Exploring Diet Quality and Dietary Practices of Low Carbohydrate Diet Followers in New Zealand

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

Master of Science

in

Nutrition and Dietetics

at Massey University, Albany

New Zealand

Tayla Knightbridge-Eager

2020

Abstract

Background: Low carbohydrate (CHO) diets are regaining popularity and media coverage, however, little is known about the dietary practices, CHO-substitution practices and nutrient intakes of low CHO diet followers in New Zealand (NZ). This study aimed to assess diet quality and understand motives, dietary practices, and food-related behaviours of low CHO diet followers in NZ.

Methods: This cross-sectional study included 74, self-identified low CHO diet followers, aged 20-45 years, via a convenience sample from Auckland, NZ. Dietary intakes were explored by total group and gender, and by level of CHO intake (very low [VL; <50 g/day], low [L; 50<100 g/day] and moderately low [ML; 100<150 g/day] CHO groups). A cut-off (150 g CHO/day) was applied to the latter and data were adjusted for age, gender and total monthly income. Food and nutrient substitution practices were assessed. Motives for following a low CHO diet, and dietary rules, practices and choices were explored using the Dietary Principles and Quality of Life questionnaire.

Results: Participants consumed a low CHO diet (65.9 g/day; 14.0% of energy intake). One-way ANCOVA was used to explore differences between low CHO groups. No group (male and female; VL, L and ML CHO) achieved the Nutrient Reference Values (NRV) for CHO (inadequate), total fat, saturated fat (SFA) and sodium (excessive) intakes. Only the ML CHO group achieved the NRV for micronutrients assessed (excluding sodium). Gender groups did not achieve NRV for calcium and potassium, women did not achieve the thiamin NRV. The VL CHO group did not achieve NRV for thiamin, folate, vitamin E, calcium, zinc, magnesium, iodine and potassium and the L CHO group for calcium, iodine and potassium.

Respondents avoided CHO and foods they once enjoyed; CHO-foods were replaced with protein- and fat-containing foods. Participants were motivated by weight-loss, convenience and ease of application.

Conclusion: Low CHO diets pose dietary risks related to excessive total fat, SFA and sodium, and inadequate fibre intakes. Diets VL and L in CHO contained inadequate quantities of micronutrients, however the ML CHO diet achieved NRV. Dietary recommendations for low CHO dieters should focus on a ML CHO intake, reducing SFA and sodium intakes, and increasing plant-based foods to achieve micronutrient recommendations.

Acknowledgements

I would like to express my many thanks to a number of persons involved in this thesis project.

Firstly, to the LOCA study participants and the LOCA study team, thank you for dedicating your time and aptitude of knowledge, thereby making this research possible.

To my supervisors, Associate Professor Rozanne Kruger, Associate Professor Carol Wham and Dr Marilize Richter, thank you for your support and expertise.

Thank you to Linda Rassam, for the tremendous positivity, kindness and encouragement you have consistently brought to the table over the past two years. I will be forever grateful for your support and friendship.

To Viola, Tania and Nico, thank you for the hours of booking participants, data collection and data entry you have contributed to this study.

To my parents, Leigh and Rex, Grant and Mereana, and to my siblings, Mandy, Brooke, and Logan. Thank you for a lifetime of endless support, patience and encouragement.

A big thank you to my partner, Blake, and to my girlfriends, Elese, Alice, Kate, Harry, Brooke, and Ami-Lee. Thank you for supporting me through the ups and the downs; for the endless patience, boundless support and bountiful laughter you have given and continue to give.

To my high school science teacher, Paul Cathersides, thank you for six consecutive years of Science; for the passion and enthusiasm you instilled in your students.

Lastly, to all of my friends and family who have encouraged and supported me over the past two years, thank you.

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Abbreviations

%EI	Percentage of Energy Intake
AI	Adequate Intake
AMDR	Acceptable Macronutrient Distribution Range
ANOVA	Analysis of Variance
ANCOVA	Analysis of Covariance
ANS08/09	2008/09 New Zealand Adult Nutrition Survey
BIA	Bioelectrical Impedance Analysis
BMI	Body Mass Index
BMR	Basal Metabolic Rate
CHO	Carbohydrate
CI	Confidence Interval
DALY	Disability-Adjusted Life Year
DPQOL	Dietary Principles and Quality of Life (Questionnaire)
EAR	Estimated Average Requirement
g	Gram(s)
GI	Glycaemic Index
GL	Glycaemic Load
HbA1c	Glycated Haemoglobin
HDL-C	High Density Lipoprotein Cholesterol
HDQ	Health and Demographics Questionnaire
HNRU	Human Nutrition Research Unit
kcal	Calories
kJ	Kilojoules
LCK	Low Carbohydrate Ketogenic
L CHO	Low Carbohydrate

LCT	Long Chain Triglyceride
LDL-C	Low Density Lipoprotein Cholesterol
LOCA	Low Carbohydrate Diet
MCT	Medium Chain Triglyceride
ML CHO	Moderately Low Carbohydrate
MUFA	Monounsaturated Fat
NK	Nutritional Ketosis
NNS97	New Zealand National Nutrition Survey 1997
NRV	Nutrient Reference Value
NZ	New Zealand
PAL	Physical Activity Level
PUFA	Polyunsaturated Fat
SD	Standard Deviation
SDT	Suggested Dietary Target
T2DM	Type II Diabetes Mellitus
TEF	Thermic Effect of Food
VL CHO	Very Low Carbohydrate
WFR	Weighted Food Record
WHO	World Health Organisation

Chapter 1: Introduction

Beginning with William Banting in 1863, public interest in low carbohydrate (CHO) diets has waxed and waned since the 1800's. Banting, a formerly obese undertaker and coffin maker, wrote about his successful weight loss which he achieved by limiting his CHO intake (Banting, 1869). Low CHO diets were later promoted by the physician, William Morgan, for the treatment of diabetes (Morgan, 1877). A century later in 1972, low CHO diets regained popularity with the publication of "Dr Atkins' Diet Revolution: The High Calorie Way to Stay Thin Forever" (Atkins, 1972). A variety of low CHO diets, such as Eco-Atkins, South Beach, Zone, and Paleo, have since been promoted (Fields, Ruddy, Wallace, Shah, & Millstine, 2016) and trialled in the management of the health conditions of obesity (El Ghoch, Calugi, & Dalle Grave, 2016), prediabetes and diabetes (Brinkworth et al., 2016; Yamada et al., 2014), epilepsy (Kenig, Petelin, Poklar Vatovec, Mohorko, & Jenko-Pražnikar, 2019; Neli et al., 2018), brain tumours (Neli et al., 2018), fibromyalgia (Ernst & Shelley-Tremblay, 2013) and diarrhoea-predominant irritable bowel syndrome (Austin et al., 2009). With the resurfacing of the Atkins diet (Atkins, 1972) as The New Atkins (Atkins, 2001) and Eco-Atkins diets (Jenkins, Wong, Kendall, & et al., 2009), then Banting 2.0 (Noakes, Proudfoot, & Creed, 2015) and now ketogenic diets (Harvey, Holcomb, & Kolwicz, 2019; Zinn et al., 2017), low CHO diets have reclaimed substantial media coverage and popularity, particularly as a dietary strategy for weight loss (Churuangsuk, Griffiths, Lean, & Combet, 2019; Churuangsuk, Kherouf, Combet, & Lean, 2018; Nakamura et al., 2016; Piia, Mari, Satu, & Nina, 2014; Seidelmann et al., 2018; Zinn et al., 2017).

The National Health Medical Research Council (NHMRC) and Ministry of Health (MOH) from Australia and New Zealand (NZ), respectively, have established evidence-based recommendations for macronutrient intakes to reduce chronic disease risk (National Health and Medical Research Council, Australian Government Department of Health and Ageing, & Health, 2006). These are termed Acceptable Macronutrient Distribution Ranges (AMDR) and are expressed as a percentage of energy intake (%EI). The AMDR for CHO, protein and fat are 45-65%EI, 15-25%EI and 20-35%EI, respectively (National Health and Medical Research Council et al., 2006). Therefore, any diet with less than 45%EI as CHO may be considered as low in CHO (Nakamura et al., 2016).The AMDR for CHO intake was dictated by an increased risk for coronary heart disease with CHO intakes >65%EI, relative to lower high-density lipoprotein cholesterol (HDL-C) and/or higher triglycerides, and obesity with intakes <45%EI, relative to higher fat and energy intakes (National Health and Medical Research Council et al., 2006). A recent prospective cohort study and meta-analysis (2018), reported associations between CHO intakes and mortality, where CHO intakes of

50-55%EI conferred the lowest risk, and CHO intakes of >70 EI% and <40 EI% the greatest risk of mortality (Seidelmann et al., 2018). However, this may be an oversimplified representation of the relationship between CHO intake and mortality, as the main macronutrient source of energy (plant- versus animal-based) influences this relationship. When plant-derived sources of fat and protein replaced CHO, a decrease in mortality was observed, but a mortality increase was found when CHO were exchanged for animal products (Seidelmann et al., 2018).

Despite a vast discrepancy in what constitutes a low CHO diet, followers typically consume less than 150 g of CHO per day (Brouns, 2018; Westman et al., 2007). Low CHO diets can further be defined as very-low (VL; <50 g/day; Brouns, 2018), low (L; 50<100 g/day; Bilsborough & Crowe, 2003) and moderately low (ML; 100<150 g/day; Brouns, 2018) in CHO. Some VL CHO dieters also restrict protein to <20%EI (Harvey, Schofield, Williden, & McQuillan, 2018; Kenig et al., 2019) and increase fat to ≥75%EI (Harvey et al., 2018); this dietary strategy is known as the ketogenic ('keto') diet. The goal of the keto diet is to induce nutritional ketosis (Westman, Yancy, Tondt, & Maguire, 2018), a catabolic state induced by CHO restriction. Limiting CHO to <50 g/day reduces blood glucose levels and corresponding insulin secretion, thus reducing the stimulus for glucose and fat storage resulting in catabolism of fat into fatty acids (Harvey et al., 2018; Masood & Uppaluri, 2019; Pogozelski, Arpaia, & Priore, 2005). These fatty acids are metabolised into acetoacetate and converted into ketone bodies (beta-hydroxybutyrate and acetone), which accumulate in the body and provide an alternate source of energy (Masood & Uppaluri, 2019).

