HEALTHY MOUTH, HEALTHY BODY: TOWARDS INTEGRATED DIETARY APPROACHES

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A THESIS SUBMITTED TO

AUCKLAND UNIVERSITY OF TECHNOLOGY

IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

2020

HUMAN POTENTIAL CENTRE

SCHOOL OF SPORT AND RECREATION

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ABSTRACT

Dental caries is a highly prevalent health issue across all age groups worldwide and is the most common chronic childhood disease in New Zealand. Concurrently, obesity and related chronic metabolic diseases are the most challenging public health problems of modern times. A common dietary behaviour – the high and frequent consumption of processed fermentable carbohydrates – is implicated in dental caries, and chronic diet-related disease. This body of work explores this challenge in New Zealand, particularly regarding the scarcity of evidence of the efficacy of dietary behaviour change interventions for the prevention of dental caries. The thesis profiles seven studies: the first three studies addressed epidemiological factors of dental caries in New Zealand children, the role of processed sugar- and starch-containing carbohydrate foods in dental caries, and the evidence regarding dietary factors that are implicated in both dental caries and other diet-related chronic disease, and the extent to which this evidence is reflected in dietary recommendations. The remaining four formative research studies provided original contributions in the development of a novel method for evaluating nutrition knowledge, the assessment of such knowledge in disparate groups of children and adults for each of general and oral health, and a qualitative investigation into beliefs about, and barriers to healthy eating.

The first of these studies investigated potential inequities in caries distribution using a retrospective review of dental records of five-year-old Auckland schoolchildren. The findings from this epidemiological study showed that children of Māori, and Pacific descent experienced significantly higher burdens of disease than children of New Zealand European or other descent. Children experiencing the highest levels of socio-economic deprivation had a nearly three-fold greater dental caries experience than children experiencing the least deprivation.

The relationship between high dietary intakes of sugar and dental caries is well established; however, there is debate about the caries risk associated with the intake of other processed fermentable carbohydrates. The aim of the second study, the systematic review, was to investigate the relationship between the consumption of processed sugar- and starch-

containing foods and dental caries. In a systematic review of prospective studies, statistically significant associations were observed between high between-meal consumption of processed sugar- and starch-containing fermentable carbohydrates and dental caries. There were mixed findings regarding total consumption of processed sugar and starch-containing foods, owing to confounding factors including the simultaneous consumption of caries-protective foods at mealtimes. Most importantly, there were no interventions that evaluated the efficacy of dietary change interventions on dental caries; this represents a significant gap in the literature on the prevention of dental caries, a chronic disease associated with dietary behaviour.

Finally, the aim of the third study, the narrative appraisal, was to incorporate the evidence regarding dietary factors in dental caries and other diet-related chronic disease and assess the extent to which this evidence is reflected in dietary recommendations. Substantial disconnects were identified between the evidence of dietary factors associated with dental caries and poor general health and dietary guideline recommendations, which underpin advice provided in health promotion initiatives.

The findings from these three studies indicate that current strategies for caries prevention are insufficient to address the burden of dental caries, and the observed large inequities in disease distribution. Advice provided in health promotion initiatives can also undermine progress in prevention, through the advocacy of foods that are harmful to dental health. In addition, there is a lack of integration of the medical and dental professions in their work towards the prevention of chronic diet-related disease. Crucially, a key gap identified in the literature was the absence of interventions that have addressed the simultaneous prevention of both dental caries and general health using dietary behaviour change. The epidemiological and biological evidence by which a poor-quality diet causes harm in oral and general health provides justification for designing dietary change interventions. The design of such interventions requires the measurement and understanding of the current knowledge and beliefs of the target populations, and of health practitioners who instigate such interventions. There may also be a range of barriers to engaging in behaviour change

and in implementing strategies for change at multiple levels; these also require consideration in the design of potential interventions.

These factors gave rise to a shift in the research direction of this thesis to a set of four formative studies yielding quantitative and qualitative data that were undertaken in the Taupō community in the North Island of New Zealand. The principal objectives of these formative studies were to measure and evaluate the beliefs of dietary behaviours and healthiness of foods in disparate groups of children and adults. Furthermore, the alignment of the beliefs and knowledge with dietary guideline advice for oral and general health was also assessed. Given that knowledge alone may be insufficient to change behaviours, the aim of the qualitative work was to gain insights of the barriers that children and adults experience to healthy eating.

The first of these formative studies was the development and validation of a set of novel card sorting exercises as a method by which nutrition knowledge of dietary behaviours and foods for oral and general health could be measured in children and adults. The card sorting exercises were valid, reliable, and acceptable for assessing beliefs and knowledge in these groups.

In the next two studies, the card sorting exercises were used to evaluate beliefs and knowledge in children, parents, and health professionals and to compare the results between these disparate groups for each of i. general health and ii. oral health. Reducing sugar intake, and eating fresh fruit and vegetables were classified as very important for general health, alongside exercising, getting outside, and getting adequate sleep. For oral health, two components were evaluated i. behaviours for oral health and ii. foods for oral health. Oral hygiene behaviours were categorised by nearly all participants as very important for oral health; conversely, dietary behaviours were categorised by fewer participants as very important for oral health. In addition, although the participants correctly judged high-sugar foods to be unhealthy for oral health, there were varied levels of understanding observed in children and adults of both the healthiness of animal produce, and the detrimental effects of processed fermentable carbohydrate foods in oral health. The categorisations of foods as

healthy and unhealthy aligned with both the beliefs about dietary behaviours, and recommendations in dietary guidelines, including foods for which there are caveats around consumption. These findings suggest that information provision through health promotion initiatives is successful in achieving knowledge acquisition in adults and children.

The final component of the formative research was the qualitative investigation into the beliefs about, and the barriers children and adults experience, in achieving healthy eating goals. A socio-ecological model of healthy eating for families was developed; themes of healthy eating included knowledge, rules around consumption of foods, preferences and enjoyment, and tradition and culture. Barriers experienced by all groups to healthy eating were social factors relating to other people, and the food environment characterised by the omnipresence of highly processed foods.

In summary, although dental caries is a significant public health challenge, there is a lack of evidence on the efficacy of interventions for caries prevention. Interventions should be a priority given the current paucity of evidence of firstly, the role of a poor-quality diet in dental caries, and secondly, the effectiveness of interventions that focus on reducing processed fermentable carbohydrate intake to decrease the risk of dental caries. The findings in this thesis regarding the common dietary factors implicated in poor oral and general health, and the formative research to evaluate nutrition knowledge and barriers to healthy eating should be used to inform the development of interventions for the prevention of chronic disease. Dietary behaviour is a complex interplay of perceptions of healthy eating, and factors beyond individual knowledge that influence dietary choices; these barriers exist within multiple socio-ecological levels. The prevention of dental caries and chronic metabolic diseases requires the input of both the dental and medical professions, and multi-level integrated approaches to improve population health.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation	Definition
ARDS	Auckland Regional Dental Service
ASA	Advertising Standards Authority
BMI	body mass index
BMJ	British Medical Journal
CI	confidence interval
COHS	community oral health service
CWF	community water fluoridation
dmft	decayed missing and filled teeth of the primary dentition
DMFT	decayed missing and filled teeth of the permanent dentition
IRR	Incidence rate ratio
MOH	Ministry of Health
NZDA	New Zealand Dental association
NHI	National Health Index
NI	not important
OECD	Organisation for Economic Co-operation and Development
OR	odds ratio
RCT	randomised controlled trial
ROS	reactive oxygen species
RR	relative risk
SD	standard deviation
SI	somewhat important
S. mutans	*Streptococcus mutans*
SSB	sugar-sweetened beverages
UK	United Kingdom
US	United States
VI	very important
vs.	Versus

Symbol	Definition
pH	acidity measurement
χ^2	chi-squared
Df	degrees of freedom
$	Dollar
g	Gram
≥	greater than or equal
>	greater than
≤	less than or equal to
<	less than
NC	not calculated
p	p-value
%	Percentage
±	plus-minus
PD	proportion difference
n	sample size
r	Spearman's correlation co-efficient
SS	statistically significant
20^{th}	Twentieth
II	Two
1,25 (OH)D	1,25-dihydroxyvitamin D or calcitriol
WMD	weighted mean difference

ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Chapters two through eight represent papers that have been published or are in the submission process to peer-reviewed journals. My contribution and the contributions of various co-authors to these papers have been outlined on page xv of this thesis. All co-authors have approved the inclusion of the joint work in this doctoral thesis.

Sarah Hancock

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August 2020

CANDIDATE CONTRIBUTION TO CO-AUTHORED PAPERS

Chapter 2	Hancock S, Thornley S, Schofield G and Zinn C. (in preparation for submission) Dental Caries in five-year-old children living in the Auckland region by ethnicity and socio-economic status.	Hancock 80% Thornley 16% Schofield 2% Zinn 2%
Chapter 3	Hancock S, Zinn, C, Schofield G. (2020). The consumption of processed sugar- and starch containing foods, and dental caries: a systematic review. *European Journal of Oral Sciences*	Hancock (85%), Zinn (10%) Schofield (5%).
Chapter 4	Hancock S, Zinn C, Schofield G, Thornley S. (2020). Nutrition guidelines for dental care vs. the evidence: Is there a disconnect? *New Zealand Medical Journal*; 133 (1509) 65-72.	Hancock 80% Zinn 7.5% Schofield 7.5% Thornley 5%
Chapter 5	Hancock S, Schofield G, Zinn C, Thornley S. (in submission) The validity and reliability of novel card sorting tasks to evaluate nutrition knowledge for general and oral health. *Journal of Nutrition and Educational Behaviour*	Hancock 80% Schofield 9% Zinn 9% Thornley 2%
Chapter 6	Hancock S, Schofield G, Zinn C. (in submission) Knowledge of children, parents and health professionals of lifestyle behaviours and foods for general health. *Public Health*	Hancock 80% Schofield 10% Zinn 10%
Chapter 7, Part 1	Hancock S, Schofield G, Zinn C. (in submission) For the health of your mouth, Part 1: Oral Health behaviours: assessing the beliefs in children, parents, and health professionals. *Pediatric Dentistry*	Hancock 80% Schofield 10% Zinn 10%
Chapter 7, Part 2	For the health of your mouth, Part 2: Healthiness of foods for oral health: Assessing the knowledge in children, parents, and health professionals. *BMC Oral Health*	Hancock 80% Schofield 10% Zinn 10%
Chapter 8	Hancock S, Schofield G, Zinn C. (in submission) Perceptions of healthy foods, and barriers to healthy eating in New Zealand children, parents, and health professionals: a thematic analysis and socio-ecological model. *Health and Place*.	Hancock 80% Schofield 10% Zinn 10%

We, the undersigned, hereby agree to the percentages of participation in the papers outlined on Page xv

Sarah Hancock Candidate	Professor Grant Schofield Primary supervisor	Dr Caryn Zinn Secondary supervisor

Dr Simon Thornley
Third supervisor

ACKNOWLEDGEMENTS

My sister was diagnosed with Type 1 diabetes mellitus at the age of eight years old in 1984. Dianna's life was altered immeasurably by this diagnosis of this chronic disease that was always present, required ongoing monitoring and control, and had the capacity anywhere and anytime, to make her very, very ill. As a witness to Dianna's complicated ongoing journey through the health system, I was always grateful for my own robust good health, and I developed an early interest in the prevention of chronic illness and the role of how and what we eat in attaining optimal health. I am immeasurably grateful to complete the PhD I was ultimately supposed to undertake relating to the prevention of another chronic disease in children, dental caries, and inter-related chronic metabolic disease of dietary cause through the life course. The irony that this includes diabetes is not lost on me, given that diabetes has a devastating impact on so many people and their families in New Zealand and worldwide more than at any time in human history.

I would like to acknowledge several organisations and people who have provided support to me for the duration of this PhD. I would firstly like to thank the Faculty of Health and Environmental Sciences for the provision of funding for PhD fees. Secondly, I would like to thank the AUT University Ethics committee (AUTEC) for the ethical approval of this research (AUTEC: 18/82, Approval: 9 July 2018).

Without data, we would not have research and I am so grateful to all the participants for their time and enthusiasm for my series of projects. I would like to thank the staff and students at Tauhara Primary School, St Patrick's Catholic School, Wairakei School, and Taupō Intermediate school for your enthusiasm for engaging in my "science project", even though some of you were taken aback by tasks that looked far less sophisticated than something you might assemble at school yourselves. Sometimes the simplest projects can provide the richest of datasets. It was a pleasure to work with all the students, and I hope you gained an appreciation for what "science" can look like. I would also like to express my thanks to the parents, and health professionals from Taupō Medical Centre, Anamata Café,

Tuwharetoa Health, and Stutz Dental Practice for their participation; I was particularly humbled by, and grateful for your honesty and trust in me with the challenges you experience in eating well and in providing dietary advice to patients.

To Professor Grant Schofield, thank you first and foremost for your mentorship and guidance of this research. I have appreciated beyond measure your enthusiasm, energy, your sense of humour, your wise advice to "trust the process", and your ability to see the larger picture. On this latter point, I particularly enjoyed creating big pictures with you to outline the multiple threads of how a poor-quality diet impacts our teeth, and how very few of us are looking at the systemic view of oral health and nutrition. I will always be grateful for your confidence and belief in my ability to complete this PhD while living in Taupō, and for sharing your wealth of knowledge with me for these projects. I once read that the best teachers are those who show you where to look, but they do not tell you what to see, and encourage you to look further. Thanks Grant, for being that teacher, and for pushing me out of my comfort zone to question everything and look further (to where the magic happens) to be a better academic.

To Dr Caryn Zinn, I have always admired you as an academic, dietitian, and author, and that admiration has grown so much over the time of my PhD. I will be forever grateful for your expertise, generosity with your abundant knowledge, attention to detail, and your time and care with this thesis. Above all, and most importantly, it has been an immense privilege to work with you and I cannot thank you enough for your friendship, kindness, and support, especially over this last year.

To Dr Simon Thornley, thank you for your infinite patience with me as I learned so much about statistics and epidemiology. However, over the last year of the Covid-19 pandemic, I have come to admire your dedication to the principles of public health, your thoughtful consideration of all costs and inequities incurred because of hard decisions made in our name by those in power, and your commitment to the principles of evidence-based medicine.

I would also like to thank the team at Great Lake Physio, and John Curtis and all the groups at Kloud Collective for the opportunities to share these workspaces with me. The companionship and support of you all made this a less lonely endeavour as a distance student at AUT. I have really appreciated the friendships with creative people doing fabulous work across multiple fields of endeavour.

To our extended family - the Cairds and the McCallums, the Hancocks and the Holmbergs - thank you for your kindness, support, and encouragement through this process. Special thanks also to Auckland-based friends and family – especially Jill Lodewyks - for having me stay with you during my study visits to Auckland; and friends in Taupō for making this journey easier and fun along the way.

To Maria and Evelyn, thank you for your patience, tolerance, love, and laughter through the last three years. You have both been wonderful. I hope what you have gained through witnessing this process is that you should always be, and remain curious, and to ask your own questions about what matters to you. In a world with some problems relating to fairness, justice, and inequities of which you are aware at a level I find inspiring, the changes you need and want to see can start with you.

Colin, the two one-syllable words "thank you" in the English language seem so pathetically small and totally inadequate to express my gratitude for your unconditional love, support, trust, and faith in me that you have shown through this PhD and our life together. I am grateful beyond words for your ability to listen (a lot), to provide gentle advice, and your strength in every single way you have been strong for all of us. I know I could never, ever, have achieved this work without you; this is truly "our PhD". I can only thank you from the bottom of my heart for all you have given me, and us.

CHAPTER 1: INTRODUCTION

Background

The connection between diet and chronic disease

Chronic disease occurred relatively infrequently in early humans, due to a much different diet than that eaten by modern humans. Anthropological studies have shown the first dietary change in human evolution involved the move from hunter-gatherer diets to the adoption of Neolithic, carbohydrate-based diets (Adler et al., 2013; Braidwood et al., 1961). The increased consumption of domesticated cereals in the Neolithic era led to a distinct increase in prevalence of calcified plaque and oral disease associated with this change in the diversity and composition of the oral microbiome (Adler et al., 2013). These oral diseases include dental caries (Aas et al., 2008) and periodontal disease, both of occurred rarely in pre-Neolithic societies (Adler et al., 2013). The scarcity of dental disease among hunter-gatherers was matched by a remarkable – by current standards - absence of systemic chronic non-communicable diseases including cardiovascular disease, diabetes, cancers, and obesity (Truswell, 1977).

The second shift in the oral microbiome took place during the Industrial Revolution coinciding with the increased availability of sugar from the Caribbean Islands. Prior to the 1870s the mid-Victorians included vegetables, fruit, fish, eggs, hard cheeses and meat, the latter of which was considered the mark of a "good diet" (Clayton & Rowbotham, 2009). During the 1870s, cheap imports of white flour, tinned meats and sugars became more readily available and dramatic increases in the prevalence of dental caries were observed (Muller & Hussein, 2017; Suddick & Harris, 1990). Life expectancy at age 5-years during the mid-Victorian period in the United Kingdom also was similar or superior to today, with an incidence of degenerative disease was 10% of what is observed currently (Clayton & Rowbotham, 2009).

Widespread migration and increased urbanisation associated with the Industrial Revolution also led to increased outbreaks of communicable diseases. This became an impetus for governments to develop methods to reduce the risk of bacterial- and food-borne illness

(Ridgway et al., 2019). The incidence of food-borne illness declined with the establishment of food policies and educational hygiene programmes that addressed food safety, adulteration, and behaviour. An early example of a behaviour change movement for health benefit was the Progressive Reformer-led social hygiene movement which engaged in behaviour education to control outbreaks of sexually transmitted diseases and regulate vice and prostitution (Curtis et al., 2011; Luker, 1998). The increased awareness of the benefits of public-private collaboration and social movements to improve health also led to the idea of good health being a consequence of behaviour (Oaten et al., 2009).

Dietary prevention of non-communicable chronic disease

Through most of human history, lack of food presented the greatest nutritional challenge (Mozaffarian, Angell, et al., 2018; Mozaffarian, Rosenberg, et al., 2018). To address this problem, governments worldwide sought to increase the availability of food by utilising a range of methods and technologies to decrease the cost of food production. The recent increases of diet-related chronic diseases including type 2 diabetes, cardiovascular diseases and some cancers can be in part attributed to these co-ordinated approaches by industry and governments (Ridgway et al., 2019).

The vitamin deficiency era

In the first half of the 20th century, hunger and micronutrient deficiencies were causes of malnutrition (Ridgway et al., 2019). During this time, many essential vitamins and minerals were identified and used in dietary strategies to prevent and treat nutritional deficiency-related diseases (American Chemical Society, 2002; Mozaffarian, Rosenberg, et al., 2018). This included the recommendation to consume Vitamin D-containing foods for the prevention of dental caries. Early exploratory research by Mellanby et al. showed a diet containing Vitamin-D rich foods including bone broth, milk, eggs, meat, fish, and vegetables, and the elimination of cereal and porridge was associated with remineralisation of decaying enamel and fewer new caries (Mellanby & Pattison, 1928, 1932; Mellanby et al., 1924). Vitamin D was identified as essential for supplying bones, teeth, and muscle with calcium, and for calcium absorption in the gut (Heaney, 2008). Other physiological processes for which Vitamin D is required are the control of hormones and cell growth, aiding neurological function, and conferring of immunological benefits (Nair & Maseeh, 2012). The promotion

of milk, meat, and eggs as part of "balanced diets" using "protective foods" became central messages for public health nutrition promotions throughout the 1920s and 1930s (Lang & Rayner, 2015; Ridgway et al., 2019).

Dietary changes on human health were studied extensively by the dentist Dr Weston Price who had noted dramatic increases in dental caries in his practice in the United States in the 1920s. Price undertook studies of indigenous populations who were not exposed to "displacing foods of modern commerce" that included refined sugars, polished rice, vegetable fats and canned foods (Price, 1945). One country investigated was New Zealand, where the diet of "non-modernised Māori" consisted of large quantities of food from the sea, mutton-birds, fern root, vegetables, and fruits. A previous study of 250 Māori skulls from an unspecified time prior to European settlement identified teeth with caries in two skulls or 0.76% of those under study (Pickerill, 1914). Further study by Price on an additional 76 skulls found that the incidence of dental caries in Māori populations was 1.2% when the data were combined with that of the earlier study. Price also investigated the teeth of "modernised" and non-modernised Māori for dental caries. In the modernised urban-living groups, in which the diet was characterised by increased consumption of processed carbohydrates, dental caries was observed in 31-50% of the population; in the most isolated groups, dental caries was observed in only 2% of the population. Price attributed the detrimental effects of oral health in modernised Māori to consumption of white flour, syrups and sweetened foods, and noted that dental decay and other "chronic diseases of lifestyle" appeared in the first generation of those who began to eat what were termed "the displacing foods of modern commerce". Additionally, Price observed of Māori:

> *"The Māori race developed a knowledge of Nature's laws and adopted a system of living in harmony with those laws to so high a degree that they were able to build what was reported by early scientists to be the most physically perfect race living on the face of the earth. They accomplished this largely through diet and a system of social organisation designed to provide a high degree of perfection in their offspring. To do this they utilised foods from the sea liberally."*
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> Price, W. (1945) Nutrition and Physical Degeneration, Chapter 12, p. 209

The findings made by Price in New Zealand – of decline in oral health upon the substitution of a traditional diet with a modern diet containing refined carbohydrates – were replicated in his other studies of indigenous populations worldwide (Price, 1945). Populations who

continued to eat traditional diets showed an almost total absence of dental caries, well-developed facial bone structure, superior immunity characterised by an absence of tuberculosis in some communities, and an absence of modern chronic diseases including cancer, rheumatic disease and auto-immune diseases (Price, 1945).

The temporal patterns of the supply of processed carbohydrates, and the incidence of chronic non-communicable diseases prior to, during, and after World War II provide evidence that the incidence of chronic general and oral diseases increase and decrease in line with changes in the supply of processed carbohydrates. There was a decrease of 29% in diabetes mortality among English women (Cleave & Campbell, 1966): concurrently, dental caries in 5-year-old British schoolchildren decreased by 28% over this time (Campbell, 1996; Cleave & Campbell, 1966; Sognnaes, 1948). More recently, sugar consumption in Iraq decreased from 50kg/person/year to 12kg/person/year because of United Nations sanctions imposed from 1990. These reductions in sugar availability were associated with decreases in dental caries burden observed in Iraqi children over a five-year period (Jamel et al., 2004).

The establishment of dietary guidelines for disease prevention

Obesity, and rising burdens of chronic non-communicable diseases were increasingly recognised as diet-related conditions leading to new research directions (Mozaffarian, Rosenberg, et al., 2018). The relationships between the high consumption of various macro- and micro-nutrients and chronic diseases were investigated during the late 1940s and early 1950s; several prospective cohort studies investigated outcomes in thousands of individuals. The emphasis on fat consumption was typical of approaches to nutrition science where the focus was reduced to single food items and specific macro- and micro-nutrients (Hoffmann, 2003).

The findings from the prominent Seven Countries study led to the premise, championed by Ancel Keys, that dietary fat intake was implicated in cardiovascular disease risk (Keys & Keys, 1959; Keys et al., 1986). What became known as the "lipid hypothesis" focused on excess fat intake, particularly saturated fat consumption and the effect of this on cholesterol, as the primary cause of chronic diseases (Keys & Keys, 1959). The dietary goals released in United States in 1977 included recommendations to reduce dietary fat consumption by 40% to 30%

of total energy intake. In addition, other recommendations for health based on the lipid hypothesis advised the adoption of a diet high in fermentable carbohydrates and low in fat to reduce systemic chronic diseases. Consequently, dental caries and other oral diseases were regarded as a local dietary side-effect (Konig, 2000).

Thomas Cleave and John Yudkin advocated an opposing hypothesis that fermentable carbohydrates were implicated in chronic oral and general disease (Hujoel, 2009). Both scientists believed that the increase in dental and other chronic diseases were caused by an excessive intake of fermentable carbohydrates. Dental caries were also considered to be an early-presenting indicator of chronic systemic diseases, and that the first-line prevention of poor oral health should involve the restriction of fermentable carbohydrates (Cleave & Campbell, 1966; Yudkin, 1972).

Ultimately, the lipid hypothesis favouring reductions in dietary fat intake gained acceptance and became a principal cornerstone of dietary guideline advice. The 1980 Dietary Guidelines for Americans were implemented, with population-level recommendations to consume a diet characterised by low fat and low cholesterol intakes (Harcombe, 2017). Dietary guidelines, established with government and industry support in other countries including New Zealand, had similar recommendations. This established a dominant and ongoing assumption that a high dietary fat intake was the principal dietary risk factor for cardiovascular diseases, and the replacement of saturated fats with vegetable oils could lower blood cholesterol levels and potentially confer benefits in cardiovascular disease prevention (Harcombe, 2017; Johns & Oppenheimer, 2018). This led to the increased production of processed foods that were fortified with micronutrients, and low in fat and cholesterol (Fletcher et al., 2004).

Government policies, motivated by both historical approaches and conventional imperatives on food security, economics, and trade, have continued to both support the food industry and emphasise the production of staple commodities (Mozaffarian, Angell, et al., 2018). Education policy measures, endorsed by governments and affiliated agencies, have been typically directed at changing individual behaviours in response to increases in chronic disease. These measures that target dietary behaviours emphasise personal responsibility and choice by encouraging adherence to recommendations in dietary guidelines, paying

attention to food and menu labelling, and counselling. Commercial pressures also affect diet quality through the marketing, advertising, and packaging of foods, which is in turn influenced by socio-cultural perceptions of norms and privilege. Agricultural policy and production practices, and trade agreements also influence food choices (Mozaffarian, Angell, et al., 2018).

Consequences of dietary guideline recommendations on chronic disease

Despite the ongoing reviews and refinements of dietary guidelines, poor quality diets and malnutrition have a substantial impact on global morbidity and mortality rates (Food and Agriculture Organisation, 2014). This has given rise to a "double burden" of malnutrition: worldwide, more than 805 million people suffer from malnutrition, and 1.9 billion people are overweight or obese (Kosaka & Umezaki, 2017; Min et al., 2018).

Historically, the solution to malnutrition was to quantify the optimal intake level of relevant nutrients to prevent disease (Ridgway et al., 2019). In particular, the healthiness of foods was based on macro- and micro-nutrients that foods did not contain, e.g. saturated fat (Mozaffarian, Rosenberg, et al., 2018). A range of prospective studies showed few benefits of reducing total fat in the diet; conversely, the results of other prospective studies and randomised controlled trials showed that the intake of healthy fats was beneficial for weight loss and blood glucose control, while foods with higher proportions of sugar and starch were implicated in chronic disease (Imamura et al., 2016; Mensink et al., 2003; Mente et al., 2009; Mozaffarian, Rosenberg, et al., 2018; Tobias et al., 2015).

Dietary recommendations for the prevention and treatment of chronic non-communicable diseases continues to be controversial. There is ongoing support of a "calories in, calories out" model of obesity based on a concept of energy imbalance in which calories from different foods are regarded as equal (Weiss et al., 2013). Caloric intake is relatively stable in most people and dietary changes are typically comprise substitution, in which increased consumption of some foods occurs with decreased intakes of other foods (Schulze et al., 2018). An increasing body of evidence shows that a more relevant focus for nutrition research may be diet composition and dietary patterns rather than the study of calorie intake and a focus on single or multiple nutrients. The composition of foods and dietary patterns

have a range of impacts on overlapping hormonal and metabolic pathways with effects on liver function, glycaemic responses and the microbiome which in turn affect satiety and psychological reward, (Ludwig & Friedman, 2014; Weiss et al., 2013).

Current strategies that emphasise single macro-or micro-nutrients such as total fat intake overlooks the importance of food processing methods, diet quality and dietary patterns in human health (Mozaffarian, Rosenberg, et al., 2018). The focus on the macro- or micro-nutrient components of food has enabled the food industry to manipulate nutrition science (Nestle, 2018), with commercial marketing of a proliferation of fortified and reformulated processed foods (Clapp & Scrinis, 2017). In particular, the sugar industry has had a substantial impact in moving the focus of public health nutrition science towards beliefs regarding the roles of dietary fat intake in heart disease (Kearns et al., 2015). Central approaches used to determine and promote the healthiness or otherwise of foods include nutrient profiling used in front-of-pack labelling, and other regulatory activities such as reformulation and food marketing (Mozaffarian, Rosenberg, et al., 2018).

Although there has been substantial growth in studies exploring the relationships between diet, health, and chronic disease it remains questionable whether this growth in available information has led to heightened understanding (Ladher et al., 2018). The ongoing increases in obesity and Type 2 diabetes were consequences of the dietary guideline recommendations that were not intended by the scientists who were the proponents of this advice. However, concerns regarding conflicts of interest in science and industry, and contradictory media messages has contributed to discord and angst within public health nutrition (Ioannidis, 2018; Ladher et al., 2018). Although established with the goal of protecting and promoting the health and wellbeing of populations, public health nutrition has instead become a field of endeavour notable for division and polarised debate based on deeply held beliefs, preferences, and biases regarding foods and dietary patterns (Ridgway et al., 2019). Typically, nutrition policy to promote optimal health and reduce non-communicable disease typically relies on consumer knowledge, through education, dietary guidelines, product labelling, star rankings, and the belief that people will make better choices because of knowledge acquisition (Mackay et al., 2019; Mozaffarian, Rosenberg, et al., 2018).

In the context of the ongoing global rise in the production of manufactured foods, it is important to assess the long-term health consequences of new foods. The healthiness of foods using the consideration of food processing levels is the subject of current widespread discourse in the scientific and public arenas regarding healthy eating at population level for the prevention of chronic disease (Monteiro et al., 2019; Monteiro et al., 2018; Monteiro et al., 2011). Technological changes in agricultural practices have given rise to food processing methods that include plant oil extraction, the widespread use of emulsifiers and thickeners, and processing of grains and starches using severe conditions (Monteiro et al., 2018). Notably, commercial processing methods of grains and starches include extrusion cooking (heating of starches at temperatures as high as 180°C, in combination with high mechanical agitation), stem-flaking, dry-autoclaving, extrusion cooking, and drum-drying (Bjorck et al., 1984; Lingstrom et al., 1989). There is increasing evidence that these food processing methods have a range of adverse effects on metabolism, and metabolic health (Monteiro et al., 2018; Mozaffarian, Rosenberg, et al., 2018).

One method of classifying foods according to benefit and harm for health is the NOVA classification system, by which foods are classified at four levels based on the extent and purpose of industrial processing (Monteiro et al., 2016; Monteiro et al., 2019; Monteiro et al., 2018). Foods categorised as Level 4 are defined as ultra-processed food products. Principal features of ultra-processed food products are that they consist of a minimum of five ingredients including sugars, oils, fats, salt, anti-oxidants, and stabilisers and preservatives to enable a long shelf-life (Monteiro et al., 2016). Ultra-processed food products are also designed to be highly appetizing and to be consumed upon purchase with no additional preparation. The composition, presentation through attractive packaging, and sophisticated marketing of these food products often promotes overconsumption (Monteiro et al., 2016). Ultra-processed products, as defined using the NOVA classification are predominant in the food supplies of various high-income countries; a recent report on the food supply in New Zealand supermarkets found that 69% of 13,000 packaged food items are considered to be ultra-processed food products (Mackay et al., 2019). In addition, there is increasing momentum with the use of the NOVA classification of foods in studies of consumption patterns of processed food (Luiten et al., 2016; Marron-Ponce et al., 2018; Moubarac et al.,

2017; Neri et al., 2019) and chronic disease (Fiolet et al., 2018; Gibney et al., 2017; Machado et al., 2019; Nasreddine et al., 2018; Rauber et al., 2018; Srour, Fezeu, Kesse-Guyot, Alles, Mejean, et al., 2019). The categorisation of foods according to the NOVA system may be more consistent with the evidence that food processing changes the nutritional value of food products (Fiolet et al., 2018; Srour, Fezeu, Kesse-Guyot, Alles, Debras, et al., 2019; Srour, Fezeu, Kesse-Guyot, Alles, Mejean, et al., 2019).

There is increasing recognition that the consumption of a diet characterised by large amounts of ultra-processed foods and a concurrent low intake of unprocessed foods, is detrimental for health (Kopp, 2019; Miclotte & Van de Wiele, 2019). The consumption of ultra-processed foods is associated with a range of metabolic distortions including inflammation, and hyperinsulinaemia and insulin resistance (Kopp, 2019). Deficiencies of a range of vitamins including Vitamin A, Vitamin D, B-vitamins, and minerals including zinc, iron, and calcium are also implicated in dysregulated metabolic processes (Miclotte & Van de Wiele, 2019). The consumption of these food products is associated with higher risks of overweight and obesity in children (Costa et al., 2019), and metabolic syndrome in adults (Martinez Steele et al., 2019; Tavares et al., 2012), cancer (Fiolet et al., 2018), and higher inflammatory-related processes within the human microbiota composition (Zinocker & Lindseth, 2018).

One typically overlooked chronic disease in public health nutrition considerations is dental caries, which is incongruous, given firstly, that a poor-quality diet is implicated in poor oral health and poor general health, and secondly, the significant burden on health care systems incurred by poor oral health. Although many adult-onset chronic diseases including inflammatory conditions, gestational type 2 diabetes, vascular disease, non-alcoholic fatty liver disease, some cancers, periodontal disease, and neurological disorders differ in presentation, the aetiology of disease can be attributed to a common cause (Crofts et al., 2015). Dental caries presents in adults, but also presents in a younger population than other diseases of dietary cause; in young preschool-age children, caries can present with marked severity which often necessitates the surgical removal of multiple teeth under general anaesthesia.

An example of the disconnection of oral health from general health in public health nutrition was illustrated at a landmark conference co-hosted by the BMJ (formerly the British Medical Journal) and the global health re-insurer Swiss Re, in June 2018. The conference was titled "Food for thought: The Science and Politics of Nutrition"; attendees included influential scientists in the field of nutrition and health (Ladher et al., 2018). Topics of discussion were the roles of dietary fats and carbohydrates in health, controversies in nutrition research and the interplays between governments, industry, and interest groups in health promotion. Subsequently, a series of articles were produced on these topics with outlines of areas of consensus, uncertainty, and future directions for nutrition research in a special issue of the BMJ in June 2018. Although the role of nutrition science in systemic chronic disease was discussed extensively, a word search of oral health terms of the entire supplement revealed no discussion of nutrition science in oral health. The word "caries" was mentioned four times, and of those four mentions, two were journal titles (e.g., "Caries Research"). A text search of the word "oral" showed 16 matches; however, "oral" was a match in longer surnames in reference lists (e.g., M*oral*es) or was found in other words including behavi*oral*, temp*oral*ity, post-doct*oral*, multisect*oral* and may*oral*.

The principal dietary risk factor for the development of caries is the consumption of a diet consisting of a high and frequent consumption of sugars (Bernabe et al., 2016; Gustafsson, 1954; Sheiham & James, 2014a, 2014b, 2015). Diet is commonly regarded as the principal aetiological factor in dental caries, through the impact of food intake on the integrity of teeth, and on the pH and composition of saliva and the oral biofilm. Typically, the focus of dental treatment is primarily on remediating cavitated caries lesions at the endpoint of disease (Jatrana et al., 2009). This treatment approach does not account for dietary factors in the disease process – a diet with high intakes of fermentable sugars, and the associations between this factor with other chronic conditions (Chapple et al., 2017; Hujoel, 2009; Hujoel & Lingstrom, 2017; Jatrana et al., 2009).

What follows is an outline of the dual model of the aetiology of caries development which shows both the local and systemic causes of dental caries due to a high intake of sugars. In particular, the common pathways by which a high sugar intake impacts both dental caries and hyperinsulinaemia, which is implicated in a wide range of metabolic diseases (Crofts et

al., 2015) will be illustrated. Strategies for both dietary and non-dietary prevention of dental caries will be briefly reviewed.

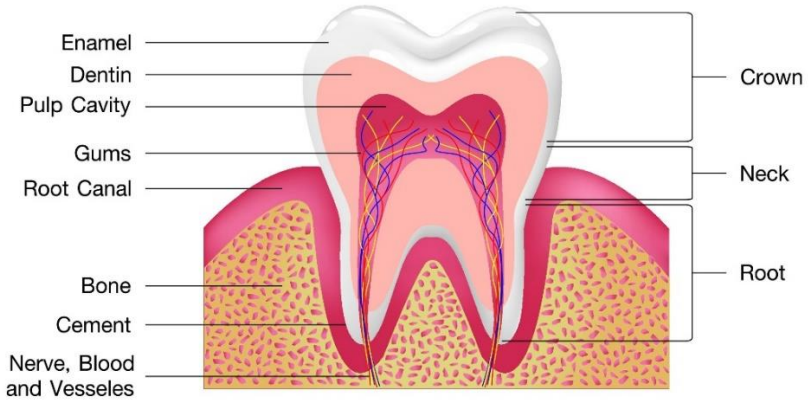
A dual model of dental caries development

Nutrition acts both locally and systemically in the caries process. An optimal intake of nutrients is required to achieve normal tooth development, which starts at the foetal stage, and is typically completed by six years of age (Alvarez, 1995). Maternal nutritional deficiencies, notably Vitamin D, disturb the mineralisation process of tooth development *in utero* resulting in teeth with defects that are increasingly vulnerable to dental caries. There is suggestive evidence that children born to mothers who experience Vitamin D deficiency during the gestational period have more dental hypoplasia in their primary teeth than children born to mothers without vitamin D-deficiencies (Schroth et al., 2014). Infants born to mothers have higher numbers of caries lesions and more severe caries experience (Schroth et al., 2016). High-sucrose diets have also been observed to have detrimental effects on the formation of dentin and enamel (Tjaderhane et al., 1994).

The relationship between dental caries and high dietary intakes of sugar is well established, through time-series analyses of whole country datasets showing rarity of dental caries prior to the consumption of refined sugar (Fisher, 1968; Sognnaes, 1949), and analyses of sugar availability during wartime and imposition of sanctions (Jamel et al., 2004). The associations between sugar intake and caries is epidemiologically demonstrated and biologically indicated through several lines of evidence including studies on the action of oral bacteria on a range of sugars in the mouth (Loesche et al., 1975) and observational studies on the role of sugars in dental caries (Sheiham & James, 2015).

The structure of the tooth is shown in Figure 1.

Figure 1. The structure of the tooth



Free image supplied by Shutterstock: www.shutterstock.com/image-vector/healthy-white-tooth-gums-bone-illustration-1429733069

The "outside-in" process of dental caries aetiology

Traditionally, the development and progression of dental caries is regarded as an "outside-in" process that occurs as a local reaction to the ingestion of fermentable carbohydrates including sucrose, glucose, lactose, and maltose within the mouth. Upon the ingestion of sugars, bacteria including *Streptococcus mutans (S. mutans), lactobacilli*, and *bifidobacteria* produce acids as a part of carbohydrate metabolism (Loesche, 1986, 1988; Loesche et al., 1975). Although oral acid-producing bacteria are present in humans in all societies (Sheiham & James, 2014b) (van Palenstein Helderman et al., 1996); it is the presence of sugar in the mouth that enables the process of caries (Sheiham & James, 2015). The pH in oral biofilms decreases from neutrality to a pH of 5.0 and results in sustained demineralisation of tooth enamel; the critical value of enamel dissolution ranges between 5.0-5.5, and depends on salivary flow (Aires et al., 2008; Southward, 2011). Repeated episodes of pH-lowering within the dental biofilm induced by the frequent intake of fermentable carbohydrates also promotes the formation of an oral biofilm with low concentrations of calcium, phosphate and fluoride, all which are important for the remineralisation of tooth enamel (Paes Leme et al., 2006).

The tooth enamel is nourished by saliva which is comprised of water, minerals, enzymes, and buffering agents (Scannapieco et al., 1993). At early stages of the caries process in the enamel, demineralisation can be halted or reversed through the uptake from saliva of calcium, phosphate, and fluoride. This process of remineralisation occurs when the pH values of the dental biofilm and calcium- and phosphate-rich saliva are above critical levels of 5.5 (Stephan & Hemmens, 1947). The presence of calcium, phosphorous, fluoride and other ions in saliva are an important component for facilitating remineralisation of demineralised enamel (Scannapieco et al., 1993). The development of enamel demineralisation to a cavitated caries lesion occurs if the remineralisation process is substantially slower than the process of demineralisation (Touger-Decker & van Loveren, 2003).

Protection from caries is also enabled by saliva through several mechanisms including: the clearance of food from the mouth; as a buffer to neutralise acid; the maintenance of super-saturation of tooth mineral; and the acquisition of the enamel pellicle formation which reduces the rate of demineralisation (Touger-Decker & van Loveren, 2003). The ability of saliva to buffer acids is essential for the maintenance of pH values of the oral biofilm. The development of enamel lesions therefore can reflect the net effect of the opposing actions of carbohydrate and saliva on the pH of the oral biofilm.

The "inside out" process of dental caries aetiology

Considering the aetiology of dental caries using only the localised response to carbohydrate fermentation as described above ignores the other evidence regarding the systemic cause of dental caries. A high sugar intake has a substantial impact on the internal nourishment of the tooth through a pathway controlled by the hypothalamus-parotid axis (Leonora et al., 1993). In addition, this systemic approach also considers the pathways by which both insulin and parotid hormone secretion controlled by the hypothalamus-parotid axis is influenced by the high consumption of sugars.

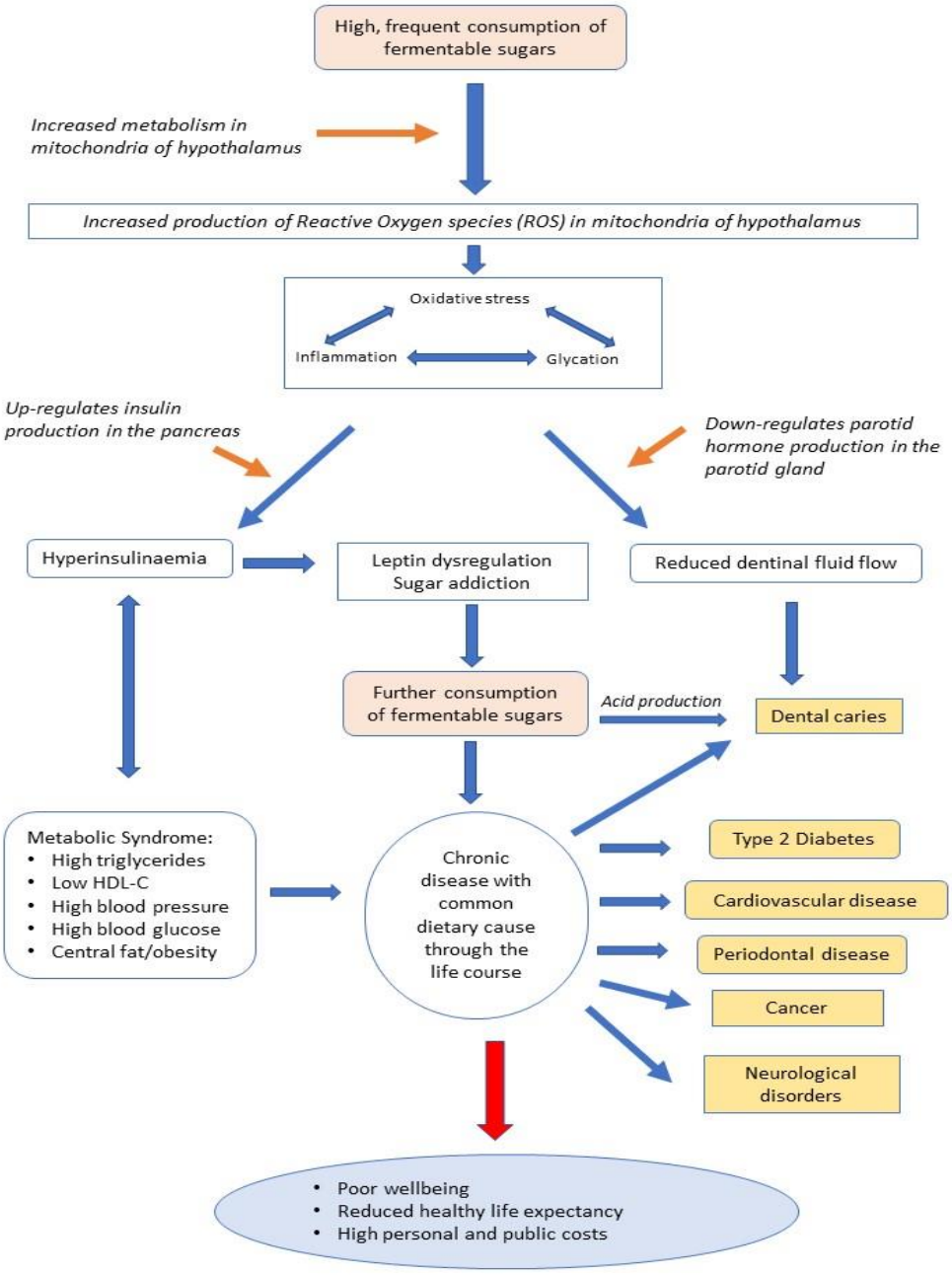
A centrifugal fluid flow through the dentin and enamel enables nourishment of the non-vascularised dentin of the tooth (Leonora et al., 1993); this fluid flow is stimulated by parotid gland secretion of parotid hormone (Southward, 2015). The parotid gland is a dual-function

gland with an exocrine function (to secrete saliva) and an endocrine function (to secrete parotid hormone to control dentinal fluid flow into the teeth) (Leonora et al., 1993). Similar to the secretion of insulin by the pancreas, the secretion of parotid hormone is controlled by the hypothalamus (Southward, 2011, 2015). Metabolic activity in the hypothalamus increases with high blood glucose, with resultant increased inflammation due to the increased production of reactive oxygen species (ROS). The hypothalamus then down-regulates parotid hormone secretion, alongside simultaneous increases in insulin production from the pancreas (Leonora et al., 2002; Southward, 2015). The downregulation of parotid hormone secretion reverses or stops the centrifugal fluid flow, resulting in malnourishment of the tooth.

Following enamel demineralisation of a malnourished tooth, progression of caries to cavitated lesions is enabled by the action of matrix metalloproteinases in the tooth in response to the production of acids within the mouth (Southward, 2015; Tjaderhane et al., 1998). This represents a dual model of dental caries that based on an "outside-in" process of causation that is initiated by a local, within-mouth process of enamel demineralization, and an "inside-out" endocrine system process caused by high and frequent intake of dietary sugars (Southward, 2011, 2015). Typically, the outside-in aetiological process of enamel demineralisation because of carbohydrate metabolism and acid production is the sole process considered in the aetiology of dental caries.

The use of the dual model comprising the inside-out process and the outside-in process may also explain the differences in effects of various acids on teeth. Acids produced through the action of bacteria on sugars can initiate a caries process while acids originating from fruit (Grobler et al., 1989), or generated from the purging actions in bulimia (Christensen, 2002), or that from gastro-oesophageal reflux disorder (Lazarchik & Frazier, 2009) usually erode only the enamel of the tooth in the mouth (Southward, 2015). These pathways and mechanisms of chronic general and oral disease represented in Figure 2.

Figure 2. The pathways and mechanisms of dental caries and chronic disease through the life course



Different but the same: similarities between causes of dental caries and metabolic disease

The resultant up-regulation of insulin production by the increased production of ROS and inflammation in the hypothalamus can cause hyperinsulinaemia which is defined as excessive production of insulin (Crofts et al., 2015). Hyperinsulinaemia is implicated in metabolic and obesity-related diseases including, type 2 diabetes, vascular disease, some cancers, inflammatory conditions including periodontal disease, and neurological disorders (Crofts et al., 2015). High levels of insulin secretion are also associated with the disruption of the satiety hormone leptin, which regulates energy balance and inhibits hunger by signalling to the brain when satiety is achieved from food consumption (Weiss et al., 2013). The consequence of the disruption to leptin promotes a cycle in which hunger and food consumption increases, leading to weight gain (Weiss et al., 2013). The frequent consumption of refined sugars is also associated with behavioural, neurochemical and brain activation responses that are characteristic of food addiction (Lennerz & Lennerz, 2018).

