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Review

Milk and Acid-Base Balance: Proposed Hypothesis versus Scientific Evidence

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Key words: acid-base equilibrium, acid excretion, bone mineral density, bone or bones, metabolic acidosis, urine

Recently the lay press has claimed a hypothetical association among dairy product consumption, generation of dietary acid, and harm to human health. This theoretical association is based on the idea that the protein and phosphate in milk and dairy products make them acid-producing foods, which cause our bodies to become acidified, promoting diseases of modern civilization. Some authors have suggested that dairy products are not helpful and perhaps detrimental to bone health because higher osteoporotic fracture incidence is observed in countries with higher dairy product consumption. However, scientific evidence does not support any of these claims. Milk and dairy products neither produce acid upon metabolism nor cause metabolic acidosis, and systemic pH is not influenced by diet. Observations of higher dairy product intake in countries with prevalent osteoporosis do not hold when urban environments are compared, likely due to physical labor in rural locations. Milk and other dairy products continue to be a good source of dietary protein and other nutrients.

Key teaching points:

- Measurement of an acidic pH urine does not reflect metabolic acidosis or an adverse health condition.
- The modern diet, and dairy product consumption, does not make the body acidic.
- Alkaline diets alter urine pH but do not change systemic pH.
- Net acid excretion is not an important influence of calcium metabolism.
- Milk is not acid producing.
- Dietary phosphate does not have a negative impact on calcium metabolism, which is contrary to the acid-ash hypothesis.

INTRODUCTION

Recently the lay press and the advertising industry has claimed there is a hypothetical association between dairy product consumption and the generation of dietary acid that is harmful to human health. This theoretical association is based on the idea that the protein and phosphate in milk and dairy products make them acid-producing foods, which cause our bodies to become acidified, creating diseases of modern civilization. However, scientific evidence does not support any of these claims. Milk and dairy products are not acid-producing foods, our bodies do not become acidified by diet, and evidence does not support associations between milk and dairy products with the diseases of modern civilization. The purpose of this review is to demonstrate alternative explanations to common criticisms of dairy products based on evidence.

SIGNIFICANCE AND NUTRITIONAL RELEVANCE

Milk and dairy products have been criticized as non-health promoting on the basis that they "cause urinary calcium loss

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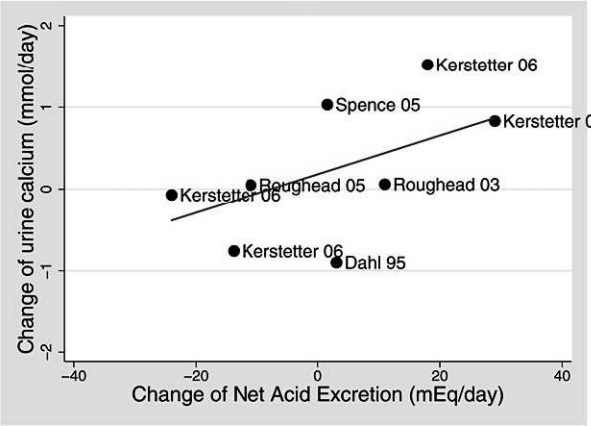

Fig. 1. The relationship between change in NAE and change in urinary calcium, limited to randomized studies that followed the Institute of Medicine's guidelines for calcium metabolism studies [8] ($R^2 = 0.406$; $p < 0.0001$). This material is reproduced with permission of John Wiley & Sons, from Fenton et al. [6].

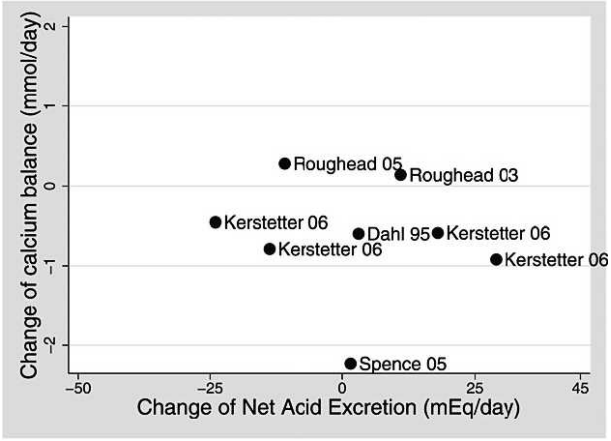

Fig. 2. The relationship between change in NAE and change in calcium balance limited to randomized studies that followed the Institute of Medicine's guidelines for calcium metabolism studies [8] ($R^2 = 0.003$; $p = 0.38$). This material is reproduced with permission of John Wiley & Sons, from Fenton et al. [6].