Furthermore, followers of low CHO diets typically do not restrict energy intake (Cipryan, Plews, Laursen, Ferretti, & Maffetone, 2018; Fields et al., 2016; Johnstone, Horgan, Murison, Bremner, & Lobley, 2008; Kenig et al., 2019; Sanada et al., 2018; Yamada et al., 2014; Zinn et al., 2017), but rather replace CHO by favouring dietary fat and/or protein (Seidelmann et al., 2018) to achieve their energy intake, subsequently exceeding the respective AMDR (Brinkworth, Noakes, Buckley, Keogh, & Clifton, 2009; Churuangsuk et al., 2019; Nakamura et al., 2016). However, the macronutrient composition of low CHO diets have been associated with appetite suppression (Pogozelski et al., 2005; Poppitt, Cameron-Smith, Lim, Liu, & Lu, 2019) and a spontaneous reduction in energy intake (Johnstone et al., 2008; Weigle et al., 2005; Zinn et al., 2017). This is attributed to the anorexigenic effects of dietary protein (Du, Markus, Fecych, Rhodes, & Beverly, 2018; Johnstone et al., 2008; Yang, Liu, Yang, & Jue, 2014) and nutritional ketosis (Hu et al., 2016).

In stark contrast to dietary guidelines and characteristics of healthful eating patterns, low CHO diets promote the consumption of animal products, high-fat dairy, salt, and dietary fat, and the restriction

of high quality CHO including vegetables, fruit, legumes, wholegrains, and low fat dairy (Naude et al., 2014), such diets which replace CHO with animal derived sources of protein and fat, increasing meat and saturated fat (SFA), increase mortality risk and should be discouraged (Seidelmann et al., 2018).

High SFA intakes are thought to increase total and low-density lipoprotein cholesterols, and increase risks for obesity, type 2 diabetes, hypertension and cardiovascular disease (CVD; National Health and Medical Research Council et al., 2006). However, reports on the relationship between SFA and CVD are contradictory, and may be influenced by the consumption of low quality CHO, such as refined and processed CHO foods (Siri-Tarino, Sun, Hu, & Krauss, 2010a, 2010b). Furthermore, both high fat intakes and the consumption of processed meat have been associated with colorectal cancer (Baghurst, Record, & Syrette, 1997; Riboli et al., 2002). Unlike low quality CHO, high quality CHO provide the body with beneficial nutrients such as vitamins, minerals, antioxidants and dietary fibre, which are good for human health (Reynolds et al., 2019).

Vitamins and minerals perform hundreds of roles in the body, including wound healing, immunity, maintenance of the skeleton and the conversion of food into energy (National Health and Medical Research Council et al., 2006). Antioxidant nutrients interact with and quench the damaging free-radicals, within the human body, to reduce the destruction of cellular organelles, such as DNA (Zampelas & Micha, 2015). Dietary fibre is essential for normal gut function, it benefits laxation, reduces plasma cholesterol and modulates blood glucose levels, and has subsequently been related to a reduction in risk for heart disease, certain cancers and diabetes (National Health and Medical Research Council et al., 2006). In NZ, major sources of dietary fibre include breads and cereals, fruit and vegetables. However, given the primary goal of CHO restriction, low CHO diets may inadvertently be low in high quality CHO and hence these beneficial nutrients, and may ultimately negatively impact health.

Dietary risks account for 9.4% of total disability-adjusted life years (DALY), thus constituting the greatest specific risk factor for health loss in NZ (Ministry of Health, 2016). Low fruit and vegetable consumption and high salt intakes, inherent to low CHO diets, contribute the largest burden to dietary risks (2.5% and 1.3% of total DALY, respectively). Furthermore, the proportion of the population achieving the NZ MOH guidelines for fruit and vegetable intakes (2+ and 3+ servings per day, respectively) has declined by more than 10% since 2011/12 (44.5% in 2011/2012 to 32.5% in 2018/19; Ministry of Health, 2019). Other notable dietary risks relevant to the low CHO diet, include high red meat consumption and low whole grain, fibre and calcium intakes (Ministry of Health, 2016). Given their growing popularity, it is plausible to caution the current and

future impacts that low CHO diets may have on health loss in NZ. The second greatest specific risk factor for health loss in NZ is high body mass index (BMI; 9.2% of DALY; Ministry of Health, 2016). Statistics NZ reported that in 2018/19, 31% of NZ Adults aged 15 years and older were obese (Ministry of Health, 2019), an increase from 28% in the 2008/09 NZ Adult Nutrition Survey (ANS08/09; University of Otago & Ministry of Health, 2011).

Individuals seeking weight-loss are opportune to a myriad of diets (McVay et al., 2014). We know that compared to a low fat diet, selection of a low CHO diet has been associated with a baseline higher fat intakes and lower CHO intakes (McVay et al., 2014). The low CHO diets have also had greater efficacy in achieving short-term (6 months) weight loss in persons living with overweight and obesity (Brehm, Seeley, Daniels, & D'Alessio, 2003; Foster et al., 2003; Naude et al., 2014; Samaha et al., 2003) but not in the long-term (1-2 years; Brinkworth et al., 2009; Foster et al., 2003). Weight-loss, regardless of how it is achieved, favours metabolic and functional changes in obesity, hypertension, hyperglycaemia, insulin resistance and dyslipidaemia (Nakamura et al., 2016; Westman et al., 2007). However, such reductions in energy intake may not be biologically or behaviorally sustainable long term (Mozaffarian, 2016).

Despite the recent and recurrent increase in public interest and following of low CHO diets, we do not know why low CHO diets are followed and little is known about these followers and how they differ from the rest of the population in terms of background, food choices and perceptions (Piia et al., 2014). Furthermore, there is little evidence as to how low CHO diets are being implemented at home by New Zealanders. Investigations need to be undertaken to asses diet quality and understand the dietary practices, habits and behaviour of this cohort to (1) better inform the suitability and sustainability of low CHO diets, and (2) develop initiatives and tailored dietary advice which provides evidenced based guidance to promote the optimal health of persons following a low CHO diet.

1.2 Aim, objectives and hypothesis:

The aim of this study was to assess diet quality and understand the motives, dietary practices, and food-related behaviours of self-reported low CHO diet followers aged 20 to 45 years old, from the Auckland region in New Zealand.

1.2.2 Objectives

Objectives of this study were to:

1. Assess the total dietary intake (macronutrients, micronutrients and energy) of low CHO diet followers, stratified by total group and gender;
2. Explore the dietary intake (macronutrients, micronutrients and energy) by level of CHO intake;
3. Assess and describe food and nutrient substitution practices;
4. Explore and understand the motives for following a low CHO diet;
5. Determine the dietary practices, food choices and food rules currently employed and how they impact on participants' lives.

1.2.3 Hypotheses

Low CHO diet followers of Auckland, New Zealand will:

1. Be consuming less than the recommended 45-65 percent of energy as CHO, with concurrent increases in protein and fat intake;
2. Replace dietary CHO with foods primarily of animal origin;
3. Avoid CHO foods in which they previously enjoyed eating.

1.3 Structure of the thesis

This thesis is presented in four chapters. The first chapter introduces the topic and the importance of this research to the New Zealand population, including the aim and objectives of the study. The second chapter presents a literature review on carbohydrates, low CHO diets, plant vs animal-derived CHO substitutions and food choices and dietary motivations. Chapter 3 presents the research manuscript, outlining and justifying the study design and procedures, the findings and discussion of the study. Conclusions will be made in chapter 4, along with the strengths, limitations and recommendations for future research.

1.4 Researchers Contributions

Table 1.1 *Researchers contributions to the LOCA study*

Researcher	Contribution to thesis
Tayla Knightbridge-Eager *Masters student*	Recruited participants, collected data, data entry and processing, conducted statistical analysis, interpretation and discussion of results, prepared thesis.
Associate Professor Rozanne Kruger *Main supervisor*	Academic supervisor; designed the LOCA study, developed methodology protocols, assisted statistical analysis and the interpretation of results, reviewed and approved all chapters of this thesis.
Dr. Marilize Richter *Co-supervisor*	Academic supervisor; designed the LOCA study, completed ethics application, developed methodology protocols, assisted statistical analysis and the interpretation of results, reviewed and approved all chapters of this thesis.
Associate Professor Carol Wham *Co-supervisor*	Academic supervisor; assisted the interpretation of results, reviewed and approved all chapters of this thesis.
Linda Rassam	Participant recruitment, data collection and data entry and processing.
Viola Lasardo	Participant recruitment and bookings, data collection and data entry.
Tania George	Data collection.
PC Tong	Organised equipment for data collection, purchased foods and petrol vouchers.
Nico Bejeck	Data entry.

Chapter 2: Literature Review

This narrative review manuscript is formatted for submission to the Journal of Human Nutrition and Dietetics (Author guidelines in Appendix C). The referencing style for the research manuscript has been changed from the guidelines to be consistent between thesis chapters.

Low carbohydrate diets and carbohydrate consumption trends in New Zealand

Tayla Knightbridge-Eager, Marilize Richter, Carol Wham, Rozanne Kruger

School of Sport, Exercise and Nutrition, Massey University, Auckland, New Zealand

2.1 Abstract

Recently, low CHO diets have gained substantial media coverage and CHO have been singled out as the macronutrient responsible for poor health and obesity. The resurgence in popularity of low CHO diets has resulted in a wide array of self-selected low CHO diets being used. This narrative review aims to profile low CHO diets, explore CHO substitution strategies, and discuss food choices and dietary motivations for following low CHO diets. Search terms, including carbohydrate, low carb*, ketogenic, New Zealand, appetite, carbohydrate quality, mortality and motives were used in EBSCOhost. Ministry of Health resources and low CHO diet books were also used. Carbohydrate consumption has been associated with mortality; with minimal risk at intakes of 50-55 percent of energy intake (%EI), high (>70%EI) and low CHO intakes (<40%EI) are associated with an increased risk of mortality. Motivated by health, weight control, and the consumption of whole foods, low CHO diets typically consist of <150 grams of CHO/day, however various low CHO diets exist, with many having inadequate nutrient intakes. Impacts of low CHO diets are mediated by the extent of CHO restriction and the source of replacement macronutrients. Diets where animal-derived sources of protein and fat replace CHO, are associated with greater mortality than those which replace CHO with plant foods. Data assessing the nutritional adequacy of low CHO diets, as they're followed by *free-living* individuals, is limited. Carbohydrate intakes of NZ adults were stable (45-47%EI) from 1997 to 2008/09 but lower in more recent studies (37-43%EI) suggesting a probable reduction in CHO intake in NZ.

