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Does processing of wholegrain foods affect salivary pH or dental plaque accumulation? A randomised crossover trial among adults with type 2 diabetes

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Abstract

Background and objectives: Whole grains are promoted within a healthy diet and for good oral health, however emerging evidence indicates that grain processing modifies digestion parameters. We have considered the effects of wholegrain processing, specifically milling, on the oral environment in free-living adults with type 2 diabetes.

Methods: Participants were randomised to two wholegrain interventions for two-weeks, separated by washout. Provided whole grains were either largely intact or finely milled. The acidity of the oral environment and oral hygiene (plaque score) were measured pre and post interventions.

Results: Twenty-eight adults with type 2 diabetes (63±12 years old, BMI 32.8±7 kg/m^2) completed both interventions. The diets consumed were nutrient and energy matched between interventions. After the two-week interventions there was no difference in oral environment acidity (Mean difference (MD) 0.13 pH 95%CI: -0.04 to 0.30) and plaque score (MD 0.10, 95% CI: -0.10 to 0.30) when comparing largely intact wholegrain foods with those that have been finely milled.

Conclusions: No differences in salivary pH or dental plaque accumulation were observed following interventions of wholegrain foods that varied in grain processing. It is unknown if interventions of longer duration may elicit differences, or if grain processing does not attenuate the oral health benefits of wholegrain consumption.

Introduction

Whole grains are recommended in healthy dietary patterns (New Zealand Ministry of Health 2015) and for good oral health (New Zealand Dental Association 2010; Halvorsrud et al. 2019). How the consumption of whole grains benefits oral health (Merchant et al. 2006) may be multifactorial. Higher wholegrain intakes may replace the intake of more simple carbohydrates (Chapple et al. 2017; Halvorsrud et al. 2019) that provide substrate for bacteria in the oral cavity (Mörmann and Mühlemann 1981). Whole grains contain antimicrobial metabolites within the bran layer (Slavin 2000) which may inhibit plaque formation and acid production. Whole grains also have an abrasive capacity while being chewed, displacing plaque and bacteria in the mouth (Nowjack-Raymer and Sheiham 2003) and enhancing oral clearance rate. Wholegrain foods in the modern food supply however, are changing towards more processed finely milled products (Grafenauer and Curtain 2018; Baker et al. 2020), reducing their abrasive capacity. How this change in the food supply towards more processed whole grains may influence oral health status has not yet been considered.

Adults with type 2 diabetes (T2DM) have greater risk of periodontal disease, dental caries, dry mouth and poor oral health outcomes overall than the population at large (Mealey and Ocampo 2007), and can benefit from higher wholegrain intakes (Reynolds et al. 2020). Previous research has indicated the benefits and cost effectiveness of treating periodontitis for oral health among patients with T2DM (Choi et al. 2020). Given the relevance of supporting both wholegrain intakes and good oral health in this subgroup of the broader population, we have conducted the first feeding study on wholegrain processing and oral health in free-living adults with T2DM.

Material and methods

This is a randomised crossover design of two interventions of two-week duration, separated by a washout period of at least two-weeks. The trial was conducted between October 2018 and April 2019 in Dunedin, New Zealand. This trial has Health and Disability Ethics Committee approval (18/STH/172). All participants provided written informed consent. The trial protocol was prospectively registered (ACTRN12618001285246). The primary cardiometabolic outcomes from this trial have been published (Åberg et al. 2020).

Participant eligibility criteria

Adults diagnosed with T2DM aged between 18 and 80 years of age were eligible. Presence of comorbidities did not exclude participation, however change in medication during the last 3 months did. Participants were recruited locally through general practices, fliers in supermarkets, online advertisements and from their participation in earlier studies.

Randomisation and blinding

The intervention order was determined by a computer-generated 1:1 block randomisation protocol. Each intervention order was stored in a separate opaque envelope and accessed sequentially once each

participant provided written consent. Participants were blinded to oral health measures during both interventions, and the outcome assessor was blinded to participant intervention. When an outcome assessor was unblinded due to something said or seen, a second assessor was called in. When a second assessor was not available at the time, digital photos of the outcome measures were taken, with participant consent, and reviewed later by a second assessor.

