Nutritional and Myocardial Aspects of Magnesium in Drinking-Water

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Zusammenfassung

In jüngster Zeit haben kanadische Untersuchungen gezeigt, daß über das Trinkwasser zugeführtes Magnesium einen marginalen Magnesiummangel verhüten und auf diese Weise helfen kann, Ischämien des Herzmuskels oder plötzlichem Herztod vorzubeugen. Verschiedene Aspekte dieser Problematik werden diskutiert im Zusammenhang mit der ungenügenden Zufuhr an Magnesium über die Nahrung in hochindustrialisierten Ländern.

Summary

Recent Canadian studies have indicated that the magnesium provided by drinking-water may prevent borderline magnesium insufficiency in some individuals, and thereby help to prevent cardiacischemia or "sudden-death" trauma. Various aspects of this topic are discussed in the context of inadequate dietary intake of magnesium in the modern-day world.

Résumé

Des récentes études canadiennes indiquent que le magnésium dans l'eau potable peut prévenir une carence marginale en magnésium, et ainsi prévenir des crises cardiaques. Plusieurs aspects de ce sujet sont discutés dans le contexte d'un apport insuffisant de magnésium dans la diète contemporaine.

The possible importance of waterborne magnesium — especially in helping to prevent illnesses such as heart disease — was suspected in the early 1960s [21]. At that time, epidemiological studies had indicated that there was less cardiac-related mortality in hard-water regions than in localities where the drinking-water was soft [17, 24]. However, subsequent surveys revealed that an inverse correlation between water hardness and human health could be demonstrated in only about ⅔ of the studies undertaken in various regions of the world [19, 23]. Also, the topic was further complicated by disagreement concerning which of the waterborne constituents might explain the association between water and health, i.e., either the hard waters contained a "protective" factor, or — conversely — soft waters contained a "toxic" factor. Several reviews were written about this topic [e.g. 22, 26]; and, although some of the reviews emphasized the probable importance of waterborne magnesium [9, 15], no consensus emerged.

Today, I would like to tell you about the relevant research that was done in Canada during the 1970s, and how a concerted effort was made to integrate these findings into a consistent pattern that might also relate to observations reported in other regions of the modern-day world. These concepts were presented in an NRC-Canada monograph issued in 1979 [16].

One aspect of the Canadian studies involved a cross-Canada survey of more than 500 tap-waters, in which 15 "candidate elements" were evaluated in terms of possible epidemiological correlations with regional death-rates for Heart Disease or "All Causes" mortality. This work was coordinated by Dr. *Lou Neri* at the University of Ottawa [20]. The results are summarized in table 1, where it can be seen that magnesium emerged as the strongest candidate in the correla-

Table 1: Mortality correlations obtained in the Canadian drinking-water survey

Statistically Significant Correlation Coefficient Between Male Mortality Rates and Certain Water Quality (Age Standardized 35–64: Combined Years 1950–52 and 1960–1962)

N	Li 522	Ca 522	Mg 522	Hardness 522	Ni 239
Canada ASHD (420+422)	−0.09*	−0.07	−0.10**	−0.09*	−0.12*
All causes	−0.09*	−0.11**	−0.18***	−0.13**	−0.17**
N	159	159	159	159	—
Ontario ASHD (420+422)	−0.24**	−0.11**	−0.27**	−0.28***	—
All causes	−0.16**	−0.16*	−0.25***	−0.21**	—

Note: Tested but found not significant; Cu, Zn, Mo, Pb, Cr, Cd, Co, Hg, Sb,
* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

Correlation Coefficident Between All Causes Mortality Rates and Water Quality, Canada (Age Standardized 35–64: Combined Years 1950–52 and 1960–1962).

Order	Canada (501 localities)	Ontario (159 Localities)
Zero order		
Mortality x Mg	−0.168*	−0.251**
x Hardness	−0.133*	−0.207**
x pH	−0.111**	−0.111
x Ca	−0.110**	−0.162***
x Li	−0.093***	−0.155***
x Zn	−0.052	−0.120
x Cd	+0.015	−0.015
x Cr	+0.063	N/A
x Cu	+0.072	+0.167***
Hardness x Li	+0.826	+0.835
First order Partial		
Mortality x Li (hardness)	+0.032	+0.033
x Hardness (Li)	−0.100	−0.144

* $p < 0.05$ ** < 0.01 *** $p < 0.001$
(from *Marier* et al., 1979).

tion matrix, i.e., inversely correlated with mortality. In comparison, the correlation with waterborne calcium was decidedly weaker, whereas a *positive* correlation with mortality was obtained for waterborne copper or lithium (using the "partial correlation" approach). Moreover, no significant correlations were found for waterborne antimony, cadmium, chromium, cobalt, lead, mercury, molybdenum, silver, or zinc.