2.2 Introduction

Low CHO diets, which typically contain less than 150 g of CHO per day (Brouns, 2018; Mark, Justin, Nancy, Laura, & Thomas, 2017; Westman et al., 2007), are a popular dietary strategy, frequently used for weight-loss (Churuangsuk, Kherouf, Combet, & Lean, 2018). However, there is

no single definition or consensus of what constitutes a low CHO diet, rather there is a variety of low CHO diets cited in popular media, such as the Low CHO High Fat (LCHF), Ketogenic and Atkins diets. Few narrative reviews have sought to compare the macronutrient distribution of these diets.

Associations between CHO intake and mortality have been confirmed (Seidelmann et al., 2018). As a percentage of energy intake (%EI), both low (<40%EI) and high (>70%EI) CHO intakes were associated with an increased risk of mortality. However, when CHO are reduced the replacement food source, as plant- or animal-derived fat and protein, modifies this association (between CHO intake and mortality; Jenkins, Wong, Kendall, & et al., 2009; Seidelmann et al., 2018).

Food choice motivations have been investigated in previous studies, which reported that health, weight control and natural content were valued by low CHO diet followers (Clarke & Best, 2019; Piia, Mari, Satu, & Nina, 2014).

2.2.1 Objectives

1. To define CHO and to summarise existing literature on low CHO diets.
2. To summarise existing literature on plant- versus animal-derived protein and fat substitutes for CHO.
3. To define food choice motivations and summarise motivations for a low CHO diet.

2.3 Methods

Where possible, the most recent research and literature was used in this narrative review (1991-2020). Studies were only included if they involved adult humans. Study designs incorporated into this review include longitudinal population-based studies, randomised controlled trials, randomised crossover trials, and cross-sectional studies. Where available, New Zealand based studies were included in this narrative review, however due to the finite research on this topic, a range of international studies were also included.

Between July 2018 and January 2020 the following key words were used in the search on EBSCOhost and Google Scholar: low carb* diet, New Zealand (786 results), low carb* diet (68771 results) , ketogenic diet, New Zealand (30 results), ketogenic diet (16980 results), nutri*, intakes, New Zealand (7106 results), nutri*, adult, New Zealand (5863 results), low carb* diet, appetite (1432 results), carbohydrate quality (36160 results), fibre OR fibre, health, effects (46332 results), sugar (1051147 results), starch (295169 results), carbohydrate, health (93941 results), carbohydrate, mortality (9277 results), low carbohydrate, motives (90 results), higher protein diets (172323 results). Of these results, the following studies were used in this literature review: low carb* diet,

New Zealand (n=5), low carb* diet (n=22), ketogenic diet, New Zealand (n=2), ketogenic diet (n=10), nutri*, intakes, New Zealand (n=2), nutri*, adult, New Zealand (n=2), low carb* diet, appetite (n=6), carbohydrate quality (n=3), fibre OR fibre, health, effects (n=2), sugar (n=2), starch (n=1), carbohydrate, health (n=3), carbohydrate, mortality (n=3), low carbohydrate, motives (n=1), higher protein diets (n=4). References from the Ministry of Health and low CHO diet books were also used to assess nutrient intakes and describe variants of the low CHO diets, respectively.

2.4 Carbohydrates

Carbohydrates (CHO), are molecules that contain carbon, hydrogen and oxygen. Carbohydrates are one of the three key macronutrients (CHO, protein and fat) inherently consumed in the diet which provide energy to the body (Kretchmer & Hollenbeck, 1991; National Health and Medical Research Council, Australian Government Department of Health and Ageing, & Health, 2006; Sinnott, 2007). Carbohydrates are broken down into glucose, by mechanical and chemical digestion, glucose then moves into the bloodstream where it will be used or stored as glycogen (storage form of CHO) or fat. Glucose is the main energy source for the human body and the preferred source for the brain (National Health and Medical Research Council et al., 2006).

Dietary CHO are found in a variety of whole (wholegrains, legumes, fruit, starchy vegetables), minimally processed (milk, bread) and ultra-processed (cakes, biscuits, confectionary) foods, and are frequently identified as being the greatest contributor to daily energy intakes (Byun, Mayat, Aggarwal, Parekh, & Makarem, 2019; de Mello Fontanelli, Sales, Carioca, Marchioni, & Fisberg, 2018; Mozaffarian, 2016).

With extensive evidence to suggest a link between diet and chronic disease, the National Health Medical Research Council (NHMRC) and Ministry of Health (MOH) established the Acceptable Macronutrient Distribution Range (AMDR; Table 2.1; National Health and Medical Research Council et al., 2006). This is an estimate of macronutrient consumption, expressed as a percentage of energy intake (%EI), which allows for an adequate intake of all other nutrients (micronutrients) whilst maximising health outcomes and reducing the risk of chronic disease (National Health and Medical Research Council et al., 2006). As CHO are a source of ‘safe’ energy, recommendations for CHO have (for most groups) been set (a) to fulfil remaining energy needs after essential protein and fat requirements have been met, and (b) based on the interpretation that there is an increased risk for coronary heart disease (CHD) at CHO intakes above 65%EI and an increased risk of obesity with CHO intakes below 45%EI (National Health and Medical Research Council et al., 2006).

Table 2.1 Acceptable Macronutrient Distribution Range [a]

Macronutrient	CHO	Protein	Fat
Percentage contribution to total energy intake	45-65	15-25	25-30

[a] National Health and Medical Research Council et al. (2006).

The AMDR range for CHO was recently confirmed (2018), where CHO intakes below 40%EI and above 70%EI were associated with an increased risk of mortality, and CHO intakes of 50-55%EI was associated with minimal risk (Seidelmann et al., 2018). Similarly, a prospective cohort study from 18 countries across five continents (PURE; Dehghan et al., 2017) found an association between CHO intakes above 60%EI and total mortality. However, the findings from the PURE study did not observe an adverse effect of fats, including saturated fat (SFA), on mortality and did not support the MOH recommendations to limit total and SFA intakes to <30 and <10%EI, respectively.

There are three main categories of CHO (sugars, starch and dietary fibre) which vary in terms of CHO quality, measured by glycaemic index (GI) and glycaemic load (GL), which refers to the rate at which the ingested CHO food is digested by the body (Breymeyer, Lampe, McGregor, & Neuhouser, 2016; Byun et al., 2019). High GI and GL foods, such as refined grains, sugar sweetened beverages and added sugars, are low quality CHO which markedly increase total energy but not nutrient intake. When high GI/GL foods are consumed and digested, the subsequent sugar molecules are quickly absorbed into the bloodstream, causing a rapid rise in blood glucose levels (BGL; Byun et al., 2019; Kim, Kim, & Lim, 2018; Reynolds et al., 2019). Alternatively, low GI/GL foods such as wholegrains, fruits, vegetables and legumes are high quality CHO, they provide beneficial nutrients such as fibre and micronutrients. The food matrix of low GI/GL foods is more complex than that of high GI/GL foods, this is harder for the body to digest, resulting in an increase in time taken for digestion and absorption, and an attenuated rise in BGL (Byun et al., 2019; Kim et al., 2018; Reynolds et al., 2019).

A recently published study (2018), utilised the data from 12027 adults, aged 19-64 years, from the fifth Korea National Health and Nutrition Examination Survey to evaluate the association between CHO quality index (CQI) and the prevalence of obesity and metabolic disorders (Kim et al., 2018). The CQI was based on fibre intake, GI, and the ratios of wholegrains to total grains (wholegrains and refined grains) and solid CHO to total CHO (solid and liquid). Individuals with the greatest CQI had the greatest consumption of solid CHO, fibre and wholegrains, the lowest consumption of

liquid CHO and refined grains, and the lowest GI (Kim et al., 2018). Higher CQI was negatively associated with the prevalence of obesity and hypertension (Kim et al., 2018), therefore, the type of CHO consumed is an important factor to consider when health outcomes are concerned (National Health and Medical Research Council et al., 2006).

2.4.1 Sugars

Carbohydrates consist of building blocks called 'saccharides' or 'sugars' which can be found naturally present in, or added to, foods. Glucose, fructose and galactose are the simplest sugars consisting of just one sugar unit (monosaccharide; Table 2.2), two monosaccharides joined forms a disaccharide. Sugars are referred to as total, added or free sugars (Mela & Woolner, 2018). Most food labelling includes 'total' sugars, which includes all mono- and disaccharides, naturally present in or added to foods (Mela & Woolner, 2018). All added sugars are also free sugars; both added and free sugars exclude naturally occurring sugars present in dairy and intact fruit and vegetables, however, unlike added sugars, free sugars include all naturally occurring sugars in non-intact fruits and vegetables (Mela & Woolner, 2018; Table 2.3).

Table 2.2 Simple sugars [a]

Monosaccharides	
Glucose	Found in many foods, commonly bound to other sugars to form larger sugars.
Fructose	Fruit sugar. Found naturally in fruit, honey and root vegetables; added to processed foods (as high fructose corn syrup).
Galactose	Found in fruits and vegetables (cherry, plum, celery, avocado), nuts, grains, low-lactose or lactose-free milk, as an artificial sweetener.
Disaccharides	
Maltose (glucose + glucose)	Found in starchy foods (grains and cereals, cooked sweet potato, bread), brewed and malted beverages (beer, whiskey, milo).
Sucrose (glucose + fructose)	Table sugar. Found naturally in many fruits, vegetables and grains, or added to processed foods (sweets, soda, baked goods, desserts).
Lactose (glucose + galactose)	Milk sugar. Naturally present in dairy products (milk, cheese, yoghurt, ice cream).

