Desalination of Water: Nutritional Considerations

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ABSTRACT: **Background:** Desalination of seawater and brackish water (mixed seawater and freshwater) provides an increasing portion of the Israeli drinking water supply. However, desalinated water contains little calcium (Ca) and magnesium (Mg), and consumers may be at risk for deficiencies of these essential minerals.

Objectives: To assess intakes of Mg and Ca from water, other beverages, and food in communities with different water supplies, and assess the proportion of individuals with intakes below the Estimated Average Requirement (EAR).

Methods: Telephone interviews were conducted using a food frequency questionnaire to assess Mg and Ca intakes by adults in four communities. The proportion of individuals with Mg and Ca intakes below the EAR were evaluated based on current intakes and on potential intakes assuming that desalinated water had been introduced countrywide.

Results: The proportion of individuals with Mg intake below the EAR was higher in Kibbutz Maagan Michael (30.6%), an agricultural settlement supplied with desalinated water, than in Hadera (16.7%), a city supplied by the National Water Carrier (NWC) ($P < 0.05$). The proportion of individuals with Ca intake below the EAR was higher in Maagan Michael (61.7%) than in the communities supplied with water from the NWC or mixed water (37.9%–48.2%), $P < 0.05$.

Conclusions: Returning Mg and Ca to desalinated water may be beneficial for raising intakes in Israeli communities supplied with desalinated water. Individuals with intake of Mg and/or Ca below the EAR may be at risk for cardiac abnormalities and other medical conditions.

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KEY WORDS: magnesium (Mg), calcium (Ca), water hardness, desalination, nutrition

The Earth has a limited supply of fresh water, and only about 2.5% of the water has a salinity low enough for drinking [1]. In many regions, particularly those with rising populations and declining rainfalls, fresh water needs exceed the available supply. To help meet demands for potable water, facilities for desalinating seawater and brackish water have been constructed in a number of countries. Israel began producing desalinated water in 1978 and 20% of current water supplies are desalinated; it is expected that by 2014, 40% of water will be desalinated, and that by 2015, 50% will be desalinated (unpublished data, Israel Water Authority, 2012).

Fresh water from the Israeli National Water Carrier is considered "hard," with concentrations of 45–60 mg calcium and 20–25 mg magnesium per liter [2]. The largest NWC source is surface water from the Kinneret (Sea of Galilee), and groundwater is added to the NWC throughout the country. Desalinated water contains little or no Ca or Mg [2]. Calcium carbonate is added to Israeli desalinated water to increase stability, reduce corrosiveness and address nutrient needs, but the resulting range of Ca concentrations in desalinated seawater, 36–44 mg Ca/L [3], is lower than levels typically found in the water carrier supply. Mg is not as yet routinely added to desalinated water produced in Israel [2].

The potential health effects associated with consumption of desalinated water in Israel and elsewhere have not been fully evaluated. Reductions in intake of Mg and Ca due to the introduction of desalinated water could potentially increase risks for cardiac abnormalities, muscle cramps, hypertension, osteoporosis, kidney stones, type 2 diabetes, metabolic syndrome, elevated C-reactive protein, migraine headache, asthma and colon cancer [4-6]. In a recent study of health effects associated with the Mg content of drinking water in three Serbian cities, Rasic-Milutinovic et al. [5] found that diastolic blood pressure was lower in subjects from Pozarevac, a municipality with high Mg concentration in water (42 mg/L), than in subjects from two cities with lower water concentrations of Mg. Pozarevac subjects had the highest serum Mg (sMg) and Ca(2+)/Mg (sCa/Mg) levels. After adjustment for age, gender and body mass index, sMg levels were independent predictors of diastolic blood pressure and triglycerides, and sCa/Mg predicted glucose levels.