Another aspect of the Canadian research involved autopsytissue analyses of 161 subjects. This work was coordinated by Dr. Terry Anderson at the University of Toronto [3], and involved two approaches for intercomparison of the subjects: (i) whether they resided in either a soft-water or a hard-water locality; and (ii) whether they had died from cardiac ischemia or from noncardiac accidental causes. The results are summarized in table 2, which shows the analytical findings in myocardial muscle. As can be seen, there was a 24% lower magnesium content in the myocardium of the cardiac-ischemia subjects, in comparison with the non-cardiac cases (Note also the 18% lower copper content, but the 28% higher calcium in the myocardium of cardiac subjects). However, the only statistically-significant difference between residents of Soft-vs-Hard water localities involved magnesium, which was about 6.4% lower in the myocardium of soft-water residents, whether-or-not they had died from cardiac ischemia. No significant difference between Soft-Hard water residents was seen for myocardial copper or calcium, and no differences whatsoever were seen for myocardial cadmium, chromium, lead, or zinc. Therefore, these findings regarding myocardial analysis corroborated the nation-wide Canadian survey based on the association between drinking-water composition versus mortalitiy; in both studies, magnesium emerged as the most probable differential feature between the Soft/Hard water residents.

Here, it must be emphasized that the heart muscle can become selectively depleted in magnesium, and that no such magnesium loss is seen in other muscles of cardiac-ischemia subjects [3, 5, 12]. The magnitude of the myocardial magnesium loss is illustrated in table 3. In Heggtveit's study, the necrosed zones of infarcted hearts had a 42% depletion of magnesium, whereas the *non*-necrosed zones of the *same* hearts showed a less drastic magnesium depletion of 19% (Note: An almost identical result was reported in a 1979 study by *Speich* et al. [27]). In table 3, it can also be seen that a 12-to-24% loss of myocardial magnesium has been observed in sudden-death or cardiac-ischemia trauma. It is therefore likely that such hearts are *not* extensively necrosed; and indeed, this is often the pathological finding at autopsy, especially in relatively young subjects who succumb to a first and fatal heart seizure. In terms of Soft-vs-Hard water residency, the 6% lower myocardial magnesium in soft-water localities represents a considerable proportion of the 12-to-24% depletion observed in sudden-death or ischemic cases (table 3); there is also the fact that the 6% depletion was seen in both the cardiac and non-cardiac subjects residing in soft-water localities (table 2). All of this is consistent with the concept that myocardial magnesium depletion (unrelated to heart seizures) can occur in regions where waterborne magnesium is low, and that such a depletion increases the vulnerability of the heart to fatal arrhythmias and associated cardiac seizures, thereby accounting for higher cardiac death-rates in these soft-water localities [3, 16, 20].

Table 2: Myocardial concentrations found in autopsy studies of cardiac and non-cardiac cases in soft- and hard-water localities

Soft waters: < 60 ppm total hardness; 27 cardiac and 54 accident cases.
Hard waters: > 300 ppm total hardness; 12 cardiac and 29 accident cases.

		Myocardial concentration, µg/g dry apical tissue			
		Cardiac cases	Accident cases	Cardiac/Accident myocardial concentration	p
Magnesium	Soft waters	697	918	0.76	<0.001
	Hard waters	744	982	0.76	
	Soft/Hard myocardial concentration	0.937	0.935		<0.01
Copper	Soft waters	13.0	15.7	0.83	<0.001
	Hard waters	13.3	16.4	0.81	
	Soft/Hard myocardial concentration	0.977	0.957		n. s.
Calcium	Soft waters	282	224	1.26	<0.05
	Hard waters	301	232	1.30	
	Soft/Hard myocardial concentration	0.937	0.966		n. s.

Note: No significant changes in myocardial concentration were found for cadmium, chromium, lead, or zinc. See text for more details. (from *Marier* et al., 1979).

