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ORIGINAL ARTICLE

How Much Calcium Is in Your Drinking Water? A Survey of Calcium Concentrations in Bottled and Tap Water and Their Significance for Medical Treatment and Drug Administration

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Abstract *Introduction:* Different forms of water vary in calcium content. High divalent ion (i.e., Ca^{2+}, Mg^{2+}, etc.) concentration is deleterious to the absorption and efficacy of the bisphosphonate group of drugs in osteoporosis treatment. Water with high calcium concentration may also present an alternate pathway of calcium administration. In either case, knowing the actual concentration is critical. *Hypothesis:* The current paper is a surveillance study. We hypothesize that there is considerable variation in the calcium concentrations in the various water sources: tap water from US and Canadian cities of different regions and purified, spring, and mineral bottled waters. In addition, we hypothesize that the water filter removes a significant amount of minerals including calcium from the water. *Methodology:* Calcium concentrations in various city tap waters, as well as an assorted number of bottled waters, were determined through the direct inspection of scientific data. The effect of filtering was also determined by mineral analysis of mineral water directly before and after filtration. *Result:* The calcium concentration of water varies from 1 to 135 mg/L across the USA and Canada. Most spring waters were found to have a relatively low calcium concentration, with an average of 21.8 mg/L. Purified waters contain a negligible calcium concentration. Mineral waters, on the other hand, were generally found to contain higher calcium concentrations, an average of 208 mg/L of calcium. Filtration was found to remove a considerable amount of calcium from the water, removing 89% on average. *Conclusion:* Calcium concentration in water varied substantially from different sources in the USA and Canada. Bottled waters presented with concentrations of calcium covering a very large range. Certain tap and bottled waters present with concentrations of calcium sufficient to exhibit a deleterious effect on bisphosphonate treatment. Alternatively, certain waters may be used as a source of calcium that may provide over 40% of the recommended daily intake for calcium.

Key words bioavailability · bisphosphonate · calcium supplements · filter · water

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Introduction

Adequate calcium intake is essential for achieving peak bone mass and subsequent prevention of osteoporosis [1–6]. Conversely, inadequate calcium intake is a risk factor for osteoporosis in humans as well as a proven etiology of bone deficiency in animal models [7, 8]. A considerable segment of the population has suboptimal daily calcium intake [9]. Based on these findings, the NIH published a Consensus Statement on recommended calcium intake for maintenance of bone health [3]. In an analysis of the hypothesis that osteoarthritis has counteractive effects toward osteoporosis, calcium deficiency and secondary hyperparathyroidism is common despite broad awareness of calcium requirements [3].

The issue of the adequate amount of water intake is not clear. There is a commonly held precept that healthy adults should drink six to eight 8-oz glasses of water a day (1.4–1.9 L). A recent and extensive review of water intake found no data to support this recommendation [10]. The author concluded that most healthy adults could count caffeinated and mildly alcoholic drinks toward their total water intake. On this basis, the average water intake (excluding that in food) in healthy adults was 674–841 mL and approximately 1.7 L when including all drinking fluids (alcohol, coffee, tea, etc.) [12]. This was considered to be more than sufficient.

Böhmer et al. [11] stated that "calcium-rich mineral waters seem to offer an interesting, effective alternative to calcium supplementation from milk and dairy products because of their comparable or possibly even better bioavailability of calcium." Given that adequate calcium can be found in specific sources of water, physicians can recommend mineral water as a calcium supplement.

Calcium concentration in water is clinically relevant for patients with osteoporosis for reasons besides that of adequate calcium intake. The bioavailability of bisphosphonates, one of the first-line therapies for osteoporosis, is hampered by concomitant ingestion of calcium [12]. Bisphosphonates are bone antiresorptive agents used in the treatment and prevention of osteoporosis, hypocalcemia caused by malignancy, Paget's disease, and other bone resorptive conditions [13–18]. Although their exact mechanism of action is not clear, bisphosphonates inhibit osteoclastic bone resorption at the mineral surface and enhance osteoclast apoptosis (cell death) by inhibiting membrane synthesis. As a result, bisphosphonates arrest bone loss, leading to quantifiable increases in bone mass [19], and decrease the risk of low-energy fracture.