Taken together, a high intake of sugars, and production of ROS in the mitochondria of the hypothalamus contributing to inflammation are implicated in the development not only of poor metabolic health, but also dental caries. Therefore, both chronically poor oral and general metabolic health can be attributed to the common dietary behaviour of a high and frequent intake of dietary carbohydrates. Affecting all age groups, dental caries is the most prevalent non-communicable disease globally; more than three billion people suffer from untreated dental caries (Marcenes et al., 2013). Despite this, dental caries, and oral health in general, is rarely considered, if at all, in the field of public health nutrition alongside dietary prevention of chronic systemic disease. This is perplexing, given the common dietary cause of dental caries and chronic disease and the evidence for caries prevention through the increased dietary intake of vitamin D- and full fat-containing foods.

Dietary prevention of dental caries

Vitamin D

Dietary intervention has long been considered as one of the principal strategies for caries prevention (Chapple et al., 2017). Confirmation of the potential for dietary intervention to arrest and eliminate dental caries was provided in a study by Mellanby and Pattison (Mellanby & Pattison, 1928). A cereal-free diet with a high concentration of foods containing calcium and Vitamin D was found to prevent and reverse tooth decay. By 1930, most dentists believed that the consumption of Vitamin D-containing foods was effective for the prevention and reversal of dental caries (Hujoel, 2019; McCollum, 1931).

The strongest level of evidence regarding the effect of Vitamin D on dental caries in children has been provided by Hujoel (Hujoel, 2013) who conducted a systematic review and meta-analysis of controlled clinical trials assessing the effect of Vitamin D on dental caries prevention. The pooled relative rate estimate of supplemental Vitamin D was 0.53 (95%CI 0.43 to 0.65). Schroth et al. evaluated national-level data on the associations between Vitamin D status and dental caries (Schroth et al., 2016). Caries in Canadian schoolchildren was significantly associated with Vitamin D levels measured as 1,25(OH)D of less than 75mmol/L and less than 50 mmol/L. Mean decayed, missing, and filled primary (dmft) and permanent teeth (DMFT) were both associated with 1,25(OH)D concentrations of less than 75nmol/L (Schroth et al., 2016).

Vitamin D may confer protection from the dental caries process through a range of mechanisms including enabling optimal odontogenesis, improving remineralisation of tooth enamel throughout life, aiding changes in the amount or biochemical composition of saliva, and the modulation of caries activity through immunological factors (Seminario & Velan, 2016). In addition, Vitamin D controls hormones and cell growth, regulates gut function and microbes, influences metabolism, and aids neurological function (Nair & Maseeh, 2012).

Dairy produce

Dietary intakes of calcium, phosphate, and protein can support healthy oral biofilms and enable enamel remineralisation. The consumption of sugars and dairy produce were evaluated in the Forsyth Institute Root Caries Study; cheese was found to have a protective

effect against dental caries (Papas et al., 1995). Inverse associations between the consumption of full-fat dairy products in young people and dental caries incidence have also been observed in other studies (Dror & Allen, 2014; Lempert et al., 2015).

Calcium, phosphates, and lipids have recognised anticariogenic properties and can be consumed via dairy produce. Inhibitory effects were observed on enamel demineralisation in *in vitro* studies of casein phosphopeptides from yogurt, with concurrent remineralisation of enamel lesions (Kashket & DePaola, 2002). Other mechanisms by which cheese may inhibit and enable reversal of the caries process include buffering of plaque acids (Kashket & DePaola, 2002). In adults, cheese consumption has been shown to restore the oral biofilm pH to neutral following consumption of sugars, and to increase the concentration of calcium in dental plaque (Kashket & DePaola, 2002).

Consequences of dietary guidelines on prevention of dental caries

The associated benefits of Vitamin D-rich foods and full-fat dairy produce in the prevention and reversal of dental caries were sidelined in the wake of the establishment of dietary guidelines that recommended reductions in fat consumption (Hujoel, 2009; van Loveren & Duggal, 2001). When diets with larger proportions of fermentable carbohydrates were deemed to prevent chronic general diseases, and recommended in government-sanctioned dietary guidelines, dental professionals were required to recommend foods traditionally associated with increased risks of dental caries (Duggal & van Loveren, 2001). Because of the dominant nature of the lipid hypothesis with a central tenet of limiting saturated fat consumption, the field of preventive dentistry became increasingly focused on non-dietary approaches for dental caries and other oral disease. The idea that dental diseases could be prevented through fermentable carbohydrate restriction became increasingly downgraded (Duggal & van Loveren, 2001).

In New Zealand, dietary recommendations provided by the the New Zealand Dental Association (NZDA) correctly includes advice to reduce sugar consumption, and to reduce between-meal consumption of high-sugar foods and beverages (New Zealand Dental Association, 2020). However, the NZDA also promotes the consumption of a diet advocated in government-endorsed dietary guidelines through online links and written collateral

distributed at dental clinics by child health practitioners (Health Education New Zealand, 2020). The recommendations in these guidelines includes advice to increase the frequency of consumption of sugar-and starch-containing foods as children age, and to choose low-fat options when eating dairy produce (Ministry of Health, 2016).

The promotion of fluoride and oral hygiene as the solution to dental caries may have been influenced by the sugar industry (Kearns et al., 2015). The narrative that dental caries is caused by the accumulation of calcified plaque on teeth, and that plaque could be physically eradicated with oral hygiene strategies became a cornerstone in the prevention of dental caries (Hujoel, 2009; Hujoel, 2019; Hujoel & Lingstrom, 2017). Studies that have investigated the effectiveness of non-dietary caries prevention strategies have been judged to be of mixed methodological quality (Hujoel, 2019). The principal problem with the advocacy of these strategies is that people continue to consume an unhealthy diet which can further increase risks of dental caries (Chapple et al., 2017).

The first-line strategy for the prevention of poor oral health became dependent on the global oral care market, comprising oral hygiene devices, rinses, fluoride delivery devices, and antimicrobials which in 2019 was worth approximately USD$44.5 billion (Statista, 2020). Over time, this has led to increased and ongoing disconnection of oral health from general health in disease prevention, despite the established associations of common dietary behaviour of a high intake of sugars in both poor oral health and poor general health. Consequently, there are few trials of interventions of whole food, reduced-carbohydrate diets in dental caries. Three small prospective studies have evaluated such diets in the context of gingival health, and bacteria associated with dental caries and periodontal disease (Baumgartner et al., 2009; Tennert et al., 2020; Woelber et al., 2016); however, data on caries outcomes is decidedly lacking.

Non-dietary prevention of dental caries

Oral Hygiene

There is consistent evidence that prevention of dental caries requires the mineralisation of teeth through the consumption of Vitamin D-containing foods; this was the preventive strategy endorsed by governmental, professional, and scientific organisations up to the

1930s (Hujoel, 2019). However, during the 1920s and 1930s an opposing conventional theory of caries prophylaxis emerged; that a clean tooth never decays (Hujoel, 2019). Early proponents of this theory believed that enamel would not decay if bacteria were not able to attach to tooth enamel and used an argument for biological plausibility based on oral hygiene practices including antiseptic oral rinses, toothpastes and toothbrushing for caries prevention. Furthermore, it was believed that the removal of bacteria by brushing and flossing teeth prevented mouth infections, an idea that was supported by some dentists including those involved in the creation of oral hygiene schools (Wright, 1923).

Oral hygiene was linked to the prevention of tuberculosis, a communicable disease that was the leading cause of death during the industrial revolution and early in the 20th century (Rubel & Garro, 1992). One founder of the Oral Hygiene Movement asserted that 95% of tuberculosis infections resulted from "diseased or ill-kept mouths" (Ebersole, 1911). Patients were advised to brush their teeth twice a day and the public was encouraged to improve their oral hygiene habits to prevent tuberculosis (Hujoel, 2019; Sgan-Cohen, 2005). This message was endorsed by the National Dental Association and supported by the oral hygiene industry that included toothpaste companies, dental supply companies and professional dental hygiene schools established by prominent dentists. In addition, the emphasis on hygiene to prevent oral disease aligned with the ideas of cleanliness of the social hygiene movement that developed in the 1910s from the coalescence of the religious social purity movement, and the anti-venereal disease movement (Simmons, 1993). These factors led to the outstanding financial success of oral hygiene products, despite a lack of evidence at the time of the therapeutic benefits of such products and strategies (Hujoel, 2019).

The biological plausibility in support of claims of therapeutic efficacy of oral hygiene products was found to be highly questionable at the time. Investigations by the American Dental Association (ADA) found no evidence in support for the clean tooth theory and that claims of therapeutic benefit of toothpastes were faddish, irresponsible, ridiculous, quackish, and constituted humbuggery and scientific skullduggery (Hujoel, 2019). However, losses of advertising revenue, the increasing participation of dentists in using oral hygiene preventives, and pressure exerted by the oral hygiene industry resulted in the amplification

of claims of therapeutic benefit that did not align with principles of evidence-based medicine (Hujoel, 2019). The influence of the sugar industry is also likely to have been influential in the promotion of oral hygiene strategies; since 1929, the sugar industry surmised that sugar was not implicated in dental caries if teeth remained clean (Kearns et al., 2015).

The clean tooth hypothesis that dental caries can be prevented with oral hygiene gained acceptance by 1945 and has become the cornerstone of public health dentistry (Hujoel & Lingstrom, 2017). Health promotion strategies have long emphasised the importance of personal responsibility for the prevention of chronic metabolic disease; similarly, health promotion strategies for the prevention of dental caries have focused on individual behaviours such as engagement in oral hygiene practices. These include tooth brushing and flossing teeth to reduce bacteria in the mouth, and the application of fluoride to remineralise tooth enamel, alongside broad advice to restrict sugar intake and eat a diet conforming to nutritional guidelines (Ministry of Health, 2008).

Systematic reviews that have examined the use of oral hygiene behaviour strategies for the prevention of caries have shown mixed overall evidence for the efficacy of such interventions for reducing caries (de Oliveira et al., 2017; de Sousa et al., 2019; Hujoel et al., 2018; Innes & Fee, 2019). Most oral health intervention studies have focused on changing oral hygiene behaviours to effect change in oral health outcomes. In a recent systematic review by de Sousa et al., a modest anti-caries effect was shown for fluoride varnishes in pre-school children (de Sousa et al., 2019). A systematic review by de Oliveira et al. found limited evidence for flossing between teeth to prevent dental caries (de Oliveira et al., 2017). Systematic reviews by Cooper et al., (Cooper et al., 2013) and Innes and Fee (Innes & Fee, 2019) found limited evidence for the efficacy of school-based interventions for preventing dental caries. Most studies in the reviews were reported to have moderate to high risks of bias. Although some interventions have been shown to increase oral health and oral hygiene knowledge, these interventions have had mixed to limited effectiveness in changing behaviours in children (Harris et al., 2012).

Fluoride

Topical fluoride applications: Fluoride exposure confers some protection against dental caries and there are three principal effects fluoride has on teeth. The presence of fluoride in saliva during the demineralisation/remineralisation cycle leads to its incorporation into the crystalline structure as fluorapatite, which is less soluble than hydroxyapatite (Featherstone, 2008). Remineralisation of the enamel is also enhanced by fluoride because it attaches to the tooth surface and absorbs calcium and phosphate ions from saliva (Scannapieco et al., 1993).

The systematic reviews by Marinho et al found that using fluoride mouth rinses and fluoride gels were associated with large reductions in dental caries in the permanent dentition of children and adolescents (Marinho et al., 2016; Marinho et al., 2015). Many of the interventions were delivered in school settings, and the evidence was judged by the review authors to be of moderate quality. A recent systematic review by Walsh et al observed a dose-response effect with the use of fluoridated toothpaste for caries prevention in children and adolescents. The authors also stated that the risk of fluorosis, a chronic condition characterized by the ingestion of excessive fluoride resulting in hypo-mineralisation of tooth enamel, should be considered when choosing fluoride toothpaste concentrations for young children (Walsh et al., 2019).

Community water fluoridation (CWF): An example of a public health strategy to address caries in communities and delivered on a collective population basis without changing behaviour is CWF. Fluoridation of the water supply is the process of adjusting the natural level of fluoride in the water supply to between 0.7ppm and 1.0ppm. The goal of CWF is to bridge inequalities in dental health and dental care (Colquhoun, 1985), given that the disease burden of dental caries is disproportionately borne by minority groups, indigenous populations, and groups of lower socio-economic status (Andre Kramer et al., 2017; Jamieson et al., 2016; Shackleton et al., 2018; Tiwari et al., 2018). A benefit of this approach is that CWF can have an impact on disease levels regardless of individual behaviour (Schluter & Lee, 2016).

Community water fluoridation is widely regarded as one of the most effective public health interventions for reducing the prevalence and severity of dental caries (Office of the Prime Minister's Chief Science Advisor and the Royal Society of New Zealand, 2014). A recent systematic review by Iheofor-Ejiofor et al found that the introduction of CWF was associated with reductions in primary dentition and permanent dentition of 35% and 26% respectively (Iheozor-Ejiofor et al., 2015). The authors stated that there were several major limitations of the included studies, which were mostly observational studies with high risks of bias within the studies. Furthermore, the extent to which the evidence was applicable to current dietary lifestyles was questioned by the review authors (Iheozor-Ejiofor et al., 2015).

Schluter and Lee used national data from 2003 to 2014 to analyse prevalence patterns of caries-free status over time, by CWF and ethnic group in New Zealand children aged five years and in Year 8 (12-13 years) (Schluter & Lee, 2016). There were statistically significant differences in caries experience between Māori and non-Māori children, and between groups exposed to community water fluoridation and groups with no water fluoridation exposure (Schluter & Lee, 2016). In addition, there were statistically significant differences in caries-free prevalence between Māori and non-Māori children at both five years of age and 12-13 years over the study period. Māori children in CWF areas experience a greater caries burden compared to non-Māori children; this was attributed by the study authors to inequality of health service access. Although CWF can reduce both the prevalence and severity of dental caries within a population (Office of the Prime Minister's Chief Science Advisor and the Royal Society of New Zealand, 2014), Māori children in CWF areas presented with more caries than non-Māori children in non-CWF areas (Schluter & Lee, 2016).

Recent data from the New Zealand Ministry of Health (MOH) shows that nationwide, 59.7% of five-year olds are caries-free in areas with CWF, compared to 59.78% of five year olds in areas without CWF (Ministry of Health, 2019). However, the proportions of Māori and Pacific children of caries-free status at age five years is substantially lower in both fluoridated and non-fluoridated areas; 42.75% and 38.87% of Maori and Pacific children respectively were caries-free at five years in CWF-areas, compared to 38.87% of Māori children and 31.9% in non-CWF areas (Ministry of Health, 2019). The low proportions of caries-free Māori and Pacific children at age five years is disconcerting and suggests that substantial inequities

exist in caries presentation in these populations that are not remedied by CWF. This suggests that current strategies to reduce caries in areas with CWF may have reached the upper limits of effectiveness and that other strategies are required (Richards et al., 2014).

Statement of the problem

Epidemiology

Globally and within New Zealand, oral diseases are among the most prevalent of all diseases (Meier et al., 2017). Dental caries is also costly to healthcare systems with proportions of expenditure of approximately 10% of health care budgets in industrialised countries (Marcenes et al., 2013; Meier et al., 2017). In addition, dental caries is also associated with a range of negative impacts on quality of life, particularly for children at critical stages of learning and development (Drummond et al., 2013).

Dental caries is the most common chronic childhood disease in New Zealand (Ministry of Health, 2019). Recent data from the Ministry of Health (MOH) showed that 40% of five-year old children were diagnosed with dental caries in 2018 (Ministry of Health, 2019), with a higher prevalence observed among Māori and Pacific children than children of other ethnicities (Broadbent, Theodore, et al., 2016; Ministry of Health, 2019). Children with dental caries are more likely to experience poor oral health throughout adulthood (Broadbent et al., 2008). The presence of caries observed in the permanent teeth are of concern because dental caries can be lifelong, progressive and cumulative, despite exposure to fluoride through water or the use of oral hygiene strategies (Bach & Manton, 2014; Broadbent et al., 2008).

Current strategies for prevention of dental caries

The predominant strategy for the prevention of dental caries adopted worldwide has been to promote prevention in children, on the assumption that if caries is prevented in this group, the burden of dental disease would be reduced in all groups (Bach & Manton, 2014). Strategies for oral health promotion in New Zealand include teaching effective oral hygiene practices, facilitating early access to preventative dental services, promoting use of topical fluorides in toothpaste, and promoting healthy eating (Jatrana et al., 2009).

Presently, the current dental delivery system and conventional prevention strategies involving the promotion of oral hygiene is not effective in attaining sustainable oral health improvements given the high prevalence of dental caries in New Zealand children. The ongoing high prevalence of caries in children and adults, and findings from the Dunedin study suggest that current strategies for prevention are insufficient for the prevention of caries at all stages of the life course (Broadbent et al., 2008; Broadbent, Zeng, et al., 2016; Shearer et al., 2012). Current approaches do not consider the dual model of the aetiology of dental caries, or the common dietary cause of both dental caries and other diet-related chronic metabolic diseases (Jatrana et al., 2009). It may be that strategies for caries prevention should be directed to addressing the principal cause of caries, namely, the consumption of a diet with a high proportion and high frequency intake of ultra-processed foods.

Dietary advice provided to dental patients typically consists of suggestions to eliminate sugary drinks and foods, and to eat a diet that broadly follows typical standard nutritional guidelines (Health Education New Zealand, 2020). Online dietary recommendations provided by the New Zealand Dental Association also includes advice to consume a diet advocated in government-endorsed dietary guidelines (New Zealand Dental Association, 2020). Dietary recommendations to prevent dental caries may not reflect the evidence of benefit observed historically regarding benefits of reducing intake of ultra-processed foods and maintaining a high intake of Vitamin D-containing foods and full fat dairy produce. Furthermore, there appears to be a large split between the practices of preventive dentistry and preventive medicine for arguably two of the major public health problems in New Zealand and internationally. The twin epidemics of dental caries health and chronic disease due to poor metabolic health share a common dietary cause. Therefore, it is timely to examine the potential for prevention of chronic poor health to be delivered by intervention that addresses the common risk factors for poor oral and general health.

Significance of the research

Unlike other chronic diseases associated with consumption of ultra-processed food products, dental caries in children represents an early and rapid manifestation of the detrimental effects of a poor-quality diet (Harris et al., 2012). Given the rates of poor oral health in New Zealand, and the relationships between dental caries and chronic diet-related disease, it is important to consider dietary interventions to reduce the risk of dental caries and for children presenting with dental caries. There are no studies that have evaluated dietary behaviour change interventions to simultaneously reduce the risk of both dental caries and chronic general disease in children. In addition, there is a paucity of evidence on dietary interventions to reduce the risk of dental caries in children.

The series of studies that follows in this thesis will contribute several novel elements and will contribute to the body of knowledge about the prevention of dental caries and chronic systemic disease both in New Zealand and internationally. Firstly, it will provide a starting point for an integrated model of chronic disease prevention in both medicine and dentistry. This work also represents the first time that the role of highly processed fermentable carbohydrate foods is widely considered to be the key aetiological factor in both dental caries and other chronic disease of dietary cause. The epidemiological study will add to the existing body of knowledge regarding the dental health in school-age children in New Zealand. The systematic review of the role of processed fermentable carbohydrates in dental caries will provide valuable information on the capacity of these foods to cause dental caries. The narrative appraisal of elements of the New Zealand dietary guidelines and the evidence on which the guidelines are based will draw together the evidence from epidemiological study, the findings of the systematic review, and evidence on the associations between dental caries and chronic disease with a common dietary cause. Importantly, this appraisal will provide information about the degree to which public health initiatives reflect evidence around healthy eating.

The overarching aim of the formative research in this thesis is to investigate the design of interventions for dietary behaviour change in families for the prevention of chronic disease of dietary cause, including dental caries. Potential interventions to address dietary

behaviours could be health practitioner-instigated interventions that involve education regarding dietary behaviour change, that would address influences on behaviour using socio-ecological approaches. An understanding of the knowledge of the target population is required alongside the involvement of the target population in the development of behaviour change interventions (Boddy et al., 2012). In this way, achievement and sustained compliance to interventions is more likely for participants (Cole & Horacek, 2009). The first part of the formative research is the development of a set of novel card sorting tasks to quantitatively evaluate knowledge of foods and behaviours for general and oral health; this will enable comparisons of knowledge to be made across disparate groups of children, parents, and health practitioners. The use of the card sorting tasks to ascertain knowledge in these groups simultaneously will represent the first time that the knowledge of foods and health-related behaviours of multiple distinct groups for both general and oral health has been collected for formative research for use in intervention design.

The second part of the formative research comprises a qualitative investigation to gain insights into ideas of healthy eating, and barriers to achieving healthy eating goals. A novel element of this study will be the concurrent exploration of these ideas in children, parents, and health professionals. In addition, the use of both inductive thematic analyses to construct themes and the deductive analysis of the themes to construct a model using socioecological approaches will provide a framework to understand relationships between beliefs about, and barriers experienced by children, parents, and health professionals to achieving healthy eating. In addition, the consideration of these relationships across different levels of influence would lead to suggestions on how to design behaviour change interventions to enable healthy eating interventions instigated by health professionals and implemented in family settings. The findings from this qualitative work will also further inform the development and delivery of acceptable and sustainable dietary lifestyle interventions for reducing risks of chronic oral and general diseases of dietary cause.

Statement of Purpose

The principal aim of this thesis is to foster greater recognition that dental caries and chronic metabolic disease are united by a common dietary cause, and that prevention of both diseases requires the input of both the dental and medical professions. The combined

prevention of dental caries and chronic metabolic disease may require both population-based and individual dietary behavioural approaches to reduce to risk of chronic diet-related disease (Jepsen et al., 2017). This thesis will explore factors regarding the burden of dental caries in young children in New Zealand, and the dietary causes of dental caries, with a focus on highly refined processed fermentable carbohydrate foods. Implementation of such interventions should encompass elements of the community and consideration of the food environments within communities; as such, the involvement of health professionals in the design and instigation of community-based interventions is critical. This thesis should then answer some questions about dietary causes of chronic poor oral and general health, and the potential focus on the intake of ultra-processed food products in dietary behaviour change interventions. To design such interventions, it is important to understand the beliefs and knowledge of populations who are the target of such interventions, and health practitioners who design and implement such interventions. There may also be a range of barriers to implementing interventions at multiple levels; these also require consideration in the design of potential interventions.

Delimitations of the thesis

- The focus of oral disease in this PhD will be dental caries. Periodontal disease is linked to dental caries and is also linked to cardiovascular disease and Type 2 diabetes through inflammatory mechanisms; in some scientific circles periodontal disease is regarded alongside retinopathy, nephropathy, poor wound healing, and vascular disease as a complication of Type 2 diabetes (Cullinan et al., 2009). Dental caries is a diet-related chronic disease presenting early in the life course in young children, and typically referred only as a local within-mouth response to the metabolism of sugars. Given it is the most common chronic childhood disease in New Zealand and may provide an early signal regarding familial eating patterns that are the target of potential interventions, the focus will remain on dental caries as the targeted chronic oral disease in this thesis.
- The aetiological model of dental disease causation is the dual model summarised earlier in this chapter, incorporating the dual processes by which dental caries occurs. The use of this model shows the relationships of dental caries to other chronic

general disease of dietary cause and provides justification for integrating oral health and general health for prevention of chronic disease. It is important to note that there is general agreement regarding the "outside-in" process by which dental caries occurs through demineralisation because of the metabolism of fermentable carbohydrates and consequent production of acids by oral bacteria.

- The research in Chapters 5 –8 represents formative research. Owing to personnel, time and budget constraints, the research was undertaken in the Taupō district of the central North Island of New Zealand. Although the findings of this research may be broadly applicable to other regions in New Zealand, there may be less applicability of the findings internationally, particularly in countries with vastly differing food, health, social and political systems.
- Given that the formative research took place in the same study population of children, parents, and health professionals, and due to the presentation format of this thesis (i.e., presenting chapters as scientific papers for publication in peer-reviewed journals) there is some duplication of material, in the recruitment methods and demographic results sections of the manuscripts in Chapters 5-8. These papers are stand-alone studies with their own abstracts, introduction, results, and discussion sections. To avoid repetition there are instructions to refer to the previous relevant paper, and brief summaries of the sections that would be otherwise duplicated in these papers.

Thesis Structure

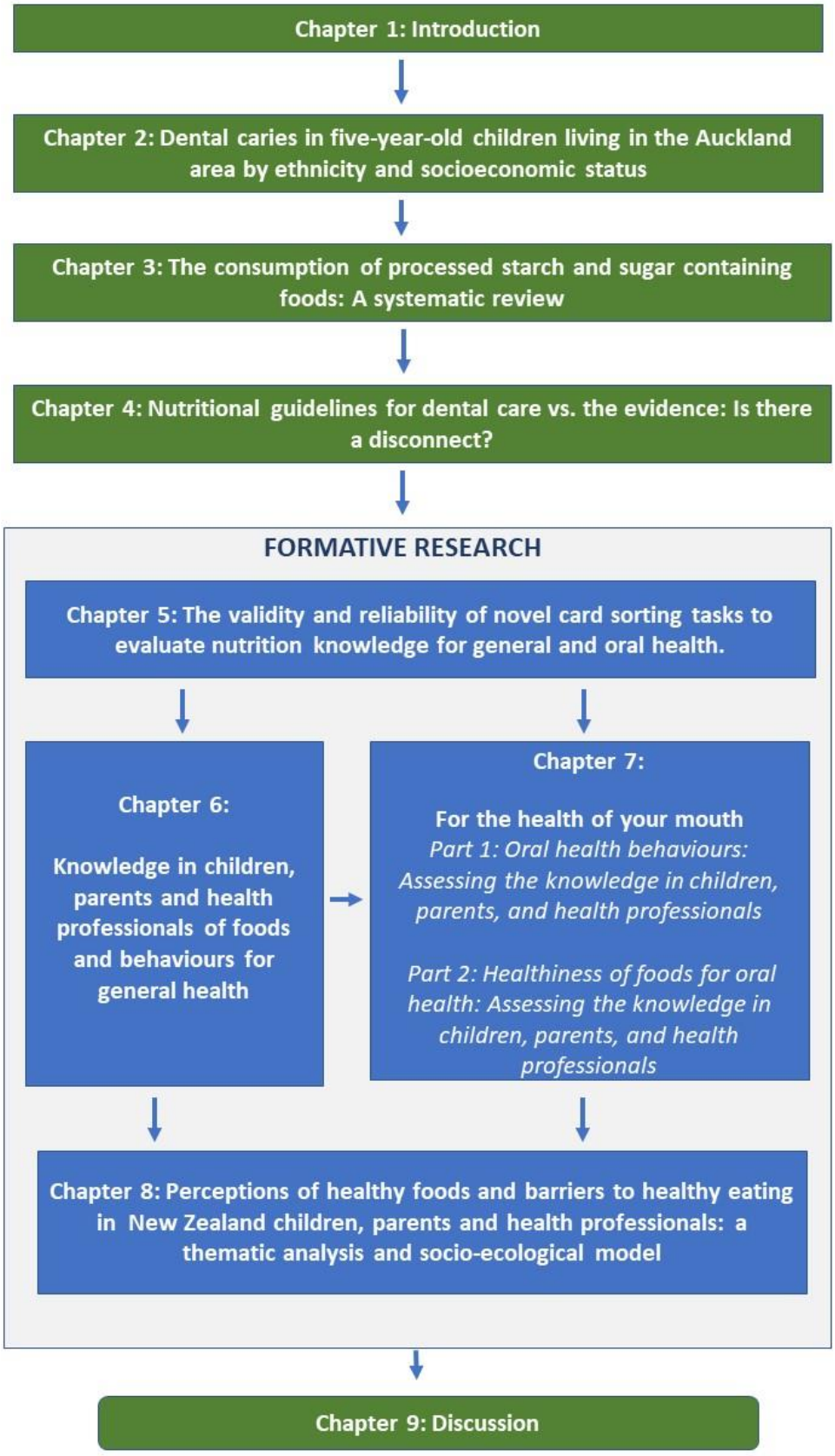
The overall structure of this thesis is summarised in Figure 3. The thesis consists of nine inter-related chapters, eight of which will be submitted as scientific manuscripts to relevant peer-reviewed journals. Chapter 1 provides a background for the thesis, outlining the significance of the topic and the interaction of the studies that follow. Chapter 2 is an epidemiological study that explores the extent of inequities in dental caries burden among ethnic and sociocultural groups within Auckland, New Zealand. Reasons for any observed inequalities in disease burden will also be discussed. Chapter 3 is a systematic review of the role of processed sugar- and starch-containing foods in dental caries; although the role of sugars in dental caries is long established, the review of all prospective studies of the role of processed sugar-and starch-containing foods in dental caries will be determined. Chapter 4

is a narrative appraisal of the evidence of dietary causes of dental caries and diet-related obesity in children and young people. In this chapter, the extent to which the research regarding the role of diet in dental caries and presentation as overweight or obese in young people is reflected in dietary recommendations for oral and general health in New Zealand will be evaluated and discussed.

Chapters 5-8 comprise formative research to inform the design of potential interventions for the prevention of both poor oral and general health in New Zealand families. The same study population of children, parents and health professionals are studied in all chapters in the formative research part of this thesis. The development of a set of novel card sorting tasks for ascertaining the knowledge of different groups – children, parents, and health professionals - will be outlined in Chapter 5. The validity and reliability of these tasks will also be established. Chapter 6 is an investigation of how children, parents, and health professionals categorise the healthiness of both foods, and the importance of a range of behaviours for general health that include dietary behaviours and oral hygiene behaviours. Chapter 7 is a two-part study: in part one, beliefs of oral health behaviours of children, parents and health professionals are evaluated. Part two is an investigation of how the groups outlined above classify foods based on perceived healthiness for oral health. An additional focus will be the categorisation of foods that are defined as ultra-processed according to the NOVA classification of foods by the extent of processing. Chapter 8 is a qualitative investigation that will involve the exploration of themes regarding beliefs of, and barriers to achieving goals of healthy eating, using a socio-ecological approach to consider a range of influences at individual, family, community, and national levels of influence. Chapter 9 will conclude the thesis with a general discussion integrating the findings from all the studies and will outline limitations of the thesis, and future recommendations and research directions arising from the research.

Each chapter is preceded by a preface, which further justifies the research that has been undertaken, and links the material from previous chapters, thereby creating both structure and flow to allow for an overall coherent thesis document.

Figure 3. Thesis Structure



CHAPTER 2: DENTAL CARIES IN FIVE-YEAR-OLD CHILDREN LIVING IN THE AUCKLAND REGION BY ETHNICITY AND SOCIO-ECONOMIC STATUS

Preface

Dental caries is typically overlooked in diet-related chronic disease in public health nutrition. This is surprising, considering that a poor-quality diet is implicated in both chronically poor oral and general health, and the significant burden on health care systems incurred by poor oral health. Dental caries can be defined as the localised destruction of susceptible dental hard tissues by the acidic by-products from bacterial metabolism of fermentable carbohydrates and malnourishment of teeth; it is the most common chronic childhood disease in New Zealand. The most recent data from the Ministry of Health (MOH) shows that 40.3% of five-year old children were diagnosed with dental caries in 2018, with a higher prevalence observed among Māori and Pacific children compared to children of other ethnicities. In addition, socio-economic status has also been associated with a higher prevalence of dental caries in child populations which suggests that substantial inequities exist in caries presentation in these populations.

The aim of this epidemiological study was to investigate the association between deprivation and ethnicity, and caries experience in young school-age children in Auckland, New Zealand's largest city. Data from the Auckland Regional Dental Service (ARDS) was merged with a hospital record dataset to enable the investigation of inequities in early childhood caries experience among five-year-old children. The implications of the high consumption of processed sugars in vulnerable groups among whom the burden of dental caries is high, and potential strategies to reduce sugar intake with the aim of improving oral health and caries and inequities associated with caries presentation is discussed. This work, using a dataset derived from a group of five-year old children characterised by socio-economic and ethnic diversity adds to the body of evidence regarding the epidemiology of dental caries in New Zealand in young children.

Abstract

The aim of the study was to examine the distribution of dental caries at school age in a dataset of Auckland schoolchildren using records from the Auckland Regional Dental Service (ARDS). The records of 26,383 children were linked to ethnic group and socio-economic status information from hospital records to examine the associations between these factors and dental caries in five-year old children from 2007 to 2015. Mean primary decayed missing and filled teeth (dmft) for five-year-old children were 2.3 (SD 3.1) for Māori, 2.8 (SD 3.3) for Pacific and 0.9 (SD 2.1) for New Zealand European or Other descent. In an adjusted quasi-Poisson regression model, cumulative caries experience was higher for Māori children (Incidence rate ratio (IRR 1.79, 95% CI 1.69 to 1.91) and Pacific children by (IRR 2.02, 95% CI 1.91 to 2.14) than children of New Zealand European and Other descent. Socio-economic deprivation was associated with statistically significant greater burdens of disease; children experiencing highest levels of socio-economic deprivation had a 2.87-fold greater dental caries experience at age five years than the least deprived group (IRR 2.87, 95% CI 2.76 to 2.99). Policies and initiatives to reduce caries are likely to have a substantial impact on oral health in Pacific and Māori children and children experiencing high levels of deprivation.

Introduction

In New Zealand, dental caries is one of the most prevalent health issues throughout the lifespan and is the most common disease of childhood (Broadbent et al., 2008; Broadbent, Zeng, et al., 2016). Data from the Ministry of Health from 2015 indicate that 40.5% of New Zealand children have carious lesions at age five years (Ministry of Health, 2019). Results from the New Zealand Health Survey (2014-2015) indicate that approximately 29,000 children had one or more of their teeth extracted within the previous 12 months because of carious lesions, and that dental caries is one of the three leading causes of hospitalisations for children. The numbers of children under 14 years of age receiving dental care under general anaesthesia increased by 65% from 4,646 in 2004/2005 to 7,755 in 2014 (Hunt et al., 2018). In addition, a 20-year review of dental admission rates found that higher rates of potentially preventable hospital admissions were observed in the 3- to 4-year-old age group,

for people of Māori and Pacific descent, and for people residing in the most deprived quintile of the NZDep 2006 index (Whyman et al., 2014). For the financial year 2017/2018, the expenditure on hospital admissions for dental care in New Zealand was NZD$49.68 million (Kanagaratnam & Schluter, 2019). Indirect costs associated with dental caries to society are substantial; one in ten adults aged 18 to 64 years have taken, on average, 2.1 days leave from work or school in the previous year (Ministry of Health, 2019). The presentation of carious lesions in primary teeth is strongly associated with ongoing caries experience in the permanent dentition and through adulthood (Broadbent, Zeng, et al., 2016).

Poor oral health is more prevalent in groups of lower socio-economic status. In a systematic review by Schwendicke et al., the odds of having any caries lesions or caries experience were greater in those with low own or parental educational or occupational background (OR 1.21, 95% confidence interval (CI) 1.03–1.41) or income (OR 1.48, 95% CI 1.34 to 1.63) than groups with higher education and income levels (Schwendicke et al., 2015).

Within New Zealand, there are also differences in the prevalence of dental caries between different ethnic groups. In an analysis of caries prevalence from 2003 to 2014, statistically significant differences were observed between Māori and non-Māori children at both five years of age, and 12-13 years in mean decayed missing and filled teeth, and between groups exposed to community water fluoridation (CWF) and groups in communities with no water fluoridation exposure (Schluter & Lee, 2016). Māori children in CWF areas also experience a greater burden of dental caries compared to non-Māori children. Recent data from the New Zealand Ministry of Health (MOH) shows that nationwide, 59.7% of five year olds are caries-free in areas with CWF, compared to 59.78% of five year olds in areas without CWF (Ministry of Health, 2019). However, the proportions of Māori and Pacific children of caries-free status at age five years is substantially lower in both fluoridated and non-fluoridated areas; 42.75% and 38.19% of Maori and Pacific children respectively were caries-free at five years in CWF-areas, compared to 38.87% of Māori children and 38.19% in non-CWF areas (Ministry of Health, 2019).

Auckland is New Zealand's largest city with a population of 1,467,800 people in 2019, which is 29.9 percent of New Zealand's population (Statistics New Zealand, 2019). Although New Zealanders of European descent comprise the majority of Auckland's population, Auckland has the largest Polynesian population of any city worldwide (Statistics New Zealand, 2019). In total, 59.3% of Aucklanders identified as European ethnicity, 10.7% as Maori, 14.6% as a Pacific ethnicity, and 23.1% as an Asian ethnicity. Three percent of the Auckland population identified as other ethnicities including Middle Eastern, Latin American, or African (Statistics New Zealand, 2019).

The Auckland Regional Dental Service (ARDS), managed by the Waitemata District Health Board, provides free dental care for pre-school and school children at their clinics in the greater Auckland area. Some mobile clinics may also be based at Kōhanga Reo and Pacific Language Nests. Preventive, restorative, and surgical dental services are provided, and are mostly undertaken by dental therapists. All children are invited to attend from birth to 13 years of age and typically, children attend the clinics annually.

The objectives of this study are to determine the associations between socio-economic status and ethnic group, and the presentation of dental caries in children within the Auckland area using a retrospective review of dental records. The use of data derived from an area of New Zealand characterised by ethnic diversity will provide further information on the links between ethnicity and socio-economic status, and dental caries.

Methods

Study population

Data was obtained from electronic dental records from ARDS clinics or at the ARDS-managed mobile clinics. The study received ethical approval through the Southern Health and Disability Ethics Committee (14/STH/133). Enrolments in this service, are estimated to range from 90-96% of school-age children. Despite high enrolments, in this service it has been estimated previously that 20% of children do not attend by the age of five years. Non-attendance may be due to a range of reasons, including absenteeism from school, and transience including movement out of the district, or movement between schools (Jelleyman & Spencer, 2008).

The dental examinations were undertaken by dental therapists for children age five years between 14 May 2007 and 27 February 2015. The disease burden of five-year olds reflects dental health at a time when parents and caregivers provide most of their child's food, and the permanent dentition have not yet erupted. Details available in the dental data for extraction included date of birth, dates of visits to the service, and ethnic group defined as Māori, Pacific or Other. Data from ARDS were then matched with hospital data that included ethnic group as reported by their parents. Responses were categorised into "Māori", "Pacific", "Indian", "Chinese", "Other Asian" or "Other/New Zealand European". Records were matched to hospital diagnosis records by a unique identifier (NHI). The group "Other" included all ethnic groups including New Zealanders of European descent and excluded all children of Asian, Indian, Chinese, Māori, and Pacific Island descent. For the purposes of this study, the other group is defined as "New Zealand European or other".

Socio-economic status was determined from the child's address using the NZDep06 index, which is an area-based index of socio-economic deprivation based on the 2006 census data from Statistics New Zealand. Variables from the 2006 census are combined into a deprivation score for each mesh-block that reflect eight dimensions of deprivation. These include car and telephone access, receipt of benefits, unemployment income, education, home ownership and living space. Mesh-blocks are the smallest geographic area defined by Statistics New Zealand, with a population of around 60 to 110 people. Deprivation scores for each area-based mesh-block in New Zealand are grouped into deciles, where '1' represents areas with the least deprivation and conversely '10' is the highest level of deprivation. The scores for each child were matched to hospital records as stated above. For this study, the deciles were grouped into quintiles so that Quintile 1 and 2 represented the least deprived groups, and quintile 9-10 represented the highest level of deprivation. Similarly, the years of examination were grouped into quartiles as shown in Table 1.

Caries measures included decayed, missing due to caries, and filled teeth (dmft) in the primary dentition. The sum of dmft was recorded, with scores ranging from 0 to 20. If a tooth was identified with a carious lesion or a lesion with restoration, the tooth is coded as "d". A tooth missing due to caries was coded as "m", and the presence of a filled tooth was labelled "f".

Analysis

Prior to the analysis, checks were made for duplicate records and implausibly entered data (for example, incorrectly recorded age values). The records for those at deprivation score of "0" were also removed. These represented small areas where NZDep was unable to be calculated. Mean dmft values and standard deviations were calculated, by sociodemographic characteristics.

The statistical analyses were focused on examining ratios of count of dental caries, by sociodemographic characteristics. A quasi-Poisson regression model analysis was undertaken in which the caries score (dmft) at the first dental examination at five years of age was the outcome. The quasi-Poisson model was used due to overdispersion in the caries outcome. Exponentiated beta-coefficients from this model represent incidence rate ratios (IRR) for caries. Independent variables in the model included ethnic group, gender, deprivation status and year of examination. In addition, a time series analysis was conducted to consider trends in these measures of caries between 2007 and 2014. Crude and adjusted regression coefficients are presented.

The analyses were performed using R software (V3.3.2.1) and iNZight (University of Auckland): significance levels were set at $p<0.05$.

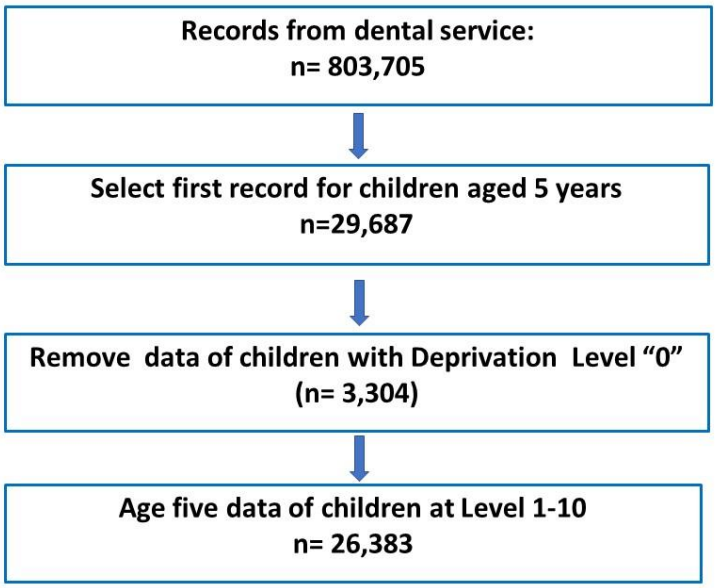
Results

There were 803,705 records of children aged between five years and 13 years of age. After the application of age restrictions and the removal of implausible data and duplicates, a total of 29,687 unique records of five-year old children were available for analysis. In the records of socio-economic status, a small proportion were coded with a decile "0", which refers to either isolated addresses from which little information can be gained and missing data, so the records for this decile were discarded. Analyses were undertaken on the remaining 26,383 records. The flow diagram in Figure 1 shows the process of elimination of duplicates and outlier values.

The characteristics of the study population divided by ethnic group, socio-economic status,

and numbers of decayed missing and or filled teeth (dmft) for the five-year olds are outlined in Table 1. Children of New Zealand European/Other descent comprised 49% of the sample.

Figure 4. Study population flow of children included in the analysis of ARDS data



The following mean caries were observed for five-year-old children by ethnic group: Māori children 2.3 (SD 3.1), for Pacific children, 2.8 (SD 3.3), and for NZ European/Other children a mean of 0.9 (SD 2.1). Mean caries was 1.2 (SD 2.4) for Indian children, 1.7 (SD 3.0) for Chinese, and 1.9 (SD 3.3) for Other Asian. Mean caries for children in these ethnic groups experiencing the highest levels of socio-economic deprivation (level 10) were 2.9 (SD 3.5) for Māori, 3.4 (SD 3.5) for Pacific and 2.4 (SD 3.4) for NZ European and Other. At the same level of deprivation, mean caries observed in Indian children were 1.3 (SD 2.5), for Chinese children 2.1 (SD 2.8), and for other Asian children 2.9 (SD 4.0).

Table 1. Mean caries in five-year-old children attending ARDS 2007-2014 by ethnic group, gender, socio-economic status, and year of examination

	Sample size	Mean (dmft) and standard deviation (SD)
Total	26,383	1.6 + 2.8
Ethnic group		
Māori	4,370	2.3 ± 3.1
Pacific	5,462	2.8 ± 3.3
Indian	1,304	1.2 ± 2.4
Chinese	1,144	1.7 ± 3.0
Other Asian	1,102	1.9 ± 3.3
New Zealand European and Other	13,001	0.9 ± 2.1
Gender		
Male (n=13,371)	13,371	1.7 + 2.8
Female (n=13,012)	13,012	1.6 + 2.7
Socio-economic deprivation		
1-2 (least deprived)	5,236	0.7 + 1.7
3 and 4	4,956	0.9 + 2.1
5 and 6	4,240	1.4 + 2.5
7 and 8	4,688	1.8 + 2.9
9 and 10 (most deprived)	7,263	2.8 +3.4
Year of examination		
2007-2008	8,496	1.7 + 2.8
2009-2010	9,150	1.5 + 2.6
2011-2012	5,266	1.7 + 2.9
2013-2014	3,471	1.6 + 2.8

dmft: decayed missing and filled teeth of the primary dentition.

The crude results of the quasi-Poisson analysis in Table 2 showed statistically significant differences between different ethnic groups, and between different groups categorised by socio-economic deprivation level. Cumulative caries experience and deprivation were strongly associated, with significantly higher burdens of disease observed as socio-economic status worsened. The IRR for dental caries for the children in the most deprived quintile was 4.30 (95% CI 4.14 to 4.45), representing a greater than four-fold higher caries burden at age five years. Caries burdens were also significantly higher for Māori children (IRR 4.15, 95% CI 3.78 to 4.55), Pacific children (IRR 6.91, 95% CI 6.34 to 7.52) and Other Asian children (2.76 95% CI 2.34 to 3.26) than children of New Zealand European or Other descent. Cumulative dental caries experience was also higher were observed in children of Indian descent, Chinese descent, and Other Asian descent. Male gender was also associated with a small but statistically higher burden of dental caries (IRR 1.07, 95% CI 1.05 to 1.09). The period term showed small average increases in caries from 2007.

Table 2 shows the adjusted incidence rate ratios from the quasi-Poisson models which estimate the associations between dental caries and each of gender, ethnic group, socio-economic deprivation, and year of examination at age five years. Statistically significant were observed: male gender, low socio-economic status, and ethnicity were factors associated with more severe caries experience where the observed associations remained significant after adjustment for confounding variables.

Statistically significant associations were also observed between socio-economic status measured using deprivation index scores, and the severity of cumulative caries experience. These differences were observed at each level of deprivation for the adjusted analyses, as shown in Table 2. Children classified as at levels 9 and 10 (i.e., experiencing the highest levels of socio-economic deprivation) had a 2.87-fold higher count of caries-affected teeth than children classified at levels 1 and 2.

Children of Māori, Pacific descent were strongly associated had higher cumulative caries experience at age five years than children of New Zealand European or Other descent. Statistically significant higher caries burdens were also observed in children of Other Asian Descent, than New Zealand European or Other children. There were no statistically significant differences in caries observed between children of Chinese or Indian descent compared to New Zealand European or Other children in the adjusted analyses.

The adjusted incidence rate ratios for the examination year showed small but statistically significant decreased caries burden from 2007-2008 to 2013-2014.

