Absorbability and utility of calcium in mineral waters

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ABSTRACT

Background: Calcium intake in North America remains substantially below recommended amounts. Bottled waters high in calcium could help close that gap.

Objectives: The objectives were to summarize and integrate published absorbability and biodynamic data concerning high-calcium mineral waters and to combine these data with hitherto unpublished analyses from my laboratory.

Design: The usual library database was searched. The absorbability of calcium from a high-mineral water labeled with tracer quantities of $^{45}$Ca was measured in human volunteers as a part of an otherwise low-calcium test meal. Published reports that used differing load sizes and meal conditions were harmonized by making corrections based on published calcium absorbability data.

Results: All the high-calcium mineral waters had absorbabilities equal to milk calcium or slightly better. When tested, all produced biodynamic responses indicative of absorption of appreciable quantities of calcium (ie, increased urinary calcium, decreased serum parathyroid hormone, decreased bone resorption biomarkers, and protection of bone mass).


KEY WORDS Calcium, calcium absorption, mineral water, calcium bicarbonate, calcium sulfate, bone resorption

INTRODUCTION

It is generally recognized that an adequate calcium intake is important for skeletal health (1, 2) and that calcium may be beneficial to several nonskeletal body systems as well (3). As a result, where regulations have permitted, food and beverage manufacturers have marketed a still-growing variety of calcium-fortified products. At the same time a corresponding interest has occurred in naturally calcium-rich mineral waters as potentially useful sources of the nutrient. Several studies have reported on the bioavailability of the calcium in such waters (4–9), and one small meta-analysis was published that contains data published through 1998 (10). In general, the reports indicate good bioavailability for the calcium in high-calcium mineral waters, but the studies to date were done under a variety of conditions and used different test loads and various endpoints. Hence, it has been difficult to formulate a single evaluation that adequately summarizes the nutritive value of the wide variety of waters as a group.

The purposes of this report were 1) to pull together the published absorbability data available through 2005, paying particular attention to test conditions and load sizes and adding previously unpublished data from my laboratory; 2) to formulate, insofar as the data permit, an overarching evaluation of the waters as a group; and 3) to point to possibly important differences in waters relating to the counter-ion accompanying their calcium.

SUBJECTS AND METHODS

Literature search

The published medical literature was searched for all articles indexed under the terms “mineral water,” “calcium,” “calcium absorbability,” “calcium bioavailability,” and “mineral water and bone.” In addition, the reference lists of all identified articles, plus the meta-analysis of Böhmer et al (10), were perused for citations that might have been missed by the literature search. In general, the articles identified fell into 3 categories: 1) studies in which calcium absorption was quantified by using calcium isotopic tracers or which contained evaluable data for estimating absorption from postabsorptive serum tracer concentrations; 2) a single study in which calcium isotopes were used and serum concentrations were reported, but fractional absorption was not estimated; and 3) biodynamic studies that reported effects of ingestion of calcium-rich mineral waters on urinary calcium, on concentrations of calcium regulatory hormones and bone remodeling biomarkers, and on bone density.

Previously unreported calcium absorbability results

My laboratory measured the absorbability of the calcium in a previously untested water (Sanfaustino; Societa Europa Ricerche Mediche, Milan, Italy) by using methods identical to those used for another Italian high-calcium mineral water (5). Briefly, the test water was labeled with a submicrogram quantity of $^{45}$CaCl$_2$ and allowed to equilibrate, sealed, for 17 h at 3 °C. The calcium content of the test water was verified in my laboratory by direct measurement, by using atomic absorption spectrophotometry. The test water was ingested at the midpoint of a low-calcium breakfast meal in adult women, and the absorption

References

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2 Supported by Creighton University Research Funds and by Societa Europa Ricerche Mediche, Milan, Italy.
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fraction was calculated from measured values of the ingested tracer in serum calcium (11, 12). This study involved human subjects and was approved by the Creighton University Institutional Review Board. Each subject gave written consent. Relevant test conditions were as set forth in Table 1.