[a] Kretchmer and Hollenbeck (1991)

Table 2.3 Total, added and free sugars [a]

	Total sugars	Added sugars	Free sugars
Includes all simple sugars (mono- and disaccharides) naturally present in or added to foods	Yes	No	No
Includes sugars, added by a manufacturer, cook or consumer, during food processing or preparation	Yes	Yes	Yes
Includes naturally occurring sugars in whole intact (fresh, cooked or dried) fruit, vegetables, or dairy products.	Yes	No	No
Includes naturally occurring sugars non-intact (pureed or juiced) fruit and vegetables.	Yes	No	Yes

[a] Mela and Woolner (2018)

To reduce the risk of obesity-related diseases and dental caries, the World Health Organisation (WHO) recommends reducing free sugar consumption to <10%EI for all persons and suggests a further reduction to less than five %EI (World Health Organization, 2015).

2.4.2 Starch

Long chains of monosaccharides, as oligosaccharides (<20 monosaccharides) and polysaccharides (>20 monosaccharides), are known as starch. Starch is the stored form of energy found in plants, the two most common starch-forming molecules are amylose and amylopectin (Nakamura, 2015). Amylose molecules are smaller and less complex than the highly branched amylopectin molecules and are therefore easier for humans to digest. Starch is found in foods commonly thought of as CHO (potato, corn, peas, rice, wheat).

2.4.3 Dietary fibre

Dietary fibre are CHO from the edible part of plants which cannot be completely broken down by mammalian digestive enzymes, remaining relatively intact when they reach the large bowel (Brown, Rosner, Willett, & Sacks, 1999; Claire et al., 2019; Lattimer & Haub, 2010). The cellular structure of fibre is relatively impermeable and acts as a physical barrier to digestive enzymes, slowing down digestion and the release of nutrients into the blood (Claire et al., 2019). There are two main types

of fibre: soluble fibre (oats, beans, psyllium) which dissolves in water to form a gel-like material, pulls in water to soften stools, and insoluble fibre (wholegrains, wheat bran, beans, fruit, vegetables) which acts as 'roughage' to increase stool bulk, 'sweep' the gastrointestinal tract and to promote laxation.

In the large bowel, soluble fibre is fermented by gut bacteria to produce short chain fatty acids and stimulates the secretion of anorexigenic gut hormones, glucagon-like peptide-1 and peptide YY (Claire et al., 2019). The increase in transit time and hormone secretion promotes longer-term satiety (Claire et al., 2019). Fibre consumption is associated with lower body weight (Byun et al., 2019; Reynolds et al., 2019), and may protect against weight gain (Claire et al., 2019). Greater satiety, lower weight gain and lower adiposity reduce the risk of hypertension (Byun et al., 2019).

The NZ MOH recommends an adequate intake (AI) of 30 g and 25 g fibre per day for adult (≥19 years) men and women, respectively (National Health and Medical Research Council et al., 2006). The AI was set to promote gut function and to reduce chronic disease risk (National Health and Medical Research Council et al., 2006).

Concurrent to NZ dietary guidelines, a recent "series of systematic reviews and meta-analysis" including 4635 adults from 185 prospective studies and 58 clinical trials reported significantly lower body weight, systolic blood pressure and total cholesterol when comparing the highest fibre consumers with the lowest (Reynolds et al., 2019). Risk reduction in all-cause, cardiovascular and stroke related mortality, and incidence of CHD, stroke, type II diabetes (T2DM) and colorectal cancer, were seen at fibre intakes of 25-29 grams/day (g/d), in a dose-response manner, with greater intakes likely to confer even greater benefits (Reynolds et al., 2019).

2.5 Carbohydrate consumption in New Zealand

Nutrition surveys have reported CHO intakes at the lower end of the AMDR for the past quarter-century (National Health and Medical Research Council et al., 2006). The National Nutrition Survey 1997 (NNS97) and the Adult Nutrition Survey 2008/09 (ANS08/09) obtained dietary data from 9357 (4636 and 4721 respectively) men and women, aged 15 years and over, in New Zealand (NZ; Russell, Parnell, & Wilson, 1999; University of Otago & Ministry of Health, 2011). Data demonstrated a stable CHO intake, of 45-47%EI daily, from 1997 until 2008/09 (Table 2.4; Russell et al., 1999; University of Otago & Ministry of Health, 2011).

Table 2.4 National carbohydrate intakes, 1997-2008/09

Year	Number of participants	Age (years)	Carbohydrate intake				Reference
			Men		Women		
			g	%EI	g	%EI	
1997	4,636	≥15	305	45	214	47	Russell et al. (1999)
2008/09	4,721	≥15	278	46.0	207	47.1	University of Otago and Ministry of Health (2011)

g: grams;%EI: percentage of energy intake

Over the past five years, NZ-based (Auckland) studies reporting the CHO intakes of pre-menopausal women, have demonstrated a reduction in CHO consumption, below the AMDR (Cao, 2018; Casale, 2015; Schrijvers, McNaughton, Beck, & Kruger, 2016; Singh, 2018). Relative to the population surveyed, these studies (2015-2018) have limited applicability to the entirety of the NZ population, however, limitations aside, CHO intakes of 37-43%EI were reported, less than both the AMDR and CHO intakes of the NNS97 and ANS08/09.

2.5.1 Sugar, starch and dietary fibre consumption

Median intakes of free, added and total sugars for adults (≥15 years) participating in the ANS08/09 were 57 g/d, 49 g/d and 107 g/d, respectively (Kibblewhite et al., 2017; University of Otago & Ministry of Health, 2011). Forty-two percent of adults adhered to the WHO recommendation to limit sugar consumption to <10%EI (Kibblewhite et al., 2017). Conversely, nearly two thirds of New Zealanders exceeded this recommendation, suggesting that public health initiatives are needed to reduce sugar consumption nationally.

Mean starch intakes, reported in the NNS97 (men: 176 g, women: 116 g), paralleled CHO consumption (Russell et al., 1999). Mean fibre intakes of NZ adults (>15 years) in the ANS08/09 were inadequate (men: 22.1 g, women: 17.5 g) and most (>80%) adults reported consuming less than the minimum of six servings of ‘grain foods’ per day recommended by the NZ MOH (Ministry of Health, 2015; University of Otago & Ministry of Health, 2011). Similarly, a downward trend in starchy food consumption, especially bread, has been observed in the United Kingdom (O'Connor, 2012). This has been attributed to consumer perceptions of starchy food as ‘fattening’, concerns

regarding wheat or gluten intolerance and allergies, and the growing popularity of low CHO diets (O'Connor, 2012).

New adult nutrition surveys would be advantageous in ascertaining the current impact of the low CHO diet on total diet consumption at a population level, to better ascertain any dietary risk.

2.6 Low carbohydrate diets

Low CHO diets, are diets in which CHO are restricted to less than 150 g/d (Brouns, 2018; Mark et al., 2017; Westman et al., 2007) or 20-40%EI (Bilsborough & Crowe, 2003; Churuangsuk, Griffiths, Lean, & Combet, 2019; Feinmann, 2018; Fields, Ruddy, Wallace, Shah, & Millstine, 2016; Nakamura et al., 2016; Naude et al., 2014; Winwood-Smith, Franklin, & White, 2017; Wylie-Rosett, Aebersold, Conlon, Isasi, & Ostrovsky, 2013) in favour of increased or unrestricted fat or protein intakes, or both (Seidelmann et al., 2018). Consequently, low CHO diets may exceed recommendations for fat and protein intakes (Brinkworth, Noakes, Buckley, Keogh, & Clifton, 2009; Churuangsuk et al., 2019; Nakamura et al., 2016). Low CHO diets frequently lack explicit energy restrictions (Cipryan, Plews, Laursen, Ferretti, & Maffetone, 2018; Fields et al., 2016; Johnstone, Horgan, Murison, Bremner, & Lobley, 2008; Kenig, Petelin, Poklar Vatovec, Mohorko, & Jenko-Pražnikar, 2019; Sanada et al., 2018; Yamada et al., 2014; Zinn, McPhee, et al., 2017) but have been seen to result in spontaneous reductions in energy intake (Johnstone et al., 2008; Weigle et al., 2005; Zinn, McPhee, et al., 2017). These ad libitum diets, popular for weight loss, are counter to conventional dietary weight loss recommendations supporting low fat, high CHO, energy-restricted diets.

A myriad of low CHO diets, of varying macronutrient compositions, referenced as g/d or as a %EI (Fields et al., 2016), have been utilised and described in literature (Table 2.5). These CHO-centric diets are typically moderately low (ML: 100<150 g/d; Brouns, 2018), low (L: 50<100 g/d; Bilsborough & Crowe, 2003), or very-low (VL: <50 g/d; Brouns, 2018; Harvey, Schofield, Williden, & McQuillan, 2018) in CHO.

