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The high heart health value of drinking-water magnesium ☆

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ABSTRACT

Universal drinking water and beverages containing moderate to high levels of magnesium (10–100 ppm) could potentially prevent 4.5 million heart disease and stroke deaths per year, worldwide. This potential is calculated with 2010 global mortality figures combined with a recent quantification of water-magnesium's inverse association with heart disease and stroke mortality. The modern processed food diet, low in magnesium and spreading globally, makes this well-researched potential of drinking-water magnesium worth serious consideration, especially in areas where insufficient dietary intake of magnesium is prevalent.

Introduction

Recent studies confirm the strong, essential role magnesium plays in the prevention of cardiovascular diseases [1,2], a role that has been long and robustly elucidated. Adequate magnesium is vital in preventing atherogenesis and inappropriate clotting, in maintaining vascular tone, electrolyte balance and a host of other cellular, biochemical and physiological processes crucial to cardiovascular function and health [3–10].

Quantification & hypothesis

People living in areas with low-magnesium water have high rates of heart attack and stroke death, higher than people living in areas of high-magnesium water who seem to be protected from this scourge [11–38]. In fact, data tells us that consumption of drinking water even moderately high in magnesium (at least 10 ppm and up to 40 ppm and higher) can be expected to reduce cardiovascular mortality by 30–35% [39].

In 2010, 25% (12.9 million deaths) of all global deaths (52.8 million deaths) were deaths due to ischaemic heart disease or stroke, a rate up from 20% of all global deaths in 1990 [40]. Could as simple a solution as providing 10–100 ppm magnesium in drinking water and beverages have saved 30% to 35% of these people, up to 4.5 million lives in 2010 alone? [39,40]. How could such a simple and inexpensive adjustment make such a huge difference?

Discussion of hypothesis

The "Magnesium-in-water" effect was long ago pinpointed as most beneficial to people on diets low in magnesium. [12,23,41–44]. Is this common? International studies as early as 1961 to 1980 showed substantial dietary magnesium shortfalls ranging from 7% to 65% below RDA [45–57]. This is certainly the case today in the USA where highly processed foods quite low in magnesium [58] make up much of the diet. Recent studies show a significant portion of all age-gender groups of Americans NOT getting their daily magnesium requirement from foods [9,59–61], with 68–89% teens and 70–80% of the elderly falling into this low-magnesium category. These are all people who could benefit from the "Magnesium-in-water" effect. The highly processed, low magnesium diet so entrenched in the USA is spreading to developing nations, and as we saw above [40], so are death rates due to heart disease. Never before has the "Magnesium-in-water" effect been more promising to the health of the USA and the world.

Magnesium in the USA food supply dropped substantially between 1900 and 2010 [7,44], mostly due to food processing advances [58]. However, significant decreases in magnesium concentration of vegetables and high-yield grains of the Green Revolution have been documented [10,62–67]. Additionally, water-softening technology has become almost universal in USA homes during the past half century, removing all magnesium and calcium from household water supplies used for cooking and drinking, among other uses.

Could drinking water high in magnesium really make a difference? Experimental animals made magnesium deficient with low magnesium food show subcellular markers linked to heart disease [68–71]. Giving drinking-water with added magnesium to these animals lessens these markers even at such low magnesium levels as 15 ppm. Water magnesium levels of 100 ppm

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can completely reverse some of these markers [68–73]. Similar to these animal study experiments, human population studies show that populations with less than 3–6 ppm magnesium drinking water have very high rates of mortality from heart disease, and that rate goes down as the magnesium concentration of their water goes up, the higher the better [74]. Experts in this field tell us that total magnesium intake must be at least 450–500 mg per day, and drinking water should contain a minimum of 25–50 ppm magnesium [75]. Two liters of 25–50 ppm magnesium water would provide 15–25% of adult RDAs. To ascertain a minimum level of effective water-magnesium we can draw from studies by Rubenowitz et al. [31–33,76] that found only daily water-magnesium intakes above 13.8 mg to be protective (i.e., 2 liters per day of 6.9 ppm magnesium water). At present, many USA potable water sources contain less than 7 ppm magnesium and most bottled waters contain little, if any, magnesium [77]. No wonder USA death rates from heart disease are so high [40].

At this time in the USA, very few high magnesium mineral waters are available. One, Adobe Springs water, appears to be an exception as it is both high in magnesium (96–110 ppm) as well as low in both calcium and sodium [77], aspects that can be important to health. Calcium intakes from food have risen substantially in the USA over the past 30 years [78], just as recommendations for calcium supplementation to prevent osteoporosis became widespread. Both of these high calcium trends have occurred in the face of low magnesium intakes, and there is rising evidence that this trend poses dangers to heart health [9,79–84].

