Soluble Fiber’s Enhancement of Calcium Absorption in the Intestine

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INTRODUCTION

Dietary fiber is defined as carbohydrates and lignin that are native to plants and resistant to human digestive enzymes. Early fiber research began in the 1930s and 1940s when McCane and Widdowson published research on fiber and its association with mineral bioavailability. One of their first papers was “Mineral Metabolism of Healthy Adults On White and Brown Bread Dietaries” which reported that mineral bioavailability was decreased by whole wheat bread compared to white bread. It was thought that phytate and fiber may be the cause for this (1). Their findings led to decades of research dedicated to understanding fiber's effect on mineral bioavailability.

Soluble dietary fiber has been shown to have the greatest impact on calcium absorption in the large intestine (2). Inulin-type fructans (ITFs) have been commonly used to investigate soluble fiber’s effect on calcium absorption. They provide added health benefits beyond basic nutrition including the increased absorption of calcium in the large intestine, making them a common functional food ingredient (3). ITFs are composed entirely of fructose units linked together by β (2-1) bonds which are resistant to hydrolysis in the human small intestine. Consequently, ITFs travel to the large intestine fully intact and once in the large intestine these soluble fibers act as prebiotics (4).

In this paper two mechanisms of enhanced calcium absorption will be reviewed. One method is the enhancement of the paracellular pathway in the intestine. The second method involves the prebiotic characteristics of soluble fiber and their influence on pH.
REVIEW OF LITERATURE

Paracellular Pathway

Absorption of calcium from the intestine can take place through the paracellular pathway. This pathway is non-saturable, involves diffusion and movement down a concentration gradient through tight junctions between the luminal and basolateral sides of the intestine (5). The tight junctions are regulated by intracellular signaling (6). Research shows that paracellular pathway activity is enhanced by the ingestion of soluble, non-digestible saccharides and that tight junctions become more permeable with the presence of soluble fiber. The increased permeability of the tight junctions increases the transport of calcium across the membrane increasing absorption (7).

Suzuki and Hiroshi studied the theory that the paracellular pathway is enhanced by the ingestion of soluble fiber. Using human intestinal Caco-2 cells grown on permeable filters they investigated the effect of four different non-digestible saccharides: DFAIII, DFAIV, fructooligosaccharides, and raffinose using four different doses, 0, 30, 50 and 100mmol/L of each fiber. A positive correlation was seen between incubation time and calcium transport across the membrane and between the non-digestible saccharide dose and calcium transport across the membrane. TEER decreased as the dose increased, increasing calcium absorption. The decrease in resistance showed that tight junctions were opening making the membrane more permeable and allowing calcium to be transported across the membrane. Calcium transport carried out by
the paracellular pathway increased by 300-400% with the use of the non-digestible saccharides (6).

**Prebiotic Characteristics and Their Influence on pH**

ITFs are known for their fermentative properties, setting them apart from other dietary fibers. ITFs reach the large intestine intact; they are then fermented by the gut’s microflora. These soluble fibers act as prebiotics stimulating the growth of beneficial bacteria bifidobacteria and lactobacilli (4). Prebiotics are non-digestible food ingredients that stimulate the growth of bacteria in the colon, improving the host’s health (2).

As these soluble fibers are fermented, they are metabolized into short-chain fatty acids (SCFAs) including acetate, propionate and butyrate. The production of these SCFAs causes the pH of the intestine to decline making calcium more soluble. Increased solubility allows the calcium to be more readily absorbed by the intestinal mucosa (8). SCFAs are also known to promote epithelial cell proliferation in the large intestine. Proliferation increases the number of epithelial cells thereby expanding the surface area available for calcium absorption promoting calcium uptake (9).