Interventions

In one intervention participants were provided with foods of largely intact whole grains (traditional oats, brown rice, and wholegrain bread made with kibbled wheat kernels) and were instructed to replace their daily grain serves with the foods provided. In the other intervention participants were provided with foods of finely milled whole grains (instant wholegrain oats, brown rice pasta, and wholegrain bread made with finely milled flour) and the same instructions to replace their daily grain serves with the foods provided. No advice was given to change the total amount of grains consumed. No further dietary or other lifestyle advice was given. The wholegrain foods provided were commercially available, 100% wholegrain foods (AACCI 2013), and matched for macronutrients and fibre. The only intentional difference between interventions was the wholegrain particle size as a result of milling.

Measurements

Participants were provided with a soft toothbrush and a triclosan-free 1450 ppm fluoride toothpaste on day one of each intervention and advised to brush twice a day. Basic oral health questions to describe the participants of this study were captured at the start of each intervention. Oral health assessment was undertaken in the morning of day 1 and 14 of each intervention with the participant fasted from 10pm the night before; and no brushing, flossing, or mouthwash use that morning.

Each participant was asked to allow their current saliva to drain from their mouth into a cup. The acidity of the oral saliva was measured using pH test strips from the GC Saliva-Check BUFFER kit. Plaque levels on the teeth were scored using the simplified oral hygiene index (Greene and Vermillion 1964) after staining with CURAPROX Plaquefinder tablets. Anthropometric, continuous glucose monitoring data, and biochemical measurements have been described previously (Åberg et al. 2020).

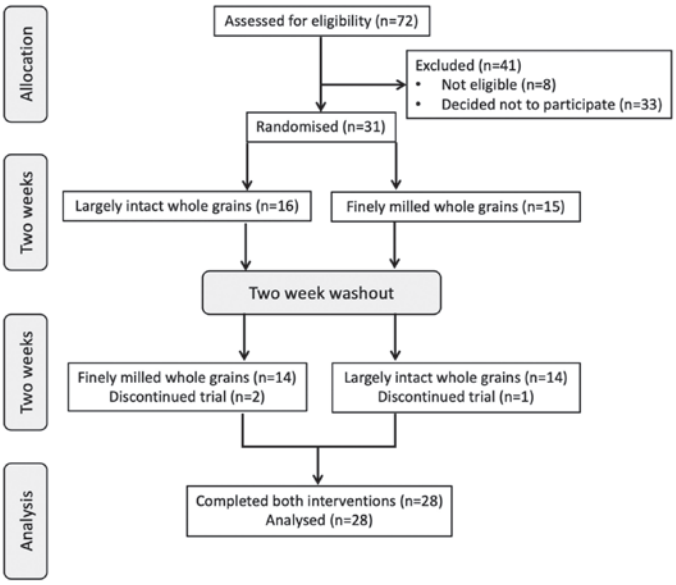

Fig 1. Flow chart of participants through the study

Statistical analysis

The sample size estimate was based on a power calculation relating to the glycaemic outcomes of this trial, making these oral health data an exploratory analysis. Briefly, the calculation (α 0.05, 1–β 0.80) indicated 28 participants were required to complete both interventions to detect within group differences in the glycaemic outcome variables considered. We compared the difference in one intervention with the difference in the other intervention with a mixed model accounting for intervention order. Results are presented as the mean difference between interventions with 95% CI. The data distribution appeared normal. The three participants without natural teeth were removed from plaque score assessment. Analysis were performed using Stata version 15 (StataCorp, TX, USA).

Results

31 participants entered the trial, 28 (90%) completed both interventions. The flow of participants through the trial is shown in *Figure 1.* Mean participant age of those completing the trial was 63±12 years, mean diabetes duration was 11.5 ± 9 years, and mean BMI was 32.8±7 kg/m^2. Eighteen (64%) participants were on oral hypoglycaemic agents, seven (25%) on both oral hypoglycaemic agents and insulin, and three (11%) participants were able to control their blood glucose with diet alone. Participants self-identified as being Māori (2), British (2), Indian (1) or New Zealand European (23). Only

Table 1. Serves of wholegrain foods consumed each day

	Breakfast	Lunch	Dinner	Oats	Bread	Rice or pasta
Largely intact grains	2.3 ± 0.9	1.8 ± 0.8	1.4 ± 0.8	1.8 ± 0.7	2.5 ± 1.1	1.2 ± 0.8
Finely milled grains	2.2 ± 0.9	1.8 ± 0.7	1.4 ± 0.8	1.6 ± 0.5	2.6 ± 1.0	1.3 ± 1.0

Values are means ± SD (N=28)