Table 2. Crude and adjusted incidence rate ratios (IRR) of dental caries burden

Variable	Crude IRR[+] (95% CI[++])	Adjusted IRR (95% CI)
Ethnic group (reference: New Zealand European and Other = 0)		
Maori	4.15 (3.78 to 4.55)	1.79 (1.69 to 1.91)*
Pacific	6.91 (6.34 to 7.52)	2.02 (1.91 to 2.14)*
Chinese	2.14 (1.84 to 2.49)	1.00 (0.90 to 1.11)
Indian	1.32 (1.13 to 1.56)	1.10 (0.98 to 1.23)
Other Asian	2.76 (2.34 to 3.26)	1.85 (1.67 to 2.04)
Gender (reference: female=0)		
Male	1.07 (1.05 to 1.09)	1.05 (1.01 to 1.09)
Deprivation Status (reference: Level 1 -2 =0, least deprived)		
3 and 4	1.43 (1.37 to 1.50)	1.34 (1.28 to 1.40)*
5 and 6	2.09 (2.01 to 2.18)	1.81 (1.74 to 1.89)*
7 and 8	2.80 (2.69 to 2.91)	2.16 (2.07 to 2.25)*
9 and 10	4.30 (4.14 to 4.45)	2.87 (2.76 to 2.99)*
Exam year (reference year: 2007-2008 = 0)		
2009-2010	1.07 (1.05 to 1.10)	0.95 (0.92 to 0.97)*
2011-2012	1.04 (1.01 to 1.07)	0.87 (0.85 to 0.89)*
2013-2015	1.15 (1.11 to 1.18)	0.94 (0.91 to 0.97)*

[+]IRR: Incidence rate ratio

[++]CI: confidence interval

*Denotes statistical significance ($p<0.05$) for the IRR (95% CI) compared to the reference variable for each outcome.

Discussion

Analysis of community dental records in Auckland shows large differences in dental caries by ethnic group and socio-economic status. By ethnic group, the highest caries experience was observed among five-year old children of Pacific and Māori descent. In addition, strong relationships were observed between caries levels in children who live in areas associated with high levels of socio-economic deprivation; there was a 2.87-fold increase in cumulative caries experience for children experiencing the highest levels of deprivation than children experiencing the least deprivation. The analyses of caries burden suggest that part of the association between ethnicity and caries status is mediated by socio-economic status, since the incidence rate ratios for socio-economic status are lower when ethnicity is included in these models.

A strength of this study is that this sample represents a large and diverse group of five-year old children in Auckland, New Zealand. The sample included many students in schools during their first year of school enrolment which means that a high proportion of all potential children would be included in the ARDS records. The data were derived from the

results of dental assessments undertaken by trained dental therapists, which mean the assessment of caries status is likely to be more accurate (Shackleton et al., 2018) than self-reported information. A possible shortcoming is the potential for selection bias, such that children with the worst dental health were not checked because of absenteeism, or because of family movement or transience between schools (Jelleyman & Spencer, 2008).

The finding of greater caries experience in children of Māori or Pacific descent at age five years is consistent with findings from previous research showing differences in caries prevalence which varies by ethnicity (Schluter & Lee, 2016), and data that show higher numbers of preventable hospitalisations for dental care in young Māori and Pacific children (Hunt et al., 2018). Children of Pacific or Maori descent experienced the highest burden of disease with diagnosed with dental caries (Shackleton et al., 2018). Although a principal goal of CWF is to reduce inequities in the distribution of caries by a method that is not dependent on population behaviour, substantial inequities exist in caries presentation in vulnerable populations.

This study provides further confirmation of greater dental caries experience in groups characterised by higher levels of socio-economic deprivation. This social gradient in oral health is found through the life course and in different populations globally (Watt et al., 2016). The findings of this study are concordant with previous research that suggests that higher levels of socio-economic deprivation experience a greater burden of poor oral health, compared to less deprived groups (Schwendicke et al., 2015; Shackleton et al., 2018). In this study, children classified as experiencing the highest levels of deprivation at Levels 9 and 10 had a 2.87-fold increase in count of dental caries at age five years compared to children in the least deprived areas. Furthermore, as shown in Table 2, worsening oral health as measured by decayed missing and filled teeth was observed at each increasing level of deprivation.

With the high burden of caries identified in this study, and high levels of public expenditure on hospital treatment of caries in young children, the question arises as to how the caries burden may best be addressed. Dental caries is the localised destruction of susceptible

dental hard tissues by the acidic by-products from bacterial metabolism of fermentable carbohydrates (Selwitz et al., 2007); the relationship between high dietary intakes of sugars and dental caries is well established (Bernabe et al., 2016). These links are indicated through several lines of evidence including studies on the action of bacteria that reside in the oral cavity on a range of sugars in the mouth (Loesche et al., 1975), time-series analyses of country level datasets (Sheiham & James, 2014a, 2014b, 2015), and within-person observational studies of the central role of sugars in the aetiology of dental caries (Moynihan & Kelly, 2014). Although CWF can reduce both the prevalence of dental caries within a population and its severity in affected individuals (Griffin et al., 2007; Kamel et al., 2013; Office of the Prime Minister's Chief Science Advisor and the Royal Society of New Zealand, 2014), the low percentages of Māori and Pacific children of caries-free status regardless of CWF exposure suggests that preventive methods to reduce caries by CWF may have reached their maximum effectiveness (Richards et al., 2014). A recent Cochrane review showed evidence of benefit for using fluoride-containing toothpastes compared to the use of non-fluoridated toothpaste; a dose response relationship was also observed in children and adolescents (Walsh et al., 2019). However, access to oral healthcare, and affordability of toothpaste and toothbrushes have been cited as a barrier to engaging in effective hygiene in vulnerable populations in New Zealand (Kaitiaki Research and Evaluation, 2015)

It may be that strategies for caries prevention should be directed to addressing the principal cause of caries, namely, the frequent consumption of a diet with a high proportion of sugars (Bernabe et al., 2016). High levels of socio-economic deprivation have been associated with food insecurity: increased dietary intakes of sugar-sweetened beverages (SSBs) have also been associated with low socio-economic status and dental caries (Marshall et al., 2007; Pieper et al., 2012). Results of a survey of New Zealand households showed those living in low income households reported having few options but to purchase affordable foods, which are characterised by very high sugar content (Kaitiaki Research and Evaluation, 2015; Landrigan et al., 2018; Ward et al., 2013). Data from Statistics New Zealand indicated that families on the lowest incomes (under NZD $35,000), were spending 58.3% of their income on food in 2015, compared to 48% in 2007 (Statistics New Zealand, 2016). Increased spending on inexpensive, high-sugar, nutrient-poor foods and beverages by families on the lowest incomes may be a reason for the higher prevalence of caries observed in groups of

low socio-economic status. This study shows that caries is strongly associated with socio-economic status; hence, interventions should be tailored towards the needs of these at-risk groups at national and community levels.

Strategies to modify the food environment that are likely to improve oral health in these settings include taxes on sugar consumption, community-based strategies to change the food environment, and dietary behaviour change interventions to decrease sugar consumption. Research relating to the effect of sugar taxes on purchasing behaviour suggests that price increases are associated with a decline in purchases of sugar-sweetened beverages (SSBs). In Mexico, the largest change in purchasing behaviour was observed among those from low socio-economic groups in a study of a new sugar tax of one peso per litre of beverage (Colchero et al., 2017). Similarly, a sugar tax of USD 0.01 per ounce was implemented on SSBs in Berkeley, California in early 2015. Consumption of SSBs decreased 21% in Berkeley and increased by 4% in comparison cities. Water consumption increased in Berkeley (+63%) than in comparison cities (+19%) (Falbe et al., 2016). In Philadelphia, the imposition of a beverage tax of USD 0.015 per ounce on sugar and sugar-substitute beverages resulted in reductions in consumption of regular soda by 40% (Odds Ratio (OR) 0.6, 95% CI 0.37 to 0.97) and energy drink by 64% (OR 0.36, 95% CI 0.17, 0.76) (Zhong et al., 2018). Concurrently, the consumption of bottled water increased by 58% (OR 1.58, 95% CI 1.13 to 2.20) (Zhong et al., 2018).

Of interest are school-based interventions, as schools can establish policies to limit sugar intake while at school and include healthy food as an integral part of the curriculum. Thornley et al. found reductions in caries-affected teeth by 0.37 dmft (95% CI 0.09 to 0.65) in a school that restricted sugar intake through a range of school- and family based behaviour change initiatives, compared to schools within the same geographical area without these restrictions (Thornley et al., 2017). These results provided evidence for oral health benefits post-implementation of a school-based nutrition policy characterised primarily by restrictions on sugar intake and represents an important area for future research.

In conclusion, the findings of this study show clear differences in caries by ethnic group and socio-economic status in dental caries in young schoolchildren in New Zealand's largest

metropolitan area. Given the principal role of dietary sugars and starches in dental caries, the persistence of inequities in the distribution of dental caries in New Zealand, it is imperative to consider the implementation of dietary interventions, advice, and policies around the restriction of sugars including at local and national government levels, and within community and family settings.

CHAPTER 3: THE CONSUMPTION OF PROCESSED SUGAR- AND STARCH-CONTAINING FOODS, AND DENTAL CARIES: A SYSTEMATIC REVIEW

Preface

Study outcomes from the epidemiological work in Chapter 2 have added to the body of research evidence that shows substantial inequities exist in the distribution of dental caries in child populations in Auckland, New Zealand. Chapter 3 moves into the evidence surrounding dental caries and nutrition and focuses specifically on what is known and what is not yet known about this relationship. The association between high dietary intakes of refined sugar and dental caries is well established; however, there is some debate about the cariogenicity of other highly processed fermentable carbohydrates. Starches are a principal component of the human diet, and cereal grains are found in a wide range of processed foods and form high proportions of total dietary intake. Previous studies of the human pH response to a range of starches show that processed starches are associated with cariogenic activity; any evidence in prospective studies of such an association would have implications regarding dietary guideline recommendations for oral health.

The aim of this systematic review was to determine the associations between both the consumption of processed sugar-and starch-containing foods, and the frequency of consumption on dental caries in prospective studies in human populations. This review of the role of these processed fermentable carbohydrate foods in dental caries provides valuable information on both the capacity of these foods to cause dental caries, and the impact of consumption frequency of such processed fermentable carbohydrates on dental caries.

The manuscript of this chapter was published in the journal, *European Journal of Oral Sciences* in November 2020.

Hancock S, Zinn C, & Schofield G. (2020). The consumption of processed sugar- and starch-containing foods, and dental caries: a systematic review. *European Journal of Oral Sciences 128 (6);* 467-475.

Abstract

The relationship between high dietary intakes of sugar (sucrose) and dental caries is well established. Processed sugars and starches have been associated with higher risks of dental caries in retrospective studies. The aim of this systematic review was to determine the relationship between the consumption of processed sugar-and starch-containing foods, and the frequency of consumption of these foods, and dental caries. Prospective studies identified in databases searched from 1970 to July 2020, and relevant retrieved papers that examined associations between the consumption of sugar- and starch-containing foods by human participants and dental caries were eligible for inclusion. Five cohort studies were identified for inclusion, all of which evaluated caries risk in young children or pre-adolescents. The between-meal consumption of processed sugar-and starch-containing foods was consistently found to be associated with greater caries experience. There were mixed findings on total consumption of processed sugar and starch-containing foods, owing to a range of confounding factors, including the simultaneous consumption of caries-protective foods at mealtimes. Although there is a paucity of research of the dietary behaviour of frequent consumption of processed sugar-and starch-containing foods in dental caries, there is some evidence of plausible associations between this dietary behaviour and dental caries. Future research should investigate the effectiveness of interventions to change the dietary behaviour of high frequency consumption of processed sugar- and starch-containing foods to decrease the risk of dental caries.

Introduction

The relationship between dental caries and high dietary intakes of sugar is well established (Bernabe et al., 2016; Sheiham & James, 2014b, 2015). In addition, dental caries experience is lower in children and adults when the consumption of free sugars is less than 10% of energy intake (Moynihan & Kelly, 2014). However, there is debate about the cariogenicity of other highly processed fermentable carbohydrates (Bradshaw & Lynch, 2013). Starches are a principal component of the human diet, and cereal grains are often a primary source of calories, proteins, minerals, and vitamins. In the Western diet, starches, particularly wheat-based grains, are found in a wide range of processed foods and form 40-75% of total

dietary intake (Kopp, 2019; Lingstrom et al., 2000; Sreebny, 1983; van Palenstein Helderman et al., 1996).

Starches are glucose polymers that differ in length and form an extensive network of branched chain structures. Starch molecules are found within starch granules. During food preparation of starches, gelatinisation occurs whereby the granules are ruptured and disintegrated by mechanical forces which causes the release of starch molecules. In the mouth, these gelatinised starches are hydrolysed by salivary and bacterial amylases into glucose, maltose, maltotriose, and low-molecular-weight dextrins (Mormann & Muhlemann, 1981). The hydrolysis of starch in the mouth is rapidly initiated, and starch-containing food particles entrapped on teeth can accumulate sugars. These sugars provide substrates for bacterial acid production which causes local pH values in the dental biofilm to fall and favour demineralisation of dental tissues (Kashket et al., 1994; Kashket et al., 1996; Scannapieco et al., 1993).

Commercial processing methods make a unique contribution to the cariogenicity of foods in the mouth. Boiled suspensions of white wheat flour or starch have been shown to be highly acidic in *in vivo* studies, and acidity was greater when these flours and starches were extrusion-cooked (cooked at up to 180°C, with low water content and high mechanical agitation) (Bjorck et al., 1984). Suspensions of white wheat flour that were subjected to increasingly rigorous processing conditions induced greater plaque acidogenicity (Lingstrom et al., 1989). Although these processing methods make food starches more digestible than boiling or baking, they may have a substantial impact on caries risk, given these observed changes in plaque pH.

Studies of the human pH response to starches have shown that processed starches are associated with cariogenic activity (Pollard, 1995). Studies of the effects of food starches in the human mouth were first conducted by Swenander-Lanke, who found that clearance times from the mouth for sugars derived from starch metabolism were longer for bread, than for potatoes or rice (Swenander Lanke, 1957). Studies by Kashket et al. (Kashket et al., 1991; Kashket et al., 1994; Kashket et al., 1996) provided evidence for a retention effect of processed starches, in which the total time that plaque pH remained below the critical level

of 5.5 exceeded that of foods containing high levels of sucrose and other fermentable sugars. The extended retention of starch-derived sugars in plaque means the effects of other sugars may also be prolonged, and the consumption of starch has a co-cariogenic effect with that of other sugars. Further, an *in situ* study by Ribeiro et al. that evaluated the acidogenicity, biochemical, and microbiological composition of the dental biofilm (alongside enamel mineralisation) found that the combination of starch and sucrose was associated with the greatest mineral loss and highest counts of the cariogenic bacterium *lactobacillus* (Ribeiro et al., 2005).

The exposure of plaque-based bacteria to starch-derived sugars is also influenced by consumption frequency. The principal dietary risk factor caries development is high and frequent consumption of sugars (Bernabe et al., 2016; Gustafsson, 1954; Sheiham & James, 2014a, 2014b, 2015). The consumption of a high-starch diet with low or negligible sugar content during two or three meals each day has been shown to be associated with low-to-negligible caries activity (Gustafsson, 1954; Harris, 1963; Newbrun et al., 1980; Scheinin et al., 1975). However, populations that consume modern Western diets comprising processed sugar- and starch-containing foods do so with a greater consumption frequency characterised by regular snacking, and abnormally high levels of insulin secretion (Weiss et al., 2013). The latter is also associated with the disruption of the satiety hormone leptin, which regulates energy balance and inhibits hunger by signalling to the brain when satiety has been achieved from food consumption (Weiss et al., 2013). The consequence of the disruption to leptin promotes a cycle in which hunger and food consumption increases, leading to continued overeating (Weiss et al., 2013). The frequent consumption of processed snacks comprising sugar and starches is also associated with food addiction characterised by similar behavioural, neurochemical and brain activation responses like those of substance abuse (Lennerz & Lennerz, 2018).

Several cross-sectional studies have investigated the roles of processed sugar- and starch-containing foods in dental caries in human populations, with mixed findings. Associations between high dietary intakes of starch-and sugar-containing foods and dental caries were observed in retrospective studies (Arcella et al., 2002; Garcia-Closas et al., 1997; Llena & Forner, 2008; Palacios et al., 2016). The snack-time intake of processed sugar- and starch-

containing foods was also associated with higher risks of caries in these studies. However, such findings should be interpreted with some caution because the observed associations cannot be regarded as causal. There are also higher risks of a range of biases associated with cross-sectional studies; these include recall bias and limitations with the retrospective recall of dietary intake, particularly that of children (Iannotti et al., 1994; Livingstone & Robson, 2000; Livingstone et al., 2004).

A recent systematic review by Halvorsrud et al. included both prospective and retrospective studies and found there was no evidence of an association between total starch intake and dental caries; however, the higher consumption of rapidly digestible starches was associated with a higher risk of caries (Halvorsrud et al., 2019). Rapidly digestible starches evaluated in that review (as defined by the review authors) included highly processed starches, refined carbohydrates, and high glycaemic index carbohydrates. Given these findings, it would be prudent to also evaluate the evidence on the consumption frequency of refined processed sugar- and starch-containing foods, since a high and frequent consumption of fermentable carbohydrates is the principal aetiological risk factor for dental caries.

The aim of this systematic review was to assess the association between the consumption of processed sugar- and starch-containing foods and caries experience over time, and to investigate the relationship of consumption frequency of these foods on caries in prospective studies of human populations.

Methods

This systematic review was conducted and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, and the methods were established prior to the conduct of the review.

Search Strategy

The electronic databases MEDLINE, (via PubMed), EBSCO, PROSPERO, and the Cochrane Central Register of Controlled Trials and the Cochrane Database of Systematic Reviews Database were searched initially for eligible studies and systematic reviews published

between 1970 and February 2018; all searches were repeated in July 2020 to identify additional eligible studies published since February 2018. The search terms were "process*" "starch*" "sugar*", "ferment*" "carbohydrate" "caries", "decay" "oral" and "teeth". The reference lists from retrieved studies, relevant reviews, and appraisal articles were also searched for relevant studies. The screening of titles and abstracts was performed by two reviewers (SH and CZ). Identified studies were assessed in full text and final inclusion was decided by SH and CZ; any disagreements were resolved by discussion.

Inclusion and Exclusion Criteria

Prospective English-language studies including randomised controlled trials (RCTs) and cohort studies, in human participants of any age that examined the association between processed starch- and sugar-containing foods, and dental caries were eligible for inclusion. The primary outcome was a measure of caries incidence or caries increment in primary, mixed, or secondary dentition diagnosed radiologically or by clinical examination using any caries index. Additional eligibility criteria were that food intake was to be assessed through a food frequency questionnaire, food diaries, or participant recall of foods eaten over any specified time. Animal studies, unpublished studies, non-English language studies, retrospective studies, studies that did not define sugar-and starch-containing food consumption by either the proportion of starches to sugars in the foods (e.g., low to high), or level of processing, or by describing the foods under study, studies that only examined beverage consumption, and *in vivo* studies of starch and sugar were excluded from the review. Studies in which it was not possible to determine whether starch-containing foods were included (e.g., studies on "sugary food" only) were also excluded.

Quality Assessment and Data Extraction

The methodological quality of the included studies was assessed using the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies developed by the National Heart Lung and Blood Institute (United States) for non-randomised studies. The study characteristics, quality assessment, and data were extracted from the reports by SH and CZ; any disagreements were resolved by discussion.

Analyses

Given the anticipated heterogeneity in participant groups, caries definition, dietary analysis and classifications of food groups pertaining to starch and sugars, the findings were summarised in a narrative review.

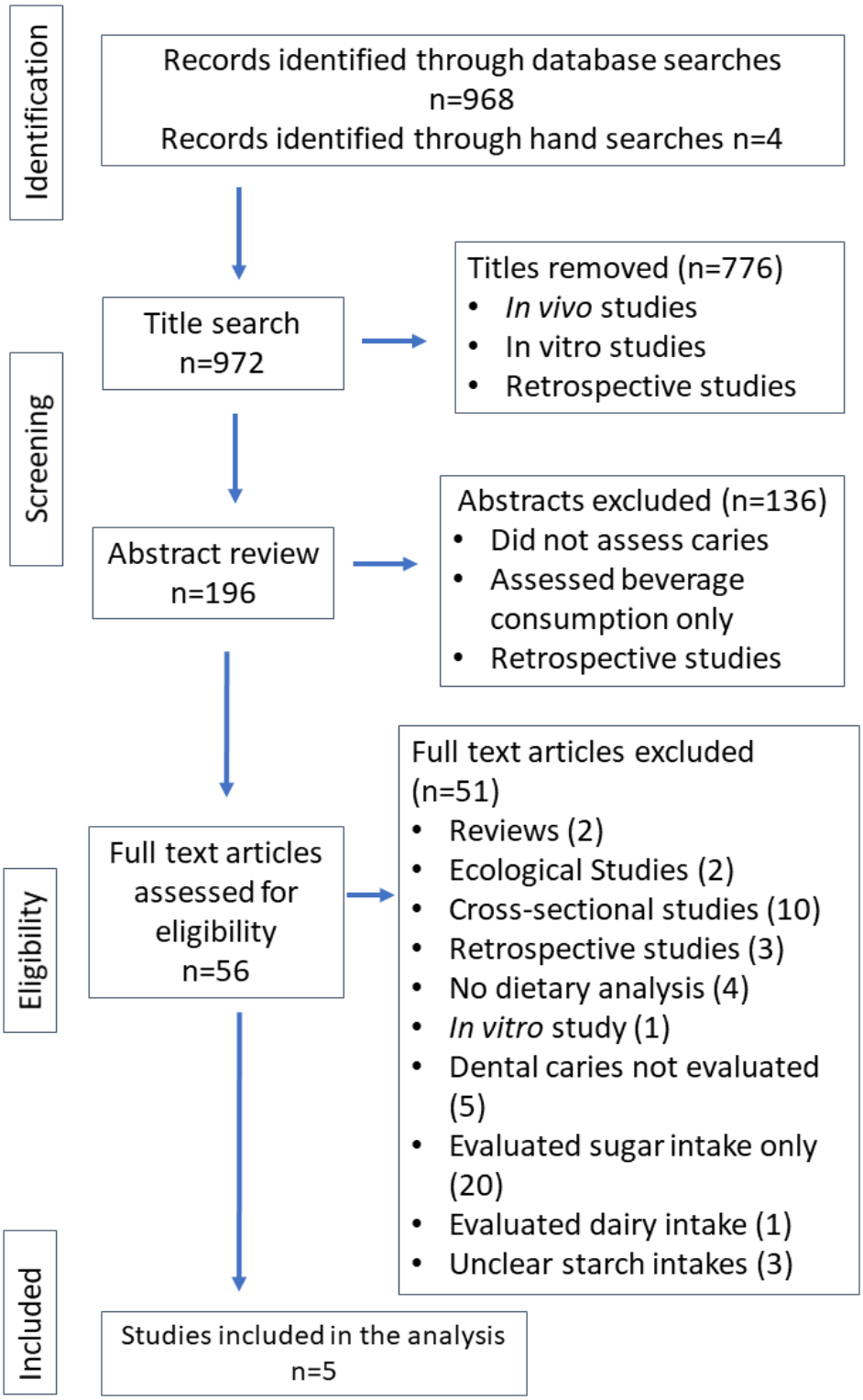
Results

Study characteristics

There were 968 studies identified in the searches. Fifty-six full-text articles were assessed and five prospective cohort studies (Campain et al., 2003; Chankanka et al., 2015; Chankanka et al., 2011; Marshall et al., 2005; Rugg-Gunn, 1987) met the criteria for inclusion. Figure 5 shows the search and selection process in a graphical flowchart.

The characteristics of the included studies are summarised in Table 3. All were conducted in industrialised countries and the samples in all the studies were children or young adolescents. The children in three studies had been recruited at birth for the Iowa Fluoride Studies (Levy et al., 2003) with follow-up occurring prospectively (Chankanka et al., 2015; Chankanka et al., 2011; Marshall et al., 2005); the samples in the remaining studies were selected as part of school-based studies in England and Australia (Campain et al., 2003; Rugg-Gunn, 1987). There were differences among the studies on the classification of processed sugar- and starch-containing foods; those are outlined in Table 3. There was some variation in the definitions of dental caries used in the studies; three studies diagnosed and reported caries as cavitated lesions only (Chankanka et al., 2015; Chankanka et al., 2011; Marshall et al., 2005). Other studies included decayed missing and filled surfaces along with non-cavitated lesions (Campain et al., 2003; Rugg-Gunn, 1987). Given the heterogeneity of food classifications and definitions of dental caries, the findings were synthesised in a narrative review to prevent any overestimation of the effect of dietary exposures on dental caries.

Figure 5. Flow chart of the study selection process



Quality Assessment

The outcome of the quality assessment for the included prospective studies is summarised in Table 4. All the studies were judged as being of "fair" quality. The most common threats to quality were the lack of sample size calculations in all studies, and losses to follow-up, which exceeded 20% in the study by Campain et al. (Campain et al., 2003). A total of 1,072 children were recruited at birth for the Iowa Fluoride Studies (Levy et al., 1998); the processes by which the children were eligible for inclusion for in the studies by Marshall et al. (Marshall et al., 2005) and Chankanka et al. (Chankanka et al., 2015; Chankanka et al., 2011) were unclear.

Data synthesis

1. *Processed sugar- and starch-containing food intake and dental caries*

There were mixed findings for the overall consumption of processed sugar-and starch-containing foods on dental caries experience. Lower rates of dental caries were observed with higher meal-time consumption of sugar- and starch-containing foods in the study by Marshall et al.; daily total exposures to sugar and starch were associated with lower dental caries experience at age five years (Marshall et al., 2005). In contrast, high consumption of sugar- and starch-containing foods were associated with higher rates of dental caries in two studies. In the study by Campain et al., higher rates for all surface caries, and pit and fissure caries were observed for low sugar/high starch foods (Campain et al., 2003). Higher caries rates were also observed with greater levels of starch in low-sugar foods. Chankanka et al. showed associations between high consumption of pre-sweetened cereals at meals and dental caries (Chankanka et al., 2015).

2. *Frequency of consumption of processed sugar and starch-containing food intakes and dental caries*

A consistent finding across the included studies was that a high frequency of consumption of processed sugar and starch-containing foods characterised by between-meal snacking was associated with higher dental caries experience and greater caries increments. Analyses of the dietary records in Campain et al. found that high starch foods were often consumed as snacks between meals; these foods were associated with higher rates of caries in that study (Campain et al., 2003). Snack-time consumption of processed sugar-and starch-containing foods was associated with higher rates of caries at age two years in Marshall et al. (Marshall

et al., 2005). Chankanka et al. reported more children (24%) who had the highest intake of processed sugar- and starch-containing foods as snacks had developed dental caries by age five years than the children with the lowest intake (11%) of processed starches as snacks (Chankanka et al., 2011). In a later study by Chankanka et al., lower consumption of milk at meals, and a greater consumption frequency of pre-sweetened cereal was associated with a greater likelihood of experiencing carious lesions of tooth enamel (Chankanka et al., 2015).

Table 3. Characteristics and results of the prospective cohort studies

Author, year	Sample size at baseline and follow-up; dropout rate	Dietary measurement; sugar/starch food definitions	Caries outcome measurement	Outcomes
Rugg-Gunn et al. 1987	N=466 Mean age 11 years, 7 months Follow-up: 2 years, n=405 Drop out 14%	Five 3-day diet diaries over two years using with an interview on day 4 with a dietitian. Weight of starch was obtained from subtracting weight of sugars from weight of available carbohydrate.	Caries increment	Starch intake and caries increment (r=-0.022, p>0.05) An increase in starch intake of 30g: decreased new caries by 0.17 DMFS (95% CI -0.54 to 0.20, p>0.05).
Campain et al. 2003	645 adolescents aged 12-13 years Follow-up: 2 years, n=504 Dropout 22%	Four 4-day records; estimations of portion sizes collected at weekdays, weekends and during different seasons. Categorisation of foods: high sugar/low starch medium sugar/medium starch low starch/medium sugar low sugar/low starch low sugar/medium starch low sugar/high starch	Caries incidence	Consumption of high starch/low sugar foods: All surface caries: (RR 1.23, 95% CI 1.06 to 1.43 p<0.05) Pit and fissure caries: (RR 1.27, 95% CI 1.09 to 1.47, p<0.05) <u>Food level sugar-starch interaction:</u> All surface caries: ($X^2_{df=2}$ 7.53, p=0.02) Pit/fissure caries ($X^2_{df=2}$ = 8.66, p=0.01)
Marshall et al. 2005	690 children aged between 1-6.8 years Follow-up: 5 years, n=398 Dropout: 42% .	Three-day food and beverage diaries at 1, 2, 3, 4, and 5 years High starch foods: processed snacks (i.e., potato chips, tortilla chips, flavoured crackers) unprocessed starches (i.e., rice, pasta, bread). High sugar and starch: Baked starch with sugar (i.e., brownies, cake, donuts) presweetened cereals (i.e., frosted flakes)	Caries increment	Mealtime exposure to starch-and sugar-containing foods 4 years (OR 0.36, 95% CI 0.15 to 0.87, p<0.05) 5 years (OR 0.31, 95% CI 0.13 to 0.73, p<0.01) 1 through 5 years (OR 0.22, 95% CI 0.10 to 0.50, p<0.001). Snack-time exposure to starch-and sugar-containing foods: 2 years (OR 2.59, 95% CI 1.05 to 6.36, p<0.05) Daily total exposures to sugar and starch 5 years (OR 0.43, 95% CI 0.21 to 0.89).
Chankanka et al. 2011	198 children aged between 5-9 years Follow-up: 4 years n=150 Dropout: 24%	Three-day diet diaries, one from ages 1-5/6 years; one from ages 7-8.5. Sugars and starches studied: baked starch with sugar (cookies, cake) unsweetened cereals pre-sweetened cereals unprocessed starches (boiled potato, bread, pasta, rice) processed starches (potato chips)	Caries increment	Snack-time intake of processed starches: New caries: OR 3.87 (95% CI 0.93, 16.16 p=0.07). Presentation with caries at age 5 years: 24% of children with highest intake vs. 11% in those with lowest intake (p<0.05)
Chankanka et al. 2015	393 children aged between 3-5 years Follow-up: 5 years, n=377 Dropout: 4%	Three-day diet diaries at ages 36, 48, and 60 months Sugars and starches studied: baked starch with sugar (cookies, cake) unsweetened cereals pre-sweetened cereals unprocessed starches (boiled potato, bread, pasta, rice) processed starches (potato chips)	Caries increment	High consumption frequencies of pre-sweetened cereals at meals, and caries increment: OR 1.34, (95% CI 1.10 to 1.65, p=0.005).

CI: confidence interval, RR: Relative risk, OR: Odds ratio DMFS: Decayed Missing and Filled Surfaces

Table 4. Quality assessment of Prospective Cohort studies

Study	Rugg-Gunn et al 1987	Campain et al 2003	Marshall et al 2005	Chankanka et al 2011	Chankanka et al 2015
Quality Criteria					
Was the research question in this paper clearly stated?	Y	Y	Y	Y	Y
Was the study population clearly specified and defined?	Y	Y	Y	Y	Y
All subjects recruited from the same or similar populations during the same time?	Y	Y	Y	Y	Y
Were inclusion and exclusion criteria pre-specified and applied uniformly to all participants	Y	Y	U	U	U
Was a sample size justification or power description provided	N	N	N	N	N
Were variance and effect estimates provided?	Y	Y	Y	Y	Y
For the analyses, were the exposures of interest measured prior to the outcome being measured?	Y	Y	Y	Y	Y
Was the timeframe sufficient that one could reasonably expect to see an association between the exposure and the outcome of it existed	Y	Y	Y	Y	Y
Did the study examine different levels of the exposure as related to the outcome	Y	Y	Y	Y	Y
Were the exposure measures clearly defined, valid and implemented consistently across all study participants?	N	Y	Y	Y	Y
Was the exposure measured more than once over time?	Y	Y	Y	Y	Y
Were the outcome measures clearly defined, valid, reliable, and implemented consistently across all study participants?	Y	Y	Y	Y	Y
Were the outcome assessors blinded to the exposure status of the participants?	NR	NR	NR	NR	NR
Was loss to follow-up 20% or less?	Y	N	N	N	Y
Were key confounding variables measured and adjusted statistically for their impact on the relationship between exposure/s and outcomes	Y	Y	Y	Y	Y
Quality Rating: Good, Fair or Poor	Fair	Fair	Fair	Fair	Fair

Y: Yes, N: No, NR: not reported

Discussion

The principal findings of this systematic review were that the high frequency consumption of processed sugar- and starch-containing foods was associated with greater dental caries experience in prospective studies of child and adolescent populations. To our knowledge,

this is the first systematic review in which the consumption frequency of processed sugar- and starch-containing foods and dental caries was evaluated. However, there were also conflicting findings on overall consumption of processed sugar-and starch-containing foods and dental caries experience. On one hand, lower rates of dental caries were observed in two studies that assessed meal-time consumption (Marshall et al., 2005) and overall consumption (Rugg-Gunn, 1987) of processed sugar and starch-containing foods. On the other hand, another study found higher rates of caries in overall consumption of foods with low amounts of sugar, but greater amounts of starch (Campain et al., 2003). Given the evidence regarding the retention of sugars on teeth, and how starch can act as a co-cariogenic agent by enabling the retention of sugars on teeth for longer periods, it is important to evaluate the association with caries of foods that contain starches and sugars, and particularly those that might not necessarily be described as "sweet", such as the foods evaluated in the included studies.

The findings in this review of the mixed evidence on starch intake and dental caries are consistent with those of Halvorsrud et al. (Halvorsrud et al., 2019) who reported that there were no associations between total starch intake and dental caries, but that the intake of rapidly digestible starches including refined, processed starches was associated with higher rates of caries. The caveats around the definitions and classifications of starch-containing foods outlined in this review and in Halvorsrud et al. (Halvorsrud et al., 2019) are important to consider in future studies of the associations of intakes of starch-containing foods with dental caries. Few studies have evaluated the risk of dental caries based on sugar and starch content of foods in human populations. There were no RCTs, and only five prospective cohort studies identified for this review; this means that the observed associations in these studies cannot be regarded as causal, and that the findings should be interpreted with some caution. This review and the systematic review by Halvorsrud et al. (Halvorsrud et al., 2019) are the only two systematic reviews that have evaluated the associations between starch intake and dental caries. In addition, this review is the only systematic review that has evaluated the associations of processed sugars and starches with dental caries, as well as the impact of intake frequency of these foods on dental caries. Previous systematic reviews of the associations between the intake of fermentable carbohydrates and dental caries have focused on high sugar, sweetened foods, and beverages with added sugars.

Searches of prospective systematic review registers indicate that most reviews on caries prevention focus on teaching oral hygiene strategies, and the prophylactic application of fluoride varnishes and gels. In addition, nearly all pre-registered protocols in the PROSPERO database for systematic reviews of the impact of processed foods on chronic diet-related diseases do not include oral diseases, including dental caries as outcomes of interest. Of interest is one non-approved protocol that evaluates the association between the consumption of ultra-processed foods and dental caries in children and adolescents by Cascaes et al. (Cascaes et al.). It is anticipated that ultra-processed foods in this review will include high sugar, sweet foods such as sugar sweetened beverages and various sweets long known to be associated with dental caries, alongside ultra-processed non-sweet foods.

There were weaknesses identified in the included studies in this review. Sugar intake may be incorrectly reported because of social acceptability biases associated with answering questions about consumption of sugar, in a dental setting. However, the information provided on starch or carbohydrate consumption is less likely to be affected by these biases, because the term "carbohydrate" includes all sugars and starches. The quality of the included studies was judged to be fair, given the losses to follow-up that exceeded 20% in some studies, and the lack of clarity over the selection of participants in the studies by Marshall et al., and Chankanka et al. (Chankanka et al., 2015; Chankanka et al., 2011; Marshall et al., 2005) in which participants were selected from a larger cohort of children enrolled in the Iowa Fluoride studies.

Mealtime exposures to starch- and sugar-containing foods were found to be associated with lower rates of dental caries in the studies by Rugg-Gunn et al. (Rugg-Gunn, 1987) and Marshall et al. (Marshall et al., 2005). Total daily exposures of these foods were also associated with a lower rates of caries at age five years in the study by Marshall et al. (Marshall et al., 2005). The observed lower rates may be in part because of controlled exposures of starch and sugar-containing foods at meals (Marshall et al., 2005). Another possibility may be that other foods simultaneously consumed at meals may clear cariogenic processed foods from the mouth or limit the decrease in pH associated with solitary snack exposures of processed foods. Foods that have been previously associated with lower caries

risk include dairy products (Dror & Allen, 2014; Grenby et al., 2001) and Vitamin D-containing foods (Hujoel, 2013; Mellanby & Pattison, 1932); these were found in two studies in this review to be more commonly consumed at meal times (Campain et al., 2003; Marshall et al., 2005). Caries-protective foods may therefore be confounders that have an impact on the effect of cariogenic foods simultaneously consumed at mealtimes, and on dental caries experience. The concurrent consumption of caries-protective foods at mealtimes alongside cariogenic foods means that it would be impractical to further attempt to determine the risk of dental caries from mealtime consumption of processed sugar- and starch-containing foods.

Conversely, the overall consumption of high starch-low sugar foods was associated with higher risks of new all-surface caries and pit and fissure caries in the study by Campain et al. (Campain et al., 2003). Low to negligible caries activity was observed in previous studies (Gustafsson, 1954; Harris, 1963; Newbrun et al., 1980) where starch consumption was also accompanied by a low sugar intake and a frequency of food intake of two or three meals per day. In the Campain et al. study, low sugar/high starch foods included breads, muffins, crumpets, crackers, some cereals, pastries, potato chips, corn chips (Campain et al., 2003). Starches, as defined by Marshall et al. (Marshall et al., 2005) and in the two studies by Chankanka et al. (Chankanka et al., 2015; Chankanka et al., 2011), included baked starch with sugar, presweetened cereals, unsweetened cereals, processed snacks and unprocessed starches (Chankanka et al., 2015; Chankanka et al., 2011; Marshall et al., 2005). Bread, potatoes, pasta, and rice were categorised as "unprocessed starches" in those three studies (Chankanka et al., 2015; Chankanka et al., 2011; Marshall et al., 2005). However, the starches present in bread and pasta have been subjected to substantial processing, and such foods are classified using the NOVA food classification system as ultra-processed products (Monteiro et al., 2016; Monteiro et al., 2019). The likelihood of concurrent consumption of caries-protective foods at mealtimes, and lack of clarity in defining sugar- and starch-containing foods in some studies means that findings on caries rates associated with these foods at mealtimes should be interpreted with some caution.

Another focus of the review was the examination of the dietary behaviour of frequency of food intake, given the association of a high sugar intake frequency with dental caries. The

evaluation of frequency of intake of these foods in this review is, to our knowledge, the first time this has been assessed in a systematic review. A major finding of this review was that the between-meal or snack-time consumption of sugar- and starch-containing foods was found to be associated with higher rates of dental caries (Campain et al., 2003; Chankanka et al., 2015; Chankanka et al., 2011; Marshall et al., 2005). This is an important finding, given the wealth of long-established evidence that a high intake frequency of high-sugar, sweet foods is associated with dental caries, and it provides further evidence that frequent intake of refined fermentable carbohydrates is implicated in dental caries. This is an important finding, given the wealth of long-established evidence of a high frequency intake of high-sugar, sweet foods are associated with dental caries, and provides further evidence that the high frequency intake of refined fermentable carbohydrates is implicated in dental caries.

The observed positive associations between snack-time intake of processed sugar- and starch-containing foods and higher rates of dental caries fulfil the Bradford Hill criteria of coherence, biological plausibility, consistency, and temporality for future investigation to determine causality. Higher rates of caries were observed during and after frequent exposures to the foods investigated in this review and confirm evidence from previous cross-sectional studies (Arcella et al., 2002; Beighton et al., 1996; Costacurta et al., 2014; Johansson et al., 2010; Llena & Forner, 2008). The associations observed in this review are also biologically plausible given the evidence from laboratory studies that have shown co-cariogenic effects of starch and sugars on both plaque pH and tooth mineralisation status (Kashket et al., 1991; Kashket et al., 1994; Kashket et al., 1996; Lingstrom et al., 1989; Pollard, 1995; Ribeiro et al., 2005). In addition, the findings on processed sugar- and starch-containing foods and dental caries are analogous to long-established evidence that is both epidemiologically and biologically supportive of high frequencies of dietary intakes of sugars in the development of dental caries (Bernabe et al., 2016; Loesche et al., 1975; Sheiham & James, 2014b, 2015). The dietary behaviour of a high frequency consumption of processed sugar- and starch-containing foods is also associated with obesity in children and adolescents (Aas et al., 2008; Chen et al., 2018; Hayden et al., 2013; Li et al., 2017), and implicated in a range of chronic health conditions (Araujo et al., 2019; Kopp, 2019; Martinez Steele et al., 2019; Tavares et al., 2012; Timonen et al., 2010; Weiss et al., 2013).

The finding of positive associations between snack-time intake of sugar-and starch-containing foods and dental caries experience has some implications for research. The plausible mechanisms by which processed sugars and starches cause harm in oral and general health - and the associations observed in this review and in previous cross-sectional studies - provide some justification for the design of controlled trials of interventions to elicit dietary behaviour change. A useful starting hypothesis would be that reducing the consumption frequency of highly processed, sugar- and starch-containing foods may reduce risk for both dental caries and other chronic diseases associated with modern Western diets. Unlike other chronic diseases associated with poor quality diets, caries in children represents an early and rapid manifestation of the detrimental effects of consuming a modern Western diet (Harris et al., 2012). In addition, the diet of very young children is wholly influenced by what is being provided by primary caregivers, and the presentation of dental caries in children may be a useful method of identifying families who are at risk of dental caries and other non-communicable diseases that are associated with the high and frequent consumption of highly processed sugars and starches. Other family members are likely to consuming a diet high in processed foods and engaging in dietary behaviours that place them at risk of poor oral health and obesity. Given the common dietary behaviour of high frequency consumption of processed foods in dental caries, obesity, and related chronic diseases of dietary origin, the study of interventions to elicit dietary behaviour change represents important health research. Such interventions should also consider upstream approaches to address inequities associated with dental caries, particularly policies and commercial imperatives that have resulted in the ubiquity of ultra-processed foods in Western diets (Kopp, 2019).

In conclusion, these findings verify that the frequent between-meal consumption of processed sugar-and starch-containing foods is associated with dental caries. Overall, there is a paucity of studies that have evaluated the role of processed sugar- and starch-containing foods on the risk of dental caries; there were no trials identified for this review that evaluated the effectiveness of reducing intake of processed sugars and starches on the risk of developing dental caries. There was insufficient evidence from the five included prospective cohort studies for the association of total processed sugar and starch intake with dental caries. The role of these food types (and the dietary behaviour of frequent snacking sugar-

and starch-containing foods) in dental caries requires further investigation, particularly given the principal role in modern Western diets of these foods, which are also associated with obesity and a range of chronic diseases. Ideally, future research should investigate the effectiveness of interventions to change dietary behaviour to decrease the risks of dental caries and other chronic diseases of dietary cause.

CHAPTER 4: NUTRITION GUIDELINES FOR DENTAL CARE VS. THE EVIDENCE: IS THERE A DISCONNECT?

Preface

The principal findings of the systematic review in Chapter 3 were that the high frequency consumption of processed sugar- and starch-containing foods were associated with an increased risk of dental caries in prospective studies of child and adolescent populations. These findings align with long-established evidence of high and frequent dietary intakes of fermentable sugars in the development of dental caries. Crucially, these findings also provide additional support for the dual model of the dental caries process outlined in Chapter 1. Briefly, the dual model consists of an "outside-in" process of enamel demineralisation, and an "inside-out" endocrine system process that results in malnourishment of teeth; both processes are responses to a high and frequent intake of processed fermentable carbohydrates. Furthermore, a high intake of sugars, and production of ROS in the mitochondria of the hypothalamus is implicated in the development of hyperinsulinaemia. High levels of insulin production are also associated with the disruption of leptin, which regulates energy balance and inhibits hunger by signalling to the brain when satiety is achieved from food consumption; disruptions of leptin signalling promote a cycle in which hunger and food consumption increases, leading to weight gain. This means that the epidemics of dental caries and the presentation of children as overweight or obese can be attributed to the common dietary behaviour of a high and frequent intake of dietary carbohydrates.

The aim of the narrative appraisal in this chapter was to use the evidence regarding the dietary causes of dental caries and obesity to evaluate the extent to which it is reflected in dietary recommendations for oral and general health. This appraisal focused on the state of the current dietary guidelines for children and young people relating to three key areas of diet in dental caries and obesity – sugar, processed sugar- and starch-containing foods, and full-fat dairy products that are associated with protection from dental caries.

Strategies for oral health promotion in New Zealand for caries prevention include teaching effective oral hygiene practices, facilitating early access to preventative dental services, promoting use of topical fluorides in toothpaste, and promoting healthy eating. Dietary advice provided to dental patients typically consists of suggestions to eliminate sugary drinks and foods, and to eat a diet that broadly follows typical standard nutritional guidelines. New Zealand dietary recommendations for both optimal oral health and weight management usually includes advice to adhere to mainstream food and nutrition guidelines, which includes consuming around half of total energy from grain-based foods (i.e., starch) and has a focus on the consumption of low-fat dairy products. Given dental caries is the most common chronic childhood disease in New Zealand, it is imperative that recommendations for healthy eating for New Zealanders reflect the evidence around diet and nutrition for the prevention of dental caries alongside that for other conditions.

The manuscript of this chapter was published in the New Zealand Medical Journal in February 2020.

Hancock S, Zinn C, Schofield G & Thornley S. (2020). Nutrition guidelines for dental cares vs. the evidence: is there a disconnect? *New Zealand Medical Journal* 133 (1509), 65-72

Abstract

Dental caries is the most common chronic childhood disease in New Zealand. Concurrently, obesity and related chronic metabolic diseases are the most challenging public health problems of modern times. There is considerable evidence that a common dietary behaviour – high frequency consumption of sugar- and starch-containing foods – is the principal aetiological factor for both dental caries, and presentation of children and young people with increased adiposity or obesity. Conversely, consumption of full-fat dairy products by children and young people is associated with reduced risks of dental caries and obesity. Government-endorsed dietary guidelines for young people correctly provide recommendations to decrease intake of high-sugar foods. However, recommendations are provided to increase the frequency of consumption of sugar-and starch-containing foods as children age, and to choose low-fat dairy produce. We contend that this advice directly contradicts evidence of the dietary causes of both dental caries and obesity. This advice also does not reflect evidence regarding observed associations between the consumption of full-fat dairy produce and reduced dental caries and obesity. We present evidence to support our contention that important elements of New Zealand's dietary guidelines have been established without due consideration of the entirety of the evidence including that which is updated, recent or evolutionary. Given the epidemics of dental caries and metabolic disease are ongoing public health challenges in New Zealand and share common dietary causes, guidelines for healthy eating should limit refined sugar-and starch-containing foods and encourage intake of full-fat dairy items.

Introduction

Dental caries is the most common chronic childhood disease in New Zealand (Ministry of Health, 2019). The most recent data from the Ministry of Health (MOH) showed that 38% of five-year old children were diagnosed with dental caries in 2017, with a higher prevalence observed among Māori and Pacific children compared to children of other ethnicities. In addition, New Zealand is experiencing an obesity epidemic; New Zealanders are the third most overweight and obese population among countries included in the OECD (Beaglehole, 2014). Approximately 67% of all New Zealanders over 15 years of age are overweight, and the prevalence of obesity is 27% (Ministry of Health, 2019).

There is now increasing scientific and public health debate that the common dietary behaviour - the high frequency consumption of sugar and starches and a concurrent reduced intake of nutrient-rich whole foods - is central to the development of dental caries, malnutrition in young children (Clarke et al., 2006), and obesity in older children (Chi et al., 2017). It is proposed that the consumption of processed sugars and starches, leads to increased insulin secretion and dysregulation of the satiety hormone leptin, resulting in a cycle of increased hunger and frequent food consumption that promotes weight gain (Weiss et al., 2013). The MOH-endorsed dietary guidelines for healthy eating in children and young people in New Zealand for healthy weight-management (Ministry of Health, 2016) correctly includes advice to limit consumption of high-sugar foods. However, these guidelines include advice for children and young people to derive most of their energy from grain-based foods and to increase the frequency of consumption of these foods as children move into adolescence. In addition, recommendations to consume dairy products involve promotion of low-fat options, despite evidence that consumption of full-fat dairy products is associated with benefits for both oral health (Campain et al., 2003), and in weight status and markers of cardiometabolic health in children and adolescents (Dougkas et al., 2019). Policy in New Zealand for dental health is focused on prevention of caries in young children with a substantial emphasis on oral hygiene promotion, and recommendations for the consumption of a diet that broadly follows MOH guidelines.