[and] accelerated skeletal calcium depletion" [1]. It has been observed that "osteoporotic bone fracture rates are highest in countries that consume the most dairy, calcium, and animal protein," and some writers have assumed that dairy products are detrimental to bone health [2,3]. This review will refute these criticisms of milk and dairy products by demonstrating alternative explanations based on evidence.

DESCRIPTION OF SUBJECT

Milk Classification as an "Acid-Producing" Food Is Based on an Imperfect Estimation Method

A highly cited food classification system defines milk as slightly acid producing [4] on the basis that milk contributes protonated sulphate and phosphate, which are acids. A portion of sulphate and phosphate are excreted in urine in protonated form, so it appears that dietary protein leads to acid excretion and this "dietary acid" is believed detrimental to bone health. The assumption of detriment to bone health is due to the consistent observation that a higher urine acid excretion is associated with higher urine calcium [5].

The food classification system is based on the concept that the PRAL represents the diet acid load, and the highly cited food lists by Remer and Manz [4] used the formula PRAL = milliequivalents of the ions ($Cl + PO_4 + SO_4 - Na - K - Ca - Mg$). Sodium and chloride are usually considered to be in equivalent amounts and thus canceled out. Therefore, phosphate and sulfate are considered protonated and representative acids being excreted that are partly balanced by calcium and magnesium considered to be hydroxylated and bases.

However, two recent systematic reviews do not support the concept that phosphate and sulfate are detrimental to bone health because urine calcium does not predict whole body calcium status [6], and phosphate does not have a negative impact on calcium metabolism [7].

Net Acid Excretion Is Not an Important Influence of Calcium Metabolism

Although urine calcium increases as net acid excretion increases, it is more important that calcium balance does not change. A multidisciplinary team of scientists at the University of Calgary performed a systematic review and meta-analysis of higher-quality studies of dietary and supplemental acid or alkali interventions to alter net acid excretion to determine whether changes of intake alter urinary calcium or calcium balance [6]. To decrease the risk of bias in this meta-analysis, studies were included only if the subjects were randomized to the interventions and the Institute of Medicine's guidelines for calcium metabolism [8] were followed. The meta-analysis revealed that higher net acid excretion from higher protein intakes was associated with higher urinary calcium excretion (Fig. 1). However, when calcium balance (whole body calcium retention) was examined, net acid excretion was not associated with calcium balance (Fig. 2). Therefore, evidence does not support the claims that acid-producing foods are detrimental to whole body calcium retention, in spite of the appearance of higher urine calcium. Studies with conclusions that are based on changes in urine calcium should not be used as confirmation of a hypothesized effect.

Although increased urine acid excretion is associated with increased urine calcium, it is not associated with changes to the whole body calcium balance. Thus, the foods that are associated with higher urine calcium must promote calcium absorption or decrease endogenous calcium secretion in the intestine to reduce fecal calcium loss.

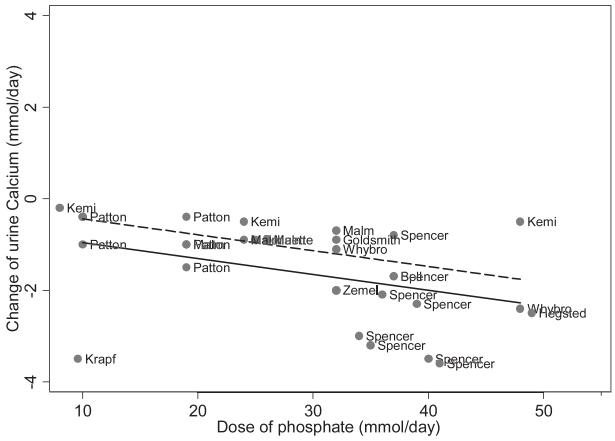

Fig. 3. Phosphate and change in urine calcium stratified by calcium intakes: Slope = −0.021, $p = 0.001$. Low calcium intakes: - - - - -; High calcium intakes: ———. This material is reproduced with permission of BioMed Central from Fenton et al. [7].

Dietary Phosphate Does Not Have a Negative Impact on Calcium Metabolism

Twelve studies of phosphate supplementation and calcium metabolism were located that included 30 interventions of 269 subjects [7] did not identify an negative effect of phosphate on calcium balance. Meta-analysis demonstrated significant decreases in urine calcium excretion (Fig. 3) and no decrease of calcium balance (Fig. 4) in response to phosphate supplements. Whether the effect of phosphate supplements were compared under conditions of high or low calcium intakes or whether the phosphate supplements were acidic or basic, the results were the same [7]. These findings were contrary to the acid-ash hypothesis, which suggests that phosphate excretion is associated with loss of bone calcium via increased excretion.