A number of ecological studies have reported associations between water hardness (a factor largely determined by Ca and Mg content) and mortality from ischemic disease or stroke [7]. A 2009 meta-analysis of case-control and cohort studies examining the possible relationship of water hardness to cardiovascular mortality concluded that the concentration of Mg in drinking water appears to be inversely related to cardiovascular mortality (pooled odds ratio of 0.75, $P < 0.001$) [8].

In reviewing health and safety aspects of water desalination, the World Health Organization stated that "in circum-

NWC = National Water Carrier

stances where a supply is moving from a source that has significant levels of calcium and magnesium to low-mineral desalinated water, it would be appropriate to consider remineralizing with calcium and magnesium salts" [9]. In light of evidence that there may be health risks from consumption of water with low mineral concentrations, we conducted a survey to obtain current data on intake of Mg and Ca by individuals in communities with different water sources. The aim of the study was to characterize the Mg and Ca intake from water and provide information needed to evaluate the potential benefits of adding these minerals to desalinated water.

SUBJECTS AND METHODS

A telephone survey of randomly selected adults living in four different Israeli communities was carried out during the summer of 2008. The sample was limited to Jewish adults to avoid confounding by potential cultural differences in water and food intake patterns. Sample communities included Kibbutz Maagan Michael, a northern Israel agricultural settlement with its own desalination plant; Hadera, a northern city supplied with water from the NWC; Eilat, Israel's southernmost city, supplied with desalinated water; and Beer Sheva, a southern city supplied with NWC water. Using nQuery Advisor Sample Size Software (Statistical Solutions Ltd, Cork, Ireland), a target sample size of 200 in each community was determined to be sufficient for detecting significant differences in Mg intake among communities. To meet this target, 2308 individuals were selected for the total initial random sample.

A modified 55 item Food Frequency Questionnaire was employed to assess intakes of water and water-based beverages (soda, fruit juices, tea, coffee) and of foods likely to contribute most to Mg and Ca intakes. Items included in the FFQ were identified as major sources of Mg and Ca based on 24 hour dietary recalls collected as part of the Israeli MABAT National Health and Nutrition Survey 1999–2001 [10]. Data were also collected on demographic information, use of water filters, working conditions, and use of nutritional supplements. Quality control of questionnaire responses included checking of frequency distributions and exclusion of outliers. If responses were missing for more than eight items in a FFQ, the FFQ was excluded from further analysis.

The survey was approved by the ethics committee of the Faculty of Agriculture at the Hebrew University of Jerusalem.

WATER AND BEVERAGE COMPOSITION

To determine the mineral composition of water consumed, water sampling was carried out in the four communities in the period September–November 2008 during routine monitoring by the National Laboratory of the Ministry of Health. The results were used in estimating Mg and Ca intakes from tap water, filtered water, and other water-based beverages. Although data were collected on home water filtration practices, Mg and Ca intakes from filtered water were not adjusted to reflect reductions in Mg or Ca content as there was insufficient information regarding the extent to which each filtration device reduces the mineral concentrations. For bottled water, Ca and Mg values were assigned according to the labeled content of the brand specified. If unspecified, the average of values from the three leading companies was used. Manufacturers of soft drinks and beer were contacted regarding the mineral composition of the water used during manufacture. For other beverages (tea, coffee, soup, syrup-based drinks) mineral values were calculated based on the type of water reported to be used and on the mineral content of added ingredients.

INTAKES OF BEVERAGES, MG AND CA

Questionnaire responses regarding the number of cups of beverages and servings of food consumed per day, week or month were converted to the daily intake basis. Mg and Ca intakes from beverages and from food were estimated using the converted questionnaire responses and the composition data described above. The proportions of each population with Mg or Ca intakes less than the estimated average requirement (the level estimated to satisfy the requirements of 50% of the population) [4,11] were estimated. Modeling was carried out to assess the potential impact of providing desalinated water to communities currently served by the NWC. The proportions of each population with Mg or Ca intakes less than the EAR were estimated to determine whether introduction of desalinated water in these communities could potentially have a negative effect on Mg or Ca status.

