Calcium Bioavailability of Leafy Greens Compared to Dairy Sources

Chelsea Schulman, MS

Calcium is a mineral essential for bone, muscle, and nerve function as well as hormonal and enzymatic activity.[1] The Recommended Dietary Allowance (RDA) for calcium ranges from 1,000-2,000 mg per day for adults, dependent on age and gender or if pregnant/lactating.[2] Within the American diet, dairy sources are the most significant contributors of calcium.[3] However, calcium is also available in substantial amounts from non-dairy sources, such as leafy green vegetables and fortified foods.[4]

The adult human body functions at a calcium balance of zero: all excess calcium is stored in the bone or excreted; inadequate calcium intake will decrease the excretory calcium losses and may be reabsorbed from bone in times of need.[5] Retention and excretion are dependent on dietary intake. Calcium absorption occurs in the duodenum and the jejunum via active transport or through passive diffusion in the ileum and large intestine. Fractional absorption is determined by calculating the ratio between oral intake and venous calcium following consumption of the stable Ca^{45} isotope-labeled food source. Cows milk has been shown to contain almost a third of the daily requirement for calcium of most healthy individuals (300 mg) and displays high fractional absorption (32.1%).[4] Fractional absorption of calcium can be reduced by co-ingestion of other nutrients such as protein, phosphorus, fat, sodium, and vitamin D. Common constituents of plant products such as phytates, oxalates, and fiber have also been shown to reduce calcium absorption, supporting the hypothesis that calcium from leafy greens is less absorbed than calcium from milk.

Spinach was one of the first leafy green vegetables to be compared to milk for the study of calcium absorption. In an early study by McLaughlin, seven healthy women consumed a diet in which 79% of the calcium was provided from milk for the first seven days, and in the following six days, spinach provided 73% of dietary calcium.[6] Lower absorption was found with the spinach diet (0.042 g) compared to milk (0.097 g), even though on average the spinach diet provided more oral calcium (0.509 g) than the milk diet (0.493 g). This was one of the first studies to conclude that calcium absorption was possible from non-dairy sources as the mere retention of calcium from spinach indicated partial absorption despite factors such as fiber and oxalate content. Heaney, Weaver, & Recker (1988) further investigated the absorption of calcium from spinach compared to milk through a randomized, crossover study with direct assessment measures of isotope-labeled food sources.[7] The calcium load for both sources was 200 mg; the absorption of calcium from spinach and milk averaged 0.051 and 0.276, respectively. The spinach test meal was determined to contain a 477.5 mg load of oxalate, which was presumed to negatively affect the calcium absorption. The relationship between oxalate content and calcium absorption was expanded further in a study by Heaney and Weaver (1989).[8] Calcium oxalate and 2% milk were given as the calcium sources. The fractional absorption from milk was determined to be 0.358, compared to 0.100 from calcium oxalate. Despite providing the same amount of calcium load within test meals (200 mg), the fractional absorption in this study was shown to be greater than reported in the earlier study by Heaney, Weaver, & Recker (1988); more research in this area is needed to determine an explanation for this occurrence.[6] The impact of oxalate content in spinach was also hypothesized to impact calcium absorption in a study by Poneros-Schnieier and Erdman (1989), which compared the bioavailability of calcium in rats from sesame seeds, almond powder, whole wheat bread, spinach, and nonfat dry milk.[9] As presumed, spinach was the food source found to have the least amount of absorbable calcium, followed by sesame seeds, almond powder, and whole wheat bread. However, the authors questioned the particular action of the chemical structure of spinach in relation to calcium absorption, as an earlier study found that chocolate, which also contains oxalate, did not impair calcium absorption in rats.[10]

It is reasonable to hypothesize that the fiber content of the spinach may have negatively impacted the calcium bioavailability of the food. However other studies have shown that low-oxalate, high-fiber vegetables do not exhibit this effect. Heaney and Weaver (1990) used similar methods from their earlier study (1988) by using isotope-labeled kale and milk to compare differences in absorption.[7] The calcium

Table 1. Fractional Absorption (%) of Calcium-Containing Foods and Supplements (Adapted from Weaver & Heany (1999) and Weaver & Plawecki (1994))[4, 18]

Food	Serving Sizes (g)	Fractional Absorption (%)
Spinach	90 g	5.1
Calcium oxalate	2-3 g	10.2
Calcium citrate	2-3 g	24.2
Calcium carbonate	2-3 g	29.6
Milk	240 g	32.1
Calcium malate	2-3 g	36.3
Kale	65 g	58.8

load of the kale and milk test meals were 288 mg and 312 mg, respectively. Blood samples were taken five hours after the test load was ingested and resulted in a fractional absorption of calcium from kale of 0.409 and 0.321 from milk. The fractional absorption of calcium from kale reported in this study is significantly greater than that reported from milk and from the fractional absorption amounts reported in the aforementioned studies; however, the authors note that the mean fractional absorption from kale displayed a confidence interval that overlapped the fractional absorption range of calcium from milk. Hence, kale may not be a superior source of calcium in comparison to milk, but calcium absorption between the two sources is comparable. As reported by Heaney and Weaver (1990), the findings from this study can be applied to other leafy, green, low-oxalate vegetables within the Brassica oleracea class.[7] This includes other varieties of kale, collards, broccoli, and cabbage which also have sources of calcium, but more research is needed to make this claim.[4]

The aforementioned research was the foundation for the now-accepted conclusion that calcium absorption is inversely proportional to oxalate content in food, including vegetables; kale specifically has been found to provide a significant amount of absorbable calcium. This is notable as it can be a challenge to meet calcium needs from diet alone when meat and dairy are excluded, as is the case with ovo-vegetarians, vegans, and individuals with lactose intolerance or milk protein allergies.[13] The research has also been hypothesized to hold external validity to include other leafy, green, low-oxalate vegetables; however, other dietary factors could impact calcium absorption such as total protein or total oxalate intake. Future research is now being focused on the cellular level of plant composition in relation to calcium content and absorbability.[13,14,15]

Complete dietary composition should be taken into account in future studies.[4] Non-dairy sources of calcium provide more fiber and less cholesterol and total fat than their counterparts; however, a serving of most milk products provides a complete source of most vitamins and minerals including riboflavin, zinc, vitamin B12, vitamin A, thiamin, phosphorus, magnesium, potassium, and, of course, calcium.[14,16] Dairy products are also less expensive than green leafy vegetables when cost per unit of estimated absorbable calcium is calculated.[3] One cup of milk contains 300 mg of calcium and 96.3 mg are absorbed, which is greater than the calcium absorbed in a ½ cup serving of spinach (5.9 mg) and kale (30.1 mg).[18] To absorb the amount of calcium equivalent to a cup of milk, an individual would need to consume 3.2 cups of kale or 16.3 cups of spinach. At this time, it is not appropriate to recommend leafy green vegetables as a superior calcium source to dairy for the aforementioned factors, as well as the lack of research.

It is important to consider alternative calcium sources to allow for optimal calcium intake in individuals with special diets or taste preferences. Given vegetable sources have a much less absorbable amount of calcium compared to dairy sources, it is recommended that those avoiding dairy products meet their calcium needs through supplementation. Absorption from calcium supplements is similar to that of milk - typically between 30%-40% (Table 1). Dietary intake of other foods in combination can decrease calcium absorption from calcium supplements, thus dairy products remain the preferred source for calcium due to the high absorbability with the least likelihood for inhibition by other factors.

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