All bisphosphonates exhibit very low oral bioavailability because of their high degree of lipophilicity, as well as their tendency to complex with divalent cations (Ca^{2+}, Mg^{2+}, and Fe^{2+}) and form insoluble salts [12, 19]. Alendronate (Fosamax®) was found to have a bioavailability of only 0.76% in postmenopausal women and risedronate (Actonel®) 0.65% [20–22]. In a study of alendronate, ingestion of breakfast within 30–60 min reduced the bioavailability by 40%, concomitant ingestion with coffee or orange juice caused a 60% decrease, and concomitant ingestion of food and coffee almost completely abolished absorption. Similar studies with other bisphosphonates have mirrored these data [23].

As a result of this pharmacokinetic property, the manufacturers of bisphosphonates recommend taking the drugs with a glass of water at least half an hour before breakfast, when divalent cations should be at their lowest level. Indeed, the informational packages for oral bisphosphonates state that they should not be ingested with mineral water and/or calcium supplements [24, 25]. It is important for patients to understand which sources of water are low in calcium (for drinking with bisphosphonates) and which are high in calcium for use as a supplement.

Common sources of drinking water include tap and bottled waters. The bottled waters include purified, spring, and mineral waters. The current study presents the calcium concentrations in the tap waters in selected US and Canadian cities, as well as the calcium content in various forms of bottled waters. It also evaluates the effects of a water filter on the calcium content of mineral waters. The possible benefits as well as the adverse affects of mineral content in water sources are addressed.

Methods

Determination of calcium in tap and bottled waters

Tap-water calcium concentrations were obtained for six to seven representative large metropolitan centers in each of five geographic areas of the USA and select cities from Canada. The concentrations were directly accessed or calculated from water quality reports (or the US Environmental Protection Agency Consumer Confidence Reports for each city). It is notable that information regarding calcium in water is often unavailable for ready analysis. Federal regulations do not require listing the calcium concentration in the water quality report, leaving the dissemination and presentation of this information to the preference of the local authorities, water companies, or utilities.

Calcium concentration is sometimes omitted from the water quality report, whereas at other times, the data are presented as water hardness or $CaCO_3$ (calcium carbonate). $CaCO_3$ dissolves into Ca^{2+} and CO_3^{2-} in the presence of dilute acid [28] but not water. There is no significant difference in solubility between calcium carbonate and various water-soluble calcium salts once they are ingested [27, 28] and exposed to the acid environment in the digestive tract. Therefore, the calcium concentration can be calculated by multiplying the given $CaCO_3$ concentration by 0.40, the ratio of the mass of calcium to the mass of the compound. In the case that a local utility does not provide this information in their report, it is often, although not always, attainable by contacting the local water utility and directing a query to a water engineer.

Another issue that must be addressed regarding this study is the somewhat common lack of uniform mineral composition of the water within one city. A very important example would be Los Angeles, the second most populated city in the USA. This city provides four water quality reports for different parts of the city. Other localities have dealt with similar problems of data presentation by giving ranges or providing many values. In those cases, we used unweighted averages or medians of ranges as representations of data. In response to our inquiries with many water companies, utilities, and authorities, we were informed that, presently, there is no way to predict with significant accuracy what percentage of the population receives a certain kind of water from a certain source; furthermore, these waters are often mixed in an irregular fashion prior to distribution. The choices we have made for the presentation of data in a meaningful and comprehensible manner are footnoted for the specific instances in the tables.

Surveys of bottled waters were examined. The spring and mineral waters were partially selected based on popularity and partially at random; six were specifically selected on the basis of market share as inferred from the sales reports from two sources (Beverage Marketing

Corporation for the USA, and http://mineralwaters.org for Europe and other localities), whereas the other five were selected at random from a list of European bottled waters. Two of the purified waters were selected based on predominant popularity, whereas two were selected on the basis of data accessibility or availability. Although a larger quantity of purified water brands would have been preferable, there is a dearth of information regarding the calcium concentration in the purified water industry.