We contend that such recommendations do not reflect the best available evidence for both healthy weight management and maintenance of optimal oral health. Given dental caries is the most common chronic childhood disease in New Zealand, it is imperative that recommendations for healthy eating for New Zealanders reflect the evidence around diet and nutrition for the prevention of dental caries alongside that for other conditions. The consideration of the hormonal theory of metabolic health may resolve the apparent contradictions between the evidence of dietary causes of caries and obesity, and advice provided in dietary guidelines. What follows is an appraisal of the evidence and the state of the current dietary guidelines for children and young people relating to three key areas of diet in dental caries and obesity – sugar, sugar and starch, and full-fat dairy products.

Diet and Dental Caries

Dental caries can be defined as the localised destruction of susceptible dental hard tissues by the acidic by-products from bacterial metabolism of fermentable carbohydrates (Selwitz et al., 2007). Carious lesions on teeth form through a complex interaction between acid-producing bacteria and consumption of fermentable sugars and is influenced by a range of host factors including saliva and dental plaque. Reports from the MOH from 2017 indicate that 40.5% of New Zealand children present with dental caries at age five years. Further, the prevalence of caries in young adolescents in New Zealand is estimated to be 38.6% (Ministry of Health, 2019).

The relationship between high dietary intakes of sugar (sucrose) and dental caries is well established. An extensive systematic review of the relationship between sugar intake and dental caries was conducted by Moynihan and Kelly (Moynihan & Kelly, 2014). Positive associations between free sugar intake and dental caries were found in 42 out of 50 studies in children, and in all five studies of adults. These links are both epidemiologically and biologically indicated through several lines of evidence including studies on the action of bacteria that reside in the oral cavity on a range of sugars in the mouth (Loesche et al., 1975). Time-series analyses of country level datasets shows low levels of dental caries prior to the consumption of refined sugar, and within-person observational studies also show the central role of sugar in the aetiology of dental caries (Moynihan & Kelly, 2014).

Other fermentable carbohydrates, particularly sugar- and starch-containing foods are also associated with an increased risk of dental caries. In the Western diet, processed starches are found in a wide range of foods and constitute a high percentage of total dietary carbohydrate (Selwitz et al., 2007). Studies of the human pH response to a range of starches and enamel/dentin demineralisation show that both sugars and starches are associated with cariogenic activity (Kashket et al., 1996). The total time that plaque pH remains below critical levels of 5.5 upon exposure to processed starch- and sugar-containing foods exceeded that of foods containing high levels of sucrose alone. Through this extended retention of starch-derived sugars in plaque, the effects of other simultaneously present sugars may be prolonged; in which event the consumption of starch has a co-cariogenic effect with that of

other sugars. The results from prospective cohort studies show that foods with a relatively low level of sugar but a high proportion of starch were associated with increased caries risk (Campain et al., 2003) and starch has been identified as an effects modifier in the relationship between dental caries and foods with low sugar levels (Campain et al., 2003).

Conversely, results from prospective cohort studies (Campain et al., 2003; Chankanka et al., 2011) and systematic reviews indicate that consumption of full-fat dairy products by children and young people is associated with reduced risks of dental caries and obesity. Neutral, or inverse associations were observed in a systematic review by Dror and Allen between consumption of milk and dairy products in children and adolescents and dental caries incidence, body fatness, bone mineralisation, and hypertension (Dror & Allen, 2014). A recent systematic review of 43 cross-sectional studies and 31 prospective studies by Dougkas et al. found that intake of milk and other dairy products are consistently found to be either not associated, or inversely associated, with obesity and indicators of adiposity in children, and that there is little evidence to support advice to limit consumption of dairy products for children on the grounds that they may promote obesity (Dougkas et al., 2019). Another review by Guo et al. found a neutral or moderate inverse association between dairy consumption and the risk of developing type-2 diabetes (Guo et al., 2019).

The main strategy for the prevention of caries adopted worldwide has been to target children, on the assumption that if caries is prevented in this group, the burden of dental disease would be reduced for all. Strategies for oral health promotion in New Zealand include teaching effective oral hygiene practices, facilitating early access to preventative dental services, promoting use of topical fluorides in toothpaste, and promoting healthy eating. However, young New Zealanders present with caries, despite the promotion of a range of oral healthcare practices for the prevention of tooth decay, and caries increases through adolescence and adulthood (Broadbent et al., 2008). The focus of conventional dental treatment is primarily on the endpoint of disease and remedial work (Jatrana et al., 2009). We argue that the current dental delivery system is not effective in achieving health improvements because this approach does not fully consider the primary cause of disease, the impact of diet and dietary behaviours on dental caries, and the common risk factors for dental caries, other oral diseases, and obesity.

Dental caries, obesity, and common risk factors

There is mixed evidence about the relationship between the prevalence of dental caries and obesity in children and adolescents. On the one hand, studies in young children have shown that early childhood caries are associated with reduced growth and malnutrition due to insufficient consumption of nutrient-rich food to meet the metabolic and growth needs of children less than two years of age (Sheiham, 2006). On the other hand, there are stronger associations observed between dental caries, and increased adiposity and obesity in older children and adolescents. Several systematic reviews have examined the cross-sectional relationship between dental caries and increased adiposity using anthropometric measures including body mass index (BMI) and waist-hip ratio (Aas et al., 2008). Hayden et al. reported a statistically significant relationship between adolescent obesity and dental caries (effect size 0.104, p=0.049) (Hayden et al., 2013). Similarly, in Chen et al., sensitivity analyses showed obese individuals presented with more dental caries than normal weight children in their primary teeth (WMD 0.52, 95% CI 0.17 to 0.87, p=0.026) (Chen et al., 2018). Finally, in a recent prospective cohort study by Li et al, longitudinal associations were observed between dental caries and central obesity measured by a waist-hip ratio among adolescents aged 15-18 years (Li et al., 2017).

An important caveat when evaluating studies of food consumption, dental caries, and obesity, is that much of the evidence comes from cross-sectional and prospective cohort studies. Hence, the observed correlations and relationships cannot be regarded as causal, and the findings should be interpreted with some caution.

There is emerging evidence that the "calories in, calories out" model of healthy weight management is too simplistic and ignores the complex nutritional, metabolic and hormonal effects of food. The complex hormonal, neural and microbial feedback systems are likely to be critical in the regulation of satiety, energy partitioning and consequently, body composition. Very young children with decayed teeth may not achieve satiety from meals comprised of a high proportion of nutrient-poor, processed foods, which in turn could then lead to between-meal snacking (Drummond et al., 2013), and abnormally high levels of insulin secretion (Weiss et al., 2013). High levels of insulin production are also associated

with the disruption of the satiety hormone leptin, which regulates energy balance and inhibits hunger by signalling to the brain when satiety is achieved from food consumption (Weiss et al., 2013). The consequence of the disruption to leptin promotes a cycle in which hunger and food consumption increases, leading to weight gain (Weiss et al., 2013). Another point is that the frequent consumption of refined snacks comprising sugar and starches is also associated with food addiction characterised by similar behavioural, neurochemical and brain activation responses like those of substance abuse (Lennerz & Lennerz, 2018).

Treatments for obesity include dietary interventions, medication, advice to engage in physical exercise, and for morbid obesity: bariatric surgery. There is general agreement within the scientific literature that effective interventions for obesity should comprise dietary interventions to improve metabolic health and achieve weight loss through the consumption of nutrient-rich whole foods (Troesch et al., 2015), long acknowledged to be associated with benefits for dental health and longevity in studies of dietary lifestyles both evolutionary and modern (Woelber et al., 2016).

The predominant dietary prescription in weight loss trials and considered as "best practice" by the MOH is a diet based on a moderate-to-high carbohydrate, moderate protein, and low fat intake, with a specific restriction on saturated fat, in the context of an energy deficit (Ministry of Health, 2016). However, there is compelling evidence from randomised controlled trials that a restricted carbohydrate intake improves adiposity, glucose metabolism, and lipid markers over and above that of the mainstream guidance system (Feinman et al., 2015). These results suggest that a carbohydrate-restriction model should feature prominently in the guidance strategy for promoting health and managing health conditions, and perhaps even be considered the first-line approach in the management of obesity. This approach typically includes less frequent eating, which may impart a dual benefit for caries prevention.

Dietary advice in New Zealand, and contradictions with scientific evidence

New Zealand dietary recommendations for both optimal oral health and weight management usually includes advice to adhere to mainstream food and nutrition guidelines.

"The Food and Nutrition Guidelines for Healthy Children and Young People (Aged 2–18 years)" are derived from a background paper produced with the purpose of providing background information for health practitioners who provide nutrition advice and develop nutrition programmes (Ministry of Health, 2016). These guidelines, endorsed by the MOH, also provide the basis for developing health education resources that are for use by the public and focus on this age group.

A significant feature of these guidelines is advice to prepare foods or choose pre-prepared foods that are low in sugar, especially added, and to limit the intake of drinks such as cordials, fizzy drinks (including diet drinks and sports drinks) and refined clear fruit juices. The authors of the guidelines recognise that foods high in sugar generally provide very few vitamins and minerals relative to their energy content and that limiting consumption of these foods can be difficult because they are widely available, often inexpensive and heavily marketed to children and young people. The guideline authors also correctly acknowledged the displacement of healthier foods from the diet, given that these foods and drinks contribute to 20% of total energy intake.

However, features of these recommendations are the inclusion of cereals and other processed carbohydrates including breads and baked goods, and strong encouragement to consume low-fat dairy products wherever possible. Additional advice is provided for increasing the frequency of consumption of carbohydrate-containing foods for young people. The advice offered in these guidelines supports high and frequent consumption of carbohydrates. This means that promoted foods include processed items such as breads and cereals, as defined by the NOVA classification system which classifies foods in relation to their degree of processing (Monteiro et al., 2019). Further, included in the MOH food suggestions are refined carbohydrates (such as cornflakes) and foods listed in the highest NOVA category of ultra-processed foods, such as plain sweet biscuits and tortillas. This advice for children contradicts evidence of the dietary causes of dental caries and contradicts the nutritional, metabolic and hormonal theory of metabolic health as the cause of obesity. Consumption of breads, cereals and other ultra-processed refined sugar-and starch-containing foods is associated with dental caries (Campain et al., 2003), is implicated in

insulin resistance (Weiss et al., 2013), and is associated with obesity in older children and adolescents (Hayden et al., 2013).

Since the introduction of dietary guidelines to reduce fat consumption, data from a range of reviews suggests the replacement of saturated fat with sugars and starches are correlated with worldwide obesity and diabetes epidemics (Harcombe, 2017). Recommendations to consume low-fat dairy products was based on the hypothesis that saturated fats were the primary dietary cause of cardiovascular disease. Although the anti-cariogenic properties of milk products are acknowledged in the guidelines, recommendations about dairy intake promote low-fat dairy products, in direct opposition to epidemiological evidence. Full-fat dairy products have not been associated with obesity in child and adolescent populations, and studies indicate that whole milk consumption is associated with favourable effects on body composition and lipid profiles of children (Dougkas et al., 2019; Dror & Allen, 2014). In Table 1, specific recommendations provided in the guidelines that relate to healthy eating for weight management and prevention of dental caries are summarised.

Table 5. Specific food and nutrition guidelines for healthy eating in children and young people pertaining to dietary factors and evidence for prevention of obesity and dental caries in young people.

<table>
<tr><th>Dietary factor</th><th colspan="2">Weight management</th><th>Optimal oral health</th></tr>
<tr><td rowspan="4">Carbohydrate intake</td><td colspan="2">"Eat a variety of foods from each of the four major food groups each day…"
• … breads and cereals, increasing wholegrain products as children increase in age.</td><td>"Eat a combination of foods at each meal, including whole grains…"

"Good oral hygiene and minimising intake of cariogenic foods and drinks are key behaviours in preventing dental caries"</td></tr>
<tr><td colspan="3">Recommendations for the "breads and cereals" food group</td></tr>
<tr><td>Specific foods included</td><td>Recommendation (per day)</td><td>Serving size examples</td></tr>
<tr><td>All breads, cereals, rice, and pasta (increasing wholegrain options as children age)</td><td>Pre-schoolers: at least 4 servings
Children: at least 5 servings
Young people: at least 6 servings</td><td>1 medium slice of bread (26g)
1 roll (50g)
1 pita pocket or tortilla (50–80g)
2 breakfast wheat biscuits (34g)
½ cup muesli (55g) ½ cup porridge (130g)
1 cup cornflakes (30g)
1 cup cooked pasta or rice (150g)
4 grainy crackers (40g)
2 plain sweet biscuits (14g)
1 cup plain popcorn</td></tr>
</table>

<table>
<tr><td rowspan="5">Fat intake</td><td colspan="2">Weight management</td><td>Optimal oral health</td></tr>
<tr><td colspan="2">"Eat a variety of foods from each of the four major food groups each day…
• milk and milk products or suitable alternatives, preferably reduced or low-fat options

"Reduced or low- fat milk and milk products are the best choices because these foods include less saturated fat, and often more protein and calcium than high-fat alternatives."</td><td>"Eat a combination of foods at each meal, including whole grains, vegetables and fruit."

"Anti-cariogenic foods and drinks are those that promote tooth remineralisation. They include foods high in calcium, phosphate, and protein, such as milk and milk products"</td></tr>
<tr><td colspan="3">Recommendations for the "milk and milk products" food group</td></tr>
<tr><td>Specific foods included</td><td>Recommendation (per day)</td><td>Serving size examples</td></tr>
<tr><td>Milk (includes calcium-fortified milk alternatives), cheese and yoghurt (choose low-fat options)</td><td>Pre-schoolers and children: at least 2–3 servings
Young people: at least 3 servings</td><td>Glass of milk or calcium-fortified milk alternative (250ml), one pot of yoghurt (150g) 2 slices of cheese (40g)</td></tr>
</table>

Part 2 of "The Food and Nutrition Guidelines for Healthy Children and Young People (Aged 2–18 years)" outlines recommendations for meal patterns of New Zealand children and young people (Ministry of Health, 2016). Three meals plus 2-3 small snacks are recommended during the day at regular times for children and young people. Examples of healthy and nutritious snacks are, according to the guideline: fruit, yoghurt, vegetable sticks with a low-fat dip (e.g., hummus or yoghurt-based dips), mini homemade 'pizzas', 'mousetraps' (toasted cheese and yeast extract spread on bread), nuts and milk. Frequent consumption of carbohydrate-containing foods is also associated with increases in insulin production, down-regulation of leptin hormone action and consequent metabolic dysregulation that promotes an increase in appetite and an alteration of weight homeostasis towards weight gain (Ludwig & Friedman, 2014).

The recommendation to consume food at a frequency of up to six eating occasions daily contradicts a well-established body of evidence showing a strong relationship between a high frequency food consumption, and dental caries and the onset of obesity in young people. The inclusion of mini sandwiches and mini homemade "pizzas" as recommended snack foods is also questionable given the high carbohydrate load of these foods. This advice is not informed by evidence that shows clear relationships between the frequent

intake of fermentable carbohydrates and the increased risk of dental caries, and other disorders attributable to a high carbohydrate diet. On the contrary, we could find no direct evidence to support both increased consumption of wholegrain products as children age, and to eat from four food groups as stipulated in the guidelines outlined in Table 1. We could not find evidence to support the recommended daily consumption of four, five, and six servings per day of breads and cereals of breads for pre-schoolers, children, and young people, respectively. In addition, given the anti-cariogenic properties of milk and other full-fat dairy products above, the advice to consume carbohydrate-containing foods as snacks rather than dairy-based food items is likely to be counterproductive.

Table 6. Specific food and nutrition guidelines for healthy eating in children and young people relating to meal patterns and evidence for prevention of obesity and dental caries in young people.

	Weight management	Optimal oral health
Food consumption frequency	"Three meals and two to three small snacks, at regular times during the day, are recommended for children and young people". "Continuous eating or 'grazing' is not recommended" "Examples of healthy and nutritious snacks are: fruit, yoghurt, vegetable sticks with a low-fat dip (e.g., hummus or yoghurt-based dips), mini-sandwiches, mini homemade 'pizzas', 'mousetraps' (toasted cheese and yeast extract spread on bread), nuts and milk"	"Have no more than six meals (including snacks) per day to allow time for teeth to re-mineralise between meals. "Choose snacks such as yoghurt and cheese, which are low in fermentable carbohydrate and promote tooth remineralisation." "Limit sugary foods and drinks, especially those that remain in the mouth for an extended time or are more likely to stick to teeth, for example, hard or chewy sweets, dried fruit, roll-ups and lollipops"

evidence that the consumption of foods containing sugar and starches is the principal aetiological factor in dental caries. Intake of these foods are implicated in the increased prevalence of both malnutrition and obesity in children and young people. However, the guidelines for "healthy eating" for children and young people have been produced without consideration of the entirety of evidence relating to the role of not only sugars, but also, starches, in the aetiology of dental caries and obesity. Furthermore, the evidence relating to reductions in dental caries and adiposity, and markers of cardiometabolic health in children with higher intakes of full fat dairy products is not reflected in national guidelines. Not only

do the dietary guidelines not incorporate the available evidence on healthy eating to prevent dental caries and obesity in young New Zealanders, but much of the advice also contradicts epidemiological evidence relating to risk factors for dental caries and obesity. Given that the epidemics of dental caries and obesity are a significant and ongoing public health challenge in New Zealand, it is imperative that the guidelines for healthy eating for young New Zealanders incorporate the best dietary advice to improve their health. It is time to update the guidelines and include a dental focus to limit sugar and starch intake and encourage intake of full-fat dairy products to prevent the epidemics of dental caries and obesity, which share a common cause.

CHAPTER 5: THE DEVELOPMENT AND DESIGN OF NOVEL CARD SORTING TASKS TO EVALUATE NUTRITION KNOWLEDGE FOR GENERAL AND ORAL HEALTH

Preface

Given the burden of dental caries in New Zealand, and the high personal and public costs of poor oral health, it is important and timely to consider dietary interventions to improve oral health and reduce the risk of chronic diet-related disease in New Zealand families. Currently, there is a paucity of research in interventions that focus on reducing consumption of processed fermentable carbohydrates for dental caries and general health outcomes. The principal aim of this thesis is to foster greater recognition that dental caries and chronic metabolic disease are united by a common dietary cause, and that prevention of both diseases requires the input of both the dental and medical professions. To design such interventions, it is important to understand the prior beliefs and knowledge of nutrition concepts as they relate to health and dental care of populations who are the target of interventions, and health practitioners who instigate such interventions. It is also essential to understand the barriers people experience to engaging in dietary behaviours for optimal health. The involvement of, and contribution by groups for whom the intervention is targeted may increase the likelihood that the interventions will be feasible, acceptable, and sustainable for participants.

The work presented in Chapters 2-4 has shown that there are substantial inequities in the distribution of dental caries in New Zealand, with a high burden of disease borne disproportionately by vulnerable groups in New Zealand. Further, a high and frequent intake of processed fermentable carbohydrates is associated with dental caries; this dietary behaviour is also implicated in chronic metabolic disease. A range of disconnects were also observed between the evidence for these dietary associations with poor oral and general health, and recommendations for healthy eating in government-endorsed dietary guidelines. At this point, the research direction of this thesis shifted, to give rise to a set of formative studies that will be presented in the following four chapters, Chapters 5-8. The objective of the formative research was to measure nutrition knowledge and beliefs of children and

adults, and to investigate barriers to healthy eating to inform the design of interventions for dietary behaviour change.

Integral features of such interventions involve education to improve knowledge in children and parents to address behaviours. Typically, the measurement of knowledge of disparate groups is derived from written questionnaires, surveys, and checklists. However, the use of these techniques may have limited utility for use in children, because of different levels of cognitive development and literacy among child groups, the attention span of children, and the presence of parents or caregivers at the time of test administration. An alternative to the use of questionnaires, surveys and checklists are card sorting tasks which accommodate varying levels of literacy across population groups under study and enables comparisons of beliefs regarding food knowledge and behaviours between disparate groups of adults and children.

The aim of this study (presented in Chapter 5) was to design and develop a set of novel card sorting exercises as a method of assessing knowledge of foods as healthy or unhealthy, and to classify a range of behaviours based on perceived importance for oral and general health. The validity and reliability of these exercises was established in this chapter. Firstly, content validity was established using the expertise of the research team and additional experts in nutrition science at Auckland University of Technology. Secondly, convergent validity was established in a sample of 12 health professionals, nine parents, and 79 children at four schools within the Taupō area. Thirdly, test-re-test reliability was evaluated in a subset of 25 children from two of the four Taupō area schools.

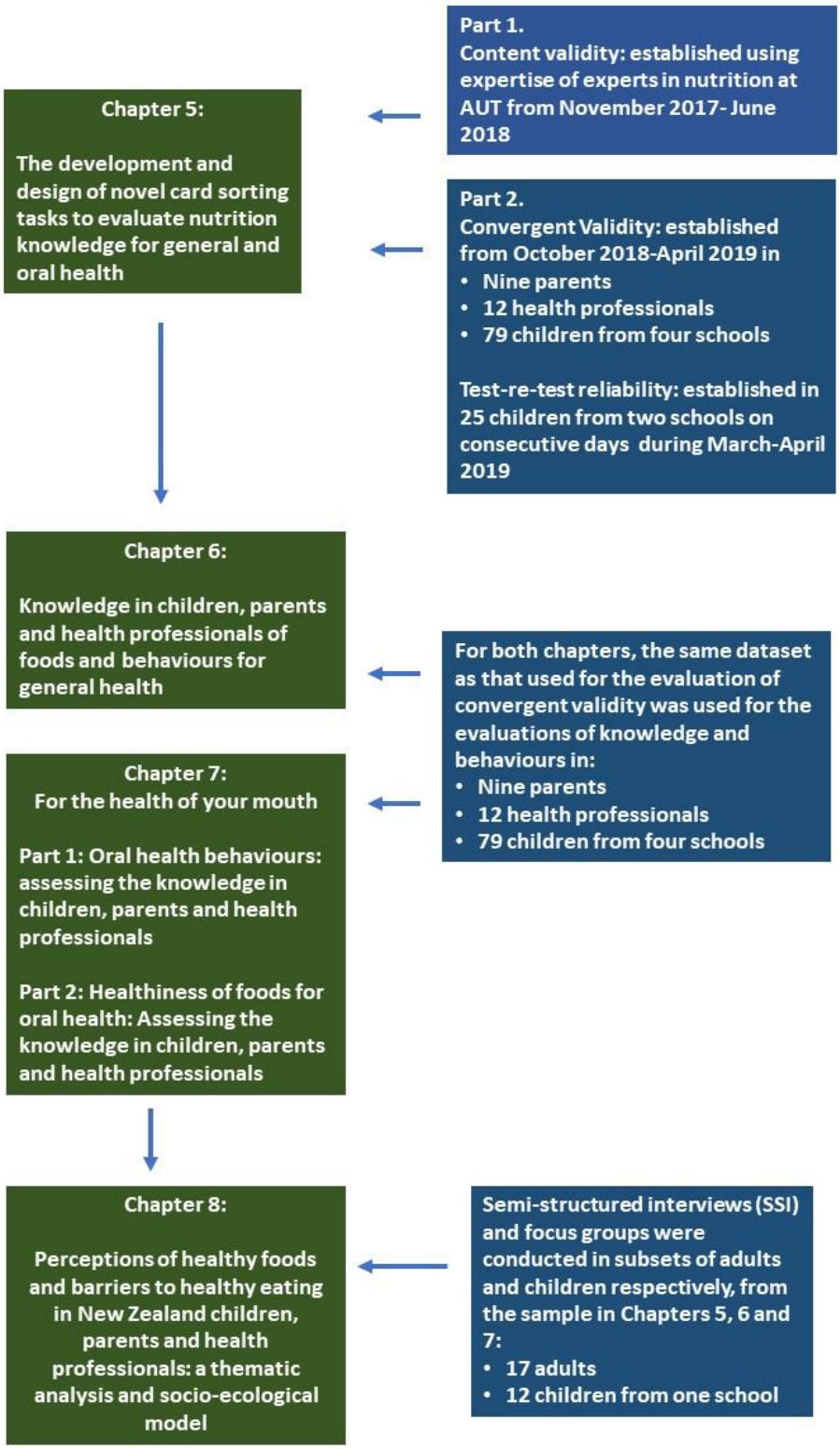
The card sorting exercises were then used to evaluate the perceived importance of behaviours and knowledge of foods in children and adults, for general health in Chapter 6 and oral health in Chapter 7. In these chapters, the dataset from the same sample of health professionals, parents, and children from the study of convergent validity in Chapter 5 were analysed. The dataset used for the analyses of behaviour perceptions and food knowledge was the same as that used for the evaluation of convergent validity.

Chapter 8 was a qualitative investigation of the beliefs of, and barriers to, healthy eating of children and adults. The adults who participated in semi-structured interviews (SSI) in this study were those adults sampled in Chapters 6 and 7. The focus group discussions with the child participants were a subset of 12 children from one of the four schools from which children were recruited for the convergent validity study in Chapter 5, and the studies comprising Chapters 6 and 7. Prior to the SSI and focus group discussions in adults and children respectively, the participants had completed the card sorting exercises.

A diagram summarising the data collection procedures and the data analysis for the formative research studies in Chapters 5-8 is overleaf in Figure 6.

The manuscript resulting from Chapter 5 has been submitted to the Journal of Nutrition Education and Behavior.

Figure 6. Study design and sampling procedures for the formative studies in Chapters 5-8



Abstract

Education to improve nutrition knowledge is a cornerstone of behavioural family-based interventions to improve health-related outcomes. However, the assessment of nutrition knowledge by questionnaires, surveys, checklists, and interviews may have limited utility in evaluating nutrition knowledge, particularly in children. The aim of this two-part formative study was to establish the validity and reliability of a novel card sorting exercise to evaluate knowledge regarding the healthiness of foods and the importance of dietary behaviours for each of general and oral health in children and adults. In Part one, the card sorting tasks were developed; content validity was established through consultation with experts in nutrition research. In Part two, the card sorting tasks underwent further validity and reliability testing. Children aged 10-13 years, parents, and health professionals living in Taupō, New Zealand completed the card sorting tasks. The convergent validity of the card sorting tasks for general and oral health was high in all participants between beliefs about dietary behaviours. Statistically significant positive associations were observed between dietary behaviour beliefs and nutrition knowledge scores of related foods for both oral and general health; chi- square scores for these associations ranged from χ^2= 32.69, (df=3, $p<0.001$) to χ^2=145.43, (df=3, $p<.0001$). Test-retest reliability of the food card sorting exercises in children was very high, with Spearman's correlations of r=1.0 and r=0.95 for the categorisations of foods for general health and oral health, respectively. The novel card sorting exercises are a valid and reliable method for assessing knowledge of dietary behaviours and foods for general and oral health, particularly in children, in whom most of the tests of validity and reliability were evaluated. The findings from evaluation methods such as card sorting exercises may have utility for the development of nutrition education interventions. In addition, it may also be used for the post-intervention assessments of family-based behavioural interventions designed to improve health outcomes.

Introduction

Behavioural family-based interventions have been shown to have short- and long-term efficacy in improving health-related outcomes (Epstein et al., 2007; Fahlman et al., 2008; Tarvonen et al., 2017). An integral feature of such interventions involves education to improve nutrition knowledge in children and parents and subsequently, to address dietary behaviours. Community nutrition education is widespread, with schools, health

professionals, health promotion agencies, and government organisations engaged in the delivery of messages that incorporate nutrition knowledge components (Spronk et al., 2014).

Nutrition knowledge is a broad concept that may include a multitude of components, including current dietary recommendations, nutrient sources, reasons for food choices and, the awareness of links between diet and disease (Graziano, 2015). The interaction between nutrition knowledge and dietary behaviours is also influenced by relationships between a range of demographic and environmental factors (Wardle et al., 2000). However, knowledge of nutrition facts, such as the healthiness or otherwise of foods, may not translate to engagement in dietary behaviours that include the ability to make healthy food choices or comprehend information on food labels, (Spronk et al., 2014). An important component of nutritional knowledge tests should be the degree to which children and caregivers can differentiate or identify foods of varying health content (Graziano, 2015). Understanding the relationship between nutrition knowledge and dietary behaviour is important, because of the evidence that suggests strong links between low nutrition knowledge and consumption of poor-quality diets and poor management of chronic disease (Chapple et al., 2017; Dickson-Spillmann & Siegrist, 2011).

There is a relative paucity of research that evaluates the knowledge of both the health value of foods, and dietary behaviours of children (Spronk et al., 2014). The nutritional knowledge of children can be viewed as an estimation for the family dietary environment, and the extent to which parents and caregivers educate and impart knowledge to children through socialisation about healthy food choices (Graziano, 2015). A potential reason for this lack of research is that written questionnaires, surveys, checklists, and interviews may have limited utility for use in children, as they may not be valid and reliable (Graziano, 2015; Wardle et al., 2000). Other limitations include the variation in researcher skills, assumptions of a shared language and the ability to enable participants to recall, analyse and verbalise information (Mammen et al., 2016), different levels of cognitive development and literacy among child groups, the attention span of children, and the presence of parents or caregivers at the time of test administration (Livingstone et al., 2004). These limitations can affect the accuracy of the information provided by children (Livingstone et al., 2004). The use of questionnaires, surveys, and checklists to ascertain nutritional knowledge regarding food and food groups

also does not allow for the comparison of beliefs regarding food knowledge between disparate groups because of the necessarily differing content of knowledge assessment tools for each group.

An alternative to the use of questionnaires, surveys and checklists are card sorting tasks in which participants are given a set of cards and asked to sort them into categories relating to specific outcomes (Blanchard & Banerji, 2016). Card sorting is a method long used to examine cognitive processes and assumes that the methods by which people sort cards into categories represents underlying mental processes regarding item classification in differing contexts (Blake et al., 2007). The use of sorting tasks has a long history in social science, particularly in psychology for the categorisation of benefits and harms in risk management (Siegrist et al., 2018; Webster et al., 2010), and consumer behaviour research (Ares et al., 2008). The use of pictures for card sorting tasks can accommodate varying levels of literacy across population groups under study (Mammen et al., 2016). Advantages of the card sort method include a brief administration time and may be an engaging process that may be particularly useful for children (Sherwood et al., 2003; Yaroch et al., 2000).

In nutrition research, card sorting tasks have been used to study knowledge in the areas of food classification (Ross & Murphy, 1999), the preferences of young children (Althubaiti et al., 2017; Bodel, 2013), knowledge of teenage girls (Sherwood et al., 2003), and to classify foods in a range of different eating settings in adults (Blake et al., 2007). The validity of card sort tasks was established in the studies of food preferences with the use of food diaries and from parents or caregivers (Bodel, 2013) and food frequency questionnaires (Yaroch et al., 2000). Although dietary histories that combine 24-hour recalls and food frequency questionnaires are regarded as a gold standard for the assessment of dietary intake, these methods can be cost- and time-intensive and may not be suitable for assessing nutrition knowledge of children. In addition, underreporting of food intake is common, and has long been acknowledged as a limitation in collecting accurate habitual dietary intake data (Livingstone & Robson, 2000; Livingstone et al., 2004; Macdiarmid & Blundell, 1998).

The aim of this formative, two-part study is to develop a set of valid and reliable card sorting tasks to ascertain and compare nutrition knowledge of foods and dietary behaviours for

optimal oral and general health in disparate groups of children, parents/caregivers and health professionals.

Methods

Part one: Development of the card sorting tasks

The concept of using sets of cards to evaluate knowledge regarding foods, and behaviours for each of general and oral health was developed by the primary researcher (SH) with input from the primary supervisor (GS) and the research team. Food cards, and separate sets of behaviours for each of general and oral health were developed. The foods chosen for the card sorting exercise were derived from the New Zealand National Children's Nutrition Survey (Ministry of Health, 2003). Twenty-four food cards were selected, in line with guidelines when designing card sorting exercises for child populations of 10-12 years of age (Blanchard & Banerji, 2016; Graziano, 2015). On each card, the foods were listed in general terms as "chicken" or "red meat". The food cards were to be assigned to categories of "good" "somewhat good", "not very good" and "very bad".

The behaviours to be evaluated were dietary and oral hygiene behaviours for oral health (Hujoel et al., 2018), and dietary and other lifestyle behaviours associated with optimal general health (Prendergast, Schofield, et al., 2016). Each behaviour was represented as a short statement such as "eating vegetables" "doing exercise" or "flossing your teeth". The behaviours were to be ranked in order from "most important" to "least important" for oral health, on a piece of A3 card with an arrow pointing downwards from the top of the card. The behaviour cards are shown in Appendix B.

To establish content validity of the card sorting tasks, the behaviour and food cards for general and oral health were developed and refined through consultation with nine experts experienced in nutrition research from the Human Potential Centre at the Auckland University of Technology (AUT). This work was necessary to test the feasibility of the card sorting tools, to determine the most appropriate way to instruct participants to complete the tasks and to determine the criteria by which the foods were categorised as "healthy" or

"unhealthy". The behaviour and food cards, and the categories into which the cards were to be classified were refined on completion of the consultation with experts.

Part two: Establishing validity and reliability of the card sorting tasks

Recruitment

Principals of primary and intermediate schools in the Lake Taupō area in the central North Island of New Zealand were approached to have their respective schools involved as a recruitment centre and study site. On receipt of principals' consent, children aged 10-13 years and parents/caregivers of children were recruited using a flyer distributed through the school's usual communication method. This age group of children was selected because it was estimated they would have the cognitive skills necessary to complete the tasks, and would be likely to have more independence in choosing foods (Gibson et al., 1998; Livingstone et al., 2004). Children were eligible if they were between 10 and 13 years of age and were literate. Parents, similarly, were eligible if one of their children between 10 and 13 years of age attended any of the study schools and were literate. All parents who responded to the advertisement were screened for eligibility and provided written informed consent to participate in the card sorting exercises. Eligible children completed assent forms for participation and data use in the presence of a parent, or member of teaching staff at the school. Health professionals including doctors, nurses, and dental professionals were also invited to participate through a general medicine practice, a dental clinic, and a community-based charitable trust. Budget, time, and resource constraints precluded further recruitment from other clinics and health service providers. All participants were reimbursed with a store voucher to the value of $10 in appreciation of their time. Ethical approval for this study was granted by the Auckland University of Technology Ethics Committee on July 8th, 2018 (18/82) and is in Appendix A.

Procedures:

The participants completed the four card sorting exercises in which brief written descriptions of behaviours on small cards for each of general and oral health were classified as either "very important", "somewhat important" and "not important" by placing the behaviour cards onto categories outlined in Appendix B. Concurrently, all participants completed a card sorting exercise where foods (e.g., cheese) were allocated to the categories of being "good"

(placement of cards in "very good" or "somewhat good" categories) or "bad" (placement of cards in the "not so good" or "very bad" categories) for each of general and oral health. There were four card sorting tasks, which also enabled four participants to complete the task simultaneously. The participating parents completed the set of four card sorting tasks on one occasion, either at their child's school or at commercial office space in Taupō. Participating health professionals provided informed consent and completed the ranking exercises as described above at their respective workplaces.

Scoring of the card sorting tasks

Participants were awarded one point for each correct categorisation of the food card sorting tasks, i.e., if they rated foods as either "healthy" (with placement of the card on the "good" categories) or "unhealthy" (in which a food card was placed in "bad" categories). A point was allocated to the participant for the correct categorisation of each food item according to the New Zealand dietary guidelines, as outlined in part 1 of this study. The maximum total score that could be attained for each food card sorting task was 24 points. The behaviour card categorisations were not scored based on any model of correctness. The categorisations of importance of each behaviour were entered into a spreadsheet and the numbers of respondents who rated each behaviour for the three categories of importance were calculated.

Photographs were taken of each participant's food and behaviour rankings with a corresponding code number for each participant; there was no photography or recording of identifiable characteristics of any of the participants.

Convergent validity

To determine the degree to which the categorisation of foods was related to the categorisations of behaviours, the scores from the categorisations of the foods as healthy or unhealthy were evaluated alongside the categorisations of behaviours as "very important", "somewhat important" and "not important" for each of dental and general health. A participant who believed that the behaviour of eating less sugar was beneficial for general and oral health, may be more likely to rate high-sugar foods including fizzy drinks, sweets, biscuits, cakes and muesli bars as detrimental or "bad" for general and or oral health

(Douglas et al., 2014; McSweeney et al., 2017; McSweeney et al., 2016; Rawlins et al., 2013). Chi-Square tests were used to ascertain any relationship between the beliefs regarding behaviours and the scores for the correct categorisations of foods by all the participants. The Fisher's exact test was used for test of statistical significance ($p<0.05$) where the response numbers were $n<5$.

Test-re-test reliability:

To evaluate the consistency of the scores of the food card sorting tasks when children were tested on two separate occasions, children from a subset of two schools completed the card sorting exercises 24 hours after initially performing the tasks. Spearman's correlation analyses were conducted, and the correlations were interpreted as either as poor (≤ 0.2), fair (0.21-0.40), moderate (0.41-0.60), good (0.61-0.80), or very good (0.81 to 1.0).

Statistical testing software in XLSTAT-Premium for Microsoft Excel was used for all analyses; significance levels were set at $p<0.05$.

Results

Part One: Development of the card sorting tasks

Upon completion of consultation with the nine nutrition experts, the following refinements were made to the card sorting tasks:

- The behaviours were to be placed by the participants onto large white A3-size card in categories of "very important" "somewhat important" and "not important" for each of dental and general health, instead of being ranked "most important" to "least important". The statements on the behaviour cards for each of general and oral health are listed in Appendix B.
- Foods were changed from being represented by words to pictures to avoid confusion about foods that can differ in appearance according to food processing. For example, a picture of a roast chicken was used, and the word "chicken" was printed underneath the picture. The names of the foods were also printed on the cards. The food pictures were royalty-free, black-and-white sketches obtained from Shutterstock via Google Images. The picture cards are shown in Appendix C.

- Instead of having the scores analysed using all four categories of "very good" "somewhat good", "not very good" and "very bad", the scores were analysed on whether the participants regarded the food as "good/healthy" (including categorisations of foods as "very good and somewhat good") or bad/unhealthy" (including categorisations of foods as "not so good" or "very bad").
- The criteria by which foods were classified as "healthy" or "unhealthy" was based on recommendations from the New Zealand Dietary Guidelines; the ratings of foods as healthy or unhealthy to gain a point for a correct score are outlined in Table 7.

Table 7. Categorisation of foods as healthy or unhealthy for general and oral health according to the current dietary guidelines model (Ministry of Health, 2016)

Healthy	Fresh fruit, Green vegetables, Root vegetables, Cheese, Milk, Unsweetened yoghurt, Nuts, Chicken, Fish, Red meat, White Beans and Chickpeas, Rice, Breakfast cereals, Pasta, Brown or Wholegrain bread
Unhealthy	Dried Fruit, Fruit juice, Bacon and salami, White bread, Fizzy drink, Crisps and chips, Sweets, Biscuits and Cakes

Part Two: Establishing validity and reliability of the card sorting tasks

Study population

Eight schools in the Taupō area were approached to recruit children to participate in the study; permission was granted from four schools to participate in the study. These schools were Tauhara Primary School, St Patrick's Catholic School, Wairakei Primary School, and Taupō Intermediate School. The demographic characteristics of the study participants are presented in Table 2. There were 79 children and 22 adults in the study; the latter group comprised 12 health professionals and nine parents. Comparison of the demographic data alongside New Zealand Ministry of Health Information regarding the demographic profile of attendees at the schools showed the study participants were representative of each of the schools and the profile of children within the greater Taupō community (Ministry of Education, 2019). The mean age of all child participants was 10.9 years. The group of health professionals was comprised of seven general practitioners, four nurses, (two general practice nurses and two community-based nurses) and one dentist. The health professionals were recruited from one general practice, a community-based provider of youth health

services, and one dental clinic. Given budget, time, and personnel constraints, it was not possible to recruit more parents and health professionals.

Table 8. Participant characteristics for the children, parents, and health professionals

	Adult participants			
Participant variable	Parents/caregivers (n=9)		Health professionals (n=12)	
Age				
25-34 (%)	11		0	
35-44 (%)	33		58	
45-54 (%)	56		25	
55-64 (%)	0		17	
Highest educational qualification				
High school (%)	11		0	
Trade (%)	33		0	
Degree (%)	56		100	
Ethnic group				
New Zealand European (%)	89		75	
Maori (%)	11		0	
Other (%)	0		25	
	Child participants (n=79)			
School	Tauhara (n=42)	Wairakei (n=12)	St Patricks (n=12)	Taupō Intermediate (n=13)
Age				
10 years (%)	31	100	17	0
11 years (%)	69	0	25	0
12 years (%)	0	0	58	77
13 years (%)				23
Gender				
Male (%)	43	25	33	23
Female (%)	57	75	67	77
Ethnic group				
New Zealand European (%)	29	83	67	100
Maori (%)	64	17	25	0
Asian (%)	4	0	8	0
Pacific (%)	3	0	0	0

Convergent validity

The results for the relationships between the dietary behaviours and the nutrition knowledge of adults of the foods corresponding to the dietary behaviours are presented in Table 9. All adults correctly categorised consuming fizzy drink and sweets as detrimental for general and oral health and eating green and root vegetables as beneficial for general and oral health.

Hence, Chi-square and Fisher's exact scores were not calculable for these tests of the associations between these dietary behaviours and corresponding foods. Statistically significant, positive relationships were observed in adults between beliefs about all dietary behaviours and the scores of the healthiness of corresponding foods except for the dietary behaviour of eating carbohydrates, and food knowledge of breakfast cereals for general health (p=0.197). No adult classified the dietary behaviour of eating carbohydrates as very important for oral health; this zero score means that a chi-square test was incalculable for the relationship between eating "carbohydrates" and the food scores for brown or wholegrain bread, and breakfast cereals.

The results of the analyses of all dietary behaviours and corresponding food knowledge of children are presented in Table 10. In child participants, statistically significant relationships were observed between the beliefs regarding dietary behaviours, and the knowledge of the healthiness or otherwise of all the foods corresponding to the respective dietary behaviours of eating less sugar, and eating each of fat, meat, vegetables, and carbohydrates.

Test-retest reliability

There were no changes in the children's scores attained for the correct categorisations of foods as good or bad for general health, providing a Spearman's correlation of 1.0. For the evaluation of reliability of the card sorting tasks for oral health, three children attained higher scores 24 hours after the initial completion of the tasks; two children increased their score by two points, and a third child improved their score by one point. The Spearman's correlation for the test-re-test reliability was r=0.950 (95% CI 0.86 to 0.98, p<0.0001).

Table 9. The importance of dietary behaviours, and the general and oral health food scores for adult participants.

Rankings and food scores for general health in adults (n=21)					***Rankings and food scores for oral health in adults (n=21)***				
Rankings of dietary behaviours, % (n)		***General health food scores relating to the dietary behaviour, % (n)***		***Chi-square results***	***Rankings of dietary behaviours, % (n)***		***Oral health food scores relating to the dietary behaviour, % (n)***		***Chi-square results***
Eating Fat		***Food score***			***Eating Fat****		***Food score***		
VI	41 (9)	Cheese	86 (18)	***SS***	VI	24 (5)	Cheese	81 (17)	***χ^2=18.83, df=3***
SI	50 (10)	Milk	90 (19)	***SS***	SI	52 (11)	Milk	91 (19)	*χ^2=23.39. df=3*
NI	9 (2)				NI	24 (5)			
Eating Meat		***Food score***			***Eating Meat****		***Food score***		
VI	43 (9)	Chicken	95 (20)	***SS***	VI	24 (5)	Chicken	95 (20)	***SS***
SI	52 (11)	Red meat	86 (18)	***SS***	SI	38 (8)	Red meat	95 (20)	***SS***
NI	5 (1)				NI	38 (8)			
Eating carbohydrates		***Food score***			***Eating carbohydrates***		***Food score***		
VI	19 (4)	Brown/wholegrain bread	81 (17)	***χ^2=17.88, df=3***	VI	0	Brown/wholegrain bread	67 (14)	NC
SI	33 (7)	Breakfast cereals	24 (5)	χ^2=4.68, df=3	SI	19 (4)	Breakfast cereals	5 (1)	NC
NI	48 (10)				NI	81 (17)			
Eating less sugar		***Food score***			***Eating less sugar***		***Food score***		
VI*	100 (21)	Fizzy drink	100 (21)	NC	VI	100 (21)	Fizzy drink	100 (21)	NC
SI*	0	Sweets	100 (21)	NC	SI	0	Sweets	100 (21)	NC
NI*	0				NI	0			
Eating vegetables		***Food score***			***Eating vegetables***		***Food score***		
VI	100 (21)	Green vegetables	100 (21)	NC	VI	100 (21)	Green vegetables	21 (100)	NC
SI	0	Root vegetables	100 (21)	NC	SI	5 (1)	Root vegetables	21 (100)	NC
NI	0				NI	0			

VI: Very important; SI: somewhat important; NI: Not important. df: degrees of freedom. NC: Not calculated because of zero scores SS: Statistically significant according to the Fisher's test.

Table 10. The importance of dietary behaviours, and the general and oral health food scores for child participants.

Rankings and food scores for general health in children (n=78)					***Rankings and food scores for oral health in children (n=79)***				
Rankings of dietary behaviours % (n)		**General health food scores relating to the dietary behaviour % (n)**		**Chi-square/Fisher's exact test results (df)**	**Rankings of dietary behaviours % (n)**		**Oral health food scores relating to the dietary behaviour % (n)**		**Chi-square/Fisher's exact test results**
Eating less sugar		***Food score***			***Eating less sugar***		***Food score***		
VI	60 (47)	Fizzy drink	97 (73)	*SS*	VI	59 (47)	Fizzy drink	100 (79)	NC
SI	22 (17)	Sweets	100 (75)	NC	SI	19 (15)	Sweets	97 (77)	*SS*
NI	18 (14)				NI	22 (17)			
Eating Fat		***Food score***			***Eating Fat***		***Food score***		
VI	58 (45)	Cheese	68 (51)	$\chi^2=62.55$, *df=3*	VI	5 (4)	Cheese	67 (53)	$\chi^2=114.81$, *df=3*
SI	30 (24)	Milk	93 (70)	$\chi^2=115.53$, *df=3*	SI	20 (16)	Milk	84 (66)	$\chi^2=145.43$, *df=3*
NI	12 (9)				NI	75 (59)			
Eating Meat		***Food score***			***Eating Meat***		***Food score***		
VI	29 (23)	Chicken	81 (61)	$\chi^2=72.46$, *df=3*	VI	16 (13)	Chicken	73 (58)	$\chi^2=52.61$, *df=3*
SI	53 (41)	Red meat	56 (42)	$\chi^2=32.69$, *df=3*	SI	41 (32)	Red meat	61 (48)	$\chi^2=32.69$, *df=3*
NI	18 (14)				NI	43 (34)			
Eating vegetables		***Food score***			***Eating vegetables***		***Food score***		
VI	95 (74)	Green vegetables	97 (73)	*SS*	VI	86 (68)	Green vegetables	100 (79)	NC
SI	4 (3)	Root vegetables	100 (75)	*SS*	SI	11 (9)	Root vegetables	97 (77)	*SS*
NI	1 (1)				NI	3 (2)			
Eating carbohydrates					***Eating carbohydrates***				
VI	24 (19)	Brown/wholegrain bread	67 (89)	$\chi^2=104.04$, *df=3*	VI	20 (16)	Brown/wholegrain bread	82 (65)	$\chi^2=60.86$, *df=3*
SI	62 (48)	Breakfast cereals	55 (20)	$\chi^2=72.80$, *df=3*	SI	52 (41)	Breakfast cereals	75 (59)	$\chi^2=58.71$, *df=3*
NI	14 (11)				NI	28 (22)			

VI: Very important; SI: somewhat important; NI: Not important. df: degrees of freedom. NC: Not calculated because of zero scores SS: Statistically significant according to the Fisher's test

Discussion

A set of novel card sorting exercises was developed to evaluate knowledge regarding behaviours and foods associated with each of optimal general and oral health in disparate groups of children and adults. The card sorting exercises showed high convergent validity in both adults and children. The food ranking scores from the card sorting tasks of food pictures for general and oral health showed very high test-re-test reliability when administered in children 24 hours after initial completion of the tasks.