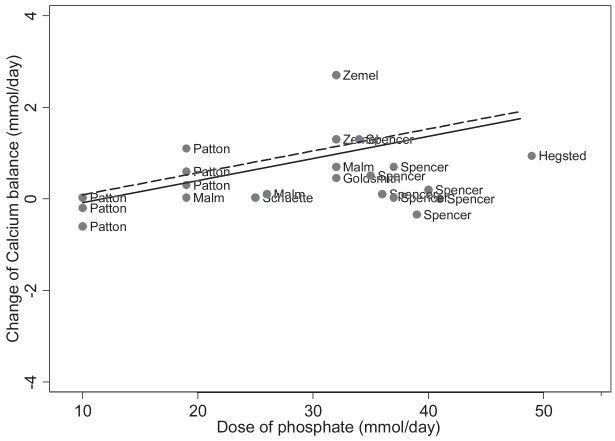

Fig. 4. Phosphate and change in calcium balance, stratified by calcium intakes: Slope = −0.048, $p < 001$. Low calcium intakes: - - - - -; High calcium intakes: ———. This material is reproduced with permission of BioMed Central from Fenton et al. [7].

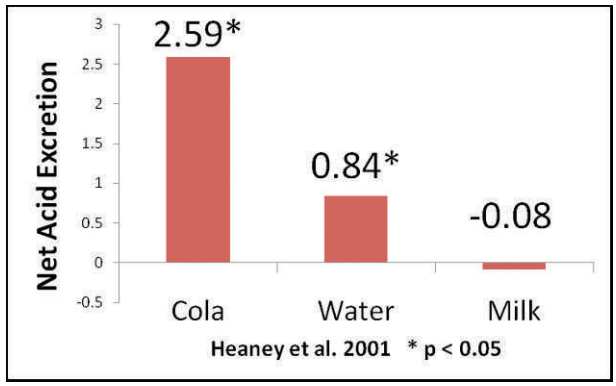

Fig. 5. Net acid excretion (mEq H^+) following ingestion of three beverages: deionized water, milk, or caffeine-free cola. In each case, bread and butter was eaten with the beverage. Source: Heaney et al. [10].

Therefore, the food classification system [4] that defines milk as slightly acid producing is not relevant to bone health because it is based on premises that are not supported by evidence.

Dairy Foods Are Not Acid Producing

Two studies that examined urine acid excretion after milk consumption [9,10] found that milk is not an acid-producing food. There are two ways to measure acid produced from foods: net acid excretion and urine pH. A study of net acid excretion after milk consumption revealed that milk has an alkali load compared with those of water and cola [10] (Fig. 5). The water used in this study was deionized water, so it would not contribute any acid or base. In another comparison from this study, cola [10] contributed a net acid load, as expected due to its phosphoric acid content.

A comparison of milk protein to soy protein demonstrated the same net acid excretion from both of these proteins [9] (Fig. 6).

In terms of urine pH, after milk consumption urine pH did not decrease but increased slightly from fasting levels ($p = 0.001$), and it was highest after milk consumption compared with cola consumption ($p = 0.01$) [10].

Alkaline Diets Alter Urine pH But Do Not Change Systemic pH

A diet designed to provide an alkaline diet load increased pH from 6.4 pH units of a modern Western diet to 7.5 pH units, a change of 1.02 pH units on average [11]. The alkaline diet did not make an important change to the blood (systemic) pH, given that the blood pH changed by only 0.0014 pH units [11]. Both the alkaline and modern diets in this study had similar energy, protein, calcium, phosphate, and sodium content [11].

Another study examined the effect of bicarbonate salts, as an alkaline intervention [12]. In this bicarbonate study, urine

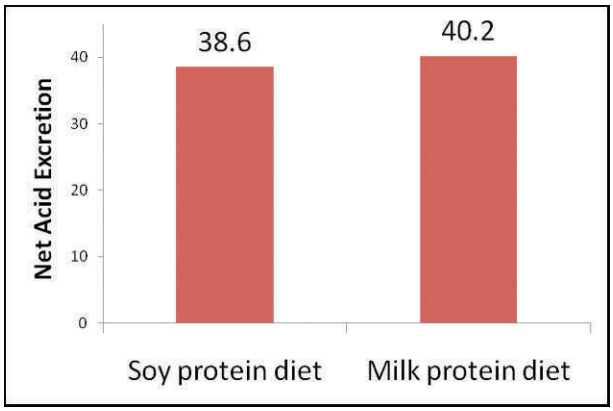

Fig. 6. Net acid excretion (mEq H^+) following ingestion of soy-based or milk-based diet, other foods were kept constant; difference was not statistically significant. In each case, bread and butter was eaten with the beverage. Source: Spence et al. [9].

