The Effect of Dietary Calcium and Other Nutritionally Relevant Divalent Cations on Fatty Acid-Soap Formation

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Abstract

A growing amount of scientific evidence appears to support a relationship between dietary calcium (Ca) and body weight where increased dietary Ca intake leads to weight reduction and the faecal excretion of several fatty acids. One possible mechanism, explaining the effect of dietary Ca on body weight and faecal fatty acid excretion, is the formation of indigestible Ca-fatty acid soaps within the gastrointestinal tract, leading to reduced fat and therefore reduced energy absorption. The objectives of this research were 1) to confirm that dietary Ca reduces fatty acid absorption and that the effect is via the formation of fatty acid soaps, 2) to explore the potential of cations other than Ca to form fatty acid soaps and 3) to investigate where in the gastrointestinal tract Ca-fatty acid soap formation occurs.

In order to investigate the presence of fatty acid-soaps in the gastrointestinal tract, an assay was developed to determine fatty acid-soaps in digesta and faeces. Faecal fatty acid-soap excretion, apparent faecal fatty acid digestibility and apparent faecal Ca digestibility were determined in the growing pig for diets containing different sources of fat (tallow, palmolein oil, olive oil and soya bean oil) and increasing concentrations of Ca (0, 2, 4 and 6 g kg^{-1} diet). Increasing concentrations of dietary Ca resulted in increased faecal fatty acid excretion ($P < 0.001$), predominantly in the form of fatty acid-soaps (> 80%) for diets containing a fat source rich in saturated fatty acids (tallow and palmolein oil). The fatty acid digestibility of these diets was reduced ($P < 0.001$) by up to 28% when the dietary Ca intake was increased from 0 g Ca kg^{-1} diet to 6 g Ca kg^{-1} diet. Moreover, faecal Ca output of the tallow-based diet, for which the fatty acid soap excretion was the greatest, was statistically higher when compared to the oil containing diets.

These results provide evidence that supports the hypothesis that dietary Ca can impair fat absorption via the formation of indigestible Ca-fatty acid soaps but that the effect is largely limited to fat sources rich in saturated fatty acids as evidenced by the reduction in Ca absorption with tallow.

Given that Ca appears to react with fatty acids to form soaps, it was decided to investigate whether other nutritionally relevant divalent cations (magnesium (Mg), zinc (Zn), iron (Fe) and copper (Cu)) were able to form fatty acid soaps. To that end, *in vitro* studies revealed that apart from Ca, other divalent cations such as Zn, Mg, Fe and Cu had the ability to form precipitates in the presence of fatty acids. In general, all the divalent cations examined formed precipitates in the presence of at least some of the fatty acids examined, although the extent to which the divalent cation-fatty acid precipitates (soaps) formed varied depending on the cation and fatty acid present. The precipitation of saturated fatty acids (lauric, myristic, palmitic and stearic acid) when incubated with Zn was comparable with that of Ca. However, the precipitation of unsaturated fatty acids (oleic and linoleic acid) with Zn was greater than that observed for Ca. For Fe and Cu, fatty acid precipitation was less than that observed for Ca.

To investigate where in the gastrointestinal tract fatty acid soaps form, growing pigs were fed diets containing either free fatty acids or an intact triacylglyceride (tallow) and calcium carbonate as the Ca source. The amount of insoluble fatty acid-soap present in the gastrointestinal tract was determined at 10 different locations within the tract. The amount of fatty acid-soaps present increased ($P < 0.05$) at the distal jejunum when the free fatty acid-based diet was fed and at the ileum when pigs received the tallow-based diets, and was correlated with the pH (regardless the diet) of the gastrointestinal tract suggesting that soaps

formed as the pH of the gastrointestinal tract increased. Fatty acid-soap formation in the small intestine of pigs receiving the free fatty acids was almost double than for pigs receiving tallow with their diet. There was little soap formation in the hind gut. With the majority of fatty acid soap formation occurring in the distal small intestine (the major absorption site of fatty acids) fatty acid-soap formation has the potential to reduce fatty acid absorption. Feeding a fat-free diet in addition to the two fat containing diets gave insight into mineral absorption in the absence and presence of dietary fat. The apparent digestibility of Ca, Mg, Zn and Fe was lower ($P < 0.05$) in the presence of dietary fat (free fatty acids or triacylglycerides) suggesting that the formation of divalent cation-fatty acid soaps may have the ability to impair the absorption of divalent cations other than Ca.

In conclusion, high dietary Ca intake leads to increased faecal fatty acid excretion in the form of insoluble fatty acid-soaps. Fatty acid-soap formation can impair the digestibility of Ca and other nutritionally relevant divalent cations such as Zn, Mg and Fe. Moreover, fatty acid-soaps appear to form mainly in the distal small intestine and appear to be associated with gastrointestinal pH. These results contribute to the knowledge of where fatty acid soap formation occurs and provide evidence that fatty acid soap formation can reduce fat absorption and thereby possibly contribute to weight loss.

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