Table 2.5 Popular low carbohydrate diets

Diet	Dietary restrictions		
Additional key features and goals	**CHO**	**Protein**	**Fat**
Low CHO Diet (Generic; Brouns, 2018; Westman et al., 2007)			
• Typically, no explicit target for total energy, protein and fat • CHO are substituted with protein and/or fat • Frequently used for weight loss and weight maintenance	<150 g/d	NR	NR
Classic Ketogenic Diet (Kenig et al., 2019)			
• Used to treat epilepsy • Energy intake tailored to requirements for growth or maintenance	2-4%EI	6-8%EI	90%EI
Very-low CHO Ketogenic Diet (Fields et al., 2016; Harvey et al., 2018; Harvey, Holcomb, & Kolwicz, 2019; Kenig et al., 2019; Zinn, Wood, Williden, Chatterton, & Maunder, 2017)			
• No explicit target for total energy intake • Goal of achieving nutritional ketosis and "keto-adaptation" (where the body shifts from using glucose to using fat as the main source of energy) • Used for weight loss, weight maintenance or altering body composition	<20-50 g/d, or 5-10%EI	13-17%EI, or as 1.5g/kg.bw	≥75%EI, or ad libitum
Low CHO High Fat (LCHF) Diet (Zinn, McPhee, et al., 2017; Zinn, Rush, & Johnson, 2018)			
• No explicit target for total energy intake • Encourages: non-starchy vegetables, meat, full-fat dairy and fats (nuts, avocado and 'healthy' oils) • Limits: fruit, legumes and starchy vegetables • Discourages: Processed foods, refined sugar, junk food, cereals and grains	<130 g/d, or <26%EI	15-25%EI	>33%EI, to fill caloric needs

The Banting Diet (Opie, 2014; Pogozelski, Arpaia, & Priore, 2005)			
• The original LCHF diet, named after William Banting who publicised this diet in the 1800's • Food-based approach: Avoid sugar, sweets, bread, beer and starchy vegetables (e.g. potato); replace these foods with meat and fish	NS	NS	NS
Real Meal Revolution (RMR)/Banting 2.0 (Opie, 2014; Real Meal Revolution, 2019)			
• LCHF/ketogenic based on the original Banting diet • Four phases: Phase 1: observation phase; Phase 2: restoration phase (medium CHO); Phase 3: transformation (low CHO, weight loss phase); Phase 4: maintenance phase • Uses a traffic light system to guide food choice: green (eat to hunger), orange (exercise control), light red (hardly ever), red (never ever), and grey (it's a grey area). Focus is on consuming meats, fish, poultry and eggs, non-starchy vegetables, and fats, and avoiding all processed and sweet foods (including processed oils), cereals, grains, gluten and starchy vegetables • Only eat when hungry and until full, eat mindfully • Claims to improve energy, induce rapid weight loss, reduce hunger, cure IBS, normalise blood pressure, cure heart burn and reflux, reverse PCOS symptoms, improve skin health	Phase 2: 50-100 g/d Phase 3: <50 g/d Phase 4: 100-150 g/d	NS	NS
Protein Power (Fields et al., 2016; Pogozelski et al., 2005)			
• Four to five meals/snacks per day • Foods limited or eliminated: gluten, legumes, starchy vegetables, high-sugar foods including candy and mango.	28-40 g/d, or ~10%EI	35%EI	>50%EI
Dr Bernstein's Diabetes Solution (Bernstein; Fields et al., 2016)			
• Restricts high GI foods. • 30 g CHO across 3 meals/day: Breakfast: 6 g, Lunch: 12 g, Dinner: 12 g	30 g/d	NR	NR

• Compliant foods: meats, eggs, tofu, non-starchy vegetables, full fat unsweetened dairy products/alternatives (excluding cow's milk), soy flour, artificial sweeteners, water, coffee, tea, sugar-free/low CHO flavourings, sodas, puddings and desserts • Non-compliant foods: foods which provide CHO including sugars, sugar alcohols, breads, cereals, grains, starchy vegetables, legumes, fruits/fruit juices, milk, low/non-fat or sweetened yoghurt, nuts, snack foods and condiments • Promotes using a low CHO diet and exercise to achieve normal blood sugars for persons living with diabetes			
Atkins (Fields et al., 2016; Heimowitz, 2014; Pogozelski et al., 2005)			
• CHO replaced with fat and protein • Four phases: Phase 1: Induction phase (to induce ketosis and weight loss) Phase 2: weight loss phase (allows nuts, seeds and berries; increase CHO in 5 g increments to find CHO tolerance); Phase 3: pre-maintenance; (allows lentils, pulses and higher CHO fruits; build CHO tolerance); Phase 4: maintenance (living a low carb life)	Phase 1: 20 g/d, or 5%EI Later phases: 80-100 g/d	35%EI	59%EI
Eco-Atkins (Fields et al., 2016; Heimowitz, 2014)			
• Vegan/vegetarian version of the Atkins diet (start at Phase 2) • Eliminates starchy foods e.g. bread, rice, potato, baked goods • Replaces high fat animal protein with vegetable protein from nuts, beans, soy products, gluten, cereals and vegetable products e.g. veggie bacon. Vegetarians may include eggs and cheese • Fat from avocado, nuts, soy products, and vegetable oils (olive oil) • Recommends daily multivitamin and fish oil/flax oil supplements for vegetarians/vegans	130 g/d, or 26%EI	31%EI	43%EI

South Beach Diet (SBD; Fields et al., 2016; Pogozelski et al., 2005; SBD Enterprises, 2019)			
• Three phases: Phase 1: low CHO, lean protein (reset the body for fast weight loss; duration: two weeks); Phase 2: weight loss (reintroduce CHO from wholegrains, fruits and vegetables, duration: until desired weight is achieved); Phase 3: maintenance (all food in moderation, duration: lifelong) • Permits CHO from some vegetables, whole fruits and wholegrains • Restricts: breads, starchy vegetables, fruit juice and sweets • Favours unsaturated fats over SFA • Three meals and three snacks per day	Phase 1: 40-50 g net CHO Phases 2-3: ≤140 g/d	NS	NS
Zone (Fields et al., 2016; Mahan & Raymond, 2017; Pogozelski et al., 2005)			
• Plate should be 1/3 lean protein, 2/3 non-starchy vegetables and a dash of fat • Some CHO are replaced with fat and protein, focus is on low GI fruits and vegetables, lean protein and unsaturated fats • Restricts high-sugar or starchy fruits and vegetables, refined and processed foods, added sugars and soft drinks, caffeinated beverages • Seven meals and snacks per day • Claims: to reduce inflammation and slow aging	40%EI	30%EI	30%EI
Paleo (Fields et al., 2016; Opie, 2014)			
• Diet consists of 55-65% animal foods and 35-45% plant foods • Limited to foods that early hunter-gathers ate, e.g. meat, fish, eggs, allows CHO as vegetables, fruits and nuts • No processed food, added sugar, grains, dairy, legumes, or potatoes	Varies based on food choices	NR	NR

CHO: carbohydrate;%EI: percent of energy intake; g/d: grams per day; g/kg.bw: grams per kilogram of body weight; GI: glycaemic index; LCHF: Low Carbohydrate High Fat; NR: no restriction; NS: not specified; PCOS: Poly Cystic Ovary Syndrome; RMR: Real Meal Revolution; SBD: South Beach diet; SFA: saturated fat

The very low CHO ketogenic (LCK) diet is an extreme variant of the low CHO diet which restricts CHO to less than 20-50 g/d (Fields et al., 2016; Harvey et al., 2018). Energy consumed on this diet should primarily come from lipids (≥75%EI; Harvey et al., 2018) and protein (<20%EI); (Kenig et al., 2019). The goal of a LCK diet is to achieve a state of nutritional ketosis or ketogenesis (Westman, Yancy, Tondt, & Maguire, 2018). This occurs when CHO are restricted to <50 g/d, reducing BGL and consequently insulin secretion, which reduces the stimulus for fat and glucose storage so the body enters a catabolic state (Harvey et al., 2018; Masood & Uppaluri, 2019; Pogozelski et al., 2005). Initially, glycogen stores will be depleted to provide glucose, the metabolic processes of gluconeogenesis (endogenous production of glucose by the liver), then ketogenesis, will action to provide the body with fuel (Masood & Uppaluri, 2019). Ketogenesis is the increased breakdown of fat into fatty acids, which are metabolised into acetoacetate and converted into ketone bodies (beta-hydroxybutyrate and acetone). Ketone bodies accumulate in the body and provide an alternate source of energy for the heart, muscle tissue, kidneys and the brain. This metabolic state is referred to as "nutritional ketosis" and will remain for as long as the body is deprived of CHO (Masood & Uppaluri, 2019).

While there is heterogeneity in the reported macronutrient composition of what constitutes a low CHO diet (Churuangsuk et al., 2018; Fields et al., 2016), two common features include their use for weight loss (Samaha et al., 2003) and their lack of explicit energy restriction (Fields et al., 2016). This increases the allure of low CHO diets for individuals seeking weight loss but who struggle to adhere to low fat and low calorie diets (Feinmann, 2018; Fields et al., 2016; Yamada et al., 2014).

The macronutrient composition of low CHO diets have been associated with appetite suppression (Pogozelski et al., 2005; Poppitt, Cameron-Smith, Lim, Liu, & Lu, 2019). This is attributed to the anorexigenic effects of dietary protein (Du, Markus, Fecych, Rhodes, & Beverly, 2018; Johnstone et al., 2008; Yang, Liu, Yang, & Jue, 2014) and nutritional ketosis (Hu et al., 2016; Johnstone et al., 2008; Mahan & Raymond, 2017; Pogozelski et al., 2005; Poppitt et al., 2019; Zinn, McPhee, et al., 2017).

The growing evidence for the use of higher protein (>20%EI) diets for successful weight loss and prevention of T2DM has been recognised (Liu, Silvestre, & Poppitt, 2015). Higher protein diets where protein is added to the diet in exchange for some of the CHO or fat portion are advantageous due to their relatively low energy density, greater appetite suppression, and the preservation of lean body mass (Bayham, Greenway, Johnson, & Dhurandhar, 2014; Castro et al., 2018; Liu et al., 2015; Poppitt et al., 2019; Romano et al., 2019). The latter is important for

individuals seeking weight loss as retaining lean body mass preserves muscle strength, functional capacity and resting metabolic rate (Castro et al., 2018). It is therefore unsurprising that these diets are cited as being more advantageous for weight loss than isocaloric 'conventional' diets (Johnstone et al., 2008). However, it is unknown whether the improved appetite control in low CHO high protein diets is related to the increase in protein intake, the decrease in CHO consumption, or both (Poppitt et al., 2019).

Ketogenic studies have been implemented in NZ and internationally (Table 2.6), despite fitting the criteria for the LCK diet, these studies had differing guidelines, macronutrient compositions and study aims; the interventions consistently resulted in low energy intakes, appetite suppression, weight loss and increased fat oxidation. These studies may not accurately reflect the LCK diets implemented by *free-living* individuals, as they had small sample sizes (n=5 to n=45) not representative of the population, and they were short in duration (36 hours to 10 weeks) possibly resulting in greater dietary adherence than sustained, long-term regimen (Brouns, 2018). With the exception of one randomised controlled trial in NZ (Zinn, McPhee, et al., 2017), which did not prescribe macronutrient targets, similar non-ketogenic low CHO studies have not been reported in NZ, therefore, it is important that this void of information be explored to better ascertain low CHO dietary practices in NZ.