The study was set in the Taupō area in the central North Island of New Zealand at primary and intermediate schools and within a general medical practice, a community-based provider of youth health services and one dental clinic. The ethnicities of the participating students at the schools also reflected Ministry of Education information of the students at the respective schools. It is likely that the demographic features of the participants are an accurate reflection of the greater Taupō community in which the study is set.

The convergent validity of the card sorting tasks for general and oral health was high in all participants between beliefs about dietary behaviours, and knowledge scores of the respective corresponding foods. In children, statistically significant relationships were observed, representing high convergent validity for each of the dietary behaviours of eating less sugar, eating fat, meat, vegetables and carbohydrates, and the respective corresponding foods for each of general and oral health. Therefore, the card sorting tasks may be a useful method for the measurement of nutrition knowledge across both general and oral health knowledge in both adults, and pre-adolescent populations.

One result where convergent validity was low, with no relationship between the importance of a dietary behaviour and knowledge of an associated food was for the behaviour of eating carbohydrates, and knowledge around eating breakfast cereals for general health. This finding may reflect a growing awareness of adults of the detrimental impact on general health of a high intake of sugar, and the recognition by this group that breakfast cereals contain high levels of sugar. There is also a wider range of information available to adults to information regarding eating for optimal general health. In addition, the population who chose to participate in this study may also have an increased interest in nutrition and may

engage with information debates taking place in mainstream media and on social media platforms regarding sugar consumption. Further exploration of adults' beliefs regarding dietary behaviours and food knowledge, and the alignment or otherwise of their knowledge and beliefs with recommendations in dietary guidelines is required.

The test-retest results of the food scores in a subset of children who completed the food picture-card sorting tasks 24 hours after initially completing the tasks were statistically significant; this indicated a high level of reliability. The children attained identical scores for both the pre- and post-test card sorting exercise of foods for general health. For the pre- and post-tests of classification of foods for oral health, there were small improvements in scores from pre- to post-test for three children. Repeated assessments could result in an intervention effect, although no intervention was intended. The children may have asked questions overnight of parents or may have learned over the 24-hour period not to categorise foods as healthy or unhealthy (Yaroch et al., 2000).

An advantage of the card sort method was that it included a brief administration time; all participants completed all four card sorting tasks in less than 20 minutes. Four participants could complete the tasks simultaneously at any time, which also decreased the time burden of the card sorting tasks when testing classroom-size populations. Potential reasons for high scores for general and oral health observed in this study may be that the card sorting approach may engage pre-adolescents more than questionnaire or other survey methods. An important advantage of this method was that the results of adults and children can be compared to assess similarities or differences regarding nutrition knowledge across these groups. The limitations of this study were the small number of adult participants in this formative study due to budget, time, and personnel constraints; this means that the statistical tests for the adult participants should be interpreted with some caution. There was also no recording of dietary data of any participants for this study, which may have provided useful information regarding the extent to which food intake reflected beliefs and ideas about behaviours and foods for oral and general health. Knowledge of nutrition facts may also not translate to the ability to choose healthier foods or enable the selection of healthier options from a range of foods and food products available (Spronk et al., 2014).

The findings from this study indicate that the novel card sorting exercises developed for this study may be valid and reliable for assessing knowledge of dietary behaviours and foods for general and oral health among disparate groups of children and adults. In addition, this method of nutrition knowledge assessment appears to be acceptable regarding respondent burden, data quality, validity, and reliability. The findings from formative evaluation methods such as card sorting exercises may have considerable utility both for the development of nutrition education interventions, and for measuring knowledge acquisition in nutrition education interventions. The set of card sorting exercises represent a low-cost, promising instrument for assessing nutrition knowledge in pre-adolescent children who are the targets of behavioural change interventions, their families, and health professionals who instigate, design, and implement such interventions.

CHAPTER 6: KNOWLEDGE OF CHILDREN, PARENTS AND HEALTH PROFESSIONALS OF LIFESTYLE BEHAVIOURS AND FOODS FOR GENERAL HEALTH

Preface

Healthy dietary behaviours in families occur within the context of other lifestyle health behaviours that contribute to optimal health. These behaviours in turn are influenced by other adults, lifestyle and social networks, the community and neighbourhood, and government policy.

The aim of this formative study was to evaluate the importance by which disparate groups of children, parents and health professionals classified dietary behaviours alongside other behaviours for optimal general health, and to assess knowledge of foods considered optimal for general health in these three groups. The behaviours and foods were categorised by the participants in these groups by using the set of novel card sorting exercises developed in Chapter 5, which enabled the comparison of results between the three groups. Dietary behaviours were classified according to the perceived importance alongside other behaviours including exercise, sleep, forming social connections, and maintaining oral health. Concurrently, the participants allocated food picture cards to categories of healthy or unhealthy, based on their knowledge of foods represented in the picture cards. The alignment of knowledge of the healthiness or otherwise of foods with recommendations in official dietary guidelines for healthy eating in children and young people were evaluated.

This study addresses some important questions about how the children and adults in the study categorise dietary behaviours alongside other lifestyle behaviours for optimal health, and the level of nutrition knowledge each group has regarding common foods. The importance of maintenance of oral hygiene was also evaluated. The alignment of beliefs about food with recommendations in dietary guidelines provided some insights about knowledge acquisition through health promotion initiatives, which are underpinned by dietary guideline advice. Another focus will be the extent to which the knowledge of dietary

behaviours and healthiness of foods aligns with evidence of foods that are associated with good health.

The manuscript resulting from this chapter has been submitted to the Journal, *Public Health*.

Abstract

Healthy dietary behaviours in children and their families are critical for current and future health. Importantly, these behaviours occur within the context of other lifestyle health behaviours including exercise, sleep, forming social connections, and other behaviours that contribute to optimal health. These behaviours in turn are influenced by other adults, lifestyle and social networks, the community and neighbourhood, and government policy. Little is known about the nutrition and health beliefs in children, parents, and health professionals, and how these beliefs align with evidence regarding healthiness or otherwise of foods. The aim of this study was to evaluate the importance of healthy dietary behaviours alongside other lifestyle health behaviours, and to assess knowledge of foods considered optimal for general health in children, parents, and health professionals. The behaviours and foods were categorised by the participants in these disparate groups by using a set of novel card sorting tasks, which enabled the comparison of results from the three groups. Exercising, getting outside, getting enough sleep, and avoiding drug and alcohol use, were classified by 92-100% of health professionals, 78-100% of parents, and 51-91% of children as very important for general health. The dietary behaviours of eating vegetables, eating less sugar, eating fruit, and drinking water were categorised by 69-100% of health professionals, 78-100% of parents, and 58-95% of children as very important for general health. The participants achieved high scores when categorising foods as healthy or otherwise according to advice in current dietary guidelines. However, there were differences in knowledge in children and adults of processed, highly refined carbohydrate-based foods, and red meat. The alignment of nutrition knowledge with recommendations in dietary guidelines suggests that health promotion initiatives that are underpinned by guideline advice are successful in achieving knowledge acquisition in children, and adults. The findings from this study suggest that there is consistent knowledge of both healthy dietary behaviours alongside other behaviours associated with optimal health, and the healthiness or otherwise of foods in children, parents, and health professionals. However, knowledge alone has little effect on behaviour and that other strategies are required for effective behaviour change to make an impact on the epidemics of chronic disease of dietary cause.

Introduction

Nutrition education is one of several central components of intervention strategies for health improvement (Blake et al., 2007). The importance of healthy eating behaviours in children, families and health professionals exists within the broader context of a range of lifestyle behaviours that contribute to optimal health. Such lifestyle behaviours associated with optimal wellbeing include nutrition, exercise, and sleep in adults (Prendergast, Mackay, et al., 2016; Prendergast, Schofield, et al., 2016) and children (Saunders et al., 2016).

Data on nutrition knowledge of foods has traditionally been derived using surveys, questionnaires, interviews and focus groups in parents (Anderson et al., 2015; Blake & Bisogni, 2003; Bottcher et al., 2017; Douglas et al., 2014; Falk et al., 2001; Kim, 2009; Lovelace & Rabiee-Khan, 2013; McSweeney et al., 2016; Rawlins et al., 2013), health professionals, (Bapat et al., 2016; Barratt, 2001; Parker et al., 2011; Pineiro et al., 2005; Poon & Tarrant, 2009; Richards et al., 2014; Shah et al., 2011), young children (Graziano, 2015; Grosso et al., 2013; Raman, 2014; Vereecken et al., 2012; Zhang & Reicks, 2017), and adolescents (Johnson et al., 2002; Osler & Hansen, 1993; Tallarini et al., 2014; Turconi et al., 2003; Tuuri et al., 2016). In studies assessing the nutrition knowledge levels of parents, healthy eating has been consistently defined in several studies as consuming foods that are "low in fat", "natural", "unprocessed" and "homemade" (Anderson et al., 2015; Blake et al., 2007; Douglas et al., 2014; Falk et al., 2001; Rawlins et al., 2013). In these studies, vegetables and fruits were most often classified as the most important foods for maintaining optimal health and preventing illness (Anderson et al., 2015; Gibson et al., 1998; McSweeney et al., 2016; Paquette, 2005), followed by foods with low levels of fat (Falk et al., 2001; Lovelace & Rabiee-Khan, 2013), salt, and sugar (Gibson et al., 1998). Foods with high levels of sugar were universally regarded as unhealthy (Anderson et al., 2015; Gibson et al., 1998). Fat, salt, and sugar have been the most frequently cited ingredients to be avoided for a diet to be perceived as healthy by participants (Falk et al., 2001; McSweeney et al., 2016; Paquette, 2005). Foods classified as healthy by some groups - including separate groups within studies – and unhealthy in other groups have included red meat (Falk et al., 2001), cheese (Anderson et al., 2015) and dairy produce (Mazahery et al., 2018). Other perceptions of healthy eating in adults have included

avoiding or limiting red meat consumption, and substituting red meat with chicken or fish, with confusion surrounding the quantities of meat people should eat (Paquette, 2005).

Studies of health professionals have found that the classification of foods as healthy or otherwise was in accordance with recommendations and advice outlined in government-endorsed dietary guidelines for healthy eating of the respective countries of study (Parker et al., 2011; Pineiro et al., 2005; Richards et al., 2014; Scarborough et al., 2007; Talip et al., 2003). Health professionals have also been observed to hold similar views to parents regarding the healthiness of foods (Paquette, 2005).

The correctness of food categorisation by study investigators typically use a model of healthiness based on government-endorsed healthy eating guidelines (Kolodinsky et al., 2007). The predominant dietary regimen considered "best practice" for healthy eating by the New Zealand Ministry of Health (MOH) is a diet based on a moderate-to-high carbohydrate, moderate protein, and low fat intake, with specific restrictions on saturated fat (Ministry of Health, 2016).

The aim of this study was to evaluate the importance of dietary behaviours, and knowledge of foods for general health alongside other lifestyle behaviours associated with optimal general health according to children, parents, and health professionals. The extent to which knowledge in these disparate groups aligns with recommendations in official dietary guidelines for healthy eating in children and young people was also evaluated.

Methods

Recruitment

The recruitment of children, parents and health professionals for this study is described in Chapter 5 of this thesis. In brief, children aged 10-12 years and parents/caregivers of children were recruited at schools in the Taupō district of the central North Island of New Zealand. Eligible children completed assent forms for participation and data use in the presence of a parent or caregiver, or member of teaching staff at school. Health professionals including doctors, nurses and dental professionals were also invited to participate through a general

medicine practice, a dental clinic, and a community-based charitable trust. All adults were screened for eligibility and provided written informed consent to undertake the card sorting exercises. All participants were reimbursed with a store voucher to the value of $10 in appreciation of their time. Ethical approval for this study was granted by the Auckland University of Technology Ethics Committee on July 8th, 2018 (18/82), in Appendix A.

Procedures

The children completed a card sorting exercise in which brief written descriptions of behaviours on small cards for general health were placed onto categories as either "very important", "somewhat important" and "not important". The behaviour cards for general health are outlined below in Table 11.

Table 11: Behaviours to be categorised as "very important" "somewhat Important" and "not important" for general health by participants

Dietary behaviours	Other lifestyle behaviours
Eating vegetables	Sleep
Drinking water	Doing some exercise
Eating fruit	Visit your doctor
Eating meat	Get outside more often
Eating carbohydrates (bread, pasta, rice, and cereals)	Maintain oral hygiene
Eating less sugar (sweet drinks, lollies, treats)	Having good friends
Eating fat (including dairy products)	Avoiding smoking drugs and alcohol
Use vitamin/mineral supplementation	Managing stress
	Have more money

The participating parents completed the same exercise either at their child's school or at commercial office space in Taupō at a time that was suitable for them. Participating health professionals provided informed consent and completed the ranking exercises as described above at their respective workplaces.

Concurrently, all participants completed a picture-card sorting exercise in which 24 food cards of royalty-free, black-and-white sketches as shown in Appendix C. The respondents

allocated the cards to categories based on how they ranked each food based on their beliefs whether it is "good" or "bad" for general health. The foods chosen for the cards were refined during the development of the card sorting exercise as described in Chapter 5.

Photographs were taken of each participant's food and behaviour rankings; there was no photography or recording of identifiable characteristics of any of the participants. The data contained in the photographs were entered on a Microsoft Excel spreadsheet, and this data was stored on a password-protected computer. The frequencies by which food were allocated to the categorised as either healthy or unhealthy, and the frequencies at which the behaviours are allocated to the three categories of importance for general health were tabulated.

Analyses

Demographic information regarding age, gender, and ethnicity were recorded of all child participants. Parents and health professionals provided additional information on employment type and highest educational attainment.

The proportions of behaviours that were rated correctly were tabulated and analysed quantitively by evaluating the frequency of which behaviours were rated "very important" for general health. The data from the picture card sorting exercise were analysed according to correctness of foods for general health based on recommendations from the New Zealand Dietary Guidelines (Ministry of Health, 2016) as outlined in Table 12.

Table 12. Categorisation of foods as healthy or unhealthy for general health according to the current dietary guidelines.

Healthy	Fresh fruit, Green vegetables, Root vegetables, Cheese, Milk, Unsweetened yoghurt, Nuts, Chicken, Fish, Red meat, White Beans and Chickpeas, Rice, Breakfast cereals, Pasta, Brown or wholegrain bread.
Unhealthy	Dried Fruit, Fruit juice, Bacon and salami, White bread, Fizzy drink, Crisps and chips, Sweets, Biscuits and Cakes

Participants were awarded one point for each correct categorisation of a food, i.e., if they rated foods as either "healthy" or "unhealthy". The maximum score that could be attained was 24 points. The proportions of correctly rated scores for each of the participant groups were compared using the Student's t-test for mean differences in proportions (PD) of correctly rated foods between each group of participants.

Results

Eight schools in the Taupō area were approached to recruit children to participate in the study; permission was granted from four schools to participate in the study, as per the study in Chapter 5. The mean age of all child participants was 10.9 years (SD 0.79). The group of health professionals was comprised of seven general practitioners, four nurses, (two general practice nurses and two community-based nurses) and one dentist. The health professionals were recruited from one general practice, a community-based provider of youth health services and one dental clinic. There were 79 children and 21 adults in the study; the latter group comprised 12 health professionals and nine parents. Budget, time, and personnel constraints meant that it was not possible to recruit more parents and health professionals.

Table 13. Participant characteristics for the children, parents, and health professionals

	Adult participants			
Participant variable	**Parents/caregivers (n=9)**		**Health professionals (n=12)**	
Age				
25-34 (%)	11		0	
35-44 (%)	33		58	
45-54 (%)	56		25	
55-64 (%)	0		17	
Highest educational qualification				
High school (%)	11		0	
Trade (%)	33		0	
Degree (%)	56		100	
Ethnic group				
New Zealand European (%)	89		75	
Maori (%)	11		0	
Other (%)	0		25	
	Child participants (n=79)			
School	**Tauhara (n=42)**	**Wairakei (n=12)**	**St Patricks (n=12)**	**Taupō Intermediate (n=13)**

Age				
10 years (%)	31	100	17	0
11 years (%)	69	0	25	0
12 years (%)	0	0	58	77
13 years (%)				23
Gender				
Male (%)	43	25	33	23
Female (%)	57	75	67	77
Ethnic group				
New Zealand European (%)	29	83	67	100
Maori (%)	64	17	25	0
Asian (%)	4	0	8	0
Pacific (%)	3	0	0	0

1. Categorisations of behaviours enabling optimal general health

Data were available for 78 children and 21 adults. The 17 behaviours categorised by the participants as very important for general health are presented in Table 14.

Exercising, getting outside, getting enough sleep, and avoiding smoking, drugs, and alcohol, were classified by nearly all health professionals and parents, and most children as very important for general health. Having good friends was classified by health professionals and children as very important for general health. Managing stress was classified by most adult participants as very important for general health. The dietary behaviours of eating vegetables, eating less sugar, eating fruit, and drinking water were categorised most participants in all groups as very important for general health. Maintaining oral hygiene was categorised by nearly all the health professionals and over half or parents and children as very important for general health.

Most child participants, and all the health professionals and parents regarded eating vegetables as very important for general health. Eating less sugar was rated very important by most health professionals and parents; just over half of the children categorised this behaviour as very important. In all three groups, eating carbohydrates was rated as "very important" by just under half of parents and one quarter of the children. No health professional categorised eating carbohydrates as very important for general health. Children were the only group in which eating fat was regarded as very important for general health by more than half of the participants in the group: less than half of parents and health

professionals believed eating fat was very important for health. Fewer than half the participants in each group categorised eating meat as very important for general health.

Table 14. Behaviours rated as "very important" for general health by health professionals (n=12), parents (n=9) and children (n=78)

Behaviour	Percentage of health professionals who categorised behaviours as very important	Percentage of parents who categorised behaviours as very important	Percentage of children who categorised behaviours as very important
Eating less sugar*	92	89	58
Eating carbohydrates**	0	44	24
Eating vegetables	100	100	95
Eating fruit	67	78	91
Eating fat, including dairy products	46	33	58
Eating meat	50	33	29
Drinking water	92	89	87
Sleep	100	89	94
Do some exercise	100	100	82
Get outside more often	75	89	69
Avoid smoking and drug use	100	89	51
Managing stress	92	78	46
Having good friends	92	44	59
Visit your doctor	33	58	85
Maintain oral hygiene	92	58	65
Use vitamin/mineral supplementation	0	11	46
Have more money	0	11	9

**Eating less sugar: foods included were lollies, biscuits, cakes, muesli bars, and fizzy drinks.*
***Eating carbohydrates: foods included were breads, pasta, rice, and cereals*

2. Categorisations of foods enabling optimal general health

a. Comparisons of participant groups using the card sorting of foods by the current dietary guidelines.

Data from photographs of food rankings were available for 75 children and 21 adults and are presented in Table 15. Just over three-quarters of the food cards were correctly categorised by the child participants and most of the adults. There were no statistically significant

differences observed between parents and health professionals. For this reason, the results for all adults were combined for further analyses. The mean percentage adult participants who classified these foods correctly was slightly higher than those for the children: this difference was not statistically significant (PD 9%, 95% CI: -12.6% to 22.7%, p=0.36).

Table 15. Mean scores for correct food classifications by children and adults of foods for general health

Participant group	Mean score from a maximum of 24 points ± SD (range)	Percentage of correct scores (range)
All Adults (n=21)	20.7 ± 2.13 (14-24)	87 (58-100)
All Health professionals (n=12)	20.0 ± 2.23 (14-22)	83 (58-92)
All Parents (n=9)	21.8 ± 1.98 (18-24)	91 (75-100)
All Children (n=75)	18.7 ± 2.48 (13-23)	78 (54-96)

SD: Standard deviation

b. Categorisations of foods by children and adults: foods classified as healthy according to current dietary guidelines

To explore where differences in how foods were rated by children and adults, the proportions of how they rated each food for healthiness were calculated. The percentages of child and adult participants who categorised each food item as correct according to advice on "healthy" foods based on the current dietary guidelines are presented in Table 16.

All participants correctly categorised fresh fruit and green vegetables as "good" for general health, and other minimally processed foods including milk, eggs, white beans and chickpeas, nuts, root vegetables, and chicken were rated as good for general health by nearly all the participants. There were no statistically significant differences between the percentages of children and adults who regarded these foods as good for general health.

There were differences in how children and adults categorised animal produce. While fish was classified as good for health by all adults, and by most children; the difference between adults and children was statistically significant (PD 17%, 95% CI: 0.09 % to 27%, p<0.05). Statistically significant differences were also observed in the categorisation of red meat where just over half of child participants rated red meat as good for general health compared to most adults (PD 30%, 95% CI: 7 to 45%, p=0.0125). Cheese and yoghurt were

both categorised by just over two-thirds of children and almost all adult participants who classified cheese and yoghurt respectively as healthy. The differences between children and adults' categorisations of cheese were not statistically significant; however, the difference between these groups for the categorisation of yoghurt was statistically significant (PD 27%, 95% CI: 7% to 39%, p=0.013).

Additional foods recommended as healthy in current dietary guidelines include cereals and breads. In this study, brown and wholegrain breads were similarly categorised as healthy by child and adult participants; this difference between groups was not statistically significant. The largest discrepancy in food type categorisation between children and adults was breakfast cereals, which were categorised as healthy by almost three-quarters of child participants but only just under a quarter of adult participants (PD 49%, 95% CI: 25 to 64%, p<0.0001).

Table 16. Categorisations of foods for general health by adults (n=21) and children (n=75) of foods classified as "healthy" using current dietary guidelines

Food	***Percentages of correct scores for children (n)***	***Percentages of correct scores for adults (n)***
Fresh fruit	100 (75)	100 (21)
Green vegetables	100 (75)	100 (21)
Root vegetables	97 (73)	100 (21)
Milk	93 (70)	90 (19)
Eggs	89 (67)	95 (20)
Nuts	88 (66)	100 (21)
Brown/wholegrain bread	89 (67)	81 (17)
White beans and chickpeas	87 (65)	90 (19)
Fish	83 (62)	100 (21) *
Chicken	81 (61)	95 (20)
Breakfast cereals	73 (55)	24 (5) *
Yoghurt	68 (51)	95 (20) *
Cheese	68 (51)	86 (18)
Rice	77 (58)	57 (12)
Red meat	56 (42)	86 (18) *
Pasta	59 (44)	62 (13)

**Denotes statistically significant differences between children and adults for the categorisation of foods (p<0.05)*

c. Categorisations of foods by children and adults: foods classified as unhealthy according to current dietary guidelines

The percentages of child and adult participants who categorised each food item as correct according to advice on "unhealthy" foods based on the current dietary guidelines are presented in Table 17.

There were no differences observed between adults and children for the categorisations of dried fruit as unhealthy. Significantly fewer child participants categorised bacon and salami (PD 37%, 95% CI 13 to 53%, p= 0.003) and fruit juice (PD 33%, 95% CI 11 to 46%, p=0.0055) as unhealthy compared to adult participants.

Sweets were correctly classified as unhealthy by all participants. High-sugar foods including fizzy drink, crisps, and biscuits cakes and muesli bars and were correctly classified as "bad" for general health by almost all adults and children. There were no statistically significant differences observed in the percentages of children and adults who correctly categorised these foods as unhealthy. Significantly fewer children classified white bread as unhealthy, compared to adults (PD 31%, 95% CI 9% to 44%, p=0.0085).

Table 17. Categorisations of foods for general health by adults (n=21) and children (n=75) of foods classified as "unhealthy" using current dietary guidelines

Food	***Percentages of correct scores for children (n)***	***Percentages of correct scores for adults (n)***
Sweets	100 (75)	100 (21)
Fizzy drink	97 (73)	100 (21)
Biscuits and cakes	92 (69)	100 (21)
Crisps and Chips	88 (66)	95 (20)
White bread	59 (44)	90 (19) *
Fruit Juice	57 (43)	90 (19) *
Bacon and salami	44 (33)	81 (17) *
Dried Fruit	27 (20)	48 (10)

** Denotes statistically significant differences between children and adults for the categorisation of foods (p<0.05)*

Discussion

The principal findings in this study were that a range of lifestyle behaviours including dietary behaviours were classified by disparate groups of health professionals, parents, and children as very important for general health. The dietary behaviours of eating vegetables and fruit,

and drinking plain water were categorised by most participants as very important for general health alongside exercising, getting enough sleep, maintaining oral hygiene, and going outside more often. These findings are in line with evidence of the associations of these behaviours with optimal health outcomes (Prendergast, Mackay, et al., 2016; Prendergast, Schofield, et al., 2016; Saunders et al., 2016). Dietary behaviours of children are influenced by other factors that contribute to optimal health, which are also impacted by social and environmental factors including family, lifestyle and social networks, the community, and government policy (Grandner, 2017). Conversely, other dietary behaviours including eating carbohydrates, eating fat, and eating meat were categorised by substantially smaller proportions of participants in each group as very important for general health.

The findings from the categorisations of foods as beneficial for general health reflected the findings regarding the beliefs about dietary behaviours of eating fresh food; most participants in each group correctly categorised fresh foods including green and root vegetables, eggs, fish, and chicken as healthy. These categorisations were in line with recommendations outlined in current dietary guideline advice for healthy eating in children and young people and used in health promotion initiatives. These findings are also in accordance with previous research indicating that beliefs about healthy eating included food quality elements of being fresh, natural, unprocessed, and homemade (Anderson et al., 2015; Rawlins et al., 2013).

There was limited understanding in children of the beneficial effects of animal products including red meat on general health. The knowledge of participants also aligned with advice in dietary guidelines for which there are caveats around consumption of chicken and red meat with recommendations to eat lean, low-fat meat. Children attained significantly lower scores than adults for the correct categorisation of fish and red meat as healthy. One potential reason for children regarding fish as less healthy may be because some children's fish consumption may be limited to fish fingers or other battered, processed fish products or as part of a takeaway or "treat meal". The context in which fish is consumed in this population of children may alter the perceived health benefit of fish which may be a reason for the differences in scores between adults and children.

Children were less likely than adults to believe that red meat is healthy. This finding aligns with previous research in which red meat (Falk et al., 2001), was classified as unhealthy by adults and children, and that "healthy eating" involved avoiding or limiting red meat consumption, and substituting red meat with chicken or fish (Paquette, 2005). Despite weak evidence of harm associated with red meat consumption (Johnston et al., 2019; Zeraatkar, Han, et al., 2019; Zeraatkar, Johnston, et al., 2019), and evidence in a recent systematic review that red meat avoidance was associated with significantly higher rates or risk of depression, anxiety, and/or self-harm behaviours (Dobersek et al., 2020), there has been increasing public and scientific debate regarding the role of red meat in both human and environmental health (Bedo, 2020). Concurrently, there has been increased promotion of both plant-based eating lifestyles, and the purported benefits of these lifestyles for physical and planetary health (Willett et al., 2019). In early 2020, the New Zealand Ministry of Education introduced a teaching resource for primary school-aged children regarding climate change for implementation for Year 7-10 students in 2021 (Ministry of Education, 2020). This resource includes recommendations to eat less meat and dairy products for both personal health and to mitigate the impacts of climate change for planetary health. These debates and initiatives that involve the integration of beliefs about food with beliefs regarding climate change beliefs have entered both mainstream discussion and decision-making processes regarding the school curriculum, which may have an impact on children's beliefs about red meat.

The study participants had a good understanding that sugar, and high-sugar products are unhealthy when assessing foods in the picture sorting exercise. Items such as fizzy drink, fruit juice, sweets, and biscuits and cakes were regarded by most children, parents, and health professionals as unhealthy. This may reflect the success of health promotion strategies involving education, and the promotion of sugar-free environments at the schools including the establishment of "water-only" policies and other sugar-free initiatives.

Although the participants had a high level of understanding of the role of high-sugar products as harmful for general health in accordance with dietary guideline and health promotion recommendations, the findings from this study showed mixed levels of knowledge regarding the role of other processed sugar- and starch-containing foods for general health. For example, brown and wholegrain bread was judged to be healthy by most of the adults and children. Three quarters of the child participants categorised breakfast

cereals as at least "good" for general health, and a quarter of the adult participants categorised breakfast cereals as good for health; this difference between children and adults was statistically significant. The categorisation of cereals by children, and of brown and wholegrain breads as beneficial for health by most participants, is reflective of both advice in current dietary guidelines and information provided in health promotion initiatives.

Currently, glucose, derived from processed sugar- and starch-containing foods, accounts for 40-75% of energy intake (Kopp, 2019). The advice offered in current dietary guidelines supports high and frequent consumption of these processed sugar- and starch-containing foods (Ministry of Health, 2016). However, the consumption of grains in processed sugar- and starch-containing foods adds to an already high total carbohydrate load, which leads to increased insulin secretion and leptin dysregulation, resulting in a cycle of increased hunger and frequent food consumption (Ludwig & Friedman, 2014; Weiss et al., 2013). Consequently, significant parts of the day are spent in the post-prandial state characterised by persistently high levels of substrate in the circulation and elevated insulin levels (Kopp, 2019). The development of insulin hypersecretion and hyperinsulinaemia is associated with weight gain and a range of chronic diseases (Crofts et al., 2016; Fiolet et al., 2018; Martinez Steele et al., 2019; Schofield et al., 2016; Tavares et al., 2012; Zinocker & Lindseth, 2018) through several mechanisms including oxidative stress associated with inflammation including inflammatory-related processes within the human microbiota composition, and abnormal activation of the sympathetic nervous system, (Zinocker & Lindseth, 2018). Deficiencies of a range of vitamins and minerals including Vitamin A, Vitamin D, zinc, iron, and calcium are also implicated in dysregulated metabolic processes (Miclotte & Van de Wiele, 2019). The consumption of these processed sugar and starch-containing foods is associated with greater risks of overweight and obesity in children (Costa et al., 2019) and related chronic diseases of dietary cause including metabolic syndrome in adults (Martinez Steele et al., 2019; Tavares et al., 2012).

In this context, the healthiness of foods using the consideration of levels of food processing is also the subject of current widespread discourse in the scientific and public arenas regarding healthy eating at population level for the prevention of chronic disease (Monteiro et al., 2019; Monteiro et al., 2018; Monteiro et al., 2011). There is increasing recognition that

the consumption of a Western diet, characterised by large amounts of ultra-processed carbohydrate-based foods, is detrimental for health (Kopp, 2019; Miclotte & Van de Wiele, 2019). Methods of classifying foods according to benefit and harm for health include the NOVA classification system, by which foods are classified according to the extent and purpose of industrial processing (Monteiro et al., 2016; Monteiro et al., 2019; Monteiro et al., 2018). Ultra-processed foods, according to this classification are defined as products with a minimum of five ingredients including refined starches, added sugars, hydrogenated oils, fats, salt, antioxidants, and stabilisers and preservatives, the latter of which ensure long shelf-lives of these products (Monteiro et al., 2016). Additional features of ultra-processed products are that they are highly palatable, packaged attractively, highly profitable, and have high health rankings according to rating systems (Monteiro et al., 2016; Monteiro et al., 2019; Monteiro et al., 2018). The omnipresence, convenience, large-size packaging and aggressive marketing of these products encourage consumption behaviours such as eating large amounts while sedentary, for example, when watching television (Monteiro et al., 2018). These dietary behaviours have detrimental impacts on other lifestyle behaviours including disruptions to sleep and reduced physical activity (Saunders et al., 2016). The categorisation of foods according to the NOVA classification system may be more consistent with the evidence that food processing changes the nutrient content of food products, and that ultra-processed products are implicated in diet-related chronic disease.

The ubiquity of ultra-processed food products associated with metabolic harm within the food environment represents an ongoing challenge in health promotion (Malhotra et al., 2018; Poti et al., 2017). Optimal approaches to promoting healthy lifestyle behaviours may be a combination of interventions to incorporate education regarding the harmful effects of ultra-processed foods on sleep and exercise, particularly given the importance with which the participants in this study classified sleep, exercise and the consumption of fresh foods for optimal general health.

In conclusion, dietary behaviours were classified alongside a range of other lifestyle behaviours as important for optimal general health by disparate groups of adult and child participants. This knowledge, and the high food knowledge scores attained by the participants in this study, suggests that information provision through dietary guidelines and

health promotion initiatives are successful in achieving knowledge acquisition in these groups. The categorisations of foods by the participants based on healthiness or otherwise reflected recommendations provided in official current dietary guideline advice. The advice offered in current dietary guidelines supports high and frequent carbohydrate consumption, which involves the promotion of ultra-processed fermentable carbohydrates such as breads and cereals. Recommendations in dietary guidelines also continue to focus on single macronutrients such as fat consumption. The categorisation of foods according to the extent of food processing as used by the NOVA classification system may be more consistent with the evidence of dietary causes of chronic disease. The emerging evidence on the relationship of a high consumption of ultra-processed food products and poor health outcomes should provide impetus to translate findings through more coherent nutritional guidelines. Optimal approaches to promoting healthy dietary behaviours are likely to be a combination of interventions at multiple levels incorporating education regarding the harms of ultra-processed foods on other healthy behaviours, and health outcomes.

CHAPTER 7: FOR THE HEALTH OF YOUR MOUTH

Preface

One of the objectives of this thesis was to explore the potential for the delivery of healthy eating interventions by using an oral health focus to reduce the risk of dental caries, obesity, and poor metabolic health. The importance of preventing poor oral health cannot be underestimated; dental caries is one of the most prevalent health issues in New Zealand across all age groups and is the most common chronic childhood disease in New Zealand. Although there is mixed evidence regarding the effectiveness of oral hygiene strategies for the prevention of dental caries, strategies for oral health promotion in New Zealand include teaching effective oral hygiene practices, facilitating early access to preventative dental services, and promoting healthy eating. The common dietary risk factor for dental caries is the high and frequent consumption of processed fermentable carbohydrate, particularly ultra-processed foods which have high amounts of refined starches and free sugars. As summarised in Chapter 4 of this thesis, the narrative appraisal, recommendations in government endorsed-dietary guidelines and oral health promotion initiatives include advice to increase the intake of carbohydrates as children age, and to choose low-fat options when consuming dairy produce. However, there is substantial evidence that a low intake of processed fermentable carbohydrates, and a higher intake of fat- and Vitamin D-rich foods are associated with protection from dental caries.

Part 1: Oral Health behaviours: assessing the beliefs in children, parents, and health professionals

The importance of caries prevention provides some justification for the exploration of how groups of children, parents, and health professionals categorise the importance of dietary, and oral hygiene behaviours for caries prevention. The aim of part one of this study was to assess how these disparate participant groups categorised the importance of dietary behaviours alongside oral hygiene behaviours for optimal oral health. The behaviours were categorised by the participants in these groups by using the set of behaviour card sorting exercises developed in Chapter 5, which enabled the comparison of results between the

three groups. The extent to which these beliefs about oral health behaviours reflects advice provided in oral health promotion initiatives was also discussed.

The manuscript of this paper has been submitted to the journal*, Community Dental Health*.

Part 2: Healthiness of foods for oral health: Assessing the knowledge in children, parents, and health professionals.

The aim of part 2 of this study was to evaluate the knowledge of the healthiness of foods for optimal oral health in children, parents, and health professionals. The set of food card sorting exercises developed in Chapter 5 were used by the participants to categorise foods for oral health; the results were compared between the three groups. The extent to which knowledge about foods in these groups aligns with recommendations provided in dietary guideline advice was evaluated, particularly knowledge of processed fermentable carbohydrates that are associated with dental caries and knowledge of fat- and Vitamin D-rich foods associated with caries prevention.

The manuscript of this journal has been submitted to the Journal, *BMC Oral Health*.

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Part 1: Oral health behaviours: Assessing the knowledge in children, parents, and health professionals

Abstract

Dental caries is the most common chronic childhood disease in New Zealand and increases through the life course. In addition, dental caries is a disease of dietary origin, and is largely preventable through consumption of a diet characterised by low intake of fermentable carbohydrates and a high intake of fat- and Vitamin D-containing foods. A range of oral hygiene behaviours are widely promoted for caries prevention, including regular toothbrushing with fluoride-containing toothpastes and flossing of teeth. The aim of this study was to evaluate the oral health behaviour knowledge of children, and parents and health professionals who would design and implement interventions for the prevention of dental caries and other diet-related disease. A novel card sorting exercise was used to directly compare the knowledge of the three groups. The participants categorised a range of dietary and oral hygiene behaviours according to levels of importance with which they believed each behaviour was for good oral health. The oral hygiene behaviours of toothbrushing and flossing teeth were categorised as very important for oral health by 100% of adult participants and 97% and 80% of child participants for each behaviour, respectively. Conversely, dietary behaviours were consistently categorised as not very important for optimal oral health. In particular, the dietary behaviour of eating fat was regarded as not important for oral health by 76% of child participants. The consistency of the views that oral hygiene was important for oral health, and the concordance of beliefs about dietary behaviours with official dietary guidelines indicates that messages conveyed through oral health promotion initiatives are learned by children and adults. The importance of consistent, evidence-based oral health promotion messages is discussed, particularly given the ongoing challenge to public health of dental caries in young people in New Zealand.

Introduction

Dental caries is the most common chronic childhood disease in New Zealand (Ministry of Health, 2019), and caries increases through adolescence and adulthood (Broadbent, Zeng, et al., 2016). Strategies for caries prevention involve teaching oral hygiene behaviours, and

promotion of healthy eating (Ministry of Health, 2008). However, systematic reviews that have examined the use of oral hygiene behaviour strategies for the prevention of caries have shown mixed evidence for the efficacy of such interventions for reducing caries (de Oliveira et al., 2017; de Sousa et al., 2019; Hujoel et al., 2018; Innes & Fee, 2019). The use of fluoride mouth rinses and fluoride gels were associated with reductions in dental caries in the permanent teeth of children and adolescents in school settings, but the evidence was judged by the review authors to be of moderate quality (Marinho et al., 2016; Marinho et al., 2015). A recent systematic review by Walsh et al. found the use of fluoride toothpaste was associated with caries prevention compared to non-fluoride toothpaste; a dose-response effect was also observed for caries prevention in children and adolescents (Walsh et al., 2019).

Dental caries is a disease of dietary origin, and is arguably preventable through the consumption of a diet characterised by a low and infrequent intake of fermentable carbohydrates (Sheiham & James, 2014a, 2015) and consumption of nutrient-rich full-fat- and Vitamin D-containing foods (Hujoel, 2013; Kashket & DePaola, 2002; Mellanby & Pattison, 1932; Papas et al., 1995). Government-endorsed dietary guidelines for young people correctly provide recommendations to decrease intake of high-sugar foods. However, recommendations are also provided to increase the frequency of consumption of carbohydrate-containing foods as children age, and to choose low-fat options when consuming dairy produce (Ministry of Health, 2016). This advice directly contradicts evidence of both the dietary causes of dental caries, and the protective associations between the consumption of full-fat dairy produce and dental caries (Hancock, Zinn, Schofield, et al., 2020).

Dietary behaviour change should be considered the principal strategy for caries prevention (Chapple et al., 2017), as carious lesions can be arrested at initial pre-cavitation stages by dietary intervention (Mellanby & Pattison, 1932). Nutrition education is one of several central components of intervention strategies for health improvement (Blake et al., 2007). To develop educational interventions around dietary behaviour change to prevent and treat dental caries in children and their families, it is imperative to understand the current

knowledge of oral health behaviours of children and caregivers, and health professionals who are involved with the design, delivery, and uptake of such interventions.

Oral health behaviour knowledge has been studied in children participating in oral health education interventions in a range of settings (Blake et al., 2015; de Villiers et al., 2016; King et al., 1988; Tolvanen et al., 2009). Although children's knowledge of oral hygiene practices has been shown to increase as a result of these interventions (Blake et al., 2015; Tolvanen et al., 2009), there is little effect on dental caries (Blake et al., 2015). The study of oral health behaviour knowledge in parents has most often evaluated the nutrition and oral hygiene behaviour knowledge of parents and caregivers in relation to the oral health status of children (Azimi et al., 2018; Baskaradoss et al., 2019; Bonotto et al., 2017; Elyasi et al., 2018; Ji et al., 2016; Mishra et al., 2018; Poutanen et al., 2006; Vermaire & van Exel, 2018). In general, inverse relationships were observed between the oral health knowledge of parents, and the presence of caries in children.

Studies of oral health knowledge have been conducted in paediatricians (Eke et al., 2015; Gereige et al., 2015; Hadjipanayis et al., 2018), general medicine practitioners (Richards et al., 2014), nurses (Lewney et al., 2019), students of dentistry, dietetics and nutrition (Shah et al., 2011), and dental hygienists (Faine & Oberg, 1995). A common finding across most studies is that regardless of oral health nutrition knowledge, few practitioners felt sufficiently skilled or confident to deliver advice in oral health nutrition (Gereige et al., 2015; Hadjipanayis et al., 2018). Threlfall et al. found that dietary advice to prevent caries given by general dental practitioners consisted of instruction to reduce the intake of "sugary foods and drinks" and to reduce the frequency of consumption of these foods (Threlfall, Hunt, et al., 2007; Threlfall, Milsom, et al., 2007). However dental professionals also suggested replacing sweet foods with savoury alternatives, and to eat sweets at mealtimes or during one eating occasion. Other advice routinely given by dental professionals included guidance regarding maintaining toothbrushing behaviours because of beliefs that it was more realistic to enable changes in oral hygiene behaviours than dietary behaviours (Threlfall, Hunt, et al., 2007; Threlfall, Milsom, et al., 2007).

The aim of this study was to evaluate the extent to which knowledge of oral health practices reflects advice provided in both oral health promotion initiatives and dietary guidelines for healthy eating, and the evidence base regarding dietary behaviours for caries prevention. An additional objective was to assess any variation between these disparate groups of participants in how they categorised dietary behaviours alongside oral hygiene behaviours achieving optimal oral health.

Methods

Recruitment

The recruitment of children, parents and health professionals for this study is described in Chapter 5 of this thesis. In brief, children aged 10-12 years and parents/caregivers of children were recruited at schools in the Taupō district of the central North Island of New Zealand. Eligible children completed assent forms for participation and data use in the presence of a parent or caregiver, or member of teaching staff at school. Health professionals including doctors, nurses and dental professionals were also invited to participate through a general medicine practice, a dental clinic, and a community-based charitable trust. All adults were screened for eligibility and provided written informed consent to undertake the card sorting exercises. All participants were reimbursed with a store voucher to the value of $10 in appreciation of their time. Ethical approval for this study was granted by the Auckland University of Technology Ethics Committee on July 8th, 2018 (18/82).

The children completed a card sorting exercise in which brief written descriptions of behaviours on small cards for oral health were placed onto categories as either "very important", "somewhat important" and "not important". The behaviours are listed in Table 18. The participating parents completed the same exercise either at their child's school or at commercial office space in Taupō at a time that was suitable for them. Participating health professionals provided informed consent and completed the ranking exercises as described above at their respective workplaces.

Photographs were taken of each participant's behaviour rankings; there was no photography or recording of identifiable characteristics of any of the participants. The data contained in

the photographs were entered on a Microsoft Excel spreadsheet, and stored on a password-protected computer. The frequencies at which the behaviours are allocated to the three categories of importance for each of oral and general health were tabulated.

Analyses:

Demographic information regarding age, gender, ethnicity was recorded of all participants. Parents and health professionals provided additional information on employment type and highest educational attainment.

The proportions of behaviours that were rated correctly were tabulated and analysed quantitatively by evaluating the frequency of which behaviours were rated "very important" or not "important" for oral health.

Table 18. Behaviours to be categorised as "Very important" "Somewhat Important" and "Not important" for oral health by participants

Oral Hygiene Behaviours	Dietary behaviours
Brushing teeth each day	Drinking plain water
Visiting the dentist for check-ups	Eating less sugar*
Flossing teeth	Eating carbohydrates**
Visiting the hygienist for cleaning	Eating more vegetables
	Eating meat
	Eating fat
	Eating fruit
	Chewing sugar-free gum

**Eating less sugar: foods included were lollies, biscuits, and cakes*

***Eating carbohydrates: foods included were breads, pasta, rice, and cereals*

Results

Eight schools were approached to recruit children to participate in the study; permission was granted from four schools in the Taupō area to participate in the study. These schools were Tauhara Primary School, St Patrick's Catholic School, and Wairakei Primary School, and Taupō Intermediate School. The demographic characteristics of the study participants are outlined in Table 19. Tauhara School and Wairakei School each enrol students from Years 1 to 6 (5-11 years). St Patricks Catholic School, a state integrated primary school caters for students from Years 1 to 8 (5-13 years). Taupō Intermediate School enrols children at Year 7

and Year 8 levels only; these children are aged between 11-13 years old. The mean age of all child participants was 10.9 years (standard deviation 0.79). The group of health professionals was comprised of seven general practitioners, four nurses, (two general practice nurses and two community-based nurses) and one dentist. The health professionals were recruited from one general practice, a community-based provider of youth health services and one dental clinic. There were 79 children and 21 adults in the study; the latter group comprised 12 health professionals and nine parents.

Table 19. Participant characteristics for the children, parents, and health professionals

	Adult participants			
Participant variable	**Parents (n=9)**		**Health professionals (n=13)**	
Age				
25-34 (%)	11		0	
35-44 (%)	33		58	
45-54 (%)	56		25	
55-64 (%)	0		17	
Highest educational qualification				
High school (%)	11		0	
Trade (%)	33		0	
Degree (%)	56		100	
Ethnic group				
New Zealand European (%)	89		75	
Maori (%)	11		0	
Other (%)	0		25	
	Child participants (n=79)			
School	**Tauhara (n=42)**	**Wairakei (n=12)**	**St Patricks (n=12)**	**Taupō Intermediate (n=13)**
Age				
10 years (%)	31	100	17	0
11 years (%)	69	0	25	0
12 years (%)	0	0	58	77
13 years (%)	0	0	0	23
Gender				
Male (%)	43	25	33	23
Female (%)	57	75	67	77
Ethnic group				
New Zealand European (%)	29	83	67	100

Maori (%)	64	17	25	0
Asian (%)	4	0	8	0
Pacific (%)	3	0	0	0

The behaviours rated by the study participants as "very important" for oral health and the frequency by which each behaviour was rated as such by participants within each group of health professionals, parents and children are outlined in Table 20.

The oral hygiene behaviours of brushing teeth and flossing teeth were categorised as very important for oral health by all parents and health professionals. "Visiting a dentist for check-ups" and "visiting dental hygienists for cleaning of teeth" were rated as "very important" by nearly all health professionals and all parents for each behaviour. Few specific dietary behaviours were ranked as "very important" in each group of parents and health professionals. "Eating vegetables" and "eating less sugar" were the only dietary behaviours categorised by all adult participants in the top five most frequently ranked behaviours as "very important" for oral health. All health professionals rated "eating less sugar" as very important for oral health; and "eating vegetables" as very important for oral health. All but one parent rated "eating less sugar" as "very important" for oral health.

The most important behaviour for good oral health for the child participants was brushing teeth at least once per day, as categorised by nearly all child participants. Other oral hygiene behaviours among the most frequently ranked as "very important" for oral health were "visiting a dentist for check-ups" by more than 80% of child participants. Three dietary behaviours were among the most frequently ranked behaviours for children; drinking plain water, eating vegetables, and eating fruit were ranked as very important by more than three quarters of the children.