Conclusion

It would be wise and forward-thinking for public health officials to consider how high-magnesium drinking water might be made available to communities, i.e., water with magnesium levels of at least 10 ppm and ideally 25–100 ppm. Bottled beverage makers might well be encouraged to consider how raising the magnesium content could improve the quality (and possibly future marketability) of their products. Certainly labeling of magnesium content in beverages and bottled waters (along with calcium and sodium) is justified.

As so well stated by Calderon and Hunter in the 2009 World Health Organization report, Calcium and Magnesium in Drinking Water, Public Health Significance (74, Page 141): . . . Epidemiological evidence supports the link between magnesium and cardiovascular mortality. Such an association is consistent with evidence of the cardiovascular effects of magnesium deprivation and of inadequate magnesium in the diets of people from developing countries. . . . . ***How strong does the epidemiological and other evidence need to be before society acts*** to reduce a potential public health threat rather than await further evidence that such a threat is real?. .. .There is a growing consensus among epidemiologists that the epidemiological evidence, along with clinical and nutritional evidence, is already strong enough to suggest that new guidance should be issued. [Bold italics added.]

Conflict of interest

Dr. Rosanoff has received small sporadic honoraria and travel funding from Adobe Springs, California, over the past ten years, always with no input as to usage of said funding. Adobe Springs sponsored research for this paper but had no role or input in the collection, analysis or interpretation of scientific literature, nor in the writing of the manuscript, nor in the decision to submit this manuscript for publication. This paper was written and researched in complete autonomy.