Abrams studied calcium absorption over an eight week period in a group of six males and seven females of different races that included Whites, Blacks, Hispanics, Asians and biracial. A stable isotope of calcium along with an inulin-type fructan known as synergy1 was consumed by the subjects followed by a 48 hour urine collection. The mean absorption of calcium was significantly increased by 5.1% with the use of ITFs. From this study, it was determined that ITFs provide a beneficial increase of colonic absorption of calcium (10).
Coudray investigated the negative correlation between pH and calcium absorption in the colon. In his study 50 rats were used and split into groups of 10 that were fed either a fructan-free diet, oligofructose, high-performance inulin (HP) branched-chain inulin (BC) or synergy1 (a 1:1 combination of oligofructose and HP-inulin) for 28 days. Urine and feces were taken from all of the rats during the last four days of the experiment to determine mineral balance and rats were sacrificed at the completion of the study to harvest the cecum and its contents. Cecal SCFAs were measured using a gas-liquid chromatography procedure. A significant increase in SCFAs were produced with the ingestion of ITFs (p<0.05). A negative correlation was found between the amount of SCFAs and the pH of the intestine. A positive correlation between the amount of SCFAs produced and the amount of soluble calcium present was noted and a negative correlation was seen between the pH of the cecal contents and the amount of calcium absorbed. Rats consuming the Synergy1 absorbed 60.3±8.5 mg/day (mean ± SD) a statistically higher amount of calcium compared to 48.0±6.5 mg/day of the control group (P<0.05) (11).

Benefits of Enhanced Calcium Absorption

As shown from the research, ITFs have a positive correlation with calcium absorption in the large intestine. This can be useful especially if calcium absorption in the small intestine becomes impaired or compromised (10). Calcium malabsorption is associated with osteopenia and osteoporosis (12). Many studies have been carried out to determine if ITFs’ enhancement of calcium absorption in the large intestine can help prevent osteopenia when calcium absorption in the small intestine becomes impaired (12,13,14,15).
Total gastrectomy severely impairs calcium absorption and decreases bone calcium content promoting osteopenia (13). Ohata tested if fructooligosaccharides (FOS) increase calcium absorption in gastrectomized rats and help to prevent the development of osteopenia. Sixteen gastrectomized rats and fourteen rats receiving a sham surgery were used. After surgery each group was split in half, half receiving a diet containing FOS and the other half consuming control diet for thirty days. Feces collections were taken from all rats. On the final day all rats were sacrificed. The left femur and left tibia were tested for their calcium content. The right femur and tibia were tested for bone mineral density (BMD). Calcium absorption was significantly higher in gastrectomized rats consuming the FOS diet compared to gastrectomized rats fed the control diet (P< 0.05). Bone calcium content of the tibia of gastrectomized rats consuming the FOS diet was 4.81± 0.40 mmol/g (mean ± SD) significantly higher than 3.91 ± 0.13 mmol/g in gastrectomized rats fed the control diet, a statistical significance of 0.03 (P<0.05). A diet containing FOS prevented a decrease of both calcium content of the bones and BMD (14).

FOS and other ITFs may be a beneficial method to increase calcium absorption and prevent osteopenia and other bone diseases. Those at risk for osteopenia cannot prevent the loss of BMD or bone calcium content solely by taking calcium supplements. Enhancing the absorption of calcium is crucial in preventing osteopenia (15). ITFs don’t only enhance the process of mineral absorption, but they enhance bone mineralization, bone density and bone resorption (3).
Conclusions

For many decades there has been research dedicated to fiber’s effect on calcium absorption. Early research showed fiber had a negative impact on calcium absorption. As research has grown and expanded, it is now seen that soluble fiber may have a positive effect on calcium’s absorption in the intestine, especially the colon.

The paracellular pathway is said to be enhanced by soluble fiber. Tight junctions open in the presence of soluble fiber making the membrane more permeable increasing the transport and absorption of calcium across the membrane.

Soluble fiber’s prebiotic characteristics increase calcium absorption in the large intestine by producing SCFAs. SCFAs decrease the colon’s pH and increases calcium’s solubility. Increase of SCFAs also enhances proliferation of the colon’s epithelial cells. The decrease in pH and the increase of surface area both contribute to the increase of calcium absorption.

Understanding the methods behind increased calcium absorption can be extremely beneficial. When calcium absorption in the small intestine is compromised or impaired malabsorption can occur. This can lead to osteopenia and other bone diseases. The use of soluble fiber, especially ITFs can help to prevent bone disease and help to maintain or even improve bone health through enhanced calcium absorption.
References