RESULTS

Bioavailability studies

All the identified studies in which calcium tracer-based methods were used for measuring calcium absorption fraction are assembled in Table 1. It lists the labeled calcium content of the waters, the principal anion associated with the water’s calcium, the load size at which absorption was tested, and the test condition (ie, on an empty stomach without food or as a part of a standardized test meal). Most pertinently, the reported (or calculated) absorption fraction for each study is given (Table 1). Note that the study by Bacciottini et al (4) reported an absorption fraction of 0.196, not the 0.464 fraction presented in Table 1. The reason for the difference is that Bacciottini et al (4) used an inappropriately small value for the volume of distribution of the absorbed tracer, ie, 15% of body weight or ≈1.0 g Ca. Although this factor provides an approximation of the quantity of calcium in extracellular fluid, it ignores the fact that tracer calcium in blood equilibrates rapidly with a substantially larger mass of calcium than that in extracellular fluid water (eg, calcium on vascular surfaces in bone). Extensive experience in my laboratory, summarized elsewhere (11, 12), shows that that the virtual “volume” of distribution at the typical sampling time is roughly 2.3–2.4 g Ca in an adult of average size, and accordingly the value reported by Bacciottini et al (4) has been elevated by a factor of 2.36 to make it comparable with reports of studies using a more accurate volume of distribution for the tracer.

It is well established that absorption fraction varies inversely with the logarithm of load size (13). Hence, direct pooling of the data in Table 1 for studies spanning a ≥2-fold range in load sizes is not useful. However, Figure 1 helps in that respect, because it plots the absorption fraction for each of the covered studies both as a function of load size and against extensive historical data for milk calcium studied over a wide range of intake loads (13) (RP Heaney, unpublished observations, 1998). The error bars for the individual studies are 2 SEMs to better display the CIs for their respective estimates and to assist visually in appreciating the extent of overlap with expected values (Figure 1).

A distinction is also made in Figure 1 (as does Table 1) among studies in which the water was ingested either as part of a standardized test meal or on an empty stomach without additional food. It has been noted elsewhere that calcium absorption is improved when the calcium source is ingested with food (14). The data assembled here are consistent with that experience. The study by Couzy et al (8) was performed without additional food, and, in the study by van Dokkum et al (6), mineral water bioavailability was assessed twice, once by itself and once with a pasta-containing meal. Mean absorbability at fasting was ≈20% lower than absorbability with coingested food. Comparable data with and without food are not available for Couzy et al (8), but, as evident in Figure 1, measured absorption in that study was less than predicted for milk calcium ingested at the same load (but as part of a standardized meal).

Three of the published studies tested milk and mineral water in a crossover design (4, 5, 8) and at comparable calcium loads and meal conditions. They permit, hence, a more secure estimate of the absorbability of the mineral water source relative to milk. The pertinent data from those studies are summarized in Table 2, and

### TABLE 1
Studies of calcium absorbability by using calcium isotopic tracers

<table>
<thead>
<tr>
<th>Reference</th>
<th>Brand</th>
<th>Calcium content mg/L</th>
<th>Anion</th>
<th>Calcium load mg</th>
<th>Meal</th>
<th>Subjects</th>
<th>AbsFx'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heaney and Dowell</td>
<td>Sangemini</td>
<td>322</td>
<td>HCO$_3^-$</td>
<td>100</td>
<td>Yes</td>
<td>18</td>
<td>0.475</td>
</tr>
<tr>
<td>Heaney and Dowell</td>
<td>Sanfaustino</td>
<td>420</td>
<td>HCO$_3^-$</td>
<td>200</td>
<td>Yes</td>
<td>15</td>
<td>0.402</td>
</tr>
<tr>
<td>Bacciottini et al</td>
<td>Uliveto</td>
<td>202</td>
<td>HCO$_3^-$</td>
<td>130</td>
<td>Yes</td>
<td>27</td>
<td>0.464</td>
</tr>
<tr>
<td>van Dokkum et al</td>
<td>Ferrarelle</td>
<td>440</td>
<td>HCO$_3^-$</td>
<td>180</td>
<td>Yes</td>
<td>12</td>
<td>0.461</td>
</tr>
<tr>
<td>Couzy et al</td>
<td>Contrex</td>
<td>467</td>
<td>SO$_4^{2-}$</td>
<td>248</td>
<td>No</td>
<td>9</td>
<td>0.236</td>
</tr>
<tr>
<td>Wynkel et al</td>
<td>Not specified</td>
<td>467</td>
<td>SO$_4^{2-}$</td>
<td>200</td>
<td>Yes</td>
<td>12</td>
<td>0.361</td>
</tr>
</tbody>
</table>

*AbsFx', absorption fraction. All values are x ± SEM.*

![Figure 1](https://academic.oup.com/ajcn/article-abstract/84/2/371/4881820/figure1)
for each study the mean quotient of measured calcium absorbability from water divided by that from milk is given. All 3 are close to a value of unity (identical absorbability), and the weighted mean ± SEM quotient for the 3 studies combined is 1.084 ± 0.043 (0.10 > P > 0.05).