Table 20. Behaviours rated as "very important" for oral health by health professionals (n=12), parents (n=9) and children (n=79)

Behaviour	Percentage of health professionals who categorised behaviours as very important (n)	Percentage of parents who categorised behaviours as very important (n)	Percentage of children who categorised behaviours as very important (n)
Brushing teeth each day	100 (12)	100 (9)	97 (77)
Flossing teeth	100 (12)	100 (9)	80 (63)
Visiting the dentist for check-ups	92 (11)	100 (9)	95 (75)
Visiting the hygienist for cleaning	92 (11)	100 (9)	56 (71)
Eating less sugar*	100 (12)	88 (8)	59 (47)
Eating vegetables	92 (11)	100 (9)	78 (62)
Drinking plain water	83 (10)	78 (7)	84 (66)
Eating fruit	8 (1)	33 (3)	76 (60)
Eating meat	8 (1)	44 (4)	16 (13)
Eating fat, including dairy products	25(3)	22 (2)	5 (4)
Chewing sugar-free gum	8 (1)	11 (1)	13 (10)
Eating carbohydrates**	0 (0)	0 (0)	20 (16)

**Eating less sugar: foods included were lollies, biscuits, cakes, muesli bars, and fizzy drinks*
***Eating carbohydrates: foods included were breads, pasta, rice, and cereals*

The proportions of participants in each group who rated the behaviours as "not important" for oral health are listed in Table 21. In contrast to the oral hygiene behaviours regarded as very important for oral health, the most frequently ranked behaviours as not important for oral health were dietary behaviours. Dietary behaviours for oral health frequently ranked as "not important" by health professionals and parents were eating carbohydrates, eating meat, eating fat, and eating fruit.

The dietary behaviour of eating fat was classified by three quarters of the child participants as not important for oral health. Eating meat was categorised as not important by just under half of the children. Other dietary behaviours categorised as not important for oral health were chewing sugar-free gum and eating carbohydrates. Eating carbohydrates was categorised as not important for oral health by 28% of all the child participants. Eating less sugar was regarded as not important by under one quarter of the child participants.

Table 21. Behaviours rated as "not important" for oral health by health professionals (n=12), parents (n=9) and children (n=79).

Behaviour	**Percentage of health professionals who categorised behaviours as not important**	**Percentage of parents who categorised behaviours as not important**	**Percentage of children who categorised behaviours as not important**
Eating carbohydrates**	75 (9)	88 (8)	22 (28)
Eating meat	33 (4)	44 (4)	34 (43)
Chewing sugar-free gum	50 (6)	56 (5)	29 (37)
Eating fat, including dairy products	33(4)	11 (1)	75 (59)
Eating fruit	25 (3)	44 (4)	3 (4)
Drinking more plain water	0 (0)	0 (0)	3 (4)
Eating less sugar*	0 (0)	0 (0)	22 (17)
Eating more vegetables	0 (0)	0 (0)	2 (3)
Brushing teeth each day	0 (0)	0 (0)	1 (1)
Visiting the dentist for check-ups	0 (0)	0 (0)	0 (0)
Visiting the hygienist for cleaning	0 (0)	0 (0)	0 (0)
Flossing teeth	0 (0)	0 (0)	1 (1)

**Eating less sugar: foods included were lollies, biscuits, cakes, muesli bars, and fizzy drinks*

***Eating carbohydrates: foods included were breads, pasta rice and cereals*

Discussion

The principal findings were that across three groups of children, parents and health professionals, behaviours consistently classified by almost all participants as very important for optimal oral health were oral hygiene behaviours including daily toothbrushing and flossing of teeth. Dietary-related behaviours were consistently categorised by all three groups as "not important" for optimal oral health, particularly dietary behaviours relating to the consumption of foods associated with protection against dental caries. These findings reflect the strong promotion of oral hygiene behaviours for prevention of dental caries in children and young people. In addition, the beliefs relating to fat-containing foods indicate that recommendations regarding the consumption of dairy produce are learned and have an impact on beliefs regarding the healthiness of these foods. There were some variations between the groups of participants; eating carbohydrates was regarded as "not important" for oral health by 28% of all child participants, compared to most adult participants (75% and 88% of health professionals and parents, respectively).

A further important finding in this study is the concordance of beliefs regarding the importance of dietary behaviours with recommendations in the current dietary guidelines. All the health professionals, and most of the participants in each group believed "eating less sugar" was very important for oral health, in line with recommendations to decrease intake of high-sugar foods. Eating fat was the most frequently categorised dietary behaviour by children as "not important" for oral health. This finding reflects advice promoted in official dietary guidelines in which consumption of low-fat options are advised for the consumption of dairy produce. One dietary behaviour in which less agreement was observed between groups was "eating carbohydrates" where 69% of health professionals and 88% of parents regarded this behaviour as "not important" compared to 28% of child participants. This may be an indication that adults are increasingly aware that carbohydrates in processed sugar- and starch-containing containing foods such as breads and cereals are sugars. There is increasing debate in mainstream media (Leslie, 2016) regarding the role of sugars in chronic disease and growing recognition that a diet characterised by the high intake of sugars are associated with substantial harm (Ludwig et al., 2018). In addition, these debates are occurring alongside other global considerations of the role of eating patterns, food system sustainability, and environmental concerns (Ridgway et al., 2019).

The strong consistency of views regarding the importance of oral hygiene behaviours across groups of children, parents and health professionals suggests that the promotion of these behaviours is successful in achieving knowledge acquisition in these groups. Previous research of interventions to improve oral health have focused primarily on the promotion of oral hygiene behaviours within clinical settings and education environments to improve oral health knowledge. Findings from this research indicate children can improve knowledge of behaviours with the implementation of multilevel oral health promotion programmes involving children, and parents, teachers, and community-based mass media initiatives (Tolvanen et al., 2009). However, the quality of the evidence of these behaviours in caries prevention has also been described as mixed (Cooper et al., 2013; de Oliveira et al., 2017; Dos Santos et al., 2018; Hujoel et al., 2018; Innes & Fee, 2019; Jaime et al., 2015). Furthermore, the promotion of these strategies has long been influenced by interest groups and industry involvement (Hujoel, 2019).

The disconnects between the evidence regarding dietary causes of dental caries and the knowledge of behaviours that are important for dental health identified in this study shows that there are substantial limitations in dental health education for the prevention of dental caries. Inconsistencies were identified in previous research within, and between groups of health professionals in the provision of dietary advice for prevention of dental caries (Richards et al., 2014; Shah et al., 2011; Threlfall, Milsom, et al., 2007). It is imperative to establish uniform delivery of messages about healthy eating for the prevention of dental caries, regarding the roles of ultra-processed, sugar-and starch-containing foods in dental caries, and protection conferred by eating foods containing dairy fat and Vitamin D. Specific nutrition advice is required, as the message of "eat less sugars" may be too simplistic, particularly given the presence of sugars in foods promoted for health benefits in current dietary guidelines (Ministry of Health, 2016).

A strength of this study was the use of a simple card sorting exercise that enabled direct comparisons of oral health behaviour knowledge across three groups of children, parents, and health professionals. In previous research in these three groups, oral health behaviour knowledge has been studied using interviews, surveys, questionnaires and focus groups. Another advantage of the card sort exercise included a brief administration time; all participants completed the card sorting tasks in less than 15 minutes. The ethnicities of the participating students at the schools also reflected Ministry of Education information of the students at the respective schools. It is likely that the demographic features of the participants are an accurate reflection of the community in which the study is set.

Potential weaknesses of this study were the relatively small numbers of adult participants, given the formative nature of this study. There was no recording of oral health behaviours or collection of dietary data from any participants in this study. In addition, there were no data collected on the oral health status of any of the participants. These may have provided useful information regarding the extent to which oral hygiene behaviours and food intake reflected beliefs and ideas about the importance of behaviours for oral health.

Dental caries in children and young people is an ongoing and significant public health challenge in New Zealand. Given that dental caries is a chronic disease of dietary origin, the

focus of oral health promotion should be focused on caries prevention via dietary behaviour change, and a review of oral health education content to incorporate the evidence regarding the dietary causes of dental caries. In addition, the delivery of oral health promotion initiatives should involve the design and implementation of behaviour change interventions at multiple levels with children, parents, and other professionals within health, educational, and community settings.

Part 2: Healthiness of foods for oral health: Assessing the knowledge in children, parents, and health professionals

Abstract

Dental caries, a preventable disease of dietary origins, is the most common chronic childhood disease in New Zealand. Evidence shows that a low intake of fermentable carbohydrates and a high intake of fat- and Vitamin D-rich foods are protective against dental caries. Recommendations provided in government endorsed-dietary guidelines, and oral health promotion initiatives, include advice to increase the intake of carbohydrates as children age, and to choose low-fat options when consuming dairy produce. The aim of this study was to evaluate the extent to which knowledge of children, parents and health professionals of foods for optimal oral health reflects advice in dietary guidelines, and the evidence base for various foods associated with increased, and decreased risks of dental caries. Using a novel card-sorting task, the participants categorised a range of foods according to their knowledge of benefits or detriments of each food for oral health. The mean percentage of correctly categorised foods by adult participants (84%) was slightly higher than that for the children (76%) this difference in proportions (PD) was not statistically significant (PD 8%, 95% CI -14 to 23, p=0.44). There were no differences between the proportions of child and adult participants in the categorisation of most fresh and minimally processed foods. The following foods were categorised as healthy by significantly lower percentages of child participants than adult participants: fish (PD 22%, 5% to 32%, p=0.019), chicken (PD 22%, 95% CI 2% to 33%, p=0.032), and red meat (PD 34%, 95% CI 13% to 46%, p=0.0031). High-sugar, ultra-processed foods were correctly characterised as unhealthy by 95-100% of adults, and 89-100% of all children. Higher percentages of child participants categorised breakfast cereals as healthy than adult participants (75% of children vs. 5% of adults, PD 70% 95% CI 49% to 79%, p<0.0001). Brown or wholegrain breads were categorised as healthy by 67% of adults compared to 82% of children; this difference was not statistically significant (PD 15%, 95% CI -4 to 37%, p=0.14). The alignment of the study participants' beliefs with recommendations in dietary guidelines suggests education through official food and nutrition guidelines and health promotion initiatives is successful in achieving knowledge acquisition in children and adults. However, recommendations to increase the frequency and intake of carbohydrates inadvertently advocate for ultra-

processed products that are associated with increased risks of dental caries. Given these challenges, it is imperative that dietary advice for oral health and caries prevention reflects the evidence of harms associated with consumption of processed sugar-and starch-containing foods and promotes the consumption of foods associated with benefits for oral health.

Introduction

There is increasing recognition of the effect of poor oral health on general health. Dental caries has dietary risk factors in common with obesity, and chronic disease for which hyperinsulinaemia and associated metabolic syndrome (Alrabiah et al., 2018; Liccardo et al., 2019; Taylor & Borgnakke, 2008) are implicated, including Type 2 diabetes (Kumar et al., 2014) and cardiovascular disease (Beck et al., 1996; Carrizales-Sepulveda et al., 2018). The endpoint of oral disease is typically when people are likely to seek dental care, often with presentation of a cavitated carious lesion causing pain, discomfort, and or infection (Jatrana et al., 2009).

The common dietary risk factor for caries and other chronic diseases is the high and frequent consumption of fermentable carbohydrate, particularly ultra-processed foods which have high amounts of refined starches and free sugars (Sheiham & James, 2014b, 2015). Upon ingestion of these foods, endogenous bacteria in the biofilms produce organic acids as a by-product of the metabolism of fermentable carbohydrates (Loesche, 1986, 1997). These lactic, formic, and acetic acids cause local pH values in the dental biofilm to fall below neutrality to critical values of 5.5 and below and results in demineralisation of tooth tissues. Slow salivary clearance rates of high starch-containing foods, and a resultant increased retention time in the mouth of these foods means the effects of other simultaneously present sugars may also be prolonged, where starch consumption has a co-cariogenic effect with other sugars (Kashket et al., 1994; Linke & Birkenfeld, 1999).

Food intake can enhance enamel remineralisation when diet contains sufficient Vitamin D, calcium, and phosphates (Hujoel, 2009; Hujoel, 2013; Kashket & DePaola, 2002). A Vitamin D-rich diet has long been associated with reduced rates of dental caries (Hujoel, 2013;

Mellanby & Pattison, 1928, 1932; Schroth et al., 2016). The consumption of cheese is associated with protection from caries (Kashket & DePaola, 2002; Papas et al., 1995) with proposed mechanisms of protection including increased salivary flow and buffering, inhibition of plaque bacteria overgrowth, and through the intake of calcium, inorganic phosphate and casein, which enhance remineralization (Touger-Decker & van Loveren, 2003). In addition, carious lesions may be arrested by remineralisation at initial pre-cavitation stages by dietary intervention with Vitamin D-rich foods (Mellanby & Pattison, 1932).

Nutrition education is one of several components of intervention strategies for health improvement (Blake et al., 2007). To develop educational interventions around dietary lifestyle change to prevent caries in children and their families, it is imperative to understand the prior food knowledge of children, and adults who would be involved in the design, implementation, and uptake of such interventions.

Studies of oral health knowledge in children have evaluated beliefs regarding foods in the context of oral health interventions occurring in school settings (Blake et al., 2015; Tolvanen et al., 2009), and associations between dental pain and intake of particular foods (Nicksic et al., 2018). The study of oral health nutrition knowledge in parents has typically evaluated the knowledge of parents and caregivers in relation to the caries status of their children (Ji et al., 2016; Mishra et al., 2018; Poutanen et al., 2006). Inverse relationships between the oral health knowledge of parents regarding oral hygiene practices and nutrition, and the presence of caries in children have been observed in these studies.

Oral health food knowledge has been studied in a range of health professionals (Eke et al., 2015; Gereige et al., 2015; Hadjipanayis et al., 2018; Richards et al., 2014; Shah et al., 2011). The classification of foods as healthy or otherwise were in accordance with recommendations and advice outlined in government-endorsed dietary guidelines for healthy eating of the respective countries of study (Parker et al., 2011; Pineiro et al., 2005; Richards et al., 2014; Scarborough et al., 2007; Talip et al., 2003). However, guidance provided in dietary guidelines regarding food intake may also not reflect the evidence of the aetiological causes of dental caries. In New Zealand, dietary advice for oral health reflects advice provided for

general health in dietary guidelines for a population free of any chronic condition, but the recommendations provided in these guidelines contradict the evidence of dietary causes of dental caries (Hancock, Zinn, Schofield, et al., 2020).

The aim of the study was to evaluate the extent to which knowledge of children, parents, and health professionals regarding foods for optimal oral health reflects advice provided in dietary guidelines for healthy eating, and the evidence base regarding foods for caries prevention. An additional objective was to assess any variation between these disparate groups of participants in how they categorised foods as healthy or unhealthy for oral health.

Methods

Recruitment:

The recruitment procedures for this study are described in Chapter 7, part one. In brief, children aged 10-12 years and parents/caregivers of children were recruited at schools in the Taupō district of the central North Island of New Zealand. Eligible children completed assent forms for participation and data use in the presence of a parent, caregiver, or member of teaching staff at school. Health professionals including doctors, nurses and dental professionals were also invited to participate through a general medicine practice, a dental clinic, and a community-based charitable trust. All adults were screened for eligibility and provided written informed consent to undertake the card sorting exercises. Parents completed the study tasks either at their child's school or at commercial office space in Taupō. Participating health professionals provided informed consent and completed the study tasks at their respective workplaces. All participants were reimbursed with a store voucher to the value of $10 in appreciation of their time. Ethical approval for this study was granted by the Auckland University of Technology Ethics Committee on July 8th, 2018 (18/82) and is in Appendix A.

All participants completed a picture-card sorting exercise in which 24 food cards were allocated the cards to categories based on how they ranked each food based on their beliefs whether it is "good" or "bad" for oral health. This method was used to enable comparisons to be made between children, parents, and health professionals. The pictures of foods were royalty-free, black-and-white sketches obtained from Google Images as illustrated in

Appendix C. The development of the card sorting tasks, and the testing of validity and reliability is outlined in Chapter 5 of this thesis.

Photographs were taken of each participant's food rankings; there was no photography or recording of identifiable characteristics of any of the participants. The data contained in the photographs were entered on a Microsoft Excel spreadsheet, and stored on a password-protected computer. The frequency whereby each food was reported in the categories pertaining to whether the food was "good" or bad" for oral health were tabulated.

Analyses

Demographic information regarding age, gender, and ethnicity were recorded of all participants. Parents and health professionals provided additional information on employment type and highest educational attainment.

The data from the picture card sorting exercise were analysed according to correctness of foods for general health based on recommendations from the New Zealand Dietary Guidelines (Ministry of Health, 2016) as outlined in Table 22. Participants were awarded one point for each correct categorisation of a food, i.e., if they rated foods as either "healthy" or "unhealthy". The maximum number of points that could be attained was 24 points. Differences between how children, parents, and health professionals rated the foods for oral health were assessed by calculating the mean differences in proportions (PD) of participants who correctly rated the foods as "good" or "bad" for oral health.

The proportions of correctly rated scores for each group were compared using the Student's t-test for mean differences in proportions (PD) of correctly rated foods between each group of participants.

Table 22. Categorisation of foods as healthy or unhealthy for oral health according to the current dietary guidelines

Healthy	Fresh fruit, green vegetables, root vegetables, cheese, milk, plain/unsweetened yoghurt, nuts, chicken, fish, red meat, white beans and chickpeas, rice, breakfast cereals, pasta, and brown or wholegrain bread
Unhealthy	Dried fruit, fruit juice, bacon and salami, white bread, fizzy drink, crisps and chips, sweets, biscuits, and cakes

Results

Eight schools in the Taupō area were approached to recruit children to participate in the study; permission was granted from four schools to participate in the study. The demographic characteristics of the child and adult participants are presented in Chapter 7, part one.

1. Comparisons of participant groups using the card sorting of foods by the current dietary guidelines model.

The mean percentages of correct scores for children, parents and health professionals are presented in Table 23.

The mean correct scores ranged from 76% of correctly categorised cards out of a possible 24 cards for the child participants, and 89% for all parents. There were no statistically significant differences observed between parents and health professionals (PD 8%, 95% confidence interval (CI): -27 - 38%, p=0.63). For this reason, the results for all adults were combined for further analyses. The mean percentage of correctly categorised foods of all adult participants (84%) were slightly higher than those for the children (76%): this difference in proportions was not statistically significant (PD 8%, 95% CI: -14 - 23%, p=0.44).

Table 23. Mean scores of correctness using current dietary guidelines for foods for oral health

Participant Group	Mean score from a maximum of 24 points ± SD (range)	Percentage of correct scores (range)
All Adults (n=21)	20.2 ± 2.49 (12-24)	84 (50-100)
All Health professionals (n=12)	19.4 ± 2.91 (12-24)	81 (50-100)
All Parents (n=9)	21.3 ± 1.22 (19-23)	89 (79-96)
All Children (n=79)	18.3 ± 2.76 (11-23)	76 (46-96)

SD: Standard deviation

2. Categorisations of foods by children and adults: foods recommended as healthy according to dietary guidelines

The proportions of child and adult participants who correctly categorised each food item as healthy according to recommendations based on the current dietary guidelines are presented in Table 24.

There were some differences in how children and adults categorised other minimally processed foods that were regarded as "good" for oral health. Fresh fruit was classified as good for oral health by all children, and by three quarters of adults; this difference was statistically significant (PD 24%, 95% CI: 10 - 45%, p<0.0001). Most minimally processed foods were correctly categorised as healthy by most participants. All participants categorised green vegetables as "good" for oral health, and other foods including root vegetables, milk, eggs, nuts, and white beans and chickpeas were rated as good for oral health by nearly all participants. There were no statistically significant differences between the proportions of children and adults who regarded these foods as good for oral health. Statistically significant proportion differences were observed in the categorisation of the following foods where more adults categorised these as good for oral health compared to children: fish (PD 22%, CI: 5 - 32%, p=0.019), chicken (PD 22%, 95% CI: 2 - 33%, p=0.032), and red meat (PD 34%, 95% CI: 13 - 46%, p=0.0031).

There were no significant differences between the proportions of children and adults in the categorisation of each of brown and wholegrain bread, and pasta for oral health. Statistically significant differences were observed between the proportions of children and adults in the

categorisation of breakfast cereals for oral health; slightly more than three quarters of children categorised breakfast cereals as healthy compared to one adult (PD 70%, 95% CI: 49 - 79%, p<0.0001).

Table 24. Categorisations of foods for oral health by adults (n=21) and children (n=79) as "healthy" using current dietary guidelines

Food	***Percentages of correct scores for children (n)***	***Percentages of correct scores for adults (n)***
Green vegetables	100 (79)	100 (21)
Root vegetables	97 (77)	100 (21)
Fresh fruit	100 (79)	76 (16) *
Milk	84 (66)	91 (19)
Eggs	87 (69)	95 (20)
Fish	78 (62)	100 (21) *
Red meat	61 (48)	95 (20) *
Nuts	80 (63)	95 (20)
White beans and chickpeas	77 (61)	91 (19)
Chicken	73 (58)	95 (20) *
Yoghurt	67 (53)	76 (16)
Cheese	67 (53)	81 (17)
Rice	72 (57)	52 (11)
Brown/wholegrain bread	82 (65)	67 (14) *
Breakfast cereals	75 (59)	5 (1) *
Pasta	58 (46)	52 (11)

**Denotes statistically significant differences between children and adults for the categorisation of foods (p<0.05).*

3. Categorisations of foods by children and adults: foods recommended as unhealthy according to dietary guidelines

The proportions of child and adult participants who categorised each food item correctly as unhealthy according to recommendations based on the current dietary guidelines are presented in Table 25.

Statistically significant differences were observed between adults and children for the correct categorisations of fruit juice (PD 37%, 95% CI 16.3 - 48.7%, p=0.0016) and dried fruit (PD 56%, 95% CI: 35 - 67% p<0.0001), each categorised as bad for oral health because of high sugar content. There were no statistically significant differences in the proportions of children and adults who categorised bacon and salami as harmful for oral health.

There were statistically significant differences in the proportions of children and adults who classified white bread as unhealthy: less than half of the children classified white bread as unhealthy, compared to nearly all adults (PD 48%, 95% CI 26 - 60%, p=0.0001). High sugar foods including fizzy drink, sweets, biscuits and cakes and crisps and chips were correctly classified as "bad" for oral health by nearly all adults and children. There were no statistically significant differences observed in the proportions of children and adults who correctly categorised each of these foods as detrimental for oral health.

Table 25. Categorisations of foods for oral health by adults and children of foods classified as "unhealthy" using current dietary guidelines

Food	***Number of correct scores for Children (n=79) (%)***	***Number of correct scores for Adults (n=21) (%)***
Fizzy drink	100 (79)	100 (21)
Sweets	97 (77)	100 (21)
Biscuits and cakes	94 (74)	100 (21)
Crisps and Chips	89 (70)	95 (20)
White bread	43 (34)	91 (19) *
Fruit Juice	58 (46)	95 (20) *
Bacon and salami	48 (38)	71 (15)
Dried Fruit	39 (31)	95 (20) *

** Denotes statistically significant differences between children and adults for the categorisation of foods (p<0.05).*

Discussion

The principal findings of this study were that the beliefs regarding healthiness of foods in disparate groups of children, parents, and health professionals reflect recommendations provided in government-approved dietary guidelines for healthy eating in children and young people. Most participants correctly categorised fresh, unprocessed foods as beneficial for oral health, and high-sugar foods as detrimental for oral health. Adults attained slightly higher scores than children for the correct categorisation of foods, but these differences were not statistically significant. There was limited and mixed understanding in children and adults, respectively, regarding the beneficial effects of animal produce including chicken, fish and red meat for oral health, and the detrimental effects of ultra-processed, carbohydrate-containing foods for oral health.

Most participants correctly categorised unprocessed foods including green and root vegetables, and eggs as beneficial for oral health. Children and adults also correctly categorised sugar, and high-sugar products as harmful for oral health when assessing foods in the picture sorting exercise. The high food knowledge scores attained by the participants in this study, and the alignment of this knowledge with recommendations in dietary guidelines, suggests that the provision of advice through dietary guidelines and health promotion initiatives can achieve knowledge acquisition in these groups. These findings are similar to those of previous research where the classification of foods as healthy or otherwise was in accordance with recommendations outlined in government-endorsed dietary guidelines for healthy eating of the respective countries of study (Parker et al., 2011; Pineiro et al., 2005; Richards et al., 2014; Scarborough et al., 2007; Talip et al., 2003).

Children attained significantly lower scores than adults for the correct categorisation of fish, chicken, and red meat as beneficial for oral health. The lower scores for the latter two foods also reflect advice in dietary guidelines regarding fat consumption, with recommendations to eat lean, low-fat animal produce (Hancock, Zinn, Schofield, et al., 2020). In addition, recommendations regarding caveats around the consumption of meat and dairy produce were also learned by children and adults through health promotion initiatives. However, the intake of Vitamin D-rich foods such as meat and fish has long been associated with reduced risks of dental caries (Hujoel, 2013; Mellanby & Pattison, 1932; Schroth et al., 2016). Further, the evidence relating to reductions in dental caries in children with higher intakes of full fat dairy products is not reflected in current dietary guidelines (Hancock, Zinn, Schofield, et al., 2020). The disconnects between the beliefs identified in this study regarding foods that are important for oral health, advice provided in dietary guidelines, and the evidence regarding dietary causes of dental caries, indicates that there are substantial limitations in oral health education for the prevention of caries through dietary intake of caries-protective foods.

Breakfast cereals were categorised by 75% of the child participants as at least "good" for oral health by compared to 5% of the adult participants who categorised breakfast cereals as good for oral health. This finding in adults may reflect the growing awareness in the general population of the high sugar content of cereal-based foods, including a range of hidden sugars. The "What the Fat? Fat's IN, Sugar's OUT" book (Schofield et al., 2015) has sold approximately 150,000 copies, and documentaries such as "That Sugar Film" (Gameau, 2015)

have been popular in Australia and New Zealand. The categorisation of cereals by children, and of brown and wholegrain breads by most participants as good for oral health aligns with advice in dietary guidelines. However, promoted foods within these guidelines include ultra-processed items such as breads and cereals, which are high processed sugar- and starch-containing foods, or in the case of porridge oats, typically consumed with added sugars (Monteiro et al., 2016; Monteiro et al., 2019; Monteiro et al., 2018). This advice contradicts long-established evidence of the role of high carbohydrate foods in dental caries (Hancock, Zinn, Schofield, et al., 2020), and in particular, evidence regarding the associations between consumption of processed sugar- and starch-containing foods and dental caries (Campain et al., 2003).

There is increasing recognition that the consumption of a Western diet, characterised by large amounts of ultra-processed carbohydrate-based foods, is detrimental for health (Kopp, 2019; Miclotte & Van de Wiele, 2019). Methods of classifying foods according to benefit and harm for health include the NOVA classification system, by which foods are classified according to the extent and purpose of industrial processing (Monteiro et al., 2016; Monteiro et al., 2019; Monteiro et al., 2018). Ultra-processed products according to this classification, include a minimum of five ingredients including sugar, oils, fats, salt, antioxidants, stabilisers and preservatives (Monteiro et al., 2016). Other additives in these products include dyes, colour stabilisers, and non-sugar sweeteners, and substances that have been manufactured using techniques including carbonating, firming, extrusion, and moulding. Ultra-processed products are hyper-palatable, packaged attractively, highly profitable, have high health ratings according to algorithm-based rating systems, and are aggressively marketed to children and young people (Monteiro et al., 2016; Monteiro et al., 2019; Monteiro et al., 2018). The displacement of minimally processed foods by ultra-processed foods is associated with unhealthy dietary nutrient profiles (Martinez Steele et al., 2019; Monteiro et al., 2019; Rauber et al., 2018) and several diet-related chronic diseases (Kopp, 2019). The high and frequent consumption of breads, cereals and other ultra-processed, carbohydrate-containing foods is also associated with dental caries (Hancock, Zinn, & Schofield, 2020).

It is imperative to establish uniform delivery of messages about the role of ultra-processed, sugar-and starch-containing foods in dental caries, and the caries-protective effects of eating

full-fat dairy produce and Vitamin D-rich foods. There is also a lack of consumer understanding of the terminology around sugars in food; this is exacerbated by the presence of sugars in ultra-processed foods promoted for health benefits in current dietary guidelines (Ministry of Health, 2016), and the ubiquity of hyper-palatable, highly profitable ultra-processed foods in the food supply that are classified as healthy using star rating systems (Mackay et al., 2019; Malhotra et al., 2018). Current suggestions to "eat less sugars" in oral health promotion may therefore be too simplistic, given this lack of universal understanding. A solution for aligning recommendations in dietary guidelines with the evidence may be to adopt a food classification system, which would also allow greater consistency with the evidence of benefits in oral health with the consumption of minimally processed, full-fat, Vitamin D-rich foods.

The use of a picture-card sorting exercise to evaluate oral health food knowledge is a novel element of this study that enabled direct comparisons of oral health food knowledge to be made across three groups of children, parents, and health professionals. The participant burden of the card sorting exercise was minimal, and acceptable to the participants with completion of the task achieved in approximately 15 minutes. The findings from the statistical testing of differences between health professionals and parents, and adults and children should be interpreted with some caution because of the low numbers of adults who participated in the study and consequent lack of statistical power. In addition, there was no recording of dietary data or oral health status of any participants for this study, which may have provided useful information regarding the extent to which dietary behaviours reflected beliefs about the healthiness or otherwise of individual foods.

Dental caries in children and young people is an ongoing and significant public health challenge in New Zealand. The beliefs and knowledge of foods for oral health identified in this study align with recommendations provided in dietary guideline advice used in health promotion initiatives. In addition, recommendations in such health promotion strategies are absorbed and learned by children and adults who are the targets of such initiatives. Guidelines have considerable influence on food knowledge and beliefs, and a range of impacts in a food supply characterised by the ubiquity of ultra-processed foods. Given that dental caries is a chronic disease of dietary origin, it is imperative that the guidelines for

healthy eating be updated using a paradigm relating to the processing of foods, given the evidence of harms for oral health associated with the consumption of ultra-processed food products.

CHAPTER 8: PERCEPTIONS OF HEALTHY FOODS AND BARRIERS TO HEALTHY EATING IN CHILDREN, PARENTS AND HEALTH PROFESSIONALS: A THEMATIC ANALYSIS AND SOCIOECOLOGICAL MODEL

Preface

In Chapters 6 and 7, the use of a novel set of card sorting exercises enabled quantitative comparisons of food and behaviour knowledge across three groups of children, parents, and health professionals. Overall, the participants had high knowledge levels of the healthiness or otherwise of foods for general and oral health. The participants' beliefs and knowledge of behaviours and foods for general and oral health were aligned with advice provided through a range of health promotion initiatives that are underpinned by recommendations in dietary guidelines. This suggests education through official food and nutrition guidelines and health promotion initiatives is successful in achieving knowledge acquisition in children and adults. However, recommendations to increase the frequency and intake of processed fermentable carbohydrates inadvertently advocates for ultra-processed products that are associated with increased risks of dental caries, obesity, and other chronic diseases of dietary cause through the lifespan.

Integral features of dietary behaviour change interventions involve education to address dietary behaviours and to improve nutrition knowledge in children and their parents or caregivers. However, familial knowledge of dietary behaviours and foods that constitute healthy eating is unlikely to be sufficient for families to consume a healthy diet. Evidence suggests that a range of factors influence the choices made for familial eating. In addition, a range of barriers have been identified to achieving healthy eating goals that include time, economic constraints, the availability of foods outside the home, and the influence of other people; these include other family members and experts, including health professionals. It is therefore important to understand the barriers that health professionals face in the instigation and prescription of nutrition education interventions to enable dietary behaviour change.

The understanding that there are multiple influences on dietary choices of families has led to the development of socio-ecological perspectives in the consideration of health behaviours. Socio-ecological models were originally developed to describe the complex ways that an individual's behaviour related to their health as a product of influences, at multiple layers within the context of societal structures that extend from individual levels to national and global influences.

This final chapter of the formative research in this thesis is a qualitative investigation to gain insights into ideas of healthy eating, and barriers to achieving healthy eating goals in groups of children, parents, and health professionals. Children participated in focus groups and the adults, in semi-structured interviews. Inductive thematic analyses were undertaken to construct themes, and the deductive analysis of the themes enabled the development of a socio-ecological model of healthy eating for families. The model incorporated beliefs about healthy eating and barriers experienced by children, parents, and health professionals to achieving healthy eating goals. In addition, the barriers experienced by health professionals in to prescribing healthy eating advice for patients were included in the socio-ecological model.

The potential for interventions instigated by health professionals and implemented in family settings, and the requirement for such interventions to be designed using socio-ecological considerations was also discussed given that future sustainable interventions should incorporate changes at community and national levels.

The manuscript of this chapter has been submitted to the journal, *Health and Place*.

Abstract

In research and practice, there has been an increased focus on the prevention of poor health in families and the promotion of healthy behaviours in children through family-based health behaviour interventions. The aim of this formative investigation was to understand the beliefs about, and barriers to healthy eating in of children, parents, and health professionals. Twelve children participated in three focus group discussions, and individual semi-structured interviews were conducted with 17 adults. Beliefs about healthy eating generated from the inductive thematic analyses of healthy eating included rules around the consumption of specific foods, and sociocultural elements for adults, consequences and preferences for children, and influences of training and professional experience for health professionals. The major themes regarding barriers experienced by children and adults in achieving healthy eating goals were social factors (e.g., the influence of parental choices on children's eating), the food environment (e.g., the convenience of ultra-processed foods), logistics (e.g., cost of food), behaviour (e.g. habitually eating unhealthy food or alcohol use), and psychological factors (e.g. sugar addiction and depression). Health professionals also faced a range of unique logistical (e.g., lack of knowledge regarding nutrition), psychological (e.g., empathy for the struggles of patients) and social barriers (e.g., attitudes of parents of overweight children) when providing healthy eating advice. A socio-ecological model of familial dietary behaviour was developed from the data, featuring child, parental, health professional, and wider community and national levels of influence. Dietary behaviour in this model represents a complex interplay of perceptions of healthy eating, and barriers that impact on the choices and abilities of disparate groups of children, parents, and health professionals regarding food consumption. The development of sustainable dietary behaviour change interventions instigated by health professionals and implemented in family settings require whole-family behaviour change education; these interventions should utilise socio-ecological approaches to target wider community influences relating to the food environment.

Introduction

The diets of children are an important contributing factors of oral and general health, and poor dietary behaviours are key determinants in the epidemics of dental caries and childhood obesity (Hayden et al., 2013). Dietary behaviours – including the acquisition,

preparation and consumption of food that affects the ability to eat healthily (Caperon et al., 2019) - are developed during childhood and are known to track into adulthood (van de Kolk et al., 2018). In research and practice, there has been an increased focus on the prevention of poor health in children and the promotion of healthy behaviours in children through family-based health behaviour interventions (Boddy et al., 2012). An integral feature of such interventions involves education to address dietary behaviours and to improve nutrition knowledge in children and their parents or caregivers (Epstein et al., 2007; Fahlman et al., 2008; Tarvonen et al., 2017). In addition, interventions that involve the whole family unit are supported in the obesity treatment literature (Golan & Weizman, 2001) because support, participation and engagement from family members may enhance adherence to the intervention. However, a child's knowledge, and parental knowledge of dietary behaviours and foods that constitute healthy eating is likely to be insufficient for families to consume a healthy diet (Golden & Earp, 2012).

Evidence shows that factors influencing choices parents and caregivers have made regarding food for their children include: the cost of food (Rawlins et al., 2013), exposure to messages from professionals engaged in early childhood care (Spence et al., 2016), products available to buy in supermarkets (Douglas et al., 2014; Lovelace & Rabiee-Khan, 2013; McSweeney et al., 2016), convenience and ease of food preparation, the family setting, the health status of their own children; and learnings from both their own children and the examples of peers, friends and family (McSweeney et al., 2016). A range of barriers have been identified in parents and caregivers to achieving healthy eating goals, including economic constraints (Rawlins et al., 2013), judgments of food portion sizes (Douglas et al., 2014), time pressures (Douglas et al., 2014; McSweeney et al., 2016), the influence of other family members (Douglas et al., 2014; Kaitiaki Research and Evaluation, 2015; Rawlins et al., 2013), the availability of cheap processed foods outside the family home (McSweeney et al., 2016; Rawlins et al., 2013), and lack of knowledge (Gibson et al., 1998; Kolodinsky et al., 2007; Rawlins et al., 2013). Parents and caregivers also believed that health professionals were likely to blame them for any health problems presenting in their children (Douglas et al., 2014).

Health practitioner involvement is regarded as a key factor for the success of lifestyle interventions aimed at the prevention and management of obesity and diet-related disease (Natale et al., 2013). Effective interventions to tackle obesity require the involvement of all parties involved, including health professionals who instigate such interventions, typically in response to patients presenting with a health problem attributable to a poor diet (Fielden et al., 2011). It is therefore important to understand the beliefs of health professionals who instigate such interventions, and barriers that these professionals face in the prescription of nutrition education interventions to enable dietary behaviour change (Ruelaz et al., 2007; Spence et al., 2016). Barriers to providing advice on healthy eating have been studied in health professionals including general practitioners, nurses, dentists, and nutrition professionals. Some barriers have included perceptions that overweight and/or obese patients lacked self-control and adherence to dietary interventions (Parker et al., 2011; Ruelaz et al., 2007), lack of rapport with patients, particularly those from minority groups (Aljafari et al., 2015), language barriers (Parker et al., 2011), and negative perceptions by patients of potential solutions on the basis of long histories of being overweight or obese (Poon & Tarrant, 2009). Lack of knowledge regarding healthy eating was also cited by some health professionals as a barrier to providing advice on healthy eating (Barratt, 2001; Bleich et al., 2014; Divaris et al., 2017; Pineiro et al., 2005; Vanderhout et al., 2019).

The understanding of multiple influences on dietary choices of families has led to the development of socio-ecological perspectives (Caperon et al., 2019). Socio-ecological models were initially developed to describe how the health behaviour of individuals is a product of influences at many levels within the context of social structures of the society of which they are a part (Golden & Earp, 2012). Eating behaviours of children are influenced by family, peers and other adults, including school teachers and health professionals, lifestyle and social networks, the community and neighbourhood, and government policy around the presence of foods at schools, which is in turn influenced by research, business interests, and ideas of specific interest groups (Golden & Earp, 2012). Optimal approaches to promoting healthy behaviours may be a combination of interventions at multiple levels with consideration of interactions between individual, interpersonal relationship, community, social and global influences. The consideration of these influences at different levels of socio-ecological models can then lead to suggestions at multiple levels of interventions to

effectively change dietary behaviour. Nutrition interventions have used socio-ecological models to focus change beyond primary target populations (Golden & Earp, 2012), including school-based interventions that have targeted students, teachers, staff administrators, and elements of the school environment (Egger & Swinburn, 1997). A socio-ecological model for the oral health of children has been previously developed by Fisher-Owens et al. (Fisher-Owens et al., 2007). This model was based on a review of population and oral health literature which considered multi-level genetic, social, and environmental factors to analyse the causes of children's oral health problems.

The aim of this study was to conduct a formative qualitative investigation to gain insights into ideas of healthy eating, and barriers to achieving healthy eating goals. Novel elements of this study were the concurrent exploration of these ideas in children, parents, and health professionals, and the use of a socio-ecological framework to create a socio-ecological model of healthy familial eating to incorporate the beliefs about, and barriers to healthy eating in families.

Methods

Recruitment:

The principal of a primary school in the Taupō area in the central North Island of New Zealand was approached to have their school involved as a recruitment centre and study site. The school was a decile 5 school located within the Lake Taupō district in the central North Island of New Zealand. On receipt of principal's consent, children aged 10 years and parents/caregivers of children were recruited using an advertisement flyer distributed through the school's usual communication method. This age group of children was selected because it was estimated they would have the cognitive skills necessary to complete the tasks, may be acquiring a mature understanding of health and are soon likely to have more independence in choosing foods (Gibson et al., 1998; Livingstone et al., 2004). Children were eligible if they were between 10 and 12 years of age and were literate. Parents, similarly, were eligible if one of their children attended the study schools and were literate. All parents who responded to the advertisement were screened for eligibility and provided written informed consent to participate in the card sorting exercise. Participants were reimbursed with a $10 store voucher. The children completed assent forms for participation and data

use in the presence of a parent, caregiver, or member of teaching staff at school. Health professionals including doctors, nurses and dental professionals were also invited to participate through a general medicine practice, a dental clinic and a community-based charitable trust comprising nurses, health promoter/educators and family support workers. All participants were reimbursed with a store voucher to the value of $10 in appreciation of their time. Ethical approval for this study was granted by the Auckland University of Technology Ethics Committee on July 8th, 2018 (18/82).

Procedures

a. Focus groups

Twelve child participants took part in focus group discussions in groups of 3-4 children. The focus groups took place in a quiet room adjacent to a classroom at the school and were conducted by the primary researcher. On arrival, the researcher introduced herself and explained that she was there to study what foods they regarded as healthy. The researcher also explained to the students that she wanted them to assume that there were no right or wrong answers to this activity. All participants completed a set of card sorting tasks to categorise the importance of a range of behaviours for each of general and oral health, and to classify foods illustrated on picture cards as either good or bad for each of general and oral health.

On completion of the card sorting tasks, verbal instructions were provided to the children about the focus group discussion to take place and they provided verbal assent prior to the recording commencing. The sessions started initially with a discussion of the picture food cards and the behaviours for each of oral and general health. The children were asked about foods they liked and foods they normally ate at home. Probing questions were asked about the benefits of following a healthy lifestyle and consequences of engaging in unhealthy behaviours. The children were also asked where, and from who they had learned about healthy eating. The focus group guide was designed to provide a structure for the discussions, but the line of questioning remained flexible. The researcher included prompts, encouraged the children to expand on their initial responses, and followed up ideas the children raised themselves. The sessions lasted between 20-30 minutes and ended when the children's input was insufficient to continue.

The focus group guide is provided in Appendix D.

b. Semi-structured interviews (SSI)

Individual semi-structured interviews (SSI) were selected for gathering a focused and in-depth account of healthy eating information from parents and health professionals. The SSIs took place at booked commercial office space within the Taupō town centre, or at the school from where they were recruited for the study. Similarly, for the health professionals, the interviews were conducted at their respective workplaces.

On completion of the card sorting exercises described above, verbal instructions were provided to the adults about the SSI to take place and they provided verbal assent prior to the interview. The SSI was developed using iterative approaches which consisted of both open- and closed-ended questions structured around topics from previous research about dietary behaviour and barriers to eating for optimal general and dental health. The SSI guide was designed to explore issues around food expenditure, influence of other family members and eating, the usefulness or otherwise of information sources about healthy eating, and any concerns or thoughts they had regarding how children and young people eat.

Open-ended questions in the SSI guide were followed by more specific probes to clarify and extend responses. Health professionals were asked questions about the provision of advice for healthy eating to patients, and any barriers or difficulties they faced in the provision of such advice.

The SSI schedules are provided in Appendix D.

Data Analysis

The interviews were recorded using an audio recording device; the recording was uploaded to a password-protected computer. To ensure anonymity, each participant was given an identity code. The identity code described the role (child, parent, or health professional) and included a unique identifier number. The data collected from the focus groups and SSIs was transcribed verbatim by the primary researcher. Data was coded, managed and analysed using NVivo qualitative data analysis software (Version 12, QSR International Pty Ltd., Australia) and then deductively analysed using the framework approach (Gale et al., 2013). This approach was pragmatic and selected to both allow themes to emerge inductively from

the data, and to allow the use of a socio-ecological framework to enable a deductive analysis and the development of a socio-ecological model of beliefs and barriers of healthy eating.

Inductive thematic analyses were used to identify and code common and unique patterns that emerged from the set of focus groups and interviews. The techniques as described by Braun and Clarke were used (Braun & Clarke, 2006) in which codes were generated from the transcribed data; there were no pre-determined codes. The codes were reviewed to allow generation of themes and sub-themes until no new themes emerged from the transcripts. Each theme was reviewed for congruency with the corresponding quotes and were checked by the primary supervisor (GS).

The purpose of identifying the themes was to enable the use of a socio-ecological framework to build a socio-ecological model to understand the perceptions of healthy eating of children, parents and health professionals, and the impacts and barriers to achieving healthy eating goals.

Results and Discussion

Twelve children returned consent forms for participation in the study. There were three boys and nine girls, and all child participants were 10 years of age on the day of the focus group sessions. Two children identified as Māori and all other children were of New Zealand European descent. Three focus groups, with four children in each group were held at the school, and each focus group lasted 20-30 minutes. Five parents were recruited through the schools. The group of health professionals comprised seven general practitioners, four nurses, (two general practice nurses and two community-based nurses) and one dentist.

1. Ideas about healthy eating in children, parents, and health professionals

The ideas and beliefs of healthy eating in the participants are summarised in Table 26. The quotes from the focus group and SSI transcripts supporting these ideas are in Tables 27 and 28 in Appendix E.

Table 26. Ideas about healthy eating in children and adults

Participant group	Idea
Children	Preferences Consequences Rules • Decreased consumption of some foods (sugar, processed foods) • Increased consumption of other foods (vegetables, fruit) • Timing of eating (e.g. no snacks prior to dinner) • Health requirements of other family members Education • Mothers • Other family members • School education
Adults	Rules • Decreased consumption of some foods (sugar, processed foods, meat, fat, alcohol) • Increased consumption of other foods (vegetables, meat, fat, fresh foods) • Balance • Moderation • Fasting Societal Elements • Culture • Tradition • Enjoyment

The principal ideas around healthy eating in children were informed by each of preferences, consequences, education and knowledge, and rules. The children showed some awareness that eating unhealthy foods were linked to adverse health consequences in the short term (vomiting), medium term (weight gain on increasing age and reaching puberty), and long term (diabetes). Sources of knowledge cited by all children were typically their mothers, in line with previous research (Gibson et al., 1998; Saied-Moallemi et al., 2008; Spence et al., 2016); in addition, dietary choices (sugar-free, vegetarian) of mothers also informed ideas of healthy eating in their respective children. These findings suggest that women, traditionally the principal providers of family food in households, are key influencers of household dietary behaviour (Golan & Weizman, 2001). All children stated that rules existed in their respective households around accessing food at home, the timing of snacks prior to dinner, and eating a dinner comprising "healthy food" prior to eating "dessert".

Similarities were observed between the children and adults, who had defined rules around the reduced consumption of high-sugar products and processed foods. The reasons for restricting these foods included the belief that excess sugar intake is a cause of obesity and related ill-health, and knowledge about the role of sugars and processed foods in food addiction. Some respondents believed restricting meat and fat intake was important for perceived health benefits, and financial and environmental reasons. Conversely, meat was regarded by other respondents as an important component of healthy eating. The opposing ideas regarding the healthiness of meat and fat reflect findings in previous research in which foods classified as healthy by some groups (Anderson et al., 2015; Mazahery et al., 2018) and unhealthy in other groups included red meat and pork (Falk et al., 2001), cheese (Anderson et al., 2015), and dairy produce (Mazahery et al., 2018). There has been increasing public and scientific debate regarding the role of dairy produce and red meat in both human and environmental health (Han et al., 2019; Johnston et al., 2019; Valli et al., 2019; Vernooij et al., 2019; Willett et al., 2019; Zeraatkar, Han, et al., 2019; Zeraatkar, Johnston, et al., 2019). These debates involving the integration of beliefs about food with beliefs regarding climate change beliefs have entered mainstream discussion which may have an impact on beliefs about red meat.

A "balanced diet" was perceived as important by several adult respondents; however, there was some variation in the definition of balance. These findings corroborate previous research where a component of healthy eating included the concept of "balanced" eating (Douglas et al., 2014; Falk et al., 2001) but in which there was little consensus on the definition of balanced eating (Anderson et al., 2015; Falk et al., 2001; Rawlins et al., 2013). Sociocultural factors were also identified by adults as important for healthy eating, including the awareness of culture, tradition, and enjoyment. Culture around eating was described with discussion of diets of Māori prior to the introduction of refined flour and sugar upon European settlement of New Zealand, and diets that newer migrants to New Zealand consume. Behaviours such as cooking with family were also referenced as traditional and a psychologically beneficial behaviour which contributed to "healthy eating".

