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

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A dissertation presented in partial fulfilment  
of the requirements for the degree of

Doctor of Philosophy in Nutritional Sciences  
at Massey University, Manawatū, New Zealand

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2016



## 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<sup>-1</sup> 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<sup>-1</sup> diet to 6 g Ca kg<sup>-1</sup> 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.



## Acknowledgement

I take this opportunity to present my gratitude to a few people that deserve special mention for their role in the accomplishment of my thesis.

First and foremost, I would like to thank my supervisors Dr. Shane Rutherford, Dr. Sharon Henare and Distinguished Professor Dr. Paul Moughan. Your advice and guidance through this project were invaluable. In particular, Shane your constant encouragement, your immense patience, and you believing in me (more than I ever did) have been appreciated over all these years. With your dedication and critical way of thinking, you always got me back on the right path, but not to forget your quotes from the Matrix or your lectures on how my literature review shall differ from the tedious journey of Frodo described in the book of 'The Lord of the Rings' made our meetings enjoyable. Sharon, I want to thank you for your continuous support, your advice and your sincere interest in my welfare. Not to forget for siding up with me that not every data set needs to be presented as a table and that graphs might be more enjoyable for the reader. Paul, I am very grateful for the opportunity you gave me to be part of the Riddet Institute nutrition team and the learning experience that has come along with the challenges throughout my PhD studies. The group internal Research Days provided a great opportunity to share research results and new experimental ideas and proofed to me that presenting in front of colleagues is not that fearful. I also want to thank you for your valuable scientific inputs, your encouragement and your substantial corrective comments.

I am thankful for the Riddet Scholarship to providing me the financial assistance during the first years of my research. I wish to thank the Riddet Institute for the opportunity of part

time work and the involvement in many interesting projects which allowed broadening of my horizon and earning my daily bread during the final years.

A special thanks goes to Dr. Carlos Montoya for providing statistical guidance to all my projects. Thank you Carlos for all the time you took to explain the statistical models to me and helping me to evaluate my results.

I also want to thank Trent Olson, Stuart Saigeman and Daniel for all their muscle work and help during my animal trials. Guys, the picture of the four of us soaping and shaving pig bums will forever stay with me.

I would like to thank all my colleagues and friends from the Riddet Institute and Massey University. Working amongst you all has been a great pleasure. In particular, thanks to Janiene Gilliland, Nok Sawatdeenaruenat, Leiza Turnbull, Dr. Peter Zhu, and Dr. Sophie Gallier for your assistance with lab equipment, sharing your laboratory skills and providing scientific advices but also for the time spent socialising in the lunch room or the sports hall.

The past years would not have been the same without the support and encouragement of my friends whom I have met throughout my studies. Carlos and Eva, you offered me a home away from home. Movie nights, family-style take away, mid-winter Christmas parties make my time in Palmerston North unforgettable. To my fellow sufferers Filomena, Sonal, Tom, Anne, being able to share experiences, highs and lows, as well as tears but not to forget the unbelievable good times have made these years memorable. The biggest thanks goes to Ajit, for always being there for me, being so kind and patient (enduring all my moods), and still being extremely supportive during the good and difficult stages of PhD life. You pushed me to continue when times were tough and I wanted to throw it all away.

Ein besonderes Dankeschon geht an meine Familie in Österreich. Ich kann euch nicht sagen wie glücklich ich mich schätzen kann, dass ich euch habe. Selbst wenn euch die Entfernung schwer gefallen ist habt ihr mich ständig ermutigt weiterzumachen und nicht aufzugeben. Wenn es finanziell eng wurde habt ihr immer angeboten mich zu unterstützen – das euch meine Ausbildung so wichtig ist bedeutet mir sehr viel und ich hoffe, dass ich euch als erster 'Doktor' in der Familie stolz mache.



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