Table 3

Type of condition examined	Depletion (%) of myocardial Mg	Reference
Necrosed zones of infarcted hearts	42	*Heggtveit* et al., 1969
non-necrosed zones of the same hearts	19	
Cardiac Ischemia fatalities	24	*Anderson* et al., 1973, 1975
Soft-water vs Hard-water localities	6.4	*Chipperfield* and *Chipperfield*, 1973
Sudden-death cardiac cases	15	*Behr* and *Burton*, 1973
Sudden-death cardiac cases	12	
Cardiac Ischemia fatalities	9 or 12	*Johnson* et al., 1979
		(consult appended bibliography)

An aditional aspect of the Canadian studies was an attempt to explain *why* waterborne magnesium might be so important [16], and this is illustrated in table 4. Note that, with the exception of the Irish Republic, the daily intake of dietary magnesium was found to be supoptimal, i.e., from 6-to-7% lower-than-recommended in U.S. women; from 25-to-30% low for U.S. men as well as for the adult population of the U.K. and West Germany; also, about 50% lower-than-recommended for both men and women in the Newfoundland region of Canada.

Tabelle 4: Surveys of dietary magnesium intake in the Western World

			Magnesium intake (mg/day)			
Authors	Country	Subjects	Age	Found	Req'd (NAS '74)	Found/Req'd %
Leverton et al. (1961)	U.S.A.	30 women	19—24	279	300	93.0
Brown et al. (1970)	U.S.A. (city)	955 men	20—>60	262	350	74.9
	Ireland (city)	887 men	20—>60	415	350	118.6
	Ireland (rural)	152 men	20—>60	472	350	134.9
Holtmeier and *Kuhn* (1972)	West Germany	1852 adults (men and women)		235	325	72.3
Hamilton and *Minski* (1972/73)	U.K.	Diet estimate*		250	325	76.9
Greger (1977)	U.S.A.	34 women	>70	283	300	94.3
		31 men	>70	251	350	71.7
Fodor et al. (1978)**	Newfoundland	105 women		143	300	47.7
		83 men		189	350	53.4

* *Greger* et al. (1978) caution that reliance on traditional "food consumption tables" overestimates dietary Mg by about 12%.
** *See Neri* and *Marier* (1978).
Note: At the Nutrition Dept. of the University of Montreal, *Srivastava* et al. have recently analyzed the self-selected diets of 30 students (15 females and 15 males) during a 3-week period; the magnesium intake averaged 238 mg/day, i. e. 73.2% of the daily requirement recommended by NAS.
(from *Marier* et al., 1979)

Table 5 presents information that has become available *since* the publication of the 1979 NRC-Canada report [16], and corroborates the general trend shown in the previous tabulation. Thus, magnesium intake ranges from "barely adequate" down to 20% suboptimal in the adult population of France; similarly, from 10-to-33% supoptimal in U.S. girls; from 25-to-30% suboptimal in Canadian university students; and about 44% suboptimal for institutionalized men and women in Northern Ireland. When these percentages are expressed in terms of actual *amounts*, the magnesium shortfall is seen to range from 17-to-157 mg/day for women, and from 38-to-161 mg/day for men.
The primary reason for the suboptimal dietary magnesium intake in the modern-day world is attributable to food processing-and-refining practices, as illustrated in table 6. Although food items such as Bran or Blackstrap Molasses have a high magnesium content, there is almost complete loss of magnesium as refining becomes more extensive; this applies to the production of white sugar, white flour, starch, and the polishing of rice. Such considerations have recently been emphasi-

Table 5: Recent Assessments of Mg Ingestion

Authors	Region	Subjects	mg/day Mg Intake	Mg Req'ment	Mg Found % Req'd
Durlach et al. (1980)	France	Adults (5 studies)	260—325	325	80—100
Huber et al. (1980)	Tennessee	9—11 yr girls (n = 60)			
		White	200—300	300	67—100
		Black	lower	300	lower
Greger et al. (1979-a)	Indiana	12—14 yr girls (n = 11)	270	300	90
Greger et al. (1979-b)	Indiana	12—14 yr girls			
		(n = 80) 1976	238	300	79.3
		(n = 76) 1977	231	300	77.0*
Srivastava (1978-9)	Montreal	University students			
		15 females	227	300	75.7
		15 men	247	350	70.6
Vir and *Love* (1979)	Belfast	Adults 65 yr institutionalized			
		90 women	169	300	56.3
		36 men	198	350	56.6