One additional tracer-based study (9) compared a calcium-rich mineral water with milk, but reported absorption fraction for neither source, and studied the 2 at different load sizes (62 and 250 mg for water and milk, respectively). Those investigators reported higher blood concentrations of the calcium isotope for the mineral water than for milk, overall, but that outcome is to be expected from such a difference in load sizes. No further quantitative conclusions are possible from those data.

**Biodynamic studies**

Several studies reported effects of high-calcium mineral waters on urinary calcium, on calciotropic hormone concentrations, and on bone remodeling biomarkers (15–24). For the most part those studies were of several weeks’ or months’ duration and showed that calcium ingested in the form of mineral waters produced qualitatively similar effects to calcium ingested as supplements or as food sources. Specifically, high-calcium mineral waters give semiquantitative evidence of absorbability by elevating urinary calcium excretion (15, 25) and by reducing serum parathyroid hormone (PTH) (19, 22–24) and bone remodeling biomarkers (17–20, 23, 24). In addition, habitual use of high-calcium mineral waters was reported to be associated with higher spine bone mineral density (26, 27) and with reduced postmenopausal bone loss (28). Those studies do not permit truly quantitative estimates of absorbability, per se, but they constitute evidence of benefit from the calcium provided by the high-calcium mineral waters and hence presumptive evidence of absorbability.

One biodynamic study was of particular interest. Guillemant et al (24) compared rehydration in endurance cyclists by using low- and high-calcium mineral waters. After 1 h of cycling at 80% maximal oxygen uptake, serum PTH had tripled in cyclists rehydrated with low-calcium water but remained essentially unchanged in cyclists rehydrated with high-calcium water. Serum carboxyterminal telopeptide was also unchanged in cyclists receiving the high-calcium water but increased by ≈50% in cyclists receiving rehydration from the low-calcium water. Bone resorption, for which carboxyterminal telopeptide is a marker, is known to be rapidly responsive to changing serum PTH concentrations, and in this situation an acute calcium stress [calcium lost in perspiration (29)] was immediately countered by increased calcium release from bone in cyclists receiving rehydration from a low-calcium water. The high-calcium water, apparently, was able to offset the sweat calcium losses and, thereby, to prevent the rise in parathyroid hormone secretion.

**DISCUSSION**

As is evident from the data of Figure 1 and Table 2, the absorbability of the calcium in all mineral waters tested to date is comparable to the absorbability of calcium in milk when studied under similar conditions. This is consistent with the conclusion reached by Böhmer et al (10) for data published through 1998. The counter-ion in most of the waters tested was bicarbonate, but data are available for 4 waters in which the counter-ion is sulfate. In one (6), the absorbability was less than that reported by other investigators for bicarbonate-containing waters. But it is doubtful that this is a reflection of the absorbability of calcium sulfate, per se. A crossover comparison with milk in the same study (Table 2) showed no difference relative to milk calcium. Hence, the somewhat lower performance for this source must be a reflection of methodologic issues or because, in that study, the calcium sources were tested without food (or both).

Also, the study by Wynckel et al (7) directly compared a high-sulfate water with low-calcium waters that had been enriched by the investigators with calcium chloride and found no difference in the absorbability of calcium at the same ingested load for waters with these different anions. In addition, Guillemant et al (18), testing a high-sulfate water (Talians; 596 mg Ca/L), found changes in PTH and in resorption biomarkers somewhat larger than those produced by tricalcium phosphate ingested at the same load, indicating absorbability at least as high as for that salt. Finally, it may be noted that calcium sulfate itself was shown in other matrices to have inherently good absorbability. It was tested both as an additive to white bread (30) and as the coagulant in calcium-set tofu (31), in both circumstances it exhibited good absorbability.