References

[1] Del Gobbo LC, Imamura F, Wu JH, de Oliveira Otto MC, Chiuve SE, Mozaffarian D. Circulating and dietary magnesium and risk of cardiovascular disease: a systematic review and meta-analysis of prospective studies. Am J Clin Nutr 2013.
[2] Chiuve SE, Sun Q, Curhan GC, et al. Dietary and plasma magnesium and risk of coronary heart disease among women. J Am Heart Assoc 2013;2:e000114.
[3] Seelig MS. Magnesium Deficiency in the Pathogenesis of Disease, Early Roots of Cardiovascular, Skeletal, and Renal Abnormalities. New York and London: Plenum Medical Book Co; 1980.
[4] Marier JR. Role of environmental magnesium in cardiovascular diseases. Magnesium 1982;1:266–76.
[5] Altura BM, Altura BT. Magnesium and cardiovascular biology: an important link between cardiovascular risk factors and atherogenesis. Cell Mol Biol Res 1995;41:347–59.
[6] Altura BM, Zhang A, Altura BT. Magnesium, hypertensive vascular diseases, atherogenesis, subcellular compartmentation of Ca^{2+} and Mg^{2+} and vascular contractility. Miner Electrolyte Metab 1993;19:323–36.
[7] Seelig MS, Rosanoff A. The Magnesium Factor. New York: Avery Penguin Group; 2003.
[8] Maier JA. Low magnesium and atherosclerosis: an evidence-based link. Mol Aspects Med 2003;24:137–46.
[9] Rosanoff A, Weaver CM, Rude RK. Suboptimal magnesium status in the United States: are the health consequences underestimated? Nutr Rev 2012;70:153–64.
[10] Rosanoff A. Changing crop magnesium concentrations: impact on human health. Plant Soil 2012.
[11] Calderon RL, Craun GF. Water Hardness and Cardiovascular Disease: a Review of the Epidemiological Studies, 1957–78. In: Organization WH, editor. Nutrients in Drinking Water. Geneva: World Health Organization; 2005. p. 116–26.
[12] Catling LA, Abubakar I, Lake IR, Swift L, Hunter PR. A systematic review of analytical observational studies investigating the association between cardiovascular disease and drinking water hardness. J Water Health 2008;6:433–42.
[13] Comstock GW. Water hardness and cardiovascular diseases. Am J Epidemiol 1979;110:375–400.
[14] Comstock GW, Cauthen GM, Helsing KJ. Water hardness at home and deaths from arteriosclerotic heart disease in Washington County, Maryland. Am J Epidemiol 1980;112:209–16.
[15] Durlach J, Bara M, Guiet-Bara A. Magnesium level in drinking water and cardiovascular risk factor: a hypothesis. Magnesium 1985;4:5–15.
[16] Durlach J, Bara M, Guiet-Bara A. Magnesium Level In Drinking Water; Its Importance In Cardiovascular Risk. In: Itokawa Y, Durlach J, editors. Magnesium in Health and Disease. Paris, France, London: J. Libbey; 1989. p. 173–82.
[17] Goldsmith NF. Water Resources Res Catalogue 5: The Contribution of Hard Water To The Calcium And Magnesium Intakes Of Adults. (Relation of Drinking Water Minerals to Cardiovascular Disease.). Washington, DC: US Dept of Interior; 1969.
[18] Leary WP. Content of magnesium in drinking water and deaths from ischaemic heart disease in white South Africans. Magnesium 1986;5:150–3.
[19] Leary WP, Reyes AJ, Lockett CJ, Arbuckle DD, van der Byl K. Magnesium and deaths ascribed to ischaemic heart disease in South Africa, A preliminary report. S Afr Med J 1983;64:775–6.
[20] Luoma H. Risk of Myocardial Infarction in Relation to Magnesium and Calcium Concentrations in Drinking Water, With Some Aspects on the Magnesium vs. Fluoride Interactions. In: Itokawa Y, Durlach J, editors. Magnesium in Health and Disease. London: J. Libbey; 1989. p. 183–90.
[21] Maksimovic ZJ, Jovanovic T, Rsumovic M, Dordevic M. Magnesium and Calcium in Drinking Water and Cardiovascular Mortality in Serbia. Yugoslavia: Serbian Academy of Sciences and Art Belgrade; 1998.
[22] Marier JR. Cardio-protective contribution of hard waters to magnesium intake. Rev Can Biol 1978;37:115–25.
[23] Marier JR. Dietary magnesium and drinking water: Effects on human health status. Compendium on Mg & its role in biology. Nutr Physiol 1990;26:85–104.
[24] Marier JR, Neri LC. Quantifying the role of magnesium in the interrelationship between human mortality/morbidity and water hardness. Magnesium 1985;4:53–9.
[25] Marier JR, Neri LC, Anderson TW. Water hardness, human health, and the importance of magnesium. National Res Coun Can Rep NRCC 1979;17581:1–119.
[26] Marier R. Role of magnesium in the "Hard-Water Story". Magnesium Bull 1986;8:194–8.
[27] Marque S, Jacqmin-Gadda H, Dartigues JF, Commenges D. Cardiovascular mortality and calcium and magnesium in drinking water: an ecological study in elderly people. Eur J Epidemiol 2003;18:305–9.
[28] Marx A, Neutra RR. Magnesium in drinking water and ischemic heart disease. Epidemiol Rev 1997;19:258–72.
[29] Punsar S, Karvonen MJ. Drinking water quality and sudden death: observations from West and East Finland. Cardiology 1979;64:24–34.
[30] Rosenlund M, Berglind N, Hallqvist J, Bellander T, Bluhm G. Daily intake of magnesium and calcium from drinking water in relation to myocardial infarction. Epidemiology 2005;16:570–6.