Water filter efficacy

The efficacy of a water filter in removing calcium was also studied. Seven bottles of Perrier®, a common mineral water with a considerable amount of calcium, were analyzed in three independent studies before filtration and after filtration through a separate Brita® filter for each bottle. The assays of calcium concentrations (Standard Methods for the Examination of Water and Wastewater) were performed by

Table 1. Calcium concentration in US and Canadian tap waters

Region	City	Calcium (mg/L)[a]		Percentage of Ca RDI[b]	Relative ranking
		Average[c]	Range		
United States					
Northeast	New York	18.8	5.4–83.3	1.9	5
	Philadelphia	67.3	33.6–103.6	6.9	24
	Nassau	12.9	0.1–24.8	1.3	3
	Delaware[a,d]	61	22–100	6.2	23
	Cleveland, OH	33	N/A	3.4	13
	Columbus[a]	47.6	39.6–50.8	4.9	18
	Pittsburgh[a,d]	53.2	27.2–79.2	5.5	20
	Average	42.0		4.3	
Midwest	Indianapolis	89.8	53–110	9.2	29
	Chicago	30.8	30.2–21.3	3.2	11
	Omaha[c]	57.6	39–90	5.9	22
	Wichita	24.4	N/A	2.5	8
	St. Paul	25	20–30	2.6	9
	Detroit	25	24–29	2.6	10
	Average	42.1		4.3	
Southwest	San Antonio	72	63–86	7.4	26
	Las Vegas	74	N/A	7.6	27
	Dallas[a]	47.2	28.4–89.2	4.8	19
	Houston[c]	38	37.1–38.8	3.9	16
	Oklahoma City[a,c]	57	24–90	5.9	21
	Phoenix[a,d]	131	82–180	13.5	33
	Average	81.1		8.3	
West Coast	Los Angeles	35	21–96	3.6	15
	San Francisco	16	4.0–31	1.6	4
	San Diego[a]	125.2	101.2–150	12.9	32
	San Jose[a]	97.5	58–192	10.0	30
	Portland[a]	34.4	N/A	3.5	14
	Seattle[d]	22	18–26	2.3	7
	Tacoma	74	N/A	7.6	28
	Average	57.7		5.9	
South	Jacksonville[a]	120	60–168	12.3	31
	Washington, DC	43.5	43–45	4.5	17
	Durham	11.3	N/A	1.2	2
	Nashville, TN[a]	30.4	N/A	3.1	12
	Memphis[a]	19.2	N/A	2.0	6
	Montgomery	8.2	2.54–12.4	0.8	1
	Miami[d]	68	24–112	7.0	25
	Average	42.9		4.4	
Total USA average		50.6		5.2	
Canada					
Ontario	Toronto	34	31.8–35.9	3.5	5
	Kitchener[c]	135.5	75.2–180	13.9	7
	Waterloo[c]	125.9	92.5–220	13.0	6
British Columbia	Vancouver[c]	1.4	0.93–2.59	0.2	1
Quebec	Montreal[d]	32	30–34	3.3	4
Nova Scotia	Halifax[a]	6.8	N/A	0.7	3
Total Canada average		48.8		5.0	

[a] Calcium concentration derived from data of hardness (calcium carbonate) concentration.
[b] Calculated for postmenopausal osteoporotic patient requirement: 1400 mg/day, drinking six 8-oz glasses of water a day.
[c] Unweighted averages of reported values.
[d] Median of the range.

Northland Laboratories. A total of 21 trials were performed with seven different bottles of water—three trials per bottle. A new filter was used for every trial. For each bottle, an average value was obtained based on the three trials.