STATISTICAL ANALYSIS

Data were analyzed using STATA Version 10.0 (StataCorp, 4905 Lakeway Drive, College Station, TX, USA). Potential demographic differences among the four sample communities and differences in the proportions of individuals with Mg or Ca intakes less than the EAR were evaluated using Pearson's chi-square test. Potential differences in intakes of water, other beverages, and mineral intakes among communities were assessed using analysis of variance (ANOVA) and *t*-tests. The Bonferroni adjustment for multiple comparisons was made in assessing differences based on variables with more than two categories.

RESULTS

A total of 813 people, or 35% of the initial sample, was interviewed. Of the completed questionnaires, 24 (3%) were either incomplete or contained incoherent answers and were not

FFQ = Food Frequency Questionnaire

EAR = estimated average requirement

Table 1. Demographic characteristics of study populations

		Beer Sheva (n=200)	Eilat (n=195)	Hadera (n=198)	Maagan Michael (n=196)
Gender*	Males	91 (45.5)	86 (44.1)	90 (45.5)	92 (46.9)
	Females	109 (54.5)	109 (55.9)	108 (54.5)	104 (53.1)
Age*	< 50 yr	112 (56.0)	118 (60.0)	99 (50.0)	94 (48.0)
	≥ 50 yr	88 (44.0)	77 (40.0)	99 (50.0)	102 (52.0)

Values are presented as n (%)
*NS (chi-square test)

included at the analysis stage. Demographic characteristics of the individuals in the final sample population are shown in Table 1. There were no significant differences between the four study communities with regard to gender or age distribution.

WATER COMPOSITION

Desalinated water from Kibbutz Maagan Michael contained lower concentrations of Mg and Ca than water from Hadera and Beer Sheva, where the water supplies are from the NWC. The Mg content of waters was 0.8 mg/L in Maagan Michael, 17.4 mg/L in Eilat, 20.5 mg/L in Hadera and 18.5 mg/L in Beer Sheva. The Ca content of water was 34.0 mg/L in Maagan Michael, 39.5 mg/L in Eilat, 94.2 mg/L in Hadera and 50.7 mg/L in Beer Sheva.

The concentrations of Mg and Ca in water sampled in Eilat, a community supplied with desalinated water, were closer to concentrations in water from Hadera and Beer Sheva than from Maagan Michael. Further investigation revealed that water from the NWC is pumped in to meet water needs. Therefore, in analyses of intake data, Eilat's water supply was characterized as mixed rather than as desalinated.

WATER FILTRATION

In Maagan Michael, where all the tap water is desalinated, only 23.5% of respondents reported using filters of any kind, whereas in Beer Sheva and Hadera, the two "control" areas, there is much more extensive use of filters (44.5% and 47.6% respectively). In Eilat, where the water is mixed, 39% reported using filters.

MG AND CA INTAKES FROM NUTRITIONAL SUPPLEMENTS

A total of 41 individuals (5.2% of the total sample) reported use of supplements potentially containing Ca and/or Mg. Because the number of supplement users was relatively small, data on intakes from supplements were not included in estimates of total Mg and Ca intakes.

BEVERAGE INTAKES

Data on mean beverage intakes in each community are displayed in Table 2. Individuals in Hadera and Maagan Michael, the two northern study communities, had similar total water intakes (7.5 and 7.4 cups/day, respectively), and there was no significant difference between total beverage intakes in these communities (13.3 and 12.3 cups/day, respectively). Average intakes of total water were lower in the northern communities than in Eilat (9.4 cups/day, $P < 0.004$), Israel's southernmost (and generally hottest) city. The mean total beverage intake in Hadera (13.3 cups/day) was significantly lower than the mean intake in Eilat (15.8 cups/day, $P < 0.001$). The mean total beverage intake in Maagan Michael (12.3 cups/day) was lower than the mean intake in both Eilat (15.8 cups/day) and Beer Sheva (14.7 cups/day, $P < 0.001$).