2. Barriers to healthy eating

The barriers for all groups are summarised below. The quotes from the focus group and SSI transcripts supporting these ideas are in Tables 28 and 29 in Appendix F. The barriers cited by health professionals in providing advice on healthy eating are presented in Table 30 in Appendix F.

a. Children

i. *Social factors*

In children, one of the principal emergent themes regarding barriers to healthy eating were social factors, a theme generated by the impacts of other people on the child's eating. Parental behaviour was a subtheme, where fathers were acknowledged by children in this study to undermine healthy familial eating goals, which has also been established in previous research of paternal dietary behaviour (Lindsay et al., 2018). Parental choices can also be a barrier to eating healthily, particularly choices parents make regarding whole-family eating, e.g., through decisions to exclude from the family diet some foods associated with health benefits.

ii. *Food environment*

The food environment was a barrier for optimal healthy eating in children, and the presence of food vendors within the community environment influenced food purchasing decisions of parents. Children also described foods that were allowed at school by staff, in the form of food orders brought to school by fast food takeaway outlets. At this school, food was also provided by breakfast clubs, for children who may miss breakfast at home for a range of reasons including poverty, or lack of organisation by the children themselves or their parents.

b. Adults

Five principal themes relating to logistics, the food environment, behaviour, mental health and social factors were identified as barriers to healthy eating for adults within the context of family eating. The barriers for adults for achieving healthy eating, including themes and sub-themes are displayed in Figure 6.

i. Logistics

Knowledge, and a lack of knowledge in all facets was noted by a range of parents and health professionals as a barrier to eating well*:* The sub-theme of knowledge also extended to knowledge gaps in growing vegetables, and cooking ability which were also identified as barriers to eating well. An important sub-theme relating to logistics was the cost of foods; the high cost of foods that respondents believed were healthy (such as multi-grain breads, meat) were cited as a barrier to eating well. Conversely, other adult participants felt that the impact of cost could be mitigated by being organised and resourceful about what to buy and where to buy food. Time factors related to being busy at the end of the day with children's after-school activities and work commitments, pressure to get very young children fed and in bed, and lack of organisation were also cited as barriers for not eating healthy foods, and instead, eating unhealthy foods.

ii. *Food environment*

The ubiquity of inexpensive ultra-processed food products in supermarkets were cited as barriers for families to maintain healthy eating behaviours. The healthiness of foods using the consideration of levels of food processing is currently the subject of current widespread discourse in the scientific and public arenas regarding healthy eating at population level for the prevention of chronic disease (Monteiro et al., 2019; Monteiro et al., 2018; Monteiro et al., 2011). There is increasing recognition that a diet characterised by large amounts of ultra-processed carbohydrate-based foods, is detrimental for health (Kopp, 2019; Miclotte & Van de Wiele, 2019). The consumption of these processed foods is associated with higher risks of overweight and obesity in children and related chronic diseases of dietary cause including metabolic syndrome (Costa et al., 2019; Martinez Steele et al., 2019), through several mechanisms including inflammation (Zinocker & Lindseth, 2018), and dysregulated metabolic processes because of deficiencies of a range of vitamins and minerals (Miclotte & Van de Wiele, 2019).

The creation of processed foods that are designed to encourage higher levels of consumption of such foods was also noted by respondents, in line with their knowledge that these foods are unhealthy and addictive (Lennerz & Lennerz, 2018). The omnipresence,

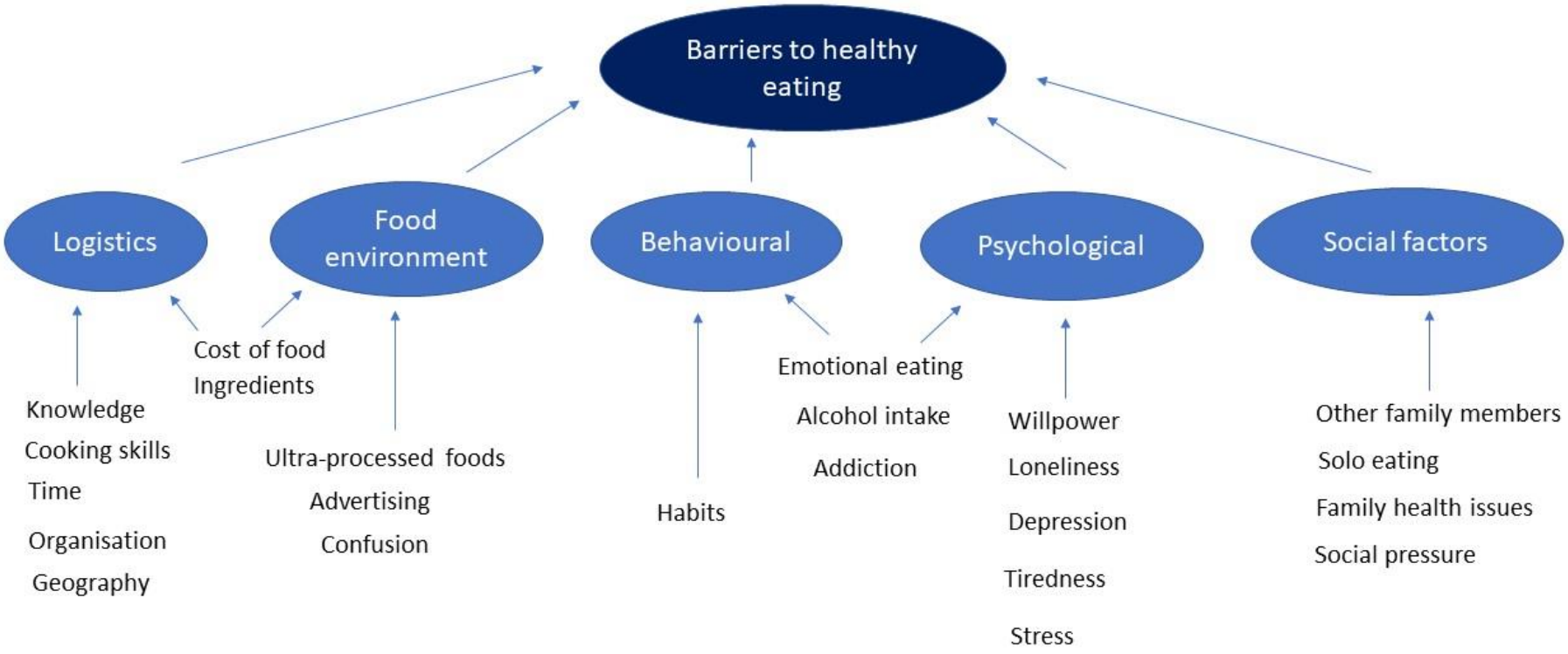
convenience, and aggressive marketing of these products that are commercialised in large portion sizes encourage snack-time food consumption during sedentary activities such as watching television (Costa et al., 2019). These dietary behaviours in turn, have well-established detrimental impacts on other lifestyle behaviours including disruptions to sleep and reduced physical activity (Prendergast, Mackay, et al., 2016; Prendergast, Schofield, et al., 2016; Saunders et al., 2016).

The use of advertising was cited as a problem by respondents, particularly through marketing that conflated imagery of familial love, fun, and care with the promotion of unhealthy food, and through the location and proliferation of fast-food outlets in areas characterised by socio-economic deprivation. Global corporations produce ultra-processed food products and engage in powerful and persuasive promotion of these food products, which impact children's preferences, desires, dietary behaviours, knowledge, and food intake (Cairns et al., 2013; Kelly et al., 2015; Russell et al., 2019; Sadeghirad et al., 2016). In addition, food companies can amplify public confusion by marketing processed products using terms including "natural" and "organic" to promote ideals relating to health (Mozaffarian & Forouhi, 2018). Confusion was noted as a barrier for preparing healthy food, owing to continual marketing that "good food" is "restaurant" standard, the variety of cooking resources for sale, and mass media coverage of multiple dietary patterns promoted as healthy including vegan, vegetarian, flexitarian, paleo, and ketogenic eating lifestyles (Mozaffarian & Forouhi, 2018; Mozaffarian, Rosenberg, et al., 2018).

iii. *Behavioural factors*

Habits that were regarded as difficult to break were cited as barriers to eating well by parents and health professionals, as longstanding habits were often formed in childhood, alongside habits that were influenced by convenience of inexpensive foods. Difficulties in changing habits were also cited as barriers to eating well; this was influenced by the idea that firstly, social support, and secondly, willpower of individuals concerned are important components of changing a behaviour or habit. Some habits were combined with psychological aspects and mental health status of the respondents that drive behaviours. One example was the combination of learned habits with elements of sugar addiction (Lennerz & Lennerz, 2018).

Figure 7. Themes and sub-themes of barriers experienced by adults to healthy eating



iv. *Psychology*

Respondents readily acknowledged that eating sugar was likely to fuel further sugar consumption, which aligned with beliefs regarding sugar addiction: that sugars contained in carbohydrates were addictive (Lennerz & Lennerz, 2018) and that the high and frequent consumption of processed carbohydrates caused metabolic dysfunction and resultant poor health. Emotional eating and alcohol use to cope with stress and tiredness were noted by respondents as behaviours not aligning with ideals around healthy eating. Poor mental health, including depression was also linked to engagement in unhealthy eating behaviours, lack of physical activity, and gaining insufficient sleep.

v. *Social Factors*

The influence of children's preferences had a substantial impact on parents' decisions regarding feeding practices in young children, which aligns with findings from previous research (Cortes et al., 2012; Harris, 2008). In addition, the behaviours of teenagers who have increased independence with food purchasing choices were found in this study to undermine parental attempts to achieve healthy familial eating. Extended family members who undermine attempts by parents to correct poor dietary behaviours were also cited as a barrier to achieving healthy eating goals; this aligns with findings from previous research (Kaitiaki Research and Evaluation, 2015). The perceived costs of eating healthy food and the competing priority of disease management of other family members were inter-related factors that were barriers to eating well. Social pressure to eat certain foods by friends and family members was a sub-theme identified by adults, particularly when embarking on a new eating lifestyle or diet. Conversely, the absence of other people, or solo eating was raised as a barrier to healthy eating.

c. Barriers faced by health professionals

i. Logistics

The principal sub-themes were knowledge and having adequate time during consultations in which to provide adequate advice regarding healthy eating. Lack of knowledge regarding nutrition was cited as a barrier to providing advice on healthy eating. Another general practitioner felt that providing specific dietary advice was outside her scope of practice. Notably, most health professionals felt their training, or current guidance about nutrition was

inadequate for discussing healthy eating with patients, which reflects findings of previous research (Barratt, 2001; Divaris et al., 2017; Pineiro et al., 2005; Vanderhout et al., 2019).

ii. Psychological factors

A lack of confidence in providing advice because of their own health issues was cited by health professionals as a barrier for providing advice to patients. This finding reflects findings of previous research by Poon et al. (Poon & Tarrant, 2009). Health professionals also reported feeling helpless when they were confronted with poor dietary choices and specific knowledge of poor choices by patients. A range of health professionals had empathy for the situations of patients; they understood how their patients may find the cost of purchasing healthy food, the pressures of modern life, and parenting difficulties can each be barriers for their patients.

iii. Social factors

Health professionals frequently cited patient attitudes as a barrier to providing advice. Attitudes outlined included expectations that health professionals could resolve most problems, and when patients became defensive and perceived that conversations about healthy lifestyle were punitive in nature when that was not the health professional's perception of these conversations. Patient-cited barriers such as lack of time or dislike of cooking, and patients who were experiencing learned helplessness about their own health conditions also made it difficult for health practitioners to build a rapport with patients and provide advice on healthy eating. Parental attitudes were also raised by health professionals, particularly regarding the disconnect between parental perceptions of the weight of their children, and the reality that their children may be very overweight; this reflects findings of previous research in this area (Doolen et al., 2009; Poon & Tarrant, 2009). The relationships with other health professionals were also cited by some health professionals as less of a barrier *per se* to providing health advice, but a source of controversy and potential conflict within the workplace.

3. A socio-ecological model of the beliefs about, and barriers to eating for health

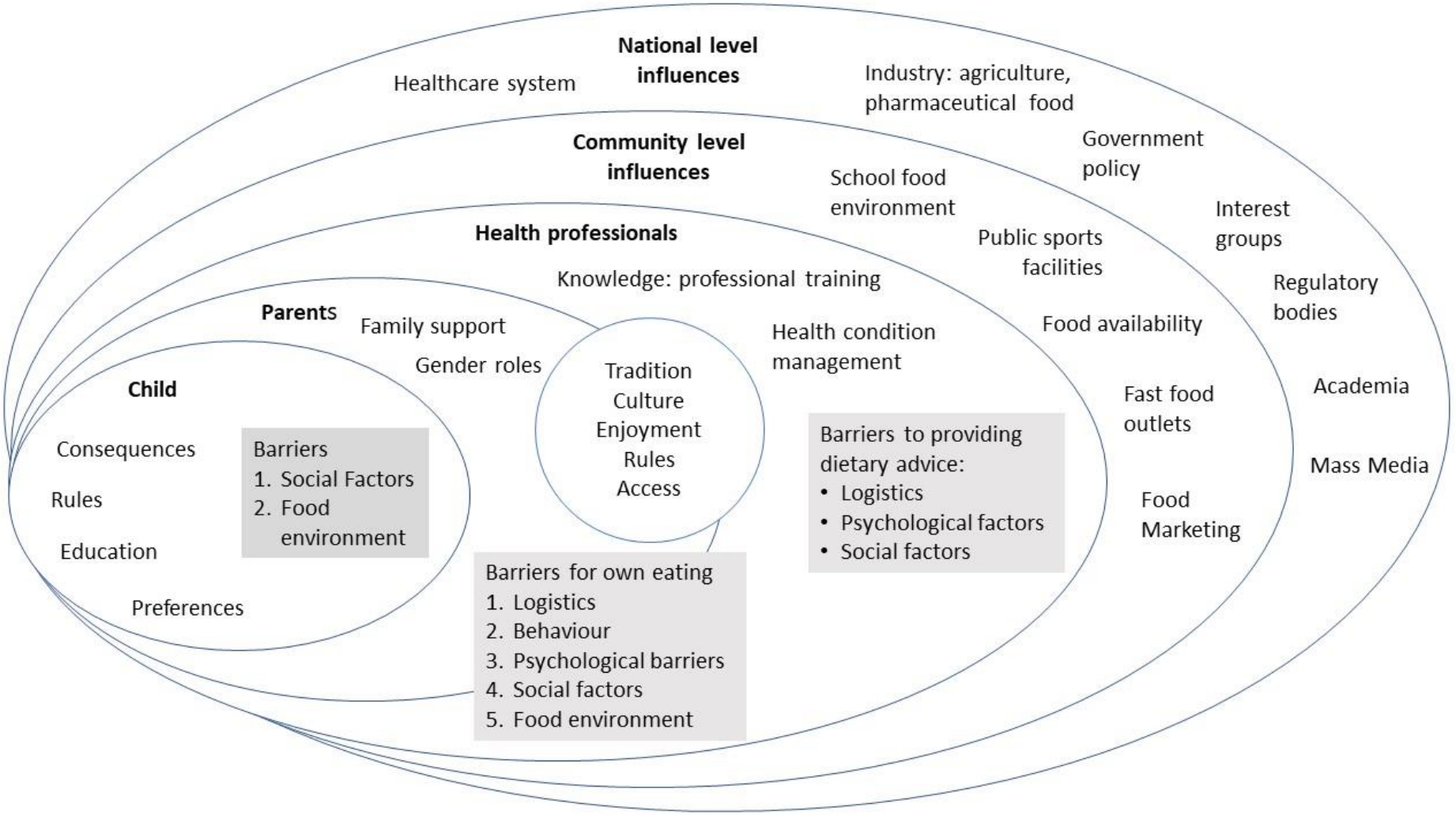
The socio-ecological model developed from the data is presented in Figure 2. The model represents a complex interplay of beliefs about healthy eating, alongside barriers that impact

on the choices and abilities of disparate groups of children, parents, and health professionals regarding food consumption. It demonstrates these multiple layers at child, parent, health professional, and community levels. The value of the proposed model in this study is the categorisation of ideas and perceptions of healthy eating, and themes regarding impacts and barriers to healthy eating, through simultaneous qualitative data collection from disparate groups of children, parents, and health professionals. Therefore, the model in this study is like the Fisher-Owens socio-ecological model of oral health that is similarly composed of multiple determinants of healthy eating (Fisher-Owens et al., 2007). These findings corroborate other research that suggests the need for multi-level health interventions, rather than single-level interventions given the barriers to healthy eating present and have influence at multiple levels in socio-ecological models (Caperon et al., 2019; Ray et al., 2016; van de Kolk et al., 2018). The model developed in this study builds upon the Fisher-Owens model by including the barriers to achieving healthy eating goals. These barriers affect both oral and general health of the populations who would be the target of dietary behaviour change interventions, and the health professionals who would instigate and deliver such interventions.

Similar ideas were identified regarding beliefs about healthy eating across all three groups of children, parents, and health professionals. Rule sets regarding the increased consumption of some foods and decreased consumption of other foods were expressed by participants in all three groups. Health professionals cited the roles of foods and healthy eating in the management of health conditions, and their knowledge based on professional training as contributing to their beliefs of healthy eating.

Five major themes of logistics, food environment, and factors relating to behavioural, psychological, and social factors as barriers to eating healthily were generated by the inductive thematic analyses. Given that social factors present barriers not only for children and adults within the family unit, but also for health professionals who instigate interventions, it is imperative that family-based health behaviour interventions are designed with consideration of the potential impacts of these factors faced by health professionals alongside those of children and parents.

Figure 8. A socio-ecological model of beliefs about healthy eating in families, and barriers to optimal dietary behaviours



The food environment as a barrier to healthy eating was another major theme to emerge from the data in all groups in this study. This finding is consistent with results from other studies (Boddy et al., 2012; Verstraeten et al., 2014). Future interventions should focus on the food environment within school, sports, and other public settings alongside the consideration of individual and family environmental influences (Verstraeten et al., 2014). In addition, a range of public health interventions are required to reduce the impact of ultra-processed foods within community environments based on recommendations suggested in Malhotra et al., including: education for family members through the health provision and school education systems emphasising harms of ultra-processed foods and benefits of minimally processed wholefoods; and restrictions on the involvement of companies associated with ultra-processed products sponsoring sports events, including local school and club-based events (Malhotra et al., 2018).

Although there was little mention of the impact of national policy by the children or adults in this study, previous research indicates that the national environment has a range of impacts on the dietary behaviours and choices of families (Boddy et al., 2012; Caperon et al., 2019; Fisher-Owens et al., 2007; van de Kolk et al., 2018; Verstraeten et al., 2014). Elements of national-level influences were listed in the outer levels of the model in Figure 7; these elements include political will to impose change (e.g., sugar taxes), government-endorsed measures (e.g. dietary guidelines), mass media coverage of health and science information, and the roles of interest groups and the food industry. The impact of industry influence on dietary behaviour is considerable; the food industry, with partners and political allies, apply a range of methods to influence science and public opinion (Kearns et al., 2015; Malhotra et al., 2018).

Conclusions

The principal findings of this formative investigation were that the dietary behaviours of families are determined by multiple layers of influence. Taken together, the inductive thematic analyses of the focus group and semi-structured interviews, and the deductive analysis using a socio-ecological framework enabled the development of a model in which familial dietary behaviour is a complex interplay of perceptions of healthy eating, and

barriers that impact on the food consumption choices of families. The model is likely to be generalisable within the New Zealand population. Barriers were also experienced by health professionals when providing dietary advice to patients. The socio-ecological model is also influenced by external drivers at community as identified in this study, which are in turn influenced at national levels. Awareness of these beliefs and barriers to healthy eating should be considered when using this model as the basis for designing, implementing, and evaluating interventions. Increasing nutrition knowledge at individual and family levels is likely to be insufficient to change dietary behaviour; future sustainable interventions should also incorporate changes at community and national levels.

CHAPTER 9: DISCUSSION

The principal aim of this thesis was to foster greater recognition that dental caries and chronic metabolic disease are united by a common dietary cause, and that prevention of both diseases requires the input of both the dental and medical professions. A range of factors were explored regarding the burden of dental caries in very young children in New Zealand, and the dietary causes of dental caries. The dietary behaviour of consuming a high and frequent intake of refined processed carbohydrates is associated with chronic disease through the life course, including dental caries. Preventive efforts are however undermined by government-endorsed advice to reduce fat intake, which involves recommendations to reduce consumption of foods associated with benefit for oral and general health, and the simultaneous endorsement of foods implicated in these chronic diseases.

The combined prevention of dental caries and chronic metabolic disease requires both collective population and individual behavioural approaches to improve population health. The design of interventions should be based on the beliefs and knowledge of populations who are the target of such interventions, and health practitioners who design and implement such interventions. Formative research was conducted to investigate the beliefs and knowledge of the New Zealand families and health professionals with a view that the findings from this research would inform the design of interventions for dietary behaviour change in families for the prevention of chronic disease of dietary cause. Beliefs about lifestyle behaviours, including dietary behaviours, and the food knowledge of disparate groups of children, parents and health professionals were broadly aligned with ideals promoted through health promotion initiatives. A range of barriers was also identified to eating to fulfil health goals; these were identified at individual, family, and community levels. Health professionals also experienced unique barriers in providing advice for healthy eating to patients. A barrier experienced across all groups to achieving healthy eating goals was the ubiquity of ultra-processed food products. The implementation of preventive interventions should encompass elements of the community, and consideration of the food environments within communities; as such, the involvement of health professionals in the design and instigation of community-based interventions is critical. The findings from the

formative research in this thesis should be used for the design of dietary behaviour change interventions that simultaneously address the twin public health challenges of poor oral health and chronic metabolic disease, given the common dietary risk factors for both conditions.

Research Summary and Implications

This thesis adds to the existing knowledge base around the burden of dental caries in young children in New Zealand, and dietary factors associated with both dental caries, and chronic metabolic disease of dietary cause. In addition, original contributions are also provided in a series of formative research studies in the measurement of nutrition knowledge, and the evaluations of beliefs and barriers to healthy eating in New Zealand families. Findings from this research should inform future interventions in behaviour change to achieve optimal health and prevent chronic disease.

Epidemiological study

Dental caries is the most common chronic childhood disease in New Zealand and is one of the most prevalent health issues across all age groups (Ministry of Health, 2019). Recent data from the Ministry of Health (MOH) showed that 40% of five-year old children were diagnosed with dental caries in 2018 (Ministry of Health, 2019), with a greater burden of disease observed among Māori and Pacific children compared to children of other ethnicities. Previous research has shown inequities in the national distribution of dental caries across ethnic groups, particularly Māori and Pacific groups. In addition, the inequities observed in these studies persisted regardless of fluoridation status of the community water supply (Schluter & Lee, 2016).

The epidemiological study adds to the body of evidence that the burden of dental caries is borne disproportionately by vulnerable groups within New Zealand. This study was conducted using data from dental examinations by the Auckland Regional Dental Service, and matched hospital records in an area of socio-economic and ethnic diversity. Caries experience was greatest in Pacific and Māori children, and children experiencing high levels of socio-economic deprivation.

High levels of socio-economic deprivation have been previously associated with higher intakes of processed sugars in New Zealand: findings of those living in low-income households have previously reported having a narrow range of choices when purchasing foods. Affordable foods for these groups included foods with high sugar content (Kaitiaki Research and Evaluation, 2015). Strategies to modify the food environment that may improve oral health include taxes on sugar consumption (Colchero et al., 2017; Falbe et al., 2016; Zhong et al., 2018), and dietary interventions to decrease sugar consumption in families where children are presenting with dental caries and for prevention in vulnerable groups (Thornley et al., 2017).

Diet, dental caries, and chronic disease of dietary cause

An additional purpose of this thesis was to explore other dietary factors in the aetiology of dental caries, with a focus on highly refined, processed sugar- and starch-containing foods. The relationship between high dietary intakes of sugar (sucrose) and dental caries are both epidemiologically and biologically supported through several lines of evidence including anthropological evidence, studies on the metabolism by oral bacteria on ingested sugars in the mouth (Loesche et al., 1975), and time-series analyses of country level datasets. In previous retrospective studies, statistically significant associations were observed between high dietary intakes, and high snack-time intakes of starch-and sugar-containing foods and dental caries (Arcella et al., 2002; Garcia-Closas et al., 1997; Llena & Forner, 2008; Palacios et al., 2016).

The findings in the systematic review of statistically significant associations between the between-meal intake of processed sugar-and starch-containing foods, and dental caries makes a considerable contribution to the knowledge base of foods implicated in dental caries. An important and novel contribution to the knowledge base of the dual model of the aetiology of dental caries is also made through this work. A frequent intake of processed sugar- and starch-containing foods is associated with dental caries through a combination of both a local response within the mouth, and a systemic response that is mediated by a pathway controlled by the hypothalamus-parotid axis (Leonora et al., 1993). In addition, insulin secretion by the pancreas is also mediated by the same metabolic and

hormone signalling pathways because of increased metabolism of the hypothalamus caused by the frequent consumption of processed sugar- and starch-containing foods.

The narrative appraisal makes a valuable contribution to the New Zealand-based literature by the evaluation of the extent to which recommendations for both healthy weight management and maintenance of optimal oral health reflect the evidence around dietary causes of dental caries, and the presentation of children and young people as overweight or obese. The appraisal drew together the evidence from the epidemiological study and the systematic review, and the current dietary guidelines for children and young people relating to three key areas of diet in dental caries and obesity: sugar, sugar and starch, and full-fat dairy products. Substantial disconnects were identified between evidence of harm from a high and frequent intake of processed fermentable carbohydrates for both dental caries and obesity in young people, and dietary guideline recommendations. These recommendations in these government-endorsed guidelines do not reflect the best available evidence for both maintenance of optimal oral health, and healthy weight management.

The consideration of the dual model of the dental caries process and the related hormonal theory of metabolic health may resolve the apparent contradictions between the evidence of dietary causes of chronic oral and general diseases, and advice provided in dietary guidelines. A high intake of processed fermentable sugar and starch-containing foods contributes to inflammation and is implicated in not only poor metabolic health, but also dental caries. The mechanisms by which processed sugars and starches cause harm in oral and general health, and the associations observed in this review provide justification for designing interventions to elicit dietary behaviour change. Unlike other chronic diseases associated with poor quality diets, caries in children represents an early and rapid manifestation of the detrimental effects of consuming a modern Western diet (Otero et al., 2015). Given that the epidemics of dental caries and metabolic disease are significant ongoing public health challenges in New Zealand and share common dietary causes, potential interventions for healthy eating should focus on prevention of chronic disease through the lifespan by limiting processed sugar-and starch-containing foods and

encourage intake of whole foods, including foods associated with protection from caries and metabolic disease.

Formative research

The implementation of interventions for dietary behaviour change should encompass elements of the community and consideration of the food environments within communities; as such, health professionals provide a crucial link between community-oriented prevention efforts and treatment follow-up for individuals and families. Therefore, the participation of health professionals in the design and instigation of community-based interventions is critical. To design such interventions, it is important to understand the beliefs and knowledge of populations who are the target of such interventions, and health practitioners who instigate such interventions. There may also be a range of barriers to implementing interventions at multiple levels; these also require consideration in the design of potential interventions.

The development of the card sorting exercises

The development and validation of a set of novel card sorting tasks represents an important contribution to the evidence base on methods to assess nutrition knowledge for comparison across disparate population groups. The card sorting tasks were developed as a means by which groups of adults and children could categorise foods as healthy or unhealthy, and to classify a range of behaviours based on perceived importance for oral and general health. Typically, nutrition knowledge of various groups is assessed using questionnaires, surveys, checklists, and interviews; these may have limited utility in evaluating nutrition knowledge, particularly in children. The novel card sorting exercises were found to be a valid, reliable, and acceptable method for assessing knowledge of dietary behaviours and foods for general and oral health in children and adults. Further research should address the use of the card sorting exercises for the post-intervention assessments of beliefs about behaviours and food knowledge as part of the evaluation of family-based interventions designed to improve health outcomes.

The study of foods and behaviours for general health

The study of the beliefs of children, parents, and health professionals regarding the healthiness of food and importance of dietary behaviours for general health makes an important contribution to the knowledge base regarding the beliefs of New Zealanders about the healthiness of foods and lifestyle behaviours. For the first time, identical card sorting tasks were used to simultaneously compare knowledge of the healthiness or otherwise of foods and beliefs between disparate groups of children, parents, and health professionals in New Zealand.

A range of lifestyle behaviours including dietary behaviours were classified by all participants as very important for general health. These findings reflected previous research regarding lifestyle behaviours: the importance of healthy eating behaviours in children, families and health professionals exists within the broader context of a range of lifestyle behaviours that contribute to optimal health. The findings from the categorisations of foods as healthy reflected the beliefs of the participants of the importance of dietary behaviours. Further, these categorisations of foods aligned with recommendations used in health promotion initiatives, which are in turn based on current dietary guideline advice for healthy eating in children and young people.

This knowledge, and the high food knowledge scores attained by the participants in this study, suggests that information provision through dietary guidelines and health promotion initiatives are successful in achieving knowledge acquisition in these groups. The categorisations of foods based on healthiness reflected recommendations provided in official current dietary guideline advice.

The studies of foods and behaviours for oral health

The two-part study comprising the simultaneous assessment of the importance of behaviours, and the healthiness of foods for oral health makes another important and novel contribution to the knowledge base regarding the beliefs of New Zealand children, parents, and health professionals about the prevention of poor oral health. Again, the beliefs of disparate groups of children, parents and health professionals were assessed using the novel card sorting tasks to enable comparisons of beliefs and knowledge between groups.

Oral hygiene behaviours including toothbrushing and flossing teeth were categorised as very important for oral health by nearly all participants. An interesting finding was that all groups felt that attending dental check-ups and having professional cleaning of teeth were very important for the maintenance of optimal oral health. The consistency of the views that oral hygiene was important for oral health, and the concordance of beliefs about dietary behaviours with advice provided in oral health education indicates that messages conveyed through health promotion initiatives for oral health, with a focus on oral hygiene strategies, are well learned by children and adults. Dietary behaviours, with the exceptions of eating less sugar and eating vegetables, were not regarded as important for oral health as maintaining good oral hygiene and having check-ups with dental professionals.

The study of disparate groups of children, parents, and health professionals regarding the health knowledge of foods for oral health provides another important original contribution to the knowledge base in this field. The findings regarding the healthiness of foods for oral health reflected knowledge regarding foods for general health summarised above. This showed that knowledge of children and adults of healthy eating aligned with advice in dietary guidelines, which are used in health promotion for oral health and general health. There was limited and mixed understanding in children and adults respectively regarding the beneficial effects of animal produce including chicken, fish and red meat on oral health, and the detrimental effects of ultra-processed, carbohydrate-containing foods in oral health. This represents a substantial disconnect between the evidence of both the dietary causes of dental caries and the benefits of caries-protective foods, and the knowledge of disparate groups of these foods which in turn, reflected dietary advice provided in health promotion initiatives.

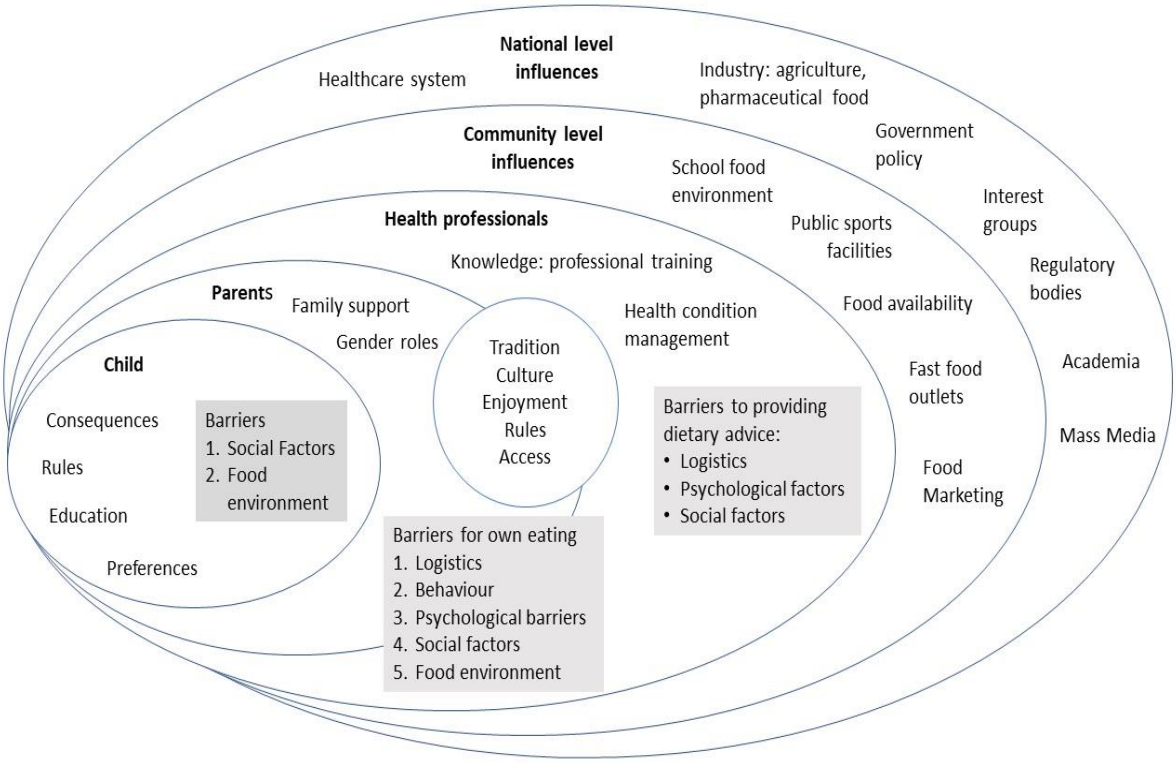
Qualitative insights: Beliefs and barriers to healthy eating

Finally, a substantive and original contribution was made using a qualitative investigation to gain insights into ideas of children, parents and health professionals about healthy eating, and barriers to achieving healthy eating goals. Novel elements of this study were the concurrent exploration of these ideas in these groups; the use of inductive thematic analyses to generate themes from the data on beliefs and barriers that impact and influence

dietary choices made by these participants; the deductive analysis of the themes using socio-ecological approaches; and the construction of a multi-level socio-ecological model of the beliefs of healthy familial eating and the barriers experienced by children, parents and health professionals to achieving healthy eating. This model of the influences that impact familial dietary behaviour across multiple levels should be considered in the design of behaviour change interventions.

There were several layers of influence within a socio-ecological model which determine dietary behaviours of families; familial dietary behaviour is a complex interplay of perceptions of healthy eating, and barriers that impact on the food consumption choices of families. Barriers were also experienced by health professionals when providing dietary advice to patients, including shortcomings in their own nutrition knowledge. The socio-ecological model was also influenced by external drivers at community level as identified in this study, which are in turn influenced at national levels. The socio-ecological model of familial eating that incorporates the beliefs and barriers of the disparate groups of children, parents, and health professionals is shown in Figure 8 below.

Figure 9. A socio-ecological model of beliefs about, and barriers to healthy eating in families



Consumer choice is also affected by wider commercial pressures which include sociocultural perceptions of norms and status, and the marketing and advertising of foods. Each of these determinants shapes decisions on food choices, which are shaped by influences that include the agricultural and food industries, trade agreements, and government policy. Therefore, dietary choices for family eating are strongly influenced by multiple inter-related factors beyond personal knowledge; these factors create barriers to making healthy dietary behaviour choices. In addition, these barriers can both introduce, and sustain existing health inequities as observed in the distribution of dental caries in New Zealand, where caries burdens are higher in vulnerable socio-economic and ethnic groups.

Limitations of the thesis

As stated in Chapter 1, the formative component of this work was undertaken only in the Taupō district of the central North Island of New Zealand. Although the findings of this research may be broadly applicable to other regions in New Zealand, there may be less applicability of the findings internationally, particularly in countries with vastly differing

food, health, social and political systems. The card sorting tasks developed for this thesis were a novel innovative idea developed as an alternative to questionnaires that may have limited efficacy for assessing knowledge in children; further study of the novel assessment methods is warranted. There were relatively few adult participants in the formative research studies, because of time, budget, and personnel constraints, which means that the results of the statistical tests between child and adult participants should be interpreted with some caution. There was no collection of data of dietary intake of any of the participants in any of the formative studies. This would have provided some information on the extent to which dietary behaviours reflected beliefs about dietary behaviours and knowledge about the healthiness values of foods for both oral and general health. There were also no assessments of dental or general health status of the participants which would have provided further information regarding the degree to which the knowledge and beliefs of the participants aligned with health behaviours and outcomes.

Recommendations arising from the thesis

What follows are a series of recommendations to be addressed at national and community levels that are informed by the findings in this thesis. Taken together, the findings regarding the common dietary causes of poor oral and general health, and the formative research to evaluate the beliefs of, and barriers to healthy eating can also be used to inform future research in behaviour change interventions for the prevention of chronic disease. The combined prevention of dental caries and chronic metabolic diseases requires the integrated input of the dental and medical professions. Collective population approaches to improve population health are also required, particularly for the creation of food environments at community levels in which unhealthy foods are not omnipresent (Jepsen et al., 2017; Malhotra et al., 2018).

National level influences

The substantial burden incurred by diet-related chronic oral and metabolic diseases through the life course means that governments should prioritise the formation of co-ordinated national food and nutrition policy strategies (Mozaffarian, Angell, et al., 2018). It is imperative that these strategies are free from food industry influence, which has a range of detrimental impacts on trade policy, public opinion, and nutrition science, which in turn,

has had adverse implications for public health nutrition guidance (Nestle, 2018). The creation of a food environment in which ultra-processed food products are ubiquitous represents an ongoing challenge in public health nutrition promotion (Hancock, Zinn, Schofield, et al., 2020; Malhotra et al., 2018).

Government policy

Currently, nutrition policy to reduce non-communicable diseases typically relies on informing the public through population education. This includes the use of dietary guidelines which inform health promotion initiatives at all stages of the life course (Mackay et al., 2019; Mozaffarian, Rosenberg, et al., 2018). An element of public health policy endorsed by governments, dietary guidelines focus on the prevention of non-communicable diseases (Tapsell et al., 2019). Research on adherence to dietary guidelines has demonstrated their efficacy in educating populations across the globe (Russell et al., 2013). The evidence in this thesis showed that the nutrition knowledge of disparate groups of children, parents, and health professionals aligned broadly with recommendations in New Zealand's current dietary guidelines for healthy eating in children and young people; this knowledge extended to beliefs about foods including full fat dairy products and meat for which there are caveats for consumption in the guidelines.

Recommendations in New Zealand's government-endorsed dietary guidelines continue to focus on reducing intakes of single macronutrients such as saturated fat. The emerging evidence on the relationships between high consumption of ultra-processed food products and poor health outcomes should provide impetus to translate findings through more coherent nutritional guidelines that are based on foods. In addition, people are more likely to understand and adopt dietary recommendations regarding foods and cohesive dietary patterns, than following advice on a range of different nutrients. Food-based classifications are used increasingly in some countries to inform nutrition guidance; one such country is Brazil where the NOVA classification scheme is used whereby foods are classified according to levels of processing (Achalu et al., 2019). Terminology such as "minimally processed", "processed" and "ultra-processed" foods are used in the set of guidelines statements for the population (Martinez Steele et al., 2016).

Taken together, an update of the dietary guidelines should principally focus on the consumption of whole foods from a range of unprocessed sources to inform ideas of healthy eating, and a decreased intake of ultra-processed foods associated with chronic disease of dietary cause. In addition, a high frequency intake of ultra-processed foods is associated with both dental caries and chronic metabolic disease, through hormonal and metabolic dysregulation that leads to increased appetite and an alteration of weight homeostasis towards weight gain (Ludwig & Friedman, 2014). Therefore, it is imperative that future guidelines on healthy eating should also include advice to reduce between-meal consumption of ultra-processed foods.

Fiscal incentives and disincentives

Interventions to address the impact of trade on the food environment should include the use of fiscal incentives and disincentives. This would eliminate the distortion of food supply in which processed foods are ubiquitous; in New Zealand, more than 70% of foods in supermarkets comprise ultra-processed foods (Mackay et al., 2019; Malhotra et al., 2018). There is consistent evidence that fiscal disincentives in the form of taxes on sugar-sweetened beverages can affect changes in purchasing choices across populations, with the greatest impact on purchasing behaviour observed in groups of lower socio-economic status (Colchero et al., 2017). Taxes on SSBs have the potential to reduce sugar consumption, prevent dental caries and reduce costs of dental care (Sowa et al., 2019). Although disincentives can be politically difficult, revenues from excise taxes can be used for other strategies. These should include the cessation of all government subsidies for sugar and other monocrops used in the production of ultra-processed foods which contribute to poor health (Malhotra et al., 2018; Mozaffarian, Angell, et al., 2018) and incentives to reduce the price of unprocessed or minimally processed foods associated with health benefit (Olsho et al., 2016). Given the inequities in caries distribution observed in Māori and Pacific groups of lower socio-economic status in New Zealand identified in the epidemiological study in this thesis, it is of utmost importance to implement these changes in fiscal policy.

Marketing and advertising

The findings of this thesis showed there is an urgent requirement to address the ubiquity, and consequent high and frequent consumption of ultra-processed foods which cause harm and represent an ongoing challenge for health promotion. The omnipresence, convenience, and aggressive marketing of these food products that are packaged in large portion sizes promote snack-time food consumption during sedentary activities such as watching television. These dietary behaviours have detrimental impacts on other lifestyle behaviours including disruptions to sleep and reduced physical activity (Prendergast, Mackay, et al., 2016; Prendergast, Schofield, et al., 2016; Saunders et al., 2016).

Global corporations produce ultra-processed food products and use influential marketing techniques directed at children. Complicating matters further, there has been a rapid shift from broadcast to digital marketing in which new and engaging techniques enable companies to directly interact with children and young people based on demographics and online behaviour (Vandevijvere et al., 2017; World Health Organization, 2016). Consequently, the pervasiveness of such marketing has substantial impacts on children's preferences, desires, dietary behaviours, nutrition knowledge, and food intake (Cairns et al., 2013; Kelly et al., 2015; Russell et al., 2019; Sadeghirad et al., 2016). In New Zealand, food advertising is regulated by the Advertising Standards Authority (ASA), which is funded by member subscriptions and advertiser levies. Membership organisations of the ASA include advertisers, agencies, and the media who work alongside an industry-managed governance board. A recent study found that the ASA does not adequately protect children from exposure to, and power of, unhealthy food and beverage marketing, when analysed according to a public health law framework (Sing et al., 2020).

Given that the ASA regulatory system is ineffective, unaccountable, and influenced by industry interests, there is a need for government-led, comprehensive, and enforceable marketing restrictions to lessen the detrimental impact of marketing on dietary behaviours on young people. Strategies to achieve these objectives include: the cessation of advertising of ultra-processed food products during prime television viewing times; the prohibition of end-of-aisle promotions of ultra-processed foods and beverages and on loss-leading in supermarkets; bans of companies associated with ultra-processed foods

from sponsoring sports events such as Ironman New Zealand in which unhealthy foods are associated with physical activity; prohibiting the endorsement of ultra-processed foods by celebrities; a ban on sales of ultra-processed foods at hospitals, and other public facilities including sports grounds; and enabling organisations concerned with public health access to all relevant information about digital food marketing (Moynihan & Miller, 2020).

The establishment of effective nutrition policies by governments continues to be hindered by insufficient capacity and lack of political will. Currently, governments worldwide are managing the consequences of the SARS-CoV-2 virus and resultant global pandemic, which has already caused unprecedented social and economic disruption. In addition, those at highest risk from adverse consequences of this virus are people with chronically poor metabolic health of dietary cause (Marhl et al., 2020). Given this, it would be prudent to invest in chronic diet-related disease with an emphasis on prevention. The health budget for 2020 was released in May 2020 by the New Zealand government; priorities for spending are for the support of health boards, maintenance of pharmaceutical budgets, capital investment in infrastructure, and ongoing support for maternity services and New Zealanders with disabilities. A re-orientation of the healthcare system with a preventive focus for government spending is necessary, considering the global challenges of the burden of diet-related non-communicable disease but also the clear links between poor metabolic health and complications of SARS-CoV-2.

Civil society engagement is required to increase public appreciation about the harmful impacts of sugar on society. The failure to engage civil society means that upstream government measures may be viewed as paternalistic and intrusive. Grassroots activism is required for the recognition that the high population intake of ultra-processed foods has multiple disease-associated impacts on society. This is of utmost importance, given the perception that dietary interventions require longer periods than government terms in office and budget cycles to achieve health benefits (Thomas & Gostin, 2013).

Community level influences

The community food environment needs to change to be less cariogenic and obesogenic to one in which the easiest options are to choose healthy foods. Schools, and other public

community-based facilities are logical and natural settings for effective nutrition policies. In the qualitative investigation in this thesis, the presence of food vendors within the community environment, including those at facilities managed by local government, influenced food purchasing decisions of parents. Children described foods that were allowed at school by staff, in the form of food orders brought to school by fast food takeaway outlets, and foodstuffs permitted for fundraising initiatives including chocolate bars and family-size pies. School staff typically grant permissions for these items to be bought and sold on school premises; these staff are viewed as authority figures by children which may also lead to the perception of children that these foods are not unhealthy.

At educational institutions, nutritional standards should be required for on-site foods and meals (Micha et al., 2018). The food industry involvement in school environments also requires regulation and restriction. There is some evidence that restricting unhealthy foods within school environments can have a positive impact on child health. In one New Zealand school-based study, a healthy food policy characterised by the restriction of sweet foods and drinks was associated with improvements in oral health status of the attending children, compared to children of similar socio-economic status (Thornley et al., 2017).

The socio-ecological model of familial eating that includes the impacts of beliefs and barriers faced by families should be used for the development of interventions to reduce the risk of chronic disease in families. Creating sustainable health improvements, therefore, may be most effective when these factors at multiple levels are targeted simultaneously. However, influencing all aspects of the environment and characteristics of an individual may be impractical and therefore interventions should focus at least on two levels of influence (Golden & Earp, 2012; Lang & Rayner, 2015). Implementation of such interventions should encompass elements of the community and consideration of the food environments within communities; as such, the involvement of health professionals in the design and instigation of interventions is crucial.

Health professionals have a unique role within community and family environments in addressing the role of nutrition in health by the dissemination of evidence-based research, advocacy for change in public health policy, and by direct action (Moynihan & Miller, 2020).

Interventions instigated by health professionals and implemented in family and community settings represent a means by which strategies for dietary behaviour change should be developed in close alignment with the model; awareness of these beliefs and barriers to healthy eating should be considered as the basis for designing, implementing, and evaluating interventions. Increasing nutrition knowledge at individual and family levels is likely to be insufficient to change dietary behaviour; future sustainable interventions should incorporate education and behaviour change strategies and be supported by changes at community levels.

Future research directions

The principal aim of this thesis was to foster greater recognition that dental caries and chronic metabolic disease are united by a common dietary cause, and that prevention of both diseases requires the input of both the dental and medical professions. There were no trials that examined presentation of children with dental caries as a means by which to recruit families to a dietary behaviour change intervention for the improvement in overall health and to reduce the risk of chronic disease. Given the disease burden of the twin epidemics of dental caries and diet-related chronic metabolic disease, and the impact of a poor-quality diet on these chronic diseases of dietary cause through the lifespan, it is important to consider the study of behaviour change interventions for children presenting with dental caries. Therefore, it would be prudent and sensible when considering the study of interventions to use a dual focus to improve oral and general health outcomes. Colleagues in Auckland have attempted to obtain government funding for such a study, by using poor oral health in children as a recruitment strategy. Although the novelty of the work and the recruitment methods are commended, the funding has yet to eventuate.