Table 2. Baseline dental health descriptors of 28 (54% women) participants

Characteristics	Response frequency
How would you describe the health of your teeth and mouth?	
Excellent	2 (7%)
Very good	10 (36%)
Good	11 (39%)
Fair	4 (14%)
Poor	1 (4%)
How many natural teeth do you have remaining?	
Over 21	16 (57%)
11 to 20	6 (21%)
1 to 10	3 (11%)
None	3 (11%)
To what extent are your missing teeth replaced by artificial teeth?	
All replaced	3 (11%)
Partially	18 (64%)
Not at all	7 (25%)
Can you bite and chew on hard food such as an apple?	
Yes, without difficulty	26 (93%)
No	2 (7%)

Characteristics	Response frequency
Have you gone to a dentist in the past 12 months?	
For a check up	5 (18%)
For dental treatment	11 (39%)
For dental treatment and a check up	4 (14%)
Have not been	8 (29%)
How often does your mouth feel dry?	
Always	1 (4%)
Frequently	6 (21%)
Occasionally	17 (61%)
Never	4 (14%)
Do you think you have gum disease?	
No	21 (75%)
Yes	4 (14%)
Don't know	3 (11%)

Table 3. Pre and post intervention measures of oral health

Measure	Largely intact whole grains		Finely milled whole grains		P difference between interventions
	Pre	Post	Pre	Post	
Oral acidity (pH)	6.6 ± 0.68	6.6 ± 0.50	6.5 ± 0.51	6.5 ± 0.58	0.143
Plaque score	1.22 ± 0.41	1.26 ± 0.42	1.35 ± 0.58	1.29 ± 0.55	0.309

Values are means ± SD

one participant was a current smoker. Wholegrain intakes were balanced between interventions, as shown in *Table 1.*

Participant baseline dental health descriptors are shown in *Table 2.* Only one participant had 'poor' self-rated oral health, although three participants had no remaining teeth. Most (93%) participants reported being able to bite and chew without difficulty. Oral health outcomes are reported in *Table 3.* There was no difference in change of the oral environment acidity between interventions (0.13, 95%CI -0.04 to 0.30). There was also no difference in the change in the plaque score between interventions (0.10, 95%CI -0.10 to 0.30).

Discussion

We did not identify a difference in oral hygiene or salivary pH in this exploratory short-term trial of wholegrain processing in adults with T2DM. Wholegrain foods were provided ad libitum to participants, reducing barriers to dietary change and enabling a difference in what wholegrain foods were consumed between interventions. The provided foods were well received by participants who consumed 5.5 serves a day. Foods were matched between interventions for fibre and macronutrient content, as well as being 100% wholegrain (AACCI 2013) enabling us to comment on the research question at hand.

This trial was designed to address the research question "does wholegrain milling influence acute markers of risk for oral health conditions?". A plausible mechanism supporting this research question were changes in starch digestibility due to milling. Largely intact whole grains are more likely to pass through the oral cavity without intra-oral breakdown of starch by salivary amylase, and the subsequent production of sugars available to bacteria (Mörmann and Mühlemann 1981). This may be particularly relevant to those with T2DM given their already elevated levels of salivary glucose (Sashikumar and Kannan 2010). A more indirect mechanism may be inflammatory modulation, as more intact whole grains pass through the small intestine to

be digested in the colon by the microbiome (Stephen and Cummings 1980) or the effects of diabetes on periodontal disease risk (Tsai et al. 2002).

This study is the first randomised trial to consider the effects of wholegrain particle size on oral health outcomes in adults with type 2 diabetes. Alongside novelty, this trial has a number of strengths. First, the interventions isolated one aspect of wholegrain intake which is the particle size of the grain after processing. While trial participants did increase fibre and wholegrain intake from before-trial levels there were no differences between wholegrain intakes in the interventions, enabling a matched comparison. Second, participants were provided with the wholegrain foods and advice to incorporate them into their usual eating patterns in a free-living setting. The characteristics of participants in this trial were similar to those reported for older adults in the most recent national oral health survey (New Zealand Ministry of Health 2010). Finally, we were able to mask the intervention to the outcome assessor in this trial, reducing potential bias in both the oral cavity acid and plaque score assessment. This trial is not without its limitations. This trial was powered on cardiometabolic risk factors and not the presented oral health outcomes, indicating that we cannot rule out a lack of association between wholegrain milling and oral health. This trial was also insufficiently powered to consider subgroup analyses by participant glycaemic control, baseline oral health, medication type, or any other variable that may contribute to understanding the reported results. The length of follow-up was also limited, meaning it was not possible to investigate differences in chronic oral health conditions such as dental caries or periodontal disease.