Thus, it seems safe to conclude both that the calcium in high-calcium mineral waters is highly absorbable and that the counter-ion has no appreciable effect on absorbability. However, this is not to say that sulfate- and bicarbonate-containing waters are otherwise equivalent. Limited evidence indicates that, for the same ingested calcium load (and hence the same absorbed calcium), the high-sulfate waters produce a greater elevation of urinary calcium (25), ie, that they, therefore, exhibit lower bioavailability (as contrasted with simple absorbability). Consistent with this conclusion is a report that high-bicarbonate waters are more effective in reducing serum concentrations of PTH and bone resorption biomarkers (19), as well as evidence indicating that, at least acutely, high bicarbonate intakes reduce urinary calcium and promote positive calcium balance (32, 33).

It might seem, therefore, that high-bicarbonate water is to be preferred over high-sulfate water, other things being equal. However, examination of the array of calcium contents of the principal high-calcium waters on the world market shows that many of the waters with calcium content above the median have sulfate as the principal counter-ion. Hence, “other things” are not quite equal, and it is possible that the higher calcium content of the high-sulfate waters offsets any difference in bioavailability.

One possible limitation of the studies covered in this review is that all used an extrinsic isotopic tracer. Doing so assumes that the isotope added to the water as a dissociated ionic species exchanges completely with the various other calcium species that may be present in the water. Failure of the tracer to equilibrate fully, in applications such as those reported here, would result in overestimation of absorbability, as I have shown for other sources (34).

**TABLE 2**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Brand</th>
<th>Subjects</th>
<th>Water/milk$^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heaney and Dowell (5)</td>
<td>Sangemini</td>
<td>18</td>
<td>1.129 ± 0.0565</td>
</tr>
<tr>
<td>Bacciottini et al (4)</td>
<td>Uliveto</td>
<td>8</td>
<td>1.093 ± 0.127</td>
</tr>
<tr>
<td>Couzy et al (8)</td>
<td>Contrex</td>
<td>9</td>
<td>0.985 ± 0.070</td>
</tr>
<tr>
<td>Weighted $\bar{x}$</td>
<td></td>
<td></td>
<td>1.084 ± 0.043</td>
</tr>
</tbody>
</table>

$^1$ All values are $\bar{x}$ ± SEM.
The standard method of validating this assumption is to compare the results of extrinsically labeled products with intrinsically labeled sources (35). Unfortunately, that is not feasible with natural calcium-rich waters, because prior introduction of iso-
tope into the geologic formations that are the sources of the calcium in these waters is not possible. However, substantial rea-
ssurance that labeling is adequate in this instance may be pro-
vided by the complementary results reported from the bio-
dynamic studies summarized in this review (15–24). Because the biodynamic methods are less sensitive than tracer-based mea-
surement, the fact that these waters elevate urinary calcium de-
tectably and reduce parathyroid hormone and resorption biomar-
kers measurably indicates at least that their calcium is suf-
39. Aalto JM, Aro A, Englund G, Tapani P. Bioavailability of calcium from tofu as compared with milk in premeno-
42. Aparicio C, Orlandi G, Gonnelli S, et al. Effect of calcium supple-
48. Guillemin J, Accaric C, de la Guerinière V, Guillemin S. Calcium in mineral water can effectively suppress parathyroid function and bone resorp-
50. Brandoli M, Guerriqui L, Boire Y, Roupe G, Bertiere MC, Beaufrere B. Higher calcium urinary loss induced by a calcium sulphate-rich min-
51. Wynckel A, Hanrotel C, Wuillai A, Chanard J, Boute D, Brazier M, de la Guerinière V, de Vernejoul MC. Biological effects of drinking-water mineral composi-
52. Authors C, authors C, authors C. Effect of mineral water consumption on potentially account for a substantial fraction of total daily calcium intake (36, 37) and hence can help close the gap between recommended and actual calcium intakes (1), such a calcium source functions much like a supplement; ie, it basically provides a single nutrient (or at most 2 in the case of the bicarbonate-rich waters). By contrast, milk, the comparator source most widely used to evaluate the bioavailability of other calcium sources, provides, in addition to its calcium, a broad array of other nutrients important for total body and skeletal health.
53. The author has no conflict of interest with respect to commercial entities producing mineral waters.
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