Table 2. Beverage intake (cups/day)[1]

		Beer Sheva (n=200)	Eilat (n=195)	Hadera (n=198)	Maagan Michael (n=196)
Water	Tap or filtered	5.3 (0.4)	5.8 (0.5)	4.9 (0.4)	6.7 (0.4)[2]
	Bottled	3.2 (0.3)	3.6 (0.3)	2.6 (0.2)	0.6 (0.1)[3]
	Total	8.5 (0.4)	9.4 (0.4)	7.5 (0.3)[4]	7.4 (0.3)[4]
Other beverages		6.1 (0.3)	6.4 (0.4)	5.8 (0.3)	4.9 (0.2)[5]
Total beverages		14.7 (0.5)	15.8 (0.5)	13.3 (0.4)[6]	12.3 (0.4)[7]

[1]Values are means (SEM); other beverages included soda/carbonated water, fruit juice and fruit nectar, soft drink, regular and diet, carbonated and non-carbonated, syrup-based drink, water-based soup, tea and coffee. Milk was not included in the beverage list but was included in the food list.
[2]Significantly different from Beer Sheva and Hadera ($P < 0.05$)
[3]Significantly different from Beer Sheva, Eilat, and Hadera ($P < 0.0001$)
[4]Significantly different from Eilat ($P < 0.004$)
[5]Significantly different from Beer Sheva and Eilat ($P < 0.003$)
[6]Significantly different from Eilat ($P < 0.001$)
[7]Significantly different from Beer Sheva and Eilat ($P < 0.001$)

Although individuals in Hadera and Maagan Michael had similar mean total water intakes (7.5 and 7.4 cups/day, respectively), the proportions of intake from tap or filtered vs. bottled water were quite different. In Maagan Michael, most of the water consumed was tap or filtered water (6.7 cups/day), with very little average intake of bottled water (0.6 cups/day). In the other communities, mean intakes of tap or filtered water ranged from 4.9 to 5.8 cups/day, and mean intakes of bottled water ranged from 2.6 to 3.6 cups/day.

MG AND CA INTAKES FROM FOOD AND BEVERAGES

There were no significant differences in Mg or Ca intakes from food among the four communities [Tables 3 and 4]; all observed differences were largely due to differences in intakes of the minerals from water and other beverages.

As shown in Table 3, the mean total daily Mg intake in Maagan Michael was 387 mg, a level significantly lower ($P < 0.003$) than in Beer Sheva (451 mg), Eilat (460 mg) and Hadera (452 mg). The proportion of individuals in Maagan Michael with Mg intake below the EAR (30.6%) was higher than in the other communities, but the difference in proportions was significant only in comparison with the proportion

Table 3. Magnesium intake (mg/day)[1]

		Beer Sheva (n=200)	Eilat (n=195)	Hadera (n=198)	Maagan Michael (n=196)
Water	Tap or filtered	25 (1.8)	25 (2.0)	25 (1.9)	1 (0.1)[2]
	Bottled	15 (1.5)	16 (1.5)	13 (1.2)	3 (0.6)[2]
	Total	40 (1.8)	42 (1.9)	38 (1.8)	4 (0.6)[2]
Other beverages		92 (4.0)	90 (4.4)	91 (4.0)	71 (2.7)[3]
Food		320 (10.2)	329 (15.5)	323 (11.3)	312 (10.6)
Total intake		451 (11.8)	460 (16.8)	452 (13.0)	387 (11.3)[4]
% with intakes below the estimated average requirement (EAR)	Current water supply	21.0 (2.9)	21.0 (2.9)	16.7 (2.6)	30.6 (3.3)[5]
	Completely desalinated water supply (modeled)	28.0 (3.2)	29.7 (3.3)	26.3 (3.1)	30.6 (3.3)