Future studies can provide further evidence in this area. Mechanistic and acute meal response studies could consider oral environment changes in the hours following the intake of meals where aspects of the food matrix vary, such as with wholegrain milling. This may include investigation of stimulated and unstimulated salivary flow rate, or salivary glucose levels. Prospective observational studies where the food frequency questionnaire or food diary used to identify habitual dietary intake can distinguish between processed and unprocessed foods which report oral health outcomes could also consider this question. Finally, larger randomised controlled trials considering dietary quality could include oral health assessment into their design, so to comment on dental caries and inflammatory gum disease.

Conclusion

Wholegrain processing did not appear to change salivary pH or dental plaque accumulation over periods of two weeks. Further research applying different study designs may be able to provide further information on aspects of food processing and oral health outcomes.

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References

AACCI. (2013). *The American Association of Cereal Chemists International (AACCI) Board of Directors approved the Whole Grains Working Group's characterization*. In: AACCI, editor.

Åberg S, Mann J, Neumann S, Ross AB, Reynolds AN. (2020). Whole-Grain Processing and Glycemic Control in Type 2 Diabetes: A Randomized Crossover Trial. *Diabetes Care*.

Baker P, Machado P, Santos T, Sievert K, Backholer K, Hadjikakou M, Russell C, Huse O, Bell C, Scrinis G. (2020). Ultra-processed foods and the nutrition transition: Global, regional and national trends, food systems transformations and political economy drivers. *Obesity Reviews*.

Chapple IL, Bouchard P, Cagetti MG, Campus G, Carra MC, Cocco F, Nibali L, Hujoel P, Laine ML, Lingström P. (2017). Interaction of lifestyle, behaviour or systemic diseases with dental caries and periodontal diseases: consensus report of group 2 of the joint EFP/ORCA workshop on the boundaries between caries and periodontal diseases. *Journal of Clinical Periodontology*. 44: S39-S51.

Choi SE, Sima C, Pandya A. (2020). Impact of Treating Oral Disease on Preventing Vascular Diseases: A Model-Based Cost-effectiveness Analysis of Periodontal Treatment Among Patients With Type 2 Diabetes. *Diabetes Care*. 43: 563-571.

Grafenauer S, Curtain F. (2018). An audit of Australian bread with a focus on loaf breads and whole grain. *Nutrients*. 10: 1106.

Greene JG, Vermillion JR. (1964). The simplified oral hygiene index. *The Journal of the American Dental Association*. 68: 7-13.

Halvorsrud K, Lewney J, Craig D, Moynihan P. (2019). Effects of starch on oral health: systematic review to inform WHO Guideline. *Journal of Dental Research*. 98: 46-53.

Mealey BL, Ocampo GL. (2007). Diabetes mellitus and periodontal disease. *Periodontology 2000*. 44: 127-153.

Merchant AT, Pitiphat W, Franz M, Joshipura KJ. (2006). Whole-grain and fiber intakes and periodontitis risk in men. *The American Journal of Clinical Nutrition*. 83: 1395-1400.

New Zealand Dental Association. (2010). Healthy mouth, healthy ageing: oral health guide for caregivers of older people. *Auckland: New Zealand Dental Association*. 3-36.

New Zealand Ministry of Health. (2015). *Eating and Activity Guidelines for New Zealand Adults*. Wellington.
New Zealand Ministry of Health. (2010). *Key findings of the 2009 New Zealand oral health survey*. Ministry of Health Wellington (New Zealand).
Mörmann JE, Mühlemann H. (1981). Oral starch degradation and its influence on acid production in human dental plaque. *Caries Research*. 15: 166-175.
Nowjack-Raymer R, Sheiham A. (2003). Association of edentulism and diet and nutrition in US adults. *Journal of Dental Research*. 82: 123-126.
Reynolds AN, Akerman AP, Mann J. (2020). Dietary fibre and whole grains in diabetes management: Systematic review and meta-analyses. *PLoS Medicine*. 17: e1003053.
Sashikumar R, Kannan R. (2010). Salivary glucose levels and oral candidal carriage in type II diabetics. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*. 109: 706-711.
Slavin JL. (2000). Mechanisms for the impact of whole grain foods on cancer risk. *Journal of the American College of Nutrition*. 19: 300S-307S.
Stephen AM, Cummings JH. (1980). Mechanism of action of dietary fibre in the human colon. *Nature*. 284: 283.
Tsai C, Hayes C, Taylor GW. (2002). Glycemic control of type 2 diabetes and severe periodontal disease in the US adult population. *Community Dentistry and Oral Epidemiology*. 30: 182-192.

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