126 mg per liter, sodium from 0 to 1,200 mg per liter, and calcium from 0 to 546 mg per liter. Evidence links magnesium deficiency to sudden death, excess sodium to hypertension, and calcium deficiency to osteoporosis. Drinking water that is high in magnesium and calcium and low in sodium will help individuals achieve the recommended daily allowances of these minerals. Because wide variations exist in the mineral contents of commercially available bottled waters, understanding the potential beneficial and harmful effects of these minerals will provide valuable information on which water to choose.

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