The use of low CHO diets remains a contentious topic in the media, the food and nutrition industry, and among groups of health professionals due to the exclusion of food groups the consequential inappropriate consumption of some macro- and micronutrients, and the limited knowledge of the long-term impacts of these diets. Some authors argue that a higher CHO diet, containing unrefined grains and fibrous foods may be more nutritionally adequate, in achieving nutrient intakes recommended by the MOH, and/or of lower energy density than low CHO diets (Bilsborough & Crowe, 2003; d'Almeida, Ronchi Spillere, Zuchinali, & Correa Souza, 2018; Jenkins et al., 2009; Reynolds et al., 2019), one author argues that with planning and preparation, a low CHO diet can also be nutritionally replete (Zinn et al., 2018). However, it would be unrealistic to believe that all *free-living* low CHO diet followers would have the required food knowledge and time to plan and prepare a nutritionally complete low CHO diet, such as those designed by dietitians (Zinn et al., 2018), when such diets inherently restrict and encourage foods counter to MOH recommendations.

Table 2.6: Ketogenic diet trials

Author (year)	Country and study design	Aim of the study	Population sample	Intervention diet (duration and composition)	Limitations and strengths	Outcome
Cipryan et al. (2018)	Czech Republic; controlled experiment.	To examine the effects of altering from HD to VLCHF diet over 4-weeks on performance and physiological responses during high-intensity interval training.	18 males; moderately trained; 18-30 years	4 weeks HD **CHO:** 48%EI **Protein:** 17%EI **Fat:** 35%EI **Energy:** NS VLCHF **CHO:** 8%EI (35 g) **Protein:** 29%EI (125 g) **Fat:** 63%EI (120 g) **Energy:** NS	Limitations: Sample size, males only. Diets were not standardised or controlled. Foods consumed during the intervention, including prior to the exercise testing, were not isocaloric.	Compared to the HD, the VLCHF diet increased fat oxidation rates and did not adversely affect performance.
Harvey et al. (2018)	New Zealand; randomised controlled clinical trial.	To investigate the effect of MCT supplementation on time to NK, mood, and symptoms of keto-induction when following a very KD.	2 males, 21 females; BMI <30 kg/m^2; 32-48 (35 ± 4) years	20 days KD **CHO:** 3-6%EI **Protein:** 13-17%EI (1.4 g/kg.bw) **Fat:** 80%EI **Energy:** females (1800 kcal/7500 kJ), males (2200 kcal/9200 kJ)*	Limitations: Small sample size; 7% readings missed on the ketometer/glucometer. Standardised diets provided as per age- and gender-adjusted average requirements but not physical activity; 97% adherence to supplementation (self-reported).	90% of MCT and 70% of LCT participants achieved NK at 7 days. Symptoms which initially worsened in both diet groups, were resolved by days four (MCT group) and five (LCT group). MCT supplementation resulted in non-significant improvements in time to

Author (year)	Country and study design	Aim of the study	Population sample	Intervention diet (duration and composition)	Limitations and strengths	Outcome
						NK and mood, and some reduced symptoms of keto-induction.
Johnstone et al. (2008)	United Kingdom; within-subject, randomised crossover, residential trial.	To compare the hunger, appetite and weight-loss responses to two ad libitum high-protein diets (30%EI), of matched energy density, with differing CHO contents (4%EI and 35%EI) in obese men.	17 males; BMI >30 kg/m^2; 20-65 years.	4 weeks HPVLC **CHO:** 4%EI **Protein:** 30%EI **Fat:** 66%EI **Energy:** ad libitum HPLC **CHO:** 35%EI **Protein:** 30%EI **Fat:** 35%EI **Energy:** ad libitum	Limitations: Applicability of these findings due to the participant characteristics (obese, aged 20-65 years, male only); and the short duration. Strengths: The within-subject, randomised crossover, design and the provision of food.	Compared to the HPLC diet, the HPVLC diet resulted in lower ad libitum energy intakes, significantly lower hunger and greater weight loss. As the energy density and protein content were held constant this reduction in hunger is due to the difference in CHO or fat intake (or both). Compared to the HPVLC, the HPLC resulted in statistically significant reductions in total and LDL-C, probably reflective of the lower fat intake. Reduced calorie intake without increased hunger may promote compliance.

Author (year)	Country and study design	Aim of the study	Population sample	Intervention diet (duration and composition)	Limitations and strengths	Outcome
Romano et al. (2019)	Italy; prospective, longitudinal study.	To evaluate the effects of a personalised VLCKD with synthetic amino acid protein supplementation on body composition and resting energy expenditure in the short-term reversal of T2DM.	10 males, 10 females; BMI 18-45 kg/m^2; with T2DM (<8 years); 25-75 (56 ± 9) years	8 weeks <u>VLCKD</u> **CHO:** 5-10%EI (<25 g/day, mainly from non-starchy vegetables) **Protein:** 60-70%EI (2 g/kg.LBM, mainly from synthetic protein supplement) **Fat:** 25-30%EI (as 20 ml extra-virgin olive oil) **Energy:** females (450-600 kcal/1900-2500 kJ), males (650-800 kcal/2700-3300 kJ)* **Other**: sodium <2000 mg/day. ≥2 L mineral water	Limitations: Limited applicability to the population living with T2DM due to the limited number of participants and the short duration. No follow-up after the study. Strengths: 100% compliance to the treatment.	Weight loss and reduction in abdominal fat mass. Initial loss (<4 weeks) of LBM stabilized by 8 weeks. Reduction in resting energy expenditure (<300 kcal/day)* (1300 kJ/day).
Veldhorst, Westerterp, van Vught, and Westerterp-Plantenga (2010)	Netherlands; randomised cross-over design.	To assess the significance of the presence or absence of CHO and the proportion of fat in high protein	20 males, 25 females; BMI 18.5-25 kg/m^2; 18-40 years.	72 h (36 h for each diet) <u>Group 1</u> <u>HP</u> **CHO:** 40%EI **Protein:** 30%EI **Fat:** 30%EI	Limitations: Short duration. Including both genders may contribute variability within the sample. Limited applicability to normal weight persons in energy balance.	A high protein diet significantly affected appetite (lowered) and fat oxidation (increased), this was greatest with the CHO free variant.

Author (year)	Country and study design	Aim of the study	Population sample	Intervention diet (duration and composition)	Limitations and strengths	Outcome
		diets in affecting appetite suppression, energy expenditure, and fat oxidation in normal weight subjects in energy balance.		**Energy density:** 4.2 kJ/g NP **CHO:** 60%EI **Protein:** 10%EI **Fat:** 30%EI **Energy density:** 4.2 kJ/g Group 2 HP-OC **CHO:** 3%EI **Protein:** 30%EI **Fat:** 70%EI **Energy density:** 4.1 kJ/g NP-E **CHO:** 60%EI **Protein:** 10%EI **Fat:** 30%EI **Energy density:** 4.1 kJ/g	Strengths: Study design, 4-week washout period. Matched energy density within groups. Males and females were included, increasing the study's relevance to the population.	Energy expenditure was not affected by the CHO content of a high protein diet. Compared to the NP diet, the glycogen-lowering exercise did not impact appetite, energy expenditure or fat oxidation of the NP-E diet.
Zinn, Wood, et al. (2017)	New Zealand; pilot case study.	To ascertain the efficacy of a tailored KD in improving performance of recreational endurance athletes.	1 male, 4 females; endurance athletes; 49-55 years.	10 weeks KD **CHO:** 50 g **Protein:** 1.5 g/kg.bw **Fat:** Ad libitum **Energy**: NS	Limitations: Study design (pilot study), small number of participants, and no standardisation of training. The study lacks an energy comparison prior to and during the study. Strengths: Participants were compliant with macronutrient thresholds	Athletes initially experienced reduced energy levels, enhanced well-being, reduced inflammation, and improvements in skin conditions. Participants increased fat oxidation, reduced body fat and reduced maximal aerobic performance.

Author (year)	Country and study design	Aim of the study	Population sample	Intervention diet (duration and composition)	Limitations and strengths	Outcome
					for 10 weeks (minus two occasions).	

HD: Habitual Western diet; VLCHF: very-low CHO high fat; CHO: carbohydrate;%EI: percentage of energy intake; kJ: kilojoules; kcal: kilocalorie; NS: not specified; MCT: medium chain triglyceride; NK: nutritional ketosis; KD: low CHO ketogenic diet; BMI: body mass index; kg/m2: kilograms/meters squared; LCT: long chain triglyceride; HPVLC: high protein (very) low CHO diet; HPLC: high protein low CHO diet; LDL: low density lipoprotein cholesterol; VLCKD: very-low-calorie ketogenic diet; T2DM: type II diabetes; g/kg.LBM: g per kilogram lean body mass; h: hours; HP: high protein; kJ/g: kilojoule per gram; NP: normal protein; HP-OC: high-protein CHO-free; NP-E: Normal protein-exercising; g/kg.bw: g per kilogram of body weight.
*kcal multiplied by a conversion factor of 4.184 to obtain kJ value. Sums rounded to nearest 100.

2.7 Macronutrient composition and plant vs animal (protein and fat) food sources as replacements for carbohydrates in the diet

While low CHO diets have been as, or more, successful than conventional low fat diets in inducing short-term weight loss (Brinkworth et al., 2009; Seidelmann et al., 2018), which, may be partially attributable to the 1:3 g water-storing capacity of glycogen (Fernández-Elías, Ortega, Nelson, & Mora-Rodriguez, 2015). The effects of low CHO diets are mediated by the extent of CHO restriction and the replacement macronutrients (Seidelmann et al., 2018). There is little to no evidence to suggest that the restriction of dietary CHO results in greater long-term weight-loss outcomes, than other weight-loss diets (Fields et al., 2016; Naude et al., 2014).