[1]Values are means (SEM); other beverages include soda/carbonated water, fruit juice and fruit nectar, soft drink, regular and diet, carbonated and non-carbonated, syrup-based drink, water-based soup, tea and coffee. Milk was not included in the beverage list but was included in the food list.
[2]Significantly different from Beer Sheva, Eilat, Hadera ($P < 0.0001$)
[3]Significantly different from Beer Sheva, Eilat, Hadera ($P < 0.002$)
[4]Significantly different from Beer Sheva, Eilat, Hadera ($P < 0.003$)
[5]Significantly different from Hadera ($P < 0.05$)

Table 4. Calcium intake (mg/day)[1]

		Beer Sheva (n=200)	Eilat (n=195)	Hadera (n=198)	Maagan Michael (n=196)
Water	Tap or filtered	68 (4.8)	57 (4.5)	115 (8.7)[2]	57 (3.0)
	Bottled	40 (4.7)	39 (4.4)	30 (3.2)	8 (1.4)[3]
	Total	107 (5.5)	96 (5.0)	145 (8.0)[2]	65 (3.0)[3]
Other beverages		110 (4.8)	106 (6.2)	143 (6.9)[2]	77 (3.1)[3]
Food		697 (26.9)	752 (35.5)	729 (28.6)	685 (23.3)
Total dietary intake		913 (28.8)	954 (37.5)	1018 (32.6)	827 (24.5)[4]
% with intakes below estimated average requirement (EAR)	Current water supply	45.5 (3.5)	48.2 (3.6)	37.9 (3.4)	61.7 (3.5)[5]
	Completely desalinated water supply (modeled)	51.0 (3.5)	49.7 (3.6)	54.0 (3.5)	61.7 (3.5)

[1]Values are means (SEM); other beverages include soda/carbonated water, fruit juice and fruit nectar, soft drink, regular and diet, carbonated and non-carbonated, syrup-based drink, water-based soup, tea and coffee. Milk was not included in the beverage list but was included in the food list.
[2]Significantly different from Beer Sheva, Eilat, Maagan Michael ($P < 0.0001$)
[3]Significantly different from Beer Sheva, Eilat, Hadera ($P < 0.0001$)
[4]Significantly different from Eilat and Hadera ($P < 0.03$)
[5]Significantly different from Beer Sheva, Eilat and Hadera ($P < 0.05$)

of individuals with Mg intake below the EAR in Hadera (16.7%) ($P < 0.05$). The mean total daily Ca intake in Maagan Michael was 827 mg, a mean intake lower than in Beer Sheva (913 mg), and significantly lower ($P < 0.003$) than in Eilat (954 mg) and Hadera (1018 mg) [Table 4]. The proportion of individuals in Maagan Michael with Ca intake below the EAR (61.7%) was significantly higher than in the other communities (37.9–48.2%) ($P < 0.05$).

Results of modeling analyses to assess the likely impact of providing desalinated water to additional Israeli communities indicated that if desalinated water is substituted for NWC or mixed water, with no other changes in water intake patterns, the prevalence of Mg intakes below the EAR would range from 26.3 to 30.6% [Table 3], and the percent of individuals with Ca intake below the EAR would range from 49.7 to 61.7% [Table 4]. In this scenario, there would be no significant differences in percent of Mg or Ca intakes below the EAR among the four communities.

DISCUSSION

The main benefits of this study are that it characterizes patterns of water consumption in Israeli communities, provides key data on intake of bottled vs. tap water among Israelis, and allows estimates of Mg and Ca intakes from food vs. water. The study explores new ground in examining the potential effects of water desalination on Mg and Ca intakes, and provides preliminary evidence that individuals consuming desalinated water may be at greater risk than individuals consuming NWC water for Mg and Ca intakes below the EARs for these nutrients. It is possible that individuals with intakes of Mg and/or Ca below the EAR may be at risk for associated cardiac abnormalities, muscle cramps, hypertension, osteoporosis, kidney stones, type 2 diabetes, metabolic syndrome, elevated C-reactive protein, migraine headache, asthma and colon cancer [4-6], and may also be at greater risk for cardiovascular mortality due to low Mg intake [7,8].