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[31] Rubenowitz E, Axelsson G, Rylander R. Magnesium in drinking water and death from acute myocardial infarction. Am J Epidemiol 1996;143:456–62.
[32] Rubenowitz E, Axelsson G, Rylander R. Magnesium and calcium in drinking water and death from acute myocardial infarction in women. Epidemiology 1999;10:31–6.
[33] Rubenowitz E, Molin I, Axelsson G, Rylander R. Magnesium in drinking water in relation to morbidity and mortality from acute myocardial infarction. Epidemiology 2000;11:416–21.
[34] Rylander R, Bonevik H, Rubenowitz E. Magnesium and calcium in drinking water and cardiovascular mortality. Scand J Work Environ Health 1991;17:91–4.
[35] WHO. Calcium and Magnesum in Drinking-Water Public health Significance. Geneva: World Health Organization; 2009.
[36] Yang CY. Calcium and magnesium in drinking water and risk of death from cerebrovascular disease. Stroke 1998;29:411–4.
[37] Yang CY, Chiu HF. Calcium and magnesium in drinking water and the risk of death from hypertension. Am J Hypertens 1999;12:894–9.
[38] Yang CY, Chiu HF, Chiu JF, Wang TN, Cheng MF. Magnesium and calcium in drinking water and cerebrovascular mortality in Taiwan. Magnes Res 1997;10:51–7.
[39] Monarca S, Zerbini I, Simonati C, Gelatti U. Drinking water hardness and chronic degenerative diseases. II. cardiovascular diseases. Ann Ig 2003;15:41–56.
[40] Lozano R, Naghavi M, Foreman K, et al. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the global burden of disease Study. Lancet 2010;380(2012):2095–128.
[41] Anderson TW, Neri LC, Schreiber G, Talbot FDF, Zdrejewski A. Ischemic heart disease, water hardness, and myocardial magnesium. Can Med Assoc J 1975;113:199–203.
[42] Marier JR. The importance of dietary magnesium with particular reference to humans. Z Vitalstoffe Zivilisationskrankh 1968;13:144–9.
[43] Marier JR. Nutritional and myocardial aspects of magnesium in drinking-water. Magnesium Bull 1981:48–54. 1a.
[44] Marier JR. Quantitative factors regarding magnesium status in the modern-day world. Magnesium 1982;1:3–15.
[45] Ashe JR, Schofield FA, Gram MR. The retention of calcium, iron, phosphorus, and magnesium during pregnancy: the adequacy of prenatal diets with and without supplementation. Am J Clin Nutr 1979;32:286–91.
[46] Brown J, Bourke GJ, Gearty GF, et al. Nutritional and epidemiologic factors related to heart disease. World Rev Nutr Diet 1970;12:1–42.
[47] Durlach J, Rayssiguier Y, Laguitton A. Le besoin en magnesium et son apport dans la ration. Med Nutr 1980;16.
[48] Greger JL. Dietary intake and nutritional status in regard to zinc of institutionalized aged. J Gerontol 1977;32:549–53.
[49] Greger JL, Gruner SM, Ethyre GM, Abernathy RP, Sickles V. Dietary intake and nutritional status in regard to magnesium of adolescent females. Nutr Rep, Int 1979;20.
[50] Greger JL, Huffman J, Abernathy RP, Bennett OA, Resneck SE. Phosphorus and magnesium balance of adolescent females fed two levels of zinc. J Food Sci 1979;44.
[51] Holtmeier HJ, Kuhn M. Zink- und magnesium-mangel beim menschen. Therapiewoche 1972;22:4536–46.
[52] Huber HG, Disney GM, Mason RL. Dietary intake and urinary excretion of magnesium in black or white preadolescent girls. Fed Proc 1980;39.
[53] Leverton RM, Leichsenring JM, Linkswiler H, Meyer F. Magnesium requirement of young women receiving controlled intakes. J Nutr 1961;74:33–8.
[54] Schroeder HA, Nason AP, Tipton IH. Essential metals in man. Magnesium. J Chronic Dis 1969;21:815–41.
[55] Seelig MS. Magnesium deficiency with phosphate and vitamin D excesses; role in pediatric cardiovascular disease? Cardiovasc Med 1978;3:637–50.
[56] Srivastava US, Nadeau MH, Gueneau L. Mineral intakes of university students - magnesium content. Nutr Rep, Int 1978;18.
[57] Vir SC, Love AH. Nutritional status of institutionalized and noninstitutionalized aged in Belfast, Northern Ireland. Am J Clin Nutr 1979;32:1934–47.
[58] Ctr for Magnesium Educ & Research. Magnesium in Refined vs. Whole Foods. http://www.magnesiumeducation.com/whole-vs-refined-food, Accessed 4/19/13,2013.
[59] Moshfegh A, Goldman JD, Ahuja J, Rhodes D, LaComb R. What We Eat in America, NHANES 2005-6: Usual Nutrient Intakes from Food and Water Compared to 1997 Dietary Reference Intakes for Vitamin D, Calcium, Phosphorus, and Magnesium. U.S. Department of Agriculture, Agricultural Research Service; 2009.
[60] Moshfegh A, Goldman JD, Cleveland LE. What We Eat in America, NHANES 2001-2002: Usual Nutrient Intakes from Food Compared to Dietary Reference Intakes. U.S. Department of Agriculture, Agricultural Research Service; 2005.