The long-term consequences, suitability and sustainability of low CHO diets is yet to be determined (Seidelmann et al., 2018), their long-term effect on mortality is controversial and may depend on the proportion of CHO consumed and the source of replacement macronutrients. Seidelmann et al. (2018) undertook a meta-analysis investigating the long-term effect of CHO intake on all-cause mortality, including 432179 participants from eight cohort studies. A U-shaped association between mortality and CHO consumption was reported, where both higher (>70%EI) and lower (<40%EI) CHO intakes were associated with greater mortality than a moderate CHO intake, with minimal risk at 50-55%EI (Seidelmann et al., 2018).

The replacement food source (animal- or plant-derived fat and protein) modified the association between CHO intake and mortality (Seidelmann et al., 2018). The risk of mortality increased when CHO were exchanged for animal-derived fat and protein but decreased when CHO were replaced with vegetable proteins and fats (Seidelmann et al., 2018).

Both plant-based and animal-based low CHO diets can result in weight loss, which irrespective of how it is achieved, traditionally results in favourable metabolic and functional changes (Brouns, 2018) including reductions in obesity, hypertension, hyperglycaemia, insulin resistance and dyslipidaemia (Nakamura et al., 2016; Westman et al., 2007), reversal of pre-diabetes and remission of T2DM (Feinmann, 2018). In consonance, the plant-based low CHO diet containing gluten, soy, nuts and vegetable oils, is associated with lower mortality and significantly reduced concentrations of low density lipoprotein cholesterol (LDL-C) to reduce the risk of CHD (Jenkins et al., 2009; Seidelmann et al., 2018). Additionally, a lower SFA intake, such as with a plant-based diet, may reduce insulin resistance and chronic inflammation, and improve endothelial function to further lower CHD risk (Jenkins et al., 2009).

In contrast, low CHO diets of animal origin tend to increase LDL-C and are associated with higher mortality (Jenkins et al., 2009; Seidelmann et al., 2018). Additionally, higher intakes of red and processed meats, recognised as carcinogens, are associated with weight gain (Trichopoulou, Psaltopoulou, Orfanos, Hsieh, & Trichopoulos, 2007), T2DM (Fung et al., 2010) and greater cardiovascular and all-cause mortality (Fields et al., 2016).

When dieters focus on a specific macronutrient composition (e.g. "low CHO") of their diet, they may inadvertently neglect micronutrients by not considering appropriate dietary or supplemental replacements. This may hold implications for health given the roles of these nutrients in acute and chronic health conditions (Gardner et al., 2010). However, there is limited data available that assesses the micronutrient content and adequacy of such diets as they are followed by *free-living* individuals (Gardner et al., 2010).

A consistent pattern of reduced micronutrient consumption with CHO-restricted weight-control diets was identified across a systematic review of 10 studies (Churuangsuk et al., 2019). Similar to other studies (Bilsborough & Crowe, 2003; Gardner et al., 2010; McSwiney & Doyle, 2019; Zinn et al., 2018), Churuangsuk et al. (2019) reported lower intakes of thiamine, folate, magnesium, calcium, iron and iodine intakes in CHO-restricted versus control diets. Their data reflect the provision of micronutrients either naturally present in, or fortified into, CHO foods, thus, the restriction of such foods results in reduced micronutrient intakes (Churuangsuk et al., 2019). Table 2.7 shows the greatest dietary contributors to micronutrients in the ANS08/09. For instance, bread and breakfast cereals are the greatest contributors to iron consumption in New Zealand adults, the restriction of such foods may therefore result in inadequate intakes and an increased risk for iron deficiency/iron deficiency anaemia (Kenig et al., 2019). Restriction of dairy products reduces iodine (Churuangsuk et al., 2019) and calcium intakes, the latter of which increases the risk of osteoporosis (Kenig et al., 2019). Long-term CHO-restriction may yield important clinical ramifications such as a life-threatening thiamine deficiency, optic neuropathy, or Wernicke's encephalopathy (Churuangsuk et al., 2019). Notably, weight loss may promote reproductive function in overweight or obese women, however the restriction of fortified foods (i.e. breads and cereals) may contribute inadequate folate and iodine consumption to increase the risk of foetal mal-development and neural tube defects (Churuangsuk et al., 2019; Desrosiers, Siega-Riz, Mosley, & Meyer, 2018).

Table 2.7: Dietary sources of micronutrients in New Zealand adults, aged ≥ 15 years

Micronutrient	Dietary source
Vitamin A (equivalents) [1]	**Vegetables** (27%), butter and margarine (11%), **milk** (6%), **bread-based dishes** (5%), egg and egg dishes (5%), cheese (5%)
Vitamin C [1]	**Vegetables** (27%), **fruit** (22%), **non-alcoholic beverages** (15%), **potatoes, kumara and taro** (13%)
Vitamin E [1]	Butter and margarine (13%), **vegetables** (11%), **fruit** (7%), **bread-based dishes** (6%), **potatoes, kumara and taro** (6%)
Thiamin (B1) [1]	**Bread** (17%), **breakfast cereals** (14%), **vegetables** (7%), **bread-based dishes** (6%), **milk** (6%), **potatoes, kumara and taro** (5%), **grains and pasta** (5%), **savoury sauces and condiments** (5%)
Riboflavin (B2) [1]	**Milk** (23%), **non-alcoholic beverages** (8%), **breakfast cereals** (6%), **vegetables** (5%), **dairy products** (5%)
Niacin [1]	Poultry (9%), **bread** (8%), **non-alcoholic beverages** (8%), beef and veal (7%), **potatoes, kumara and taro** (6%), fish and seafood (6%), **grains and pasta** (6%), **vegetables** (5%), **milk** (6%)
Vitamin B6 [1]	**Fruit** (13%), **vegetables** (10%), **potatoes, kumara and taro** (10%), poultry (7%), **breakfast cereals** (6%), **bread** (5%), **non-alcoholic beverages** (5%), **grains and pasta** (5%), beef and veal (5%)
Vitamin B12 [1]	**Milk** (21%), beef and veal (11%), fish and seafood (10%), egg and egg dishes (6%), **bread-based dishes** (6%), poultry (6%), **non-alcoholic beverages** (5%), cheese (5%)
Folate [3]	NA. Dietary sources include **vegetables**, **fruit**, **wholegrain cereals** and fortified foods
Calcium [1]	**Milk** (27%), **bread** (10%), **non-alcoholic beverages** (10%), cheese (8%), **vegetables** (6%), **dairy products** (6%), **bread-based dishes** (5%)
Iron [1]	**Bread** (12%), **breakfast cereals** (10%), **vegetables** (8%), **grains and pasta** (7%), beef and veal (7%), **potatoes, kumara and taro** (6%), **bread-based dishes** (5%), **non-alcoholic beverages** (5%)

Micronutrient	Dietary source
Zinc [1]	Beef and veal (10%), **bread** (10%), **grains and pasta** (9%), **milk** (7%), **bread-based dishes** (7%), **vegetables** (6%), poultry (5%), pork (5%)
Potassium [1]	**Potatoes, kumara and taro** (13%), **vegetables** (12%), **non-alcoholic beverages** (10%), **milk** (10%), **fruit** (10%), **bread** (5%)
Selenium [1]	**Bread** (15%), fish and seafood (12%), poultry (10%), **bread-based dishes** (7%), egg and egg dishes (7%), **grains and pasta** (6%), pork (5%)
Iodine [1-3]	NA. Dietary sources include foods of marine origin (e.g. fish and seaweed), **dairy products**, foods fortified with iodised salt (e.g. bread), processing aids containing iodine
Cholesterol [1]	Egg and egg dishes (13%), poultry (12%), beef and veal (9%), **milk** (8%), fish and seafood (8%), **bread-based dishes** (7%), pork (5%)
Dietary fibre [1]	**Bread** (17%), **vegetables** (16%), **potatoes, kumara and taro** (12%), **fruit** (12%), **grains and pasta** (8%), **breakfast cereals** (5%)
Magnesium [1, 3]	NA. Dietary sources include green vegetables, **legumes**, peas, beans, nuts and some shellfish

NA: no intake data available in the ANS08/09; [1] University of Otago and Ministry of Health (2011); [2] Churuangsuk et al. (2019); [3] National Health and Medical Research Council et al. (2006)

Foods in **bold** are those often explicitly restricted in a low carbohydrate diet.

The consensus supporting micronutrient inadequacy has been challenged; Zinn et al. (2018) argues that low CHO nutrition does not specifically exclude food groups but focuses on including wholefood CHO and reducing processed and high GL foods, stating that a well-planned low CHO diet can be nutritionally replete (Zinn et al., 2018). This argument is staged on a meal plan of CHO intakes of 61-69 g/d (10-13%EI) which incorporates dairy products, nuts and seeds, vegetables, berries and fats. As per the rationale behind NRV, the body requires an adequate intake of micronutrients to maintain normal metabolic function, however, despite reduced micronutrient intakes and the associated risks, there is no current guideline on the use of micronutrient supplementation in energy restricted diets (Churuangsuk et al., 2019) therefore it is important to ascertain and quantify which micronutrients are under-consumed to determine how these micronutrients can be replaced.

Of 2601 adults, aged 15-64 years, surveyed in Finland, seven percent identified themselves as low CHO diet followers (Piia et al., 2014). Over half (57%) of which were currently trying to lose weight. Compared to other respondents, low CHO diet followers agreed on the healthiness of wholegrains, fruits and vegetables and on the harmfulness of refined grains; they consumed more fresh vegetables, butter, eggs and chicken and more frequently avoided CHO, sugars and refined grain products (Piia et al., 2014). Low CHO diet followers valued the health and weight-managing aspects of food and placed less emphasis on the social value of and pleasures connected to food (Piia et al., 2014), defying the human constructs and connections built upon the sociality and sharing of food. Compared to low fat dieters, low CHO diet followers have been seen to have significantly lower CHO and higher fat intakes at baseline, prior to selecting a low CHO or low fat diet (McVay, Voils, Coffman, Geiselman, Kolotkin, Mayer, Smith, Gaillard, Turner, & Jr.Yancy, 2014).