* one-third of the subjects were ingesting less than 66% of the daily Mg requirement.
(consult appended bibliography)

zed by Caddell in the U.S.A. [6], by *Durlach* in France [8], and by *Abdulla* in Sweden [1]. Here, it must be remembered that bulk cereals have traditionally served as the most plentiful sources of dietary magnesium commonly available to mankind. Thus, the extensive magnesium loss during modern-day food refining appears ominously important, and this — in turn —implies added importance to the intake of waterborne magnesium in the modern-day world.
As presented in foregoing tabulations, the magnesium shortfall in several regions of the world ranges all the way from 17 to 161 mg/day. However, the question arises concerning how much magnesium can be supplied by drinking-water. Figure 1 illustrates the contribution of drinking-water to the daily magnesium intake in four distinct regions of the U.S.A. It can be seen that, for each 100 units of Total Hardness, these drinking-waters provide 17mg/day of magnesium [16]. *Schroeder* had reported [24] that the average Total Hardness of drinking-water in 163 U.S. metropolitan areas was 118; in terms of the graph shown in fig. 1, such waters would provide about 20 mg/day of magnesium.
Another question that arises is the one that asks: "Can waterborne magnesium make a difference in the death-rate attributable to cardiac mortality?". The data presented in table 7 indicate that this may indeed be the case. Note that, in the 25 U.S. cities with the lowest coronary death-rates [25], the drinking-waters supplied almost twice the magnesium — along with ⅓ less calcium — than was supplied by the average U.S. metropolitan waters [24], even though the Total

Table 6: Loss of magnesium (and calcium) during food refining

Authors	Food item	ppm dry weight Mg	Ca	Relative % Mg lost
Aslander (1964)	Blackstrap molasses	5206	7573	—
	Bakery syrup	680	2580	86.9
	Raw molasses	170	2088	96.8
	Table syrup	140	266	97.3
	Raw sugar	6	611	>99.9
	Lump sugar	2	5	>99.9
	Powdered sugar	0.2	4	>99.9
Czerniejewski et al. (1964)	Bran	6880	1280	—
	Shorts	5410	1330	21.4
	Red dog	3420	1100	50.0
	Germ	2680	480	61.0
	Wheat	1670	450	75.7
	low-grade flour	1560	460	77.4
	First clear flour	650	300	90.6
	Patent flour	270	210	96.0
	Farina	210	190	99.9
Schroeder (1971)	Wheat	1502		—
	Flour	299		80.0
	Unpolished rice	1477		—
	Polished rice	251		83.3
	Corn	644		—
	Starch	22		96.7
	Molasses	250		—
	Raw sugar	6		62.4
	White sugar	2		99.0
Hamilton and *Minski* (1972/73)	Barbados brown sugar	1760	1650	—
	Demerara sugar	144	81	92.0
	Refined sugar	2	12	99.9
	Granulated sugar	0.5	26	>99.9

(from *Marier* et al., 1979)

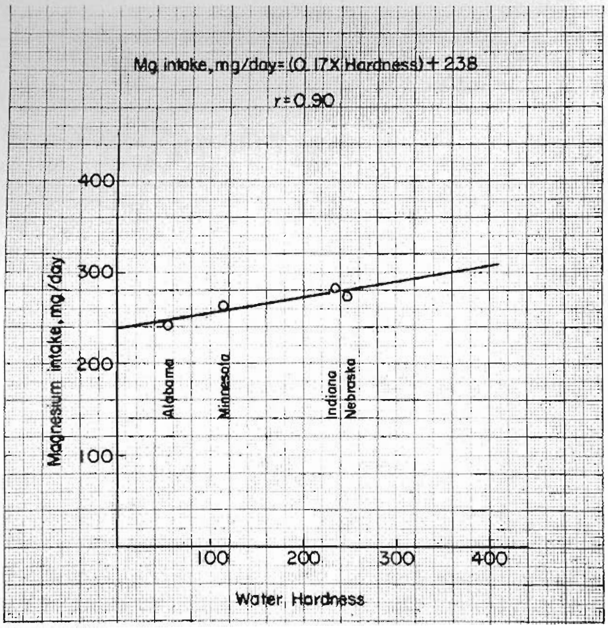

Fig. 1: (from *Marier* et al. 1979)

