The Effect of the Alkali Load of Mineral Water on Bone Metabolism: Interventional Studies¹,²

Peter Burckhardt*  
Clinique Bois-Cerf, Lausanne, Switzerland

Abstract
Alkali supplements decrease bone resorption and increase bone mineral density. Alkali diets also lower bone resorption. Mineral waters alone could have such an effect. In several subsequent studies in humans, bicarbonate-rich alkali mineral waters with low potential renal acid load values were shown to decrease bone resorption markers and even parathyroid hormone levels. This effect seems to be stronger than that of acidic calcium-rich mineral waters and could also be demonstrated in calcium sufficiency. J. Nutr. 138: 435S–437S, 2008.

Introduction and Discussion
The impact of an alkali load on bone health has been demonstrated in humans mainly by 2 studies. In the first (1), 60–120 mEq of oral K-bicarbonate improved calcium balance in healthy postmenopausal women. In the second study (2), 30 mEq daily of oral K-citrate given over 1 y improved bone mineral density (BMD)³ significantly in postmenopausal women with low BMD, whereas 30 mEq daily of K-chloride decreased BMD. It could be concluded from these studies that daily supplementation with 1 or the other of the 2 alkali supplements might be advisable for population-targeted interventions. But it is unlikely that such a regimen would meet high adherence over the long term in patients at risk for osteoporotic fractures, outside a research protocol.

Therefore, it seemed interesting to us to examine the question of whether an alkali load by natural nutritional means can influence bone metabolism. For this a series of interventional trials have been performed in human volunteers under variable dietary conditions. They are summarized in Table 1. After the demonstration by a short-term study that diets that are different in their alkali load but not in their calcium content have different effects on bone resorption markers (3), it became evident that mineral waters represent a practical vector of nutritional alkali. Indeed, in that short-term study in normal volunteers on a very strict diet, mineral water contributed essentially to the nutritional alkali load.

In general, mineral waters are recommended in the prevention of osteoporosis only because of their calcium content. Indeed, the calcium in mineral water immediately lowers parathyroid hormone (PTH) and bone resorption markers (4). The long-term effect of calcium in mineral water on bone resorption was also demonstrated by a controlled study (5) but in women who were on a low calcium intake. This positive result could have been expected because any calcium supplementation in such conditions will lead to an improved calcium metabolism. But the eventual benefit of an alkali load provided by mineral water needed to be assessed. This was done by some interventional trials.

For quantifying the alkali load of a mineral water, the content of bicarbonate was used as an indirect parameter. As a biologically weak anion, bicarbonate decreases the acid load. Calcium in mineral waters is most frequently associated with sulfates. There is a significant correlation between calcium and sulfate in mineral waters, as discussed below, and only a few waters, especially those rich in bicarbonate, deviate from this rule. These considerations led to further analysis of the results of these trials and to the use of potential renal acid load (PRAL) instead of bicarbonate. PRAL assesses directly the content of the acidifying or alkalizing components of food. The more negative the PRAL, the more alkali the food. PRAL values were calculated with the formula of Remer and Manz (6), adapted to mineral waters. The original PRAL formula could not be applied to mineral waters because of the sulfates. In food, sulfates stem from cysteine and methionine, which are consumed with dietary proteins. In mineral waters, where sulfates are in solution, the molecular weight and the resorption rate of sulfate alone have to be taken into account and not those of the amino acids stemming from dietary proteins (T. Remer, personal communication, 2007).

In the above-mentioned controlled study (3), significant inhibition of bone resorption was obtained with a special diet and 2 L of a mineral water providing 4868 mg bicarbonate and a PRAL of −124 mEq/d, whereas the control diet containing the

---

¹ Published in a supplement to The Journal of Nutrition. Presented as part of the Second International Acid-Base Symposium, Nutrition–Health–Disease, held in Munich, Germany, September 8–9, 2006. Financial support for this symposium was provided by Protina Pharmaceutical Company. Guest Editors for the supplement publication were Thomas Remer and Juergen Vormann. Guest Editor disclosures: J. Vormann is a consultant to Protina Pharmaceutical Company. T. Remer received an unrestricted research grant from Protina Pharmaceutical Company.

² Author disclosure: P. Burckhardt, no conflicts of interest.

³ Abbreviations used: BMD, bone mineral density; CTX, C-telopeptides; PRAL, potential renal acid load, a value for acid/alkaline balance in foods, calculated as PRAL = [0.00049 SO₄ (mg)] + [0.027 Cl (mg)] + [0.037 P (mg)] − [0.021 K (mg)] − [0.026 Mg (mg)] − [0.0413 Na (mg)] − [0.013 Ca (mg)]; PTH, parathyroid hormone.

⁴ To whom correspondence should be addressed. E-mail: p_burckhardt@bluewin.ch.
same amount of calcium, protein, salt, and energy and a less alkaline mineral water had no such effect. Whether this inhibition of bone resorption was caused by the increased bicarbonate or potassium intake could not be determined. Both are reported to have a positive effect (7), but the effect of potassium on calcium excretion is linked to potassium in the urine (8), and this was not elevated in this study. In any case, this short-term study showed that it was possible to decrease bone resorption by a nutritional alkali load.