[61] Nicklas TA, O'Neil CE, Fulgoni 3rd VL. The role of dairy in meeting the recommendations for shortfall nutrients in the American diet. J Am Coll Nutr 2009;28(Suppl 1):73S–81S.
[62] Davis DR. Declining fruit and vegetable nutrient composition: what Is the evidence? HortScience 2009;44:15–9.
[63] Fan M-S, Zhao F-J, Fairweather-Tait SJ, Poulton PR, Dunham SJ, McGrath SP. Evidence of decreasing mineral density in wheat grain over the last 160 years. J Trace Elem Med Biol 2008;22:315–24.
[64] Ficco DBM, Riefolo C, Nicastro G, et al. Phytate and mineral elements concentration in a collection of Italian durum wheat cultivars. Field Crops Res 2009;111:235–42.
[65] Mayer A. Historical changes in the mineral content of fruits and vegetables. Br Food J 1997;99:207–11.
[66] Murphy KM, Reeves PG, Jones SS. Relationship between yield and mineral nutrient concentrations in historical and modern spring wheat cultivars. Euphytica 2008;163:381–90.
[67] White PJ, Broadley MR. Historical variation in the mineral composition of edible horticultural products. J Hort Sci Biotechnol 2005;80:660–7.
[68] Altura BM, Shah NC, Jiang XC, et al. Short-term magnesium deficiency results in decreased levels of serum sphingomyelin, lipid peroxidation, and apoptosis in cardiovascular tissues. Am J Physiol Heart Circ Physiol 2009;297:H86–92.
[69] Altura BM, Shah NC, Li Z, Jiang XC, Perez-Albela JL, Altura BT. Magnesium deficiency upregulates serine palmitoyl transferase (SPT 1 and SPT 2) in cardiovascular tissues: relationship to serum ionized Mg and cytochrome c. Am J Physiol Heart Circ Physiol 2010;299:H932–938.
[70] Altura BM, Shah NC, Li Z, et al. Short-term magnesium deficiency upregulates sphingomyelin synthase and p53 in cardiovascular tissues and cells: relevance to the de novo synthesis of ceramide. Am J Physiol Heart Circ Physiol 2010;299:H2046–2055.
[71] Shah NC, Liu JP, Iqbal J, et al. Mg deficiency results in modulation of serum lipids, glutathione, and NO synthase isozyme activation in cardiovascular tissues: relevance to de novo synthesis of ceramide, serum Mg and atherogenesis. Int J Clin Exp Med 2011;4:103–18.
[72] Sherer Y, Shaish A, Levkovitz H, et al. Magnesium fortification of drinking water suppresses atherogenesis in male LDL-receptor-deficient mice. Pathobiology 1999;67:207–13.
[73] Sherer Y, Shoenfeld Y, Shaish A, Levkovitz H, Bitzur R, Harats D. Suppression of atherogenesis in female low-density lipoprotein receptor knockout mice following magnesium fortification of drinking water: the importance of diet. Pathobiology 2000;68:93–8.
[74] Calderon RL, Hunber P. Epidemiological Studies and the Association of Cardiovascular Disease Risks With Water Hardness, Calcium and Magnesium in Drinking Water Public health Significance. Geneva: WHO; 2009. pp. 108–142.
[75] Altura BM, Altura BT. Atherosclerosis and Magnesium. In: WHO, editor. Calcium and Magnesium in Drinking-Water Public health Significance. Geneva: WHO; 2009. p. 75–81.
[76] Monarca S, Donato F, Zerbini I, Calderon RL, Craun GF. Review of epidemiological studies on drinking water hardness and cardiovascular diseases. Eur J Cardiovasc Prev Rehabil 2006;13:495–506.
[77] Azoulay A, Garzon P, Eisenberg MJ. Comparison of the mineral content of tap water and bottled waters. J Gen Intern Med 2001;16:168–75.
[78] Rosanoff A. Rising Ca:Mg intake ratio from food in USA Adults: a concern? Magnes Res 2010;23:181–93.
[79] Bolland MJ, Avenell A, Baron JA, et al. Effect of calcium supplements on risk of myocardial infarction and cardiovascular events: meta-analysis. BMJ 2010;341:c3691.
[80] Bolland MJ, Grey A, Avenell A, Gamble GD, Reid IR. Calcium supplements with or without vitamin D and risk of cardiovascular events: reanalysis of the women's health initiative limited access dataset and meta-analysis. BMJ 2011;342:d2040.
[81] Li K, Kaaks R, Linseisen J, Rohrmann S. Associations of dietary calcium intake and calcium supplementation with myocardial infarction and stroke risk and overall cardiovascular mortality in the Heidelberg cohort of the European prospective investigation into cancer and nutrition study (EPIC-Heidelberg). Heart 2012;98:920–5.
[82] Reid IR, Bolland MJ, Avenell A, Grey A. Cardiovascular effects of calcium supplementation. Osteoporos Int 2011;22:1649–58.
[83] Reid IR, Bolland MJ, Sambrook PN, Grey A. Calcium supplementation: balancing the cardiovascular risks. Maturitas 2011;69:289–95.
[84] Seelig MS. Increased need for magnesium with the use of combined oestrogen and calcium for osteoporosis treatment. Magnes Res 1990;3:197–215.

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