Calculations

Calculations of the percentage of recommended intake supplied by each water source were based on a healthy adult recommended daily intake (RDI) of 1000 mg of calcium and the average water intake of 1.7 L [3, 10]. The calcium concentration of municipal tap waters was determined and presented in averages and ranges (where available).

Bottled and mineral water calcium concentrations were collected and classified into purified waters (from municipal aqueducts), spring waters (originating in a free-flowing spring), and mineral waters [originating from a free-flowing spring and containing >250 parts per million of total dissolved solids (TDS)]. No further analysis was performed on the purified waters, as these consistently contained a negligible amount of mineral content. The mineral and spring water calcium and magnesium concentrations were collected from the sources described above. Averages and standard deviations were calculated for spring water, mineral water, and a combined category of spring and mineral waters.

Results

Tap water

We surveyed the calcium concentration in tap water in the USA to determine their contribution to the recommended calcium requirements. We found substantial variability in tap water calcium concentrations. Table 1 presents select large American and Canadian cities classified by region. In the USA, tap water calcium concentrations varied from 8.3 mg/L in Montgomery, AL, to 131 mg/L in Phoenix, AZ. The average calcium concentration was 50.6 ± 29.4 mg/L, and the percentage of RDI of calcium satisfied by six 8-oz glasses per day varied from 0.85 to 13.5%, with an average of 5.2%. There was no statistically significant difference between regions.

Canadian cities were equally diverse: the tap water calcium concentrations varied from 1.4 mg/L in Vancouver

Table 2. Calcium concentration in bottled and mineral waters

Brand	Origin	Calcium (mg/L)[a]	Percentage of Ca RDI[b]	Sodium (mg/L)	Magnesium (mg/L)
Purified					
Dasani (Coca Cola)	USA	<10[c]	<1		
Acquafina (Pepsi Cola)	USA	0	0.0		
Penta	USA	0	0.0		
Sparkletts (Purified)	USA	0	0.0		
Spring water					
Great Bear	USA	1.3	0.1	1.7	1
Poland Spring	USA	4.1	0.4	1.5	1
Deep Rock	USA	5.2	0.5	N/A	60
Volvic	France	9.9	1.0	9.4	6.1
Duke	Belgium	10	1.0	5	6
Fiji	Fiji	17	1.8	0	13
Arrowhead	USA	20	2.1	12.1	3.5
Maxim's	Italy	20.2	2.1	3.9	1.6
Deer Park (MD)	USA	26.5	2.7	1.1	2.6
Zephyrhills	USA	58	6.0	5.1	3.9
Valvert	Belgium	67.6	7.0	1.9	2
Average		21.8	2.2	4.2	9.2
Mineral water					
Chaudfontaine	Belgium	65	6.7	44	18
Aix les Banes	France	72	7.4	14	38
Evian	France	78	8.0	5.5	23
Léberg	Belgium	112	11.5	10	47
Perrier	France	147	15.2	9	3.4
Eau de Source-Oliviers	France	157	16.2	14	21
Azur	Germany	177	18.2	176	29.9
San Pellegrino	Italy	208	21.4	43.6	55.9
Gerolsteiner Sprudel	Germany	347	35.7	119	108
Sanfaustino	Italy	414	42.6	17.4	17.2
Prince Noir	France	528	54.3	9	78
Average		208	21.4	42	40

[a] Data from http://www.mineralwaters.com.
[b] Calculated for postmenopausal osteoporotic patient requirement: 1400 mg/day, drinking six 8-oz glasses of water a day.
[c] Inferred from total dissolved solids, reported to be less than 10 mg/L.

Table 3. Calcium in Perrier® water before and after Brita® filtration

	Before filtration	After filtration
Calcium levels (ppm)	156	16.5
Avg. % remaining		10.6

to 135.5 mg/L in Kitchener. The corresponding RDI percentages varied from 0.15 to 13.9%. The average for Canada was 48.8 ± 53.2 mg/L. The average percentage of the daily requirement satisfied was 5.0%.