The lack of nutrition knowledge was cited by health professionals in this thesis as a barrier to providing advice on healthy eating. This is an important area for future research; the participants in the formative studies believed regular checks with doctors and dental professionals were important behaviours for general and oral health, respectively. Health professionals are regarded as knowledgeable in diet and nutrition by the general population. Specialist training in evidence-based nutrition as part of continued medical

education should address these knowledge deficits of health professionals and improve health practitioner confidence in prescribing dietary behaviour change. This would enable future research in the expansion of nutrition counselling services within healthcare, and the evaluation of both nutrition education of health professionals, and health professional-led dietary behaviour interventions.

Dietary interventions should coalesce around the consumption of whole foods from unprocessed sources to inform ideas of healthy eating that include vegetables, fruit, nuts, seeds, eggs, fish, and meat. In particular, the role of full fat dairy products and meat should be emphasised, given that these foods are associated with protection against dental caries, favourable anthropometric profiles, and prevention of chronic metabolic disease. Given that access to healthy foods was cited as a barrier to healthy eating by adults in the qualitative work, potential interventions should include provision of foods cited as difficult to access; this may change consumption behaviours around these foods.

The high and frequent consumption of ultra-processed foods that cause harm through a range of mechanisms represent an ongoing challenge for health promotion, particularly as it was a barrier to healthy eating across all groups in this thesis. These dietary behaviours also have detrimental impacts on other lifestyle behaviours including disruptions to sleep and reduced physical activity. Given that study participants in this thesis regarded sleep and exercise as important for good health, it would be prudent to include these behaviours as part of behaviour change interventions to foster good health.

An important finding of this thesis was that multiple factors beyond the individual knowledge of children and adults influence dietary choices. Knowledge alone is not sufficient for behaviour change, and a range of barriers were identified in this thesis to making healthy dietary behaviour choices. An important component of dietary behaviour change interventions should incorporate education, goal setting and positive psychology to enable behaviour change strategies to enable healthy eating choices. These strategies may address barriers experienced by adults that include logistical problems such as lack of time and organisation, and behavioural issues relating to habit formation and emotional eating responses.

Conclusions

The twin epidemics of dental caries in children and diet-related chronic disease represent two of New Zealand's largest public health challenges. Poor oral and general metabolic health through the life course can be attributed to the common dietary behaviour of a high and frequent intake of processed fermentable carbohydrates found in ultra-processed foods. This body of work has made several important contributions regarding the burden of dental caries in very young children in New Zealand, the dietary causes of dental caries and chronic metabolic disease, and factors for consideration when designing interventions with a novel combined focus to improve oral and general health. It is likely that nutrition interventions for the prevention of dental caries in children can improve overall health; however, there is a paucity of prospective studies that emphasise dietary intervention to improve both dental and general health. The design of such interventions should incorporate the beliefs of healthy eating in the populations under study and health practitioners who design and implement such interventions. The nutrition and dietary behaviour knowledge of children and adults aligned with ideals advocated through health promotion initiatives. A barrier experienced in families and health professionals to achieving healthy eating goals was the ubiquity of ultra-processed food products within the food environment. A range of recommendations were made to mitigate the impact of the current food environment which contributes to poor health. The findings from this thesis should be used to inform the design of dietary behaviour change interventions that simultaneously address poor oral health and chronic metabolic disease, given the common dietary risk factors for both conditions.

National-level measures to address dietary intake of unhealthy food requires civil society engagement. Dietary behaviours are not solely related to individual choice; multiple interacting policy, environmental, social, and demographic factors affect food choices. Given these factors, the inter-related strong messaging by the food industry, and the endorsement by governments and regulatory bodies that dietary behaviour and health status is a function solely of personal responsibility can be viewed as senseless. The ubiquity of ultra-processed unhealthy food within the food environment has detrimental health-associated impacts, many of which are disproportionately borne by young people

who are particularly vulnerable to the consequences of a poor-quality diet through childhood. The prevention of dental caries and chronic metabolic disease to gain improvements in health requires the integration of collective population and individual behavioural approaches.

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APPENDICES

Appendix A: Auckland University of Technology Ethics Committee (AUTEC) approval for the formative research studies.

9 July 2018

Grant Schofield
Faculty of Health and Environmental Sciences

Dear Grant

Re Ethics Application: **18/82 Understanding beliefs and insights of health professionals and families regarding healthy eating for general and dental health**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).
Your ethics application has been approved for three years until 5 June 2021.

Standard Conditions of Approval

1. A progress report is due annually on the anniversary of the approval date, using form EA2, which is available online through http://www.aut.ac.nz/research/researchethics.
2. A final report is due at the expiration of the approval period, or, upon completion of project, using form EA3, which is available online through http://www.aut.ac.nz/research/researchethics.
3. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form: http://www.aut.ac.nz/research/researchethics.
4. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
5. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.

Please quote the application number and title on all future correspondence related to this project.

AUTEC grants ethical approval only. If you require management approval for access for your research from another institution or organisation then you are responsible for obtaining it. You are reminded that it is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.
For any enquiries, please contact ethics@aut.ac.nz
Yours sincerely,

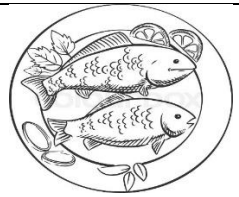
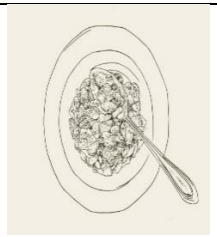
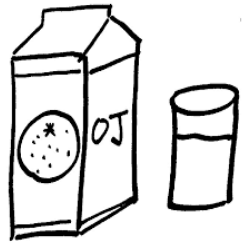
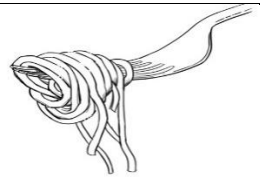
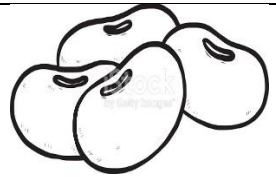
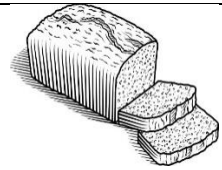
Kate O'Connor
Executive Manager
Auckland University of Technology Ethics Committee
Cc: sarah.hancock@aut.ac.nz; caryn.zinn@aut.ac.nz; Simon Thornley

Appendix B. Behaviours to be ranked as "very important" "somewhat important" and "not important" for each of general health and oral health

General Health behaviours	Oral Health behaviours
Eating vegetables	Brushing teeth each day
Sleep	Visiting the dentist for check-ups
Drinking water	Flossing teeth
Eating fruit	Visiting the hygienist for cleaning
Doing some exercise	Drinking plain water
Visit your doctor	Eating less sugar (sweet drinks, lollies, treats)
Get outside more often	Eating more vegetables
Eating less sugar (sweet drinks, lollies, treats)	Eating fruit
Maintain oral hygiene	Eating meat
Eating fat (including dairy products)	Eating carbohydrates (bread, pasta, rice, and cereals)
Having good friends	Chewing sugar-free gum
Avoiding smoking drugs and alcohol	Eating fat (including dairy products)
Managing stress	
Use vitamin/mineral supplementation	
Eating meat	
Eating carbohydrates (bread, pasta, rice, and cereals)	
Have more money	

**Eating less sugar: foods included were lollies and sweets, biscuits, cakes, and muesli bars, fizzy drinks, and crisps and chips.*
***Eating carbohydrates: foods included were breads, pasta, rice, and cereals*

Appendix C. Card Pictures of foods to be allocated to categories by children, parents/caregivers and health professionals based on beliefs regarding benefit of harm of the foods for each of dental and general health

 Cheese	 Milk	 Eggs	 Yoghurt	 Nuts	 Dried fruit
 Green vegetables	 Fresh Fruit	 Root vegetables	 Fish	 Chicken	 Red Meat
 Sweets	 Biscuits, Cakes and Muesli bars	 Crisps and Chips	 Breakfast cereals	 Fruit Juice	 Fizzy drink
 Pasta	 Rice	 White beans and chickpeas	 Bacon and Salami	 White bread	 Brown bread

Appendix D: Interview schedules for the child focus groups and the semi-structured interviews for parents and health professionals

Child Focus Group Interview Schedule

- Why do you think some of the foods in the card-sorting exercise were healthy? Not healthy
- What do you like eating?
- Why?
- Do you like to eat those foods in the cards that you have organised yourself?
- Why, or why not?
- Do you have any rules at home regarding what you eat?
- If so, what are they?
- Who have you learned about healthy food from?
- Are there any reasons why you don't eat food that you've think is healthy

Semi-structured interviews for parents and health professionals

- You've just completed the card-sorting exercises…did you have anything to say about the foods on the cards in that set of tasks?
- Do you eat these foods often?
- For what reasons do you eat the foods you do?
- What do you think a healthy diet looks like?
- Does anyone in your family eat different foods from yourself?
- Do you have any concerns regarding the food your child eats?
- Is there any information or ideas regarding raising healthy children that you would like to know more about?
- How healthy do you feel now?
-

Regarding your own eating and health goals…. are any of these barriers for you to achieving your own eating and health goals?

Time	Willpower
Cost of food?	Social pressure
Knowledge regarding food	Alcohol intake
Cooking ability	Anything else

Other Questions

- Of those barriers, could you please elaborate in more detail about these?
- Does the cost of food have any impact on your food choices?
- Is there any pressure from other family members driving choices about what you buy for your family?
- If you answered yes, can you please elaborate on this?

Further questions for Health Professionals

- Do you ever give nutrition or dietary advice during a consultation for any of children/adults as part of your practice? If so, what does this consist of?
- What barriers are there for you to giving dietary advice in the groups above?
- What barriers do you see for your patients in eating according to your advice? Is there any information or ideas regarding diet and nutrition for families that you would like to know more about?

Appendix E: Supplementary Material from the focus groups with children and semi-structured interviews with adults.

Table 27. Children's ideas about healthy eating

Preferences
• FG1, Child 2: I like to eat fish • FG1, Child 3: I love spaghetti Bolognese, and I love sushi and I also like eating nuts and bars, my mum makes these muesli bars with oats and just a little bit of chocolate and apricots • FG2, Child 2: But what I really like for dinner is steak and fish and ribs or something that involves meat • FG3, Child 4: I like to eat greens, and fruit and fish, all the healthy stuff • FG3, Child 1: I like eating candy because it's really yum,…but I know it's not good for me but I like it
Consequences
• FG1, Child 1: I'm not allowed to scoff lollies because I did that once and I chundered • FG1: Child 1: My pop has a sister named J she has a boyfriend he has diabetes and once they came to my house. When they came down last time we had these cheese and crackers and salami but he couldn't have some of that because it has sugar in it…. but he had the crackers and he had the grapes • FG1, Child 2 Eating too much sugar causes diabetes….and drinking too much alcohol • FG1, Child 2 So if you drank a whole jar of fizzy drink this big and this wide (gesticulates with hands) you would probably get diabetes when you are older • FG3, Child 2: As you get older you do start to put on some weight, and you need to watch what you eat
Rules
1. Reduced consumption of foods a. Processed foods • FG1, Child 1: I only get nutragrain once a year. • FG3, Child 1 As a treat, well for us, my mum doesn't usually buy the packeted food like in town she just buys the healthy food…..My mum uses paper bags, or she buys a big giant bag of chips and then puts them into smaller bags • FG3, Child 1:" …and my mum she also buys, for breakfast, my dad…like for breakfast, now I know cereals aren't that good for you, but my Dad has muesli…. He has that with fruit • FG3, Child 2: well that depends what cereal you have if you have oatmeal, well that's good but if you have those coco pops, they're bad for you because they have loads of sugar a. Sugar • FG1, Child 1: I'm also on kind of like a diet but I can't eat fizzy drink for three months. Because my dad works at a Coke thing where he sells a lot of fizzy and he brings heaps home so I drink it. So I'm on a drink diet

- FG1, Child 3: "my Mum she's like a total health nerd… she says we're not allowed to do this or eat that because it has sugar in it. Like one time we asked "Can we have a bag of chips?" and she's like "No. Because it has sugar in it"
- FG1, Child 3: during the 6 week holidays I was at my cousin's for three of them and on the third day of the second week my cousin's Dad – I was there alone – but we wanted a banana I think or an apple and he said you should eat too much of that it has sugar but we went "Yes, but Healthy sugar" ……Um it's the things that grow in the fruit like the pips and stuff
- FG1, Child 2: My Dad he hides kiwifruit, we have them sometimes because my dad wants them, but we keep that away from my brother but apparently kiwifruit has bad sugar in them but he wanted to keep them all to himself. But I've learned that fruit is good, and they're yum. More than vegetables, but I've learned that from school and my Mum.

2. Increased consumption of other foods
   a. Vegetables

FG1, Child 1: *I have to eat all my vegetables. Sometimes I'd rather not, but that's the rule.*
FG3, Child 3: *Yeah, I mean what's the point of eating food before you eat that yummy dinner with vegetables which are very good for you, and you might not be hungry. If we don't eat our dinner we're not allowed dessert*

   b. Fruit

- FG3, Child 2 My mum doesn't buy us packets of food it's only for a treat. She buys us fruit, vegetables, she buys grain bread, and we don't have Nutella

3. Timing of eating (not after 4pm, having dinner before dessert)

- FG3, Child 2: Yeah, I mean what's the point of eating food before you eat that yummy dinner with vegetables that are very good for you and you might not be hungry. If we don't eat our dinner we're not allowed dessert
- FG1, Child 2: But like also you have to if we're having dessert we only have it once a week because or like twice a week but if we don't eat our dinner we don't get it or if we've been naughty which for me is annoying

4. Health of other family members (allergies, diabetes etc.)

- FG1, Child 2: "….we're not allowed to eat peanuts or kiwifruit around my brother and we're not allowed to tease him about it
- FG1, Child 3" my brother, he's allergic to kiwifruit… but we have them sometimes because my dad wants them , but we keep that away from my brother but apparently kiwifruit has bad sugar in them but Dad wanted to keep them all to himself.

Education

Mothers

- FG1, Child 3: But I've learned that fruit is good and they're yum, more than vegetables. I've learned that from school and my mum.
- Who have you learned about healthy eating from?
- FG2, Child 2 my Mum
- FG2, Child 1: mum, my parents, nurses

- FG2, Child 3: my mum and Dad

Family dietary choices

- FG3, Child 2: Um my mum she used to make sugar-free everything like muffins but we never used to eat them … She would say "I'm trying to keep you healthy" but we would be like "but we don't like them" and now she's started doing the healthy food thing again she's started doing that again.
- FG2, Child 3: I'm a vegetarian and my family are vegetarians too, to keep us healthy

Education at school:

- FG 2, Child 2**: S**ometimes Harold comes in that caravan
- FG2, Child 3: Oh yeah, Yeah Harold, and someone holding that puppet does a visit…..They tell us the five a day thing with vegetables and fruit, but they don't do that much now they just tell you to be kind and stuff.

Table 28. Adults ideas of healthy eating

- **Rules about healthy eating**

1. Reduced consumption of foods
    a. Sugar

- HPR010 Oh I have very unhealthy diet actually, well I go through spurts, It's um stress and habit and emotional coping and there's some physiologic sugar addiction so I have trouble, if I get started eating sugar I have a very hard time stopping eating sugar.
- HPR005: I think that carbohydrates are addictive, and when they cut them out people no longer need willpower, because their hormonal profile has come back to normal…..I think the biggest factor is that people are addicted to carbohydrates and that's causing metabolic dysregulation and a lot of things cascading from that.
- HPR010, female GP "…well the simplest quick advice is to stop eating sugar just to quit sugar. And I include in that noodles, white rice, bread, white potatoes, it just turns right into sugar when you eat it, so that counts as sugar. One thing I do say is don't eat white food"
- HPR008, Male GP "….definitely, I mean I think the child obesity epidemic speaks for itself, and I think the sugar intake is a fairly obvious culprit….Definitely, so I think that sugar is the no.1 contributor. I'd define a healthy diet as …. avoiding a lot of sugar.
- PAR001, female: I have to really control myself in terms of biscuits and cakes and things like that, which I think are really bad, but especially at night when I'm relaxing, I start looking for food and typically for sugary food, not so much in the afternoon, I used to have a really bad 3 o'clock thing
-

    b. Processed foods

- HPR001: Just try and reduce the processed stuff but it does smell nice and taste nice doesn't it? … We did live to a ripe old age, but you didn't have the processed foods and you didn't have the processed foods and the nibbly stuff we've got now and the convenience foods, that are full of all sorts of sugars and fats"
- PAR004: we have a little book that tells me about the numbers on the back of the packets; and that concerns me, read the preservatives and colours, especially the colours when you read what they can do to your body, that concerns me those ingredients…"
-

c. Meat

- HPR014: cutting back on red meat in general and other meats more slowly, and eventually I would like to get to the point where I only eat fish but not other kind of hot-blooded animals, that's personal choice really also because I think the more content vegetables and fruits etc that you can have, not animal meals that you can get, the benefits you can have for your body and also from a very personal point of view, pain relief and prevention of cardiovascular conditions.
- HPR008: We were very strict vegetarians, almost vegan for several years and I got called on really since my training by Joel Furman who wrote a book called "Eat to Live" which really impacted me from a dietary standpoint about red meat and dairy really not being an essential part of a normal balanced diet… and really if we're honest, not healthy either of them, and should really be treated just like sugar.
- HPR004: I think there's an awareness about red meat costing more in terms of our environment and money-wise, just to access it to get it from A to B is so much more expensive in terms of cost to the land is very expensive but there's more efficient forms of protein and they're better for you,(right) so yeah I think that's a growing awareness, in a lot of groups but definitely in the young ones coming through. My daughter frequently reminds me about it, she's environmentally aware, that's part of her work. There's certainly a shift away from the traditional type of food I would have eaten at her age.
-

d. Fat

- HPR008: for every calorie you take in you need the nutrients coming in so you know the protein just has lots of fats, saturated fats, you know dairy has tremendous amounts of fats neither have any minerals vitamins or other essential bits that contribute to your health

e. Alcohol

- HPR007: Alcohol wise recently I've sort of changed it up a bit but I had for a while been drinking one craft beer per night however one craft beer can be several units of alcohol or so and I tend to find my weight goes up if I do that.
- PAR003 Um with alcohol you know I like to have a glass of red wine or sometimes in the weekend a glass of bubbles and I know that's just extra calories but I do enjoy that as well, just to wind down but I know I don't need that it's just extra calories yeah….Oh yes with not smoking I've tended to drink more white wine. I mean I don't get drunk but I just, I know I don't need two glasses a night when my 15 year old stresses me out (laughs wryly) (yeah)I would have normally gone for a smoke something like that (so you got to go outside) yeah and it was a total 10 minutes of time dedicated and I could just think whoa, I don't have to worry about anything a habit I guess.

2. Increased consumption of other foods

a. Vegetables

- PAR001: we're eating better quality food, eat a lot more vegetables as in salads and things I mean we can almost eat salad every day whether it's winter or summer um, but then I' ve always tried to eat what's in season as well (yep) that what I've been raised that's what we believe even in terms of our religious beliefs, you know the word of wisdom, talks about eating vegetables and fruits in season and in moderation, so I've always tried to work to that
- HPR001: well I yes you try and look at healthy eating, I certainly heard from other listening to other dietitians, I've certainly increased my pulses, because I didn't really know about that so I add that to a lot of my meals or mince with salads, so I do try and eat healthily….as I say understanding a wee bit more about the pulses, the lentils and the chickpeas that was definitely something.
- HPR008: I'd define a healthy diet as um primarily plant-based... Just looking at my own diet I try to eat probably 75% vegetables or vegetable-based foods and then just add 25% will come from all other food groups.
- HPR014: mostly vegetables fruit and all sorts of variations you can do with that….also because I think the more content vegetables and fruits etc. that you can have, …the benefits you can have for your body and also from a very personal point of view, pain relief and prevention of cardiovascular conditions ….But the region I come from is very versatile in that there are a lot of vegetables, leaf salad products fruit at a high level all year long, there is a lot less meat in the diet of the typical person….The further south you go because of growers etc., you find that people eat a lot less greens than what they should be having.
-

b. Fat

- HPR006: when I trained it was the plate was a hand-sized version of what we have now protein and da-de-da and that was and interestingly I had a conversation in the cafeteria with a guy called professor Sir John Scott and I had a cheese scone and margarine and he said don't eat that crap he said it would be better for you and the dairy industry if you ate butter and even back then he was saying that you know these artificial fats were not good for you and they really aren't".
- HPR006: Um so people are a bit fat phobic and I've actually re-learned that fat is not something we should fear…. But like we eat a lot of cheese, we actually eat a lot of bread it's a different type of bread, it's olives, olive oil, that's our main fat, I would say, we use olive oil to dressing on salads, none of these fancy dressings you buy already prepared pre-bottled in the supermarket. Just olive oil a bit of salt spices, a bit of oregano that's delicious…and I am actually quite liberal with how I drizzle that over salads, vegetables…"
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c. Meat

- PAR001: We are normally quite good sort of eating quite basic sorts of foods really, we have salad, meat, … we're quite happy just to have meat and salad. …We're way past, we are way past I think we only try to buy good food Yeah, so we're not buying really cheap cuts of meat unless it's for a casserole (or a recipe that specifically states this) yeah, specifically , we only ever buy sirloin or eye fillet …. We only eat good meat anyway.
-

d. Home-made foods

- HPR006: At this point in time, nutritional choice, and I think I'm making healthier food choices now…. cooking my meals at home …

- HPR002: Often it's finding out about what they eat, um and it will be a simple word about getting back to basics, back to eating as close to nature, and home-cooked meals as possible, ….It's challenging with food because it's like eat this food but not that food. …just really simple stuff …. It would be good to get back to some simple food prepared well. That doesn't take hours and hours to cook"

3. Balance

- HPR001 "but X (daughter) who is quite fit and active, I definitely was aware of her need to maintain a good balanced diet, but she's not as active now so I'm not aware that I do have to make sure she's not eating too much that's unhealthy …. So well definitely encouraging breakfast lunch and tea. No snacking in between times, lots of fruit, so that's where I definitely I don't scrimp, we've always got fruit in the fruit basket, low fat milk, and well, definitely encouraging breakfast lunch and tea….so a balanced diet is lots of fruit and vege, reduced meat and increased water.
- PAR001: even though the food I was eating for dinner was good, it wasn't as balanced as I would like so instead of having steak, salad and mushrooms which is what I planned, it was just really quick to cook the steak and the mushrooms at the same time and then I flagged eating the salad because it was going to take longer.
- HPR004: "…well I guess a balanced diet just means don't eat too much of one thing. For me it's spreading through the different food types, but it goes back to the pyramid which isn't quite so in fashion as it used to be of course but it still helps me to know the areas in which we should be minimising for me, and then talking to other people about that if that's what they want to know about, and how do I change this."
- HPR008: So I think that most people are trying to balance the intake of foods that are not healthy but that you enjoy eating more because of the taste or because they fill you up better or feel more satisfying than the foods you know are healthier or that may not appeal to your taste as much…. for every calorie you take in you need the nutrients coming in so you know the protein just has lots of fats, saturated fats, you know dairy has tremendous amounts of fats neither have any minerals vitamins or other essential bits that contribute to your health, you know so the difficulty is those tend to be the nicest tasting foods and so it's balancing, it's kind of a balancing act.

4. Moderation

- PAR001: I'm not so good, I'm not very good at saying, well actually I can be extreme, I can be all or nothing it's very difficult to have or to be moderate with me, I just go on eating it or I avoid it, try to avoid altogether.

5. Fasting

- HPR007: Yeah, I got interested in fasting probably about 6-7 years ago I suppose um and there are periods where I'll do it, I wouldn't term it religiously but consistently and I started doing it for reasons of body weight but these days I do it a bit more because I find it helpful for mood and concentration and focus. And I do believe genuinely that our body is designed to function better if we go for decent periods of time without food especially as you get older … I'm doing intermittent fasting at the moment, the 5:2 that is Michael Mosley's approach to lose weight, I've previously been successful doing that…"

Sociocultural elements of healthy eating

Culture

- HPR004: based on ministry of Health advice or - yes so basic food types meaning grains and vegetables and fruit and fats –it has pictures of foods it also is applicable across cultural groups, you have to be careful with that sometimes too, that we're not confronting what people might normally eat in their own environment and that we can somehow get it into the New Zealand context of how we eat. Like for instance Asian people have a lot of rice and fried dishes.
- HPR008: I think the same thing as what we've seen with smoking cessation will drive changes in diet it will be more of a cultural kind of thing. Make it socially unacceptable. We are some way from it. I don't think there is any slowdown of the good food market it's easy to demonise the fast food industry as being culprits one way or another but there are healthy options and I don't think the money can be always and excuse I think if you're diligent, put some effort towards it, you can eat healthy no matter what your budget is.

Tradition

- HPR006"…..culturally speaking I had a couple of Maori patients a few weeks ago and I asked them if they thought that Pacific Islander people – if they have, … well they probably ate lots of fish and protein and game meat and so I would say their genetic system is not ready to withstand the onslaught of carbs that they have these days"
- HPR007: there's a whole culture we have around food consumption as well too, in France and Italy, they sit down and eat all sorts of things …..whereas when you think about the stereotypical nonna or maternal figure making a huge meal with family around and people helping and bantering and knowing one another I think it is part of our lifestyle that has been pushed out and that's part of the reason people don't understand much about food and how beneficial it is to have home cooked food with there being an atmosphere of togetherness around food preparation"

Enjoyment

- PAR001: But then my mother has a love of cooking and I actually don't mind cooking, I like cooking especially when I've got time, but I also love baking. I'm most probably more of a baker than a cook, but I do enjoy food and I do enjoy preparing good food and X (husband) and I, I think have become slightly snobbish when it comes to food because we struggle when we go out.
- PAR002:.at least if we can come home and create something…you can gain happiness by creating something"

Appendix F: Barriers to healthy eating experienced by children, parents, and health professionals

Table 29. Barriers to healthy eating experienced by children

Theme: Social factors, with supporting quotes from the coded transcripts
• My brother is allergic to kiwifruit. My Dad he hides kiwifruit, we have them sometimes because my dad wants them, but we keep that away from my brother but apparently kiwifruit has bad sugar in it, but Dad wanted to keep them all to himself" (FG1, Child 3). • I'm a vegetarian, and my family are vegetarians, to keep us healthy…. We don't eat red meat or chicken" (FG2, Child 3).
• Theme: Food environment, with supporting quotes from the coded transcripts
• When I play rugby in the morning, I play like at 10 o'clock and then I finish and then Mum says what are we going to have for lunch and then we go and get a pie, or chips. Or if we're not going to be home for a while, I get some cash to put in the machine for some food. I normally would get lollies or chips"(FG2, Child 2). • "We get Subway lunches at school; Mum can order that online before school. School wouldn't let you do that if Subway was bad for you" FG2, Child 2; • "Here we can actually get breakfast at school, it's toast and spreads in case you miss out on breakfast at home" (FG2, Child 1).

Table 30. Barriers to healthy eating experienced by adults

Theme: Logistics, with Sub-themes and supporting quotes from the coded transcripts
Knowledge • "…there's a lack of basic understanding of what good food is … or what do you even do with something like a leek for example (HPR002) • "I think so, particularly for some of the younger mums, they're away from whanau and extended family who perhaps might have taught them, they might not have had the parenting or the opportunity to learn what to do with um, a cabbage (yeah) (laughs) or that there is not just one way to cook a cabbage, you can use it for all kinds of things (it would be quite nice not to have boiled cabbage!) ….so maybe it's about they might not have been exposed to that kind of food, the things that might help, things that are reasonably healthy (hmmm) and can be made quite tasty." (HPR004) ***Cooking ability*** • "…I want to eat healthy, and I want to eat healthy fresh vegetables but I don't know and no one's taught me how to cook them so they taste nice so our basic meals are meat and three veges and the veges are always just boiled or steamed. I don't really know how to make a nice meal with veges so I would like more knowledge on how to cook healthy stuff and things like chickpeas and beans and lentils. I always read that they are healthy but I don't really know how to cook them so we don't eat those particular healthy foods" (PAR004) • "Some people have access to gardens and some families do have good gardens, but that's a knowledge thing too, even how to grow vegetables in certain places and that growing certain things here is a different is going to be different than growing them in Tauranga for instance" (HPR004). ***Cost***

- "We're definitely not eating as much bread, but she does quite like toast in the morning so I do find that good breads are expensive and we justify that by buying multigrain, but it's still the cheaper one which I'm sure is full of salt, …so definitely curtailing that and we are cutting down on our meat definitely, and we got the …the cookbooks and they're vegetarian. We didn't intend to go vegetarian, but it is cheaper" (HPR001)
- "…there's a fruit and vege truck that comes to town once a week and they have really affordable options, so the cost of food isn't really a barrier for me it's just where you shop…. the cost of food – if you're going to spend $5 on a bulk muesli bars or something unhealthy or you could spend the $5 on pears. I don't think it's expensive to eat healthy, it's what you choose to buy. (PAR004)

Time factors

- "So time so as far as being more prepared… I don't get home until maybe 5.30 so um and basically I'm just trying to cook a basic meal that's just so I can get the kids fed by 6, 6.30 type of thing so they can go to bed by a certain time also so yeah, it it's time, being all prepared" (PAR003)
- "The time one is that just feeling pushed for time at the end of the day…..especially when you've got kids and their activities and stuff like that as well, and um you plan quick things you know so you can just get it smacked out and get kids bathed fed, bed sometimes (HPR012) "… um my two year old, well … sometimes he doesn't want breakfast because he'll sleep until 8 o'clock in the morning and I have to leave by 8.15 and (he's allergic to dairy) so he might have a glass of soy milk in a sippy cup or something like that so I know that'll fill him up and he won't want something to eat and I'm like that's not really good, but at least there is something in his tummy" (PAR004).

Theme Behavioural Factors, with Sub-themes and supporting quotes from the coded transcripts

Habits

- "….Just habit I suppose and what we were brought up with but I know some things, you know and a lot of it is to do with ease, as well like quick meals and stuff" (HPR012, nurse, parent);
- "…Definitely, so I think that is the no.1 contributor and if left unchecked it's going to lead to massive problems unfortunately so I would say I'm very concerned about children's diets and some of the habits they develop early … you know things just really evolve out of habit and I'm aware of myself you can, not eat biscuits in the evening, you know, you never had them in the house but if you buy a pack then you start to replenish that just like anything else that you run out of, and I think that that's the biggest barrier is that we are such creatures of habit and once you get into a schedule that works in your favour, if it's a good routine you can sustain it once it's the habit is there but if it's not good it can be really, really difficult to change because a lot of us have a fairly set work routine, a fairly set home routine, even a fairly set weekend routine into where every day and minute you could probably say where you are going to be and that would include your meals, I would say" (HPR008, GP, parent)

Willpower

- "…changing habits that they've had for decades, that takes an effort by everyone", with specific example provided; "If you're a dessert person, and you have dessert on Monday and Tuesday comes around and there's no dessert and you can go (assumes sad voice) 'oh it's no dessert day, that's too bad" and so I think you end up looking at the day (interruption) …so I think the barrier is 1. the habit and breaking the habit and 2. I think is really willpower because if you are going to break the habit and you can acknowledge that your current habit is unhealthy, you have to have the willpower to make the change (and do something about it) or else you are just stuck and you're going to make excuses

which is the opposite of having willpower and that's getting out of it so you can understand people dealing with that." HPR008

Habits and food addiction

- "Yeah and I think that confusion creates another barrier because people who have issues with overeating eating processed foods, eating sugary food, with overweight and diabetes already have an abnormal relationship with food so if they could eat healthy, they would already be doing it….. I don't know how to do it but to separate that pleasure principle for sugar, salt and fat together because there's this pleasure principle with food and we have to break that habit so you can taste your food again" (HPR010).

Theme: Psychology with Sub-themes and supporting quotes from the coded transcripts

Emotional eating and alcohol use

- "…with not smoking I've tended to drink more white wine. I mean I don't get drunk…. I know I don't need two glasses a night when my 15-year-old stresses me out (laughs wryly) I would have normally gone for a smoke something like that (so you got to go outside) yeah and it was a total 10 minutes of time dedicated and I could just think whoa, I don't have to worry about anything, a habit I guess (PAR003)
- "Um with alcohol you know I like to have a glass of red wine or sometimes in the weekend a glass of bubbles and I know that's just extra calories but I do enjoy that as well, just to wind down but I know I don't need that it's just extra calories yeah" (HPR008)

Sugar addiction

- "Oh I have very unhealthy diet actually, well I go through spurts, It's um stress and habit and emotional coping and there's some physiologic sugar addiction so I have trouble, if I get started eating sugar I have a very hard time stopping eating sugar. (HPR010)
- "…and also with the kids, they don't want to eat fruit and vegetables all the time, they like their sugary snacks. Although I try to limit it, but they're cheaper as well, and keeps them happy (HPR012)
- "…it's that blaming people for being gluttonous but I think that carbohydrates are addictive, and when they cut them out people no longer need willpower, because their hormonal profile has come back to normal…..But I think the biggest factor is that people are addicted to carbohydrates and that's causing metabolic dysregulation and a lot of things cascading from that. (HPR005.)

Depression

- "I think personally I see a lot of bad habits whether its eating, smoking drinking…inactivity I see a lot of them that sometimes cause, and sometimes effect actually with mental health problems ….. some doctors when a patient comes in and says "I can't sleep very well" and "ok, here's some sleeping tablets" rather than "why can't someone sleep" remembering that one of the most common causes people can't sleep is depression, so yeah and the other thing is that you know sometimes it becomes a bit of a downward spiral the persons anxious or upset for some reason they eat too much, they become overweight, they become anxious and da de da de da, on it goes. (HPR007).

Theme: Food environment with Sub-themes and supporting quotes from the coded transcripts

Ultra-processed food products

- We get quite a few children who are hungry, malnourished…it could be borderline if it was left so if children are getting food and being malnourished they're the ones who are living on packets of noodles every day at school, they're probably going to get a bit malnourished after that, a winter or summer of that , you're not going to be doing quite so well…yeah." (HPR004)

- "It's difficult because we have a lizard brain that's like this is yummy good food and we have food scientists tailoring junk food so we consume more…..so how do you not be tempted in this society with the food environment and the presence of food and junk food everywhere all around us yes so it can be difficult. There's a reason being overweight and obese is an epidemic" (HPR010, female GP) "…Definitely my teenagers … with their friends they tend to get pizza and or and especially at weekends or if they don't make their lunch - because I don't make their lunches anymore they'll just use their pocket money to buy rubbish at the tuck shop or whatever it's called" (PAR004, female)

Advertising

- "…McDonalds, um, lovely adverts, that was an advert for McDonalds b4 Christmas you get watching it because it's nice and oh, it's for McDonalds, with a grandfather taking the kids, which was lovely but the two different messages really" (HPR001, parent)
- "I'm from Auckland originally and when we're talking about obesity and other stuff it's a combination of those things in fact marketers put KFCs and McDonalds and burger King everywhere close by people with less means to afford healthy food so …I think buying healthy food is something they are just not used to and is fairly expensive…..the way that marketers have, intentionally or unintentionally led people down a very, very, very bad road which is geared towards more sugar" (HPR006, male GP)

Confusion

- "I think also people go into a bookshop to get a recipe book but they're confronted with… a bewildering array of cookbooks and there's … those food programmes on TV – yeah, I don't think there's ever been such a range of cooking shows on TV and people feel inadequate or inferior if they're not producing family food that looks like the restaurant quality food. And I think that has an effect on how people might feel about food when they are preparing food themselves for their families and when we're all bombarded with all these ideas of what good food should look like and how it's presented really" (HPR002 female GP, parent)

Theme: Social Factors with Sub-themes and supporting quotes from the coded transcripts

Children's preferences

- "Yes, so unfortunately we've got one picky eater, and that's the biggest challenge for me in that he is very limited in what he will eat. So he has a preference for chicken, he will occasionally eat fish, I can get him to eat smoothies, he'll eat brown bread and he'll eat crackers, and maybe the occasional apple, so very limited with him… and catering to the picky eater is the biggest challenge and trying to eat him to eat healthy so continually trying to get him to try foods that he'll be spitting out but continuing to reintroduce those foods…..So we're pretty much on a schedule which started us from early on so that it's sort of a mealtime for the kids is breakfast snack, lunch, snack, dinner, snack, and the meal may not be much bigger than a snack at times, yeah and keeping him from getting irritable (HPR004, female GP, parent)

Teenagers

- "And then my 15 year old she's so conscious about her weight and so she's like 'I'm not eating dinner!' and later in the night she's snacking on 6 pieces of toast and I'm like 'ohhh' yes, T my 15-year-old she's working part time at LS (local restaurant), so on a late night…., because she wouldn't have had dinner at home, she's would have got a takeaway dinner from LS, yeah, from there like pizza or wedges or gosh, and will eat it at 9 at night and I'm like ooohhh, no" (PAR003)

Extended family

- "Yeah definitely… my parents pick up my two year old, so sometimes because it's so late or whatever I tend to eat what they've made for dinner sometimes which is sometimes they might have a high fat roast that kind of stuff, yeah, or sausages….they tend to have a high fat, high meat and I just eat it for convenience because then I don't have to cook when I get home". (PAR003)
- "…Usually the dental nurse is already working on that with the parents but sometimes I also have to gauge the parents' response because sometimes you have parents that are just not willing to change. In that case you may tell the child "please don't have lollies", "after eating lollies please brush your teeth" but if you have five aunties who are giving them lollies what can you do? You need the five aunties coming in so you can teach them too and stop doing that and to give something else to the child instead……Because their mothers are working or away, for whatever reason and some parents feel some difficulty in taking on relatives regarding provision of sweets to the child because they are grateful for the support, and care provided but it is tough for them to see their children being given sweets that they themselves would not have been given as children. So, the grandparents are treating the children and the children are receiving sweets on a very regular basis from a caregiver" (HPR014)

Health issues of family members

- "Because when we do go really healthy which we do now and then because we need to, my husband is a Type 1 diabetic, Um, it just seems, the grocery bill is heaps bigger. And you get less for it…and with the kids, they don't want to eat fruit and vegetables all the time, they like their sugary snacks. Although I try to limit it, but they're cheaper as well, and keeps them happy….Yeah he's not the best at it, keeping on top of things, and I'm not, probably not as supportive as I should be with him in that. But we know what he needs to eat and what he shouldn't eat and stuff like that. But we're not 100% on the ball all the time ……Is anybody? (HPR012, female, nurse, parent)

Social pressure

- **"**Um I suppose when you go on a more…., I wouldn't call what I am doing with keto now as restrictive, but some people well at the start I felt a bit embarrassed when for a start people would go "what are you doing, you're on a diet, not eating sugars, what do you mean, you don't want a biscuit?" Or a bit of chocolate or whatever and I'm "no I'm just not eating it" and once you're past that first bit of embarrassment – which is a bit silly but that's how it is, - then it's no problem at all so yeah (HPR006)
- Well there's one thing with the bodybuilding side of it it's like when people are trying to force me like my mum when I see her "can you have something else?" so even she did it the other day so it's "why can't you have that?" as opposed to asking me what I could have (PAR010)
- "My husband likes us to eat meat a lot and I like to have some nights where we don't eat meat, so we compromise on that and we do half and half so half of the week's meals have meat and the other half I try not have meat (yeah). Other extended family members, like when we go to my grandparents' house for a drink, they have unhealthy food on the table that's the only option, it's quite fattening food, cheese and salami, um yeah". (PAR004).
-

Solo eating

- "…. So yeah, I think also I live by myself and I like to cook but I'm tired when I get home and cooking for one there's kind of challenges with that so I end up making less healthy choices with cooking for one and being home by myself and I end up with more easy food than healthy food….Well it's either having to cook a lot and have lots of leftovers, or you know just making a mess for one piece of chicken. (HPR010, female, GP).

Table 31. Barriers experienced by health professionals in providing dietary advice

Theme: Logistics, with sub-themes and supporting quotes from the coded transcripts
Knowledge • "…I don't think we were well versed on nutrition as undergrads (at medical school?) no, and if it's changed a lot from 15 years ago ….we did nutrition maybe in third year, which would have been a semester-long paper, but it wasn't fully on nutrition, it would sort of be physiology with a nutrition component, ….but it was very non-applicable to the patient, it was like Krebs cycle and basic biochemistry,…metabolism, and how quickly the body will burn grams of this or whatever, so I don't remember it being all that applicable and then you go out into clinical medicine experience or exposure and I don't recall there being any specific good nutritional teaching." (HPR002, female GP) • "To be honest, I don't feel like my nutrition background is very strong. You know I can give basic advice and direction … well I suppose not so much nutritional knowledge, but being able to adequately provide things like great meal plan advice, give carb counting, … we have a diabetic nurse who is our go-to person who would advise patients on specific diabetic diet, advise you know generally I feel like I know what foods are appropriate for a healthy diet, but saying I could adequately design a diet specific to a patient I feel that is probably not my forte". (HPR004) • "…I would send an uncontrolled diabetic to them and they would get the message indicating that it was alright to eat hash browns and toast for breakfast and a sandwich with bread at lunch and pasta for dinner and …that this was OK and you know … I would be frustrated by that so I would try to do more of the teaching myself but it's difficult because you don't have the time in your consults to do a lot of it…. I don't have time in my consultations to give a coaching session. (HPR010, female GP) ***Time*** • I find it difficult because of time constraints because I think I'm capable of telling someone even if they are educated, or come from a different culture, If I had time, I could probably do it but time is the main constraint and then you have the cultural barriers, education level of some people but I'd say time would be a big thing for me (HPR006)
Theme: Psychological Factors with sub-themes and supporting quotes from the coded transcripts
Confidence • "One thing I was thinking about for me is that I struggle with my weight and my relationship with food and here I am giving dietary advice and so sometimes that can be challenging for me as I feel like a hypocrite when I haven't got it figured out yet so that can be a kinda hard as a physician, but yeah, I did want to mention that…If I had to pick something I would say young adult men are more challenging to give advice to for me……the unfortunate pressure that young men feel to be right all the time and maybe it also has something to do with being a middle aged female giving advice to a 20-something male. (HPR010) ***Helplessness*** • "…But you've got the tuck shop there at school and they do come in with their pies and their fizzy and you're thinking "what do I say, how do I approach this?" so yeah". (HPR001, nurse) • "…People seem motivated during the consult, you get them all geed up and ready to go, but you try to follow these people but they've just disappeared back into obscurity again. And they just keep on doing what they were doing, until the next year". (HPR009, nurse)

Empathy

- "Yeah I think I'm spending a bit more money on food, I think fresh produce, veges, meat, fish, they're a bit expensive which is a barrier, well not so much for me but I imagine it would be a barrier for other people with less financial means" (HPR006)
- "With dealing with this on a day to day basis and feeling knowledgeable about the subject, I still have a hard time making healthy food decisions and looking after my general health so finding how difficult it is for me, with everything else going for me you know in the sense of having a stable home life, access to you know I can join the gym, I've got income, transportation, I've got the motivation, I've got the willpower, all those things in place and I've not got a slam dunk to just be as healthy as I want to be and I don't have any excuses" (HPR008).
- "What I'll say is like parents say well you offer them healthy dinner and they don't want to eat it and an hour later if they want a snack you give them the healthy food again…. I've never parented but I've seen how parenting is and it looks really, really, hard. So I can understand why that's challenging (HPR010, female GP)

Access

- "In this area you might not be able to get all the things you would like to make a particular recipe, not that I'm going to be making complicated things, but I enjoy cooking, but often you can't get some of the things that you can in bigger centres. There are also people who live in the countryside who don't have a car or are working shifts so they physically can't get to markets (HPR004).
- "…sometimes it's hard for working mums to access the cheapest things where and when they are the cheapest, like getting to the market, perhaps getting down to the vegetable market when there are, say on a Saturday morning when they have been working shifts, either then or overnight or there are ten other things to do with kids so they might not always be able to pick up cheap vegetables" (HPR004).

Theme: Social factors with sub-themes and supporting quotes from the coded transcripts

Patient attitudes

- "I'll try and have a discussion with the parent about the fruit juice thing and sugar in general, but it's weird you know, people come back at you like "you're punishing me because you're telling me to have water" I try to make it clear to people that may be what it seems like, but because I want to see you in better health, yeah….Maori patients more frequently will say 'the doctor had a good growl at me" whereas that's not my perception of how that conversation went. (HPR007).
- "…but if the person's answer to "do you like to cook" or are you interested in cooking more to eat healthier?" if they say "I don't think I'd be able to have the time to do it" or "I don't like cooking" then it's, the follow-up is kinda moot, you can't suggest recipe ideas because you'd get 'as I told you, I don't really cook'" (HPR008).

Learned Helplessness

- "…So when you add a barrier of getting some conflicting information I think it's in my experience people have a lot of discouragement already about diet because anybody who's overweight wants to lose weight and they haven't been able to or they would have so when you start talking to people about nutrition and diet they just go euuuunnngh because they've tried and tried and tried, and it's a battle they've been fighting for a very long time… Like I said earlier there are people who say they've tried this and tried that but nothing works" ….I think the hardest thing is older people who have lived with diabesity

and trying and trying and trying the low fat, calorie in, calorie out things for decades and they're just beyond discouraged… and they've been told that they will never get off medication and it's a progressive disease so I think there's a lot of discouragement and hopelessness around it" (HPR010).
- "The idea that patients have that a drug will fix problems (HPR007)

Parental attitudes
- "The common scenario is a large parent with a large child who doesn't see it as a problem or doesn't want to bring it up because you don't want to upset the child (HPR007)
- "I was looking at going down the referral pathway and getting Mum in because these kids aren't the ones doing the shopping they're not buying the food that's in the cupboard so it's um trying to get the parents to engage too, erm if there are only sweets and chippies in the cupboard well what else can he bring to school? But then you raise the question to the teenager himself about the food at home and he got very defensive about his Mum and what she was buying so there's issues there" (HPR001)

Other health professionals
- "it would be nice if we could get a little bit of agreement, you know there's 10 of us doctors who work here you want to hear what each of them thinks is a healthy diet, and you realise that people are not even getting the same message reinforced over and over again, it can be widely differently, fasting, vegetarian, to very low calorie, to very low carbohydrate, and that being presented can sound so different to the patient even if they're 100% on board, coupled with them googling in healthy breakfast ideas or healthy dinner ideas, or healthy eating for pre-diabetes, and then whatever else they might do in their own time and whatever their family might think…that leads to confusion" (HPR008)
- "…sometimes I find especially with the keto diet that there's been a bit of resistance from dietitians themselves…. when you hear patients that are told "I'm sorry I'm not going to support you because I don't believe in the keto diet" well when that comes from a health professional I think that's pretty serious and I've heard that from a patient of mine and I was very disappointed….That seems like a challenge to work with other health professionals who are just following a different paradigm. You feel a bit, you have to be ready to defend your ground so you really have to know what you are talking about the reasons, the studies, which is good I'm learning a lot, I don't mind but you have to be ready to defend your ground from comments and yeah it's difficult" (HPR006)
- "I've had a dietitian questioned my diagnosis of diabetes after a patients HbA1c dropped from 52 down to 33 she questioned the initial diagnosis in the first place after 4 months……Interesting their thought was that the patients might not have had diabetes because this just does not happen, according to them. My response would have been 'Wow! How did this happen, tell me about this, this is exciting' but to actually question whether it was real was – yeah. ….. but I don't question it because I've seen it over and over again. But yeah, the pushback is coming" (HPR005).
- I've just been reading through the …policy document from … a general practice site to clamp down on treating outside of guidelines and it's aimed at integrative medicine practitioners but I can see where prescribing a ketogenic diet is going to fit - or not - in there. It looks like there are aiming at homeopathy and intravenous Vitamin C and nutrient prescribing … which is going to get interesting around these moves to implement some structure on GPs operating outside of guidelines. (HPR005).