However, in this particular study the diet was strictly controlled and could not be applied to a longer trial. For a long-term trial and for the prevention of osteoporosis, it would be easier to propose a given mineral water. Mineral waters have a prolonged metabolic effect. When 1 L is consumed during the day, pH and calcium content of the fasting urine of the next morning are still increased, depending on the bicarbonate and calcium content of the consumed water (M. Jeanneret-Ramos and P. Burckhardt, unpublished data). This explains why the consumption of a bicarbonate-rich mineral water in a study over 4 wk decreased the bone resorption markers in the 24-h urine by 25%. Calcium did not rise despite the increased calcium intake, another sign of probably improved calcium balance. Interestingly, a calcium-rich water used as control, which increased urinary calcium excretion by 31%, had no effect on bone resorption (9). In other words, the bicarbonate-rich water lowered the markers of bone resorption despite the fact that it contained less calcium than the control water. The high sulfate content of the latter might have contributed to the extent that it eventually enhanced renal calcium losses. The observed effect of the bicarbonate-rich water on bone resorption could also be caused at least partially by the higher potassium content in the mineral water. The potassium concentration was 50 mEq/L, but the urinary potassium excretion did not increase above that on the control water.

This advantage of an alkaline, bicarbonate-rich water could be further demonstrated when such a water was compared with a water that contained the same high amount of calcium but was acid, even in a situation of calcium and estrogen sufficiency (10). Although the latter had no effect on bone resorption over 4 wk, the bicarbonate- and calcium-rich water significantly decreased the bone resorption markers C-telopeptides (CTX) by 16% and PTH by 17%. This could be explained by the high intake of bicarbonate (3.258 g/d) and the important difference in PRAL. In addition, the concentration of sulfates was high in the acid water, which reportedly has a calciuric effect. This may have prevented a beneficial effect of the calcium on bone resorption, but urinary calcium excretion did not increase more in this group. Therefore, it could not be confirmed that sulfates enhance calcium excretion.

These studies have shown that alkali, bicarbonate-rich mineral waters, especially waters with a strongly negative PRAL value, decrease bone resorption, even when compared with mineral waters with a higher calcium content, and even in the situation of a sufficient calcium intake. This could lead to the recommendation that certain mineral waters that contain calcium and bicarbonate, i.e., calcium-rich waters with a strongly negative PRAL, can contribute to the prevention of bone loss.

A partial demonstration of that was made by a study (11) in which a bicarbonate- and calcium rich water decreased bone resorption markers and PTH, whereas the control water, rich in calcium, had no such effect. But this study was performed in calcium-deficient postmenopausal women on a calcium intake of only 400 mg/d. In such a situation, the mineral water rich in calcium only should have a beneficial effect. This was not the case because it was extremely rich in sulfates and had an exceptionally high PRAL value.

The results obtained with mineral waters must be sufficiently analyzed with respect to the other components and not only to calcium and bicarbonate. Potassium plays a role because it decreases calcium (8), but its concentration is usually low in mineral waters. Sulfates should also be considered as acid components in addition to the acid or alkali load expressed by PRAL.

It has to be kept in mind that the PRAL values do not include bicarbonate because of its quick metabolization. When the PRAL values of mineral waters are calculated, it first appears that they are positive in waters with a high concentration of sulfates. The effect of sulfates may counterbalance the effect of calcium because sulfates are reported to increase calcium excretion in animals. In humans, the reports are conflicting (12,13), but even if such a calciuric effect exists, it was not seen in the studies presented here. It must at least be assumed that high concentrations of sulfates may counterbalance the beneficial effect of calcium, but not totally, otherwise a calcium- and sulfate-rich water would not have shown beneficial effects in calcium deficiency (5). In addition, there is a significant positive correlation between the calcium and the sulfate concentration in mineral waters ($P < 0.001$ in 21 randomly chosen European mineral waters), which

<table>
<thead>
<tr>
<th>Subjects (reference)</th>
<th>Duration</th>
<th>Brand of mineral waters</th>
<th>Dietary intake</th>
<th>Total intake</th>
<th>PRAL of mineral waters</th>
<th>Effect on urinary CTX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca-deficient osteoporotics (5)</td>
<td>6 mo</td>
<td>Talians</td>
<td>290</td>
<td>1530</td>
<td>596</td>
<td>566</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Placebo water</td>
<td>71</td>
<td>8</td>
<td>12</td>
<td>546</td>
</tr>
<tr>
<td>Young male volunteers (3)</td>
<td>4 d</td>
<td>Vichy Celestine</td>
<td>3245</td>
<td>2784</td>
<td>180</td>
<td>1713</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Badoit</td>
<td>1410</td>
<td>3840</td>
<td>400</td>
<td>1308</td>
</tr>
<tr>
<td>Young female volunteers (9)</td>
<td>4 wk</td>
<td>Quilazac</td>
<td>2528</td>
<td>215</td>
<td>361</td>
<td>1040</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contrex</td>
<td>605</td>
<td>1781</td>
<td>728</td>
<td>1040</td>
</tr>
<tr>
<td>Ca-deficient postmenopausal women (11)</td>
<td>4 wk</td>
<td>Ferarelle</td>
<td>2179</td>
<td>4</td>
<td>606</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Antica Forca</td>
<td>282</td>
<td>1551</td>
<td>560</td>
<td>400</td>
</tr>
<tr>
<td>Young female volunteers (10)</td>
<td>4 wk</td>
<td>Knyczanca</td>
<td>3258</td>
<td>14</td>
<td>822</td>
<td>965</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adelbodner</td>
<td>437</td>
<td>1740</td>
<td>780</td>
<td>965</td>
</tr>
</tbody>
</table>

1 Mineral water and diet together: -123.9 vs. -6.7 mEq/d.
2 Compared with control group.
contributes to confounding results. A few exceptional waters have a high calcium and a relatively low sulfate concentration but are rich in bicarbonate, such as the French Quezac and the Polish Krynica- zanka waters. These waters may be of particular interest. Considering all that, it appears that alkali mineral waters with a low PRAL value and a high content of bicarbonate exert an inhibitory effect on bone resorption that exceeds the effect of mineral waters that are only rich in calcium.

**Literature Cited**