Bottled water

Within the bottled water category (Table 2), mineral waters demonstrated the highest average calcium concentration, 208.3 mg/L. Spring waters present with an average concentration of 21.8 mg/L. There is, however, some overlap in the ranges of spring and mineral waters: Valvert® spring water has a higher calcium concentration than Chaudfontaine® mineral water. There are thus exceptions to the general observation that waters with a greater concentration of TDS have a greater concentration of calcium. Purified bottled waters consistently contained negligible calcium concentrations. Of the mineral waters, Sanfaustino® and Prince Noir® brands have calcium concentrations that account for over 40% of the RDI. One glass per day would satisfy nearly 7% of the daily requirement.

Filtration

Studies of the effects of filtration using the Brita® filter revealed that the Brita® filter removed, on average, 89.4% of the calcium. There was variability of the Brita® function, with postfiltration concentration ranging from 0.8 to 30.3%. It is notable that the seven new filters used for the seven different trials present with significantly varied efficacy. In our current example, one specific sample retained over 38 times the calcium of the lowest sample. Both samples were filtered using two different previously unused filters from the same brand. The standard deviation of the percent remaining was 3.19. It is highly unlikely that this is an individual and unrepresentative manufacturing error because of the persistent variability throughout the seven trials. It may, however, be specific to the group of filters selected for our purposes. The filtration treatment left Perrier® water with a substantially lower calcium concentration, in the same range as tap and spring waters (Table 3).

Discussion

Calcium concentrations in water vary significantly according to the source. In most instances, US bottled spring and purified waters have similar calcium concentrations to tap water. Mineral waters, in general, and tap water in a few regions of the USA and Canada (Phoenix, Dallas, Jacksonville, and Kitchener) have much higher calcium concentrations. In terms of the recommended calcium intake, the highest calcium waters can contribute up to 13% (tap waters) and 54% (mineral waters) of the suggested daily calcium intake. All the purified water brands presented in the data have negligible concentrations of calcium.

The physician recommending calcium supplements may be met with poor compliance because of irritation or discomfort produced by calcium medications or general low compliance with any supplement in pill form [29]. If dietary sources also pose problems such as lactose intolerance, it may be advisable to prescribe certain specific waters, especially of the mineral kind with high calcium concentrations as a supplement. It may also be suggested to the patient that this kind of water be used as their primary drinking water. Mineral waters that are particularly attractive alternative means of calcium administration are the Sanfaustino® and Prince Noir® brands, which are high in calcium and have a relatively low Na^+ content.

Whereas some waters may be useful as a source of calcium, the same waters have the potential to inhibit bisphosphonate absorption. The addition of ionized magnesium increases the divalent ion binder by approximately 20%, further compounding the potential interference with bisphosphonates. Unfortunately, Merck and Procter & Gamble report that they have no specific data regarding the maximum amount of calcium that may be ingested without exerting adverse affects on the bioavailability of their bisphosphonate drugs. No study performed to date suggests a specific upper limit of calcium intake for bisphosphonate absorption.

It is important that physicians are aware of the mineral content of tap water in their regions. Drinking water may contribute significantly to the daily calcium intake for patients with calcium-deficient diets. The caution against ingesting bisphosphonates with mineral water should be extended to tap waters in some North American cities. In such cases, ingestion of bisphosphonates with specific bottled spring or purified waters would have less potential interference with absorption.

The Brita filter was shown to remove a considerable amount of calcium from water. Any water put through the Brita filter cannot be considered a viable source of calcium, as was demonstrated by the decrease in the calcium concentration of Perrier water. Conversely, even waters with a high concentration of calcium would not inhibit bisphosphonates after filtration through the Brita system.

There is a lack of experimental evidence regarding the specific or approximate maximum calcium intake that would not interfere with bisphosphonate absorption. True limits need to be established. The various water sources utilized by patients potentially provide a broad range of calcium concentrations. The medical team should determine the calcium concentration in their local water supply and available bottled water to limit calcium when prescribing bisphosphonates and maximize the calcium at other times to help meet the daily requirement.

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