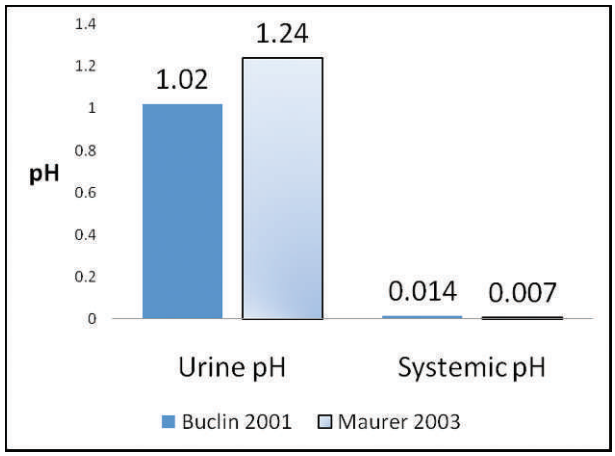

Fig. 7. Changes in urine and systemic pH from an alkaline diet and bicarbonate salts. Sources: Buclin et al. [11] and Maurer et al. [12].

pH changed similarly as it did in the alkaline diet, from 5.8 to 7.1 pH units, and blood again did not change significantly (from 7.04 to 7.411 pH units) [12]. In both cases, the urine pH changed by more than 50 times that of blood pH [11,12] (Fig. 7).

Given that the reference interval (normal range) for blood pH is 7.35–7.45, the change of 0.014 pH units is equivalent to only one half of one standard deviation. For the vast majority of people with systemic pH in the reference interval (pH 7.35–7.45) an increase of pH by 0.014 is within the measurement error. In contrast, metabolic acidosis refers to systemic pH $<$ 7.35.

Osteoporosis Is Prevalent in Sedentary Cultures

It has been noted that "osteoporotic bone fracture rates are highest in countries that consume the most dairy, calcium, and animal protein," and some writers have assumed that dairy products have no benefits to bone health [2,3]. It has been assumed that the association between higher fracture rates of industrialization must be due to the acid excretion of the high protein diet [3]. This quote refers to observations that compare one culture with another, making an assumption that the cause of the differences in bone fractures is due to dietary differences. It is not correct to make an assumption about causes based on observations, particularly when these observations are at the cultural level, because individual lifestyles are not considered and there are many differences that could be the cause. This error in assumptions is summed up by the phrase: "correlation does not imply causation" and is an ecologic fallacy, namely, the "bias that may occur because an association observed between variables on an aggregate level does not necessarily represent the association that exists at an individual level" [13].

Other important risk factors for bone fractures and osteoporosis differences between milk-consuming cultures and Asian cultures include genetic differences, the amount of physical labor (which is highly anabolic to bone), possibly the amount of sunshine (vitamin D), and possibly even different hospital discharge and transfer practices that may make counting fractures difficult [14]. Any of these risk factors could account for differences in fracture rates, and thus it is not correct to assume that calcium and dairy foods are ineffective or unimportant on the basis of observational data. In fact, urban sites in Asia, where physical activity is perhaps similar to that of Western cultures, have almost identical fracture rates [15,16].

Evidence supports bone protective roles for both calcium and protein. A recent systematic review and meta-analysis reaffirmed calcium's role in supporting bone strength [17]. Furthermore, recent research suggests that sufficient protein intake is needed for the maintenance of bone integrity [6,9,18–22]. In summary, regarding the quote, "osteoporotic bone fracture rates are highest in countries that consume the most dairy, calcium, and animal protein," the evidence does not support these observations across cultures.

The nutritional strengths of dairy products are considerable: They are a good source of high biologic value protein [23] and are the primary source of calcium in the diet in Europe [24], North America [25,26], and even in China [27].

The lay press has claimed a hypothetical association among dairy product consumption, generation of dietary acid, and harm to human health based on the theoretical idea that the protein and phosphate in milk and dairy products make them acid-producing foods, which cause our bodies to become acidified, creating disease. However, we found through a comprehensive systematic review of this theory based on randomized or prospective cohort studies and focused on the higher-quality randomized studies that no aspect of this theory is supported by the evidence [28]. Additionally, evidence does not support the theory that an alkaline diet is protective of bone health [28].

CONCLUSION

In conclusion, better-quality evidence reveals that milk and dairy products do not cause metabolic acidosis. Furthermore, dairy products do not produce acid upon metabolism, and our bodies do not become acidified by the modern diet. Additionally, evidence does not support associations of milk and dairy products with osteoporosis once physical activity and other factors are considered. Milk continues to be a good source of dietary protein, calcium, and other nutrients.

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