Hardness of the two groups of waters was almost identical. This introduces yet another topic, i.e., that solitary reliance on the "Total Hardness" designation of water can be very misleading . . . something that will be illustrated again, later in this presentation. But, in terms of table 7, note that the very hard Ontario waters supplied approximately 59 mg/day of magnesium, which is about 3-fold higher than the amount supplied by "average" U.S. metropolitan waters. And, when we remember that thes shortfall in magnesium intake ranges from 17 to 161 mg/day, the Ontario-type drinking-waters can indeed provide an appreciable amount of magnesium, and this waterborne supplement may rectify an otherwise-inadequate magnesium status in some regions. However, note that the very hard British waters contribute the same low amount of magnesium that is provided by the "average" U.S. metropolitan waters; this may explain why British researchers have been unable to find any significant correlation relating to waterborne magnesium.

Table 7: Compositional diversity of drinking-waters, and how this affects intake of waterborne magnesium

Authors	Locale	Total hardness	Ca mg/L	Mg mg/L	Daily Mg intake from 2 litres water (mg/day)
Schroeder (1960)	163 U.S. metropolitan areas	118	31.1	9.75	19.5
Schroeder (1966)	25 U.S. cities with lowest mortality-rates from coronary disease	125	22.5	16.5	33.0
Anderson et al. (1975)	5 Ontario soft waters	33	8.9	2.8	5.6
	3 Ontario hard waters	421	119.4	29.4	58.8
Crawford et al. (1968)	9 British soft waters	31	8.5	2.5	5.0
	6 British hard waters	293	102.0	9.25	18.5

(from *Marier* et al., 1979)

Incidentally, the foregoing intercomparisons of waterborne magnesium intakes are based on an estimated daily intake of 2 liters of water, in all forms (e.g., tea, coffee, soups, reconstituted beverages, etc.).

One final topic has already been alluded to, and this aspect is illustrated in table 8. Here, it must be emphasized again that waters of very similar Total Hardness can differ enormously in their respective calcium and magnesium contents. Perhaps this factor explains at least *some* of the confusion that has plagued the so-called "Water Hardness" field. Nevertheless, it must be stipulated that waterborne magnesium is probably not "the only answer" to the question posed by the Soft-vs-Hard water controversy. Indeed, *Arden* [4] has presented some very persuasive evidence in support of the toxic potential represented by corrosive (i.e., unbuffered and acidity-prone) soft waters, especially as this factor is inversely correlated with waterborne calcium in the U.K. and may thus explain the situation in the British Isles. Such corrosive soft waters have a tendency to solubilize trace-elements such as lead from plumbing conduits [16].

But nevertheless, the magnesium-related concepts delineated in the 1979 NRC-Canada monograph [16] have received support in a subsequent 1979 report issued by the U.S. National Academy of Sciences, entitled "Geochemistry Of Water In Relation To Cardiovascular Disease" [18]. These statements can be found in the U.S. report. . . .

> ". . . magnesium levels of tissues may be related to drinking-water . . . One possible (cardiovascular) mechanism is that enough magnesium is present in some hard waters to prevent borderline magnesium deficiency in some persons, thereby reducing their

Table 8: An illustration of how waters with similar Total Hardness can have very dissimilar Ca and Mg contents

Authors	Year	Region*	Total hardness	mg/L Ca	Mg
Crawford et al.	1968	U.K. (6)	293	102.0	9.25
Hankin et al.	1970	California (18)	312	58.5	40.0
Anderson et al.	1975	Ontario (3)	421	119.4	29.4
Dawson et al.	1978	Texas (1)	470	21.0	100.0
DeFulvio and *Olori*	1975	Lille (France)	661	238.0	16.0
DeFulvio and *Olori*	1975	Pisa (Italy)	676	133.9	79.1

* (Brackets indicate the number of localities included in the compilation; these hardness values are therefore not representative of entire geographic regions).
(from *Marier* et al., 1979)

"liability to sudden cardiac death as a result of arrhythmia . . . More attention should be given to the role that magnesium plays in the 'water chemistry vs food-chain vs cardiovascular' relationship. Additional attention should be directed toward the relation between the concentration of individual chemical constituents in water and cardiovascular diseases, rather than considering 'lumped' parameters such as hardness . . . Confirmatory evidence is needed to assess the important possibility that (the) magnesium levels in human tissues may be related to the element concentration in drinking-water . . .".

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