A difference of about 20 mg Mg/L was found between tap water supplies in Maagan Michael, where all tap water is desalinated, and Hadera, where all tap water is from the NWC. The average Mg intake from beverages and food by residents of Maagan Michael, 387 mg/day, was significantly below average Mg intakes in Beer Sheva, Eilat and Hadera. The proportion of individuals with Mg intake below the EAR was significantly higher in Maagan Michael (30.6%) than in Hadera (16.7%). Modeling analyses indicate that the prevalence of low Mg intake would be relatively high in Beer Sheva (28%), Eilat (29.7%) and Hadera (26.3%) were desalinated water to be introduced into those communities, assuming that there was no associated change in beverage intake patterns.

Despite the addition of Ca to desalinated water, a difference of 60 mg Ca/L was found between tap water supplies in Maagan Michael and Hadera. Average Ca intakes from beverages and food in Maagan Michael (827 mg/day) were lower than in Beer Sheva, Eilat and Hadera, and the proportion of individuals with Ca intake below the EAR was significantly higher in Maagan Michael (61.7%) than in each of the other areas (49.7–54.0%). Results of modeling analyses indicate that the proportion of individuals with Ca intake below the EAR would increase if desalinated water was introduced into Eilat, Hadera and Beer Sheva, assuming that there is no associated change in beverage intake patterns.

Our findings indicate that Mg and Ca intakes may be significantly lower among individuals consuming desalinated water than among individuals consuming water from the NWC or mixed sources, assuming that there is no effect of water filtration on Mg and Ca intakes. The proportion of individuals with Mg and Ca intakes below the EAR is also lower when desalinated water is consumed in place of NWC water. These results suggest that supplementation of desalinated water with Mg, and further supplementation of desalinated water with Ca, may be beneficial for raising total Mg and Ca intakes in Israeli communities consuming desalinated water. Given the increasing dependence in Israel on desalinated water, larger studies covering a greater population are needed for monitoring and to provide vital information on the impact of desalination on Ca and Mg intakes. A long-term study could also provide data regarding the impact on health. Very recently, a pilot project to add Mg to desalinated water was approved by the Israeli government, and results of this project will be used for determining future policy on the addition of minerals to desalinated water.

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Capsule

Relative trends in hospitalizations and mortality among infants by the number of vaccine doses and age, based on VAERS, 1990–2010

Goldman and Miller investigated the Vaccine Adverse Event Reporting System (VAERS) database 1990–2010 and identified cases that specified either hospitalization or death among 38,801 reports of infants. Based on the types of vaccines reported, the actual number of vaccine doses administered, from 1 to 8, was summed for each case. Linear regression analysis of hospitalization rates as a function of the number of reported vaccine doses and patient age yielded a linear relationship with r2 ¼ 0.91 and r2 ¼ 0.95, respectively. The hospitalization rate increased linearly from 11.0% (107 of 969) for two doses to 23.5% (661 of 2817) for eight doses and decreased linearly from 20.1% (154 of 765) for children aged ‹ 0.1 year to 10.7% (86 of 801) for children aged 0.9 year. The rate ratio (RR) of the mortality rate for 5–8 vaccine doses to 1–4 vaccine doses is 1.5 (95% confidence interval 1.4–1.7), indicating a statistically significant increase from 3.6% (95% CI 3.2–3.9%) deaths associated with 1–4 vaccine doses to 5.5% (95% CI 5.2–5.7%) associated with 5–8 vaccine doses. The male-to-female mortality RR was 1.4 (95% CI 1.3–1.5). Their findings show a positive correlation between the number of vaccine doses administered and the percentage of hospitalizations and deaths. Since vaccines are given to millions of infants annually, it is imperative that health authorities have scientific data from synergistic toxicity studies on all combinations of vaccines that infants might receive. Finding ways to increase vaccine safety should be the highest priority.

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Eitan Israeli

"A coincidence is God's way of remaining anonymous"

Anonymous