Diets with extravagant media publicity, such as the low CHO diet, affect the food choices of diet followers and of non-followers (Piia et al., 2014). This has been seen in Finland, where the increasing popularity of the low CHO diet has increased butter and cream consumption beyond what can be explained solely by the altered consumption habits of low CHO diet followers, suggesting that the popularity of the low CHO diet is influencing the food choices of non-dieters, who are now also consuming more of these products (Piia et al., 2014). This may yield health ramifications for the general population, such as increases in cardiovascular disease and obesity, due to increases in total fat, SFA and energy intakes.

The popularity of low CHO diets may also be linked to the reduction in CHO consumption reported in the aforementioned NZ-based studies (Cao, 2018; Casale, 2015; Schrijvers et al., 2016; Singh, 2018) therefore, the planners of nutrition policies should examine new diets and the food choices made by their followers, as they emerge, to better ascertain how such diets affect food culture and the food choices of the whole population, not just the dieters themselves (Piia et al., 2014).

2.8 Food choices and dietary motivations

Food choice motivations such as health, weight control, cost, sensory appeal and ethical concerns surrounding food are related to age, sex and income, they shape consumer preferences and choices (Clarke & Best, 2019). The motivation to use a specific diet or dietary pattern relies on food preferences and the perceived beneficial effects on health and body weight (Clarke & Best, 2019; McVay, Voils, Coffman, Geiselman, Kolotkin, Mayer, Smith, Gaillard, Turner, & Yancy, 2014).

Food preferences and weight loss efficacy are more important to consumers than food costs, food intolerances and the perception that a diet may harm their health (McVay, Voils, Coffman, Geiselman, Kolotkin, Mayer, Smith, Gaillard, Turner, & Yancy, 2014).

Diet motivations, health beliefs and behaviours were assessed via an online survey, to profile low CHO high fat (LCHF) dieters in Australia (Clarke & Best, 2019). Three-hundred-and-thirty participants (men=43, women=287), aged 18 to 72 years, completed the survey, of which one third (33.0%) were non-dieters, nearly half (44.2%) were LCHF diet followers, and the remainder (22.7%) followed 'other' diets (Clarke & Best, 2019). Motivations of health, weight control, natural content, mood and sensory appeal were valued by LCHF dieters, however animal welfare, price and convenience were not valued so highly (Clarke & Best, 2019), thus aligning with low CHO diet principles which encourage 'raw' unprocessed foods and meat consumption.

2.9 Conclusion

While research has identified an association between CHO intakes and mortality, influenced by replacement nutrients, and food choice motivations important to low CHO dieters, there is little research that has examined the dietary practices and diet quality of persons following this re-emerging dietary pattern as *free-living* consumers (Clarke & Best, 2019). Knowing how consumers are following this diet would provide valuable insight into the nutritional adequacy of the various low CHO diets, and what nutritional risks (if any) these diets pose on human health.

Chapter 3: Research study manuscript

This manuscript is formatted for submission to the Journal of Human Nutrition and Dietetics (Author guidelines in Appendix C). The referencing style for the research manuscript has been changed from the guidelines to be consistent between thesis chapters.

Dietary Practices and Nutrient Intakes of Low Carbohydrate Diet Followers in New Zealand

Tayla Knightbridge-Eager, Marilize Richter, Carol Wham, Rozanne Kruger

School of Sport, Exercise and Nutrition, Massey University, Auckland, New Zealand

3.1 Abstract

Background: Low carbohydrate (CHO) diets are regaining popularity and media coverage in New Zealand (NZ), however, little is known about the dietary practices, CHO-substitution practices and nutrient intakes of self-identified *free-living* low CHO diet followers.

Methods: The current cross-sectional study collected data from 74 (54 women, 20 men) self-identified low CHO diet followers, aged 20-45 years, from Auckland, NZ. They completed 4-day weighed food records (WFR), including at least one weekend day, and a dietary principles and quality of life (DPQOL) questionnaire.

Total dietary intake of low CHO diet followers, stratified by total group and gender, were compared to nutrient reference values (NRV) and the latest NZ nutrition survey. With a cut-off of 150 g CHO per day, data was adjusted for age, gender and total monthly income, and dietary intake was explored by level of CHO intake, as very low (VL; <50 g), low (L; 50<100 g) and moderately low (ML; 100<150 g) CHO groups.

Food and nutrient substitution practices were assessed, motives for following a low CHO diet, dietary practices, food choices and food rules were explored.

Results: Male and female participants consumed a low CHO diet (65.9 (52.1-79.7) g/d; 14.0 (11.4-16.7) percent of energy intake (%EI)) which did not achieve NRV for calcium and potassium. Men but not women achieved the Estimated Average Requirement (EAR) for thiamin. No low CHO group achieved the Acceptable Macronutrient Distribution Range (AMDR) for CHO (inadequate), total fat and saturated fat (SFA; excessive) intakes. All low CHO groups consumed sodium above recommendations, the ML group achieved the NRV for all other micronutrients measured.

However, the VL CHO group did not achieve NRV for thiamin, folate, vitamin E, calcium, zinc, magnesium, iodine and potassium and the L CHO group for calcium, iodine and potassium.

Respondents frequently avoided foods they once enjoyed and CHO-foods, replacing them with foods containing mostly protein and fat. Most participants experienced self-reported weight-loss and were motivated by weight-loss, convenience and ease of application.

Conclusion: Low CHO diets followed by our participants pose dietary risks relative to the excessive total fat, SFA and sodium, and inadequate fibre contents. Diets very low and low in CHO contained inadequate quantities of micronutrients, however the moderately low diet achieved the NRV (excluding sodium).

3.2 Introduction

In New Zealand (NZ), two greatest specific risk factors for health loss are dietary risks and high body mass index (BMI) which account for 9.4% and 9.2% of total disability-adjusted life years (DALY), respectively (Ministry of Health, 2016). Dietary risks such of low vegetable and fruit intakes and high sodium intakes contribute the largest dietary burdens (2.5% and 1.3% of total DALY, respectively; Ministry of Health, 2016). Data from NZ Health Survey's show an increasing prevalence of obesity, from 26.5% in 2006/07 to 30.9% in 2018/19 (Ministry of Health, 2019). This is of grave concern as high BMI is linked to cardiovascular disease (CVD) and type II diabetes incidence (Ministry of Health, 2016).

High BMI has been linked to dieting in adults (Kruger, Galuska, Serdula, & Jones, 2004; Siahpush et al., 2015) therefore, this incidence of high BMI has presumably led to the increase in overweight and obese adults seeking weight loss. Despite being opportune to a myriad of diets (McVay et al., 2014), the low carbohydrate (CHO) diet is of widespread popularity (Brinkworth, Noakes, Buckley, Keogh, & Clifton, 2009). Notably, while any type of calorie reduction may result in short-term weight-loss, and will favour metabolic and functional changes in obesity, hypertension, hyperglycaemia, insulin resistance and dyslipidaemia (Nakamura et al., 2016; Westman et al., 2007), such diets may not be biologically or behaviorally sustainable (Mozaffarian, 2016).

While there is no one consistent definition that constitutes a low CHO diet (Wylie-Rosett, Aebersold, Conlon, Isasi, & Ostrovsky, 2013), low CHO diets have often been defined as follows: very-low (VL; <50 g; Brouns, 2018), low (L; 50<100 g; Bilsborough & Crowe, 2003) and moderately low (ML; 100<150 g; Brouns, 2018) in CHO. Followers typically consume energy ad libitum (Cipryan, Plews, Laursen, Ferretti, & Maffetone, 2018; Fields, Ruddy, Wallace, Shah, & Millstine, 2016; Johnstone, Horgan, Murison, Bremner, & Lobley, 2008; Kenig, Petelin, Poklar Vatovec, Mohorko, & Jenko-Pražnikar, 2019; Sanada et al., 2018; Yamada et al., 2014; Zinn et al., 2017) and favour increased or unrestricted fat and/or protein intakes (Seidelmann et al., 2018) which may consequently exceed the Acceptable Macronutrient Distribution Range's (AMDR; Brinkworth et al., 2009; Churuangsuk, Griffiths, Lean, & Combet, 2019; Nakamura et al., 2016). The AMDR, expressed as a percentage of total energy intake (%EI), for CHO, protein and fat are 45-65%EI, 15-25%EI and 20-25%EI, respectively (National Health and Medical Research Council, Australian Government Department of Health and Ageing, & New Zealand Ministry of Health, 2006).

In agreement with the AMDR for CHO intake, a recent study (2018) reported an association between CHO intake and mortality, where high (>70%EI) and low (<40%EI) CHO intakes conferred the greatest risk, and intakes of 50-55%EI, the lowest risk (Seidelmann et al., 2018). However, mortality reduced when CHO were exchanged for plant-derived sources of fat and protein but increased when exchanged for animal sources, thus, macronutrient source (plant versus animal) is an important factor to consider when reducing CHO intake (Seidelmann et al., 2018).

Known as a the ketogenic diet, low CHO diet followers may restrict CHO (<50 g) and protein (<20%EI; Harvey, Schofield, Williden, & McQuillan, 2018; Kenig et al., 2019) to favour a high fat diet (≥75%EI; Harvey et al., 2018). The goal of the ketogenic diet is to induce nutritional ketosis, a catabolic state induced by CHO restriction, which has been used, historically, in the treatment of obesity and diabetes (Westman, Yancy, Tondt, & Maguire, 2018). CHO restriction reduces blood glucose and therefore insulin secretion, thus reducing the stimulus for glucose and fat storage, resulting in catabolism (Harvey et al., 2018; Masood & Uppaluri, 2019; Pogozelski, Arpaia, & Priore, 2005). When the glucose yield from glycogenolysis and gluconeogenesis is insufficient to meet the body's glucose requirements, ketogenesis provides an alternate fuel source as ketone bodies, which supply the heart, muscle tissue and kidneys with energy (Masood & Uppaluri, 2019).

The macronutrient composition of low CHO diets have been associated with appetite suppression (Pogozelski et al., 2005; Poppitt, Cameron-Smith, Lim, Liu, & Lu, 2019), due to the anorexigenic effects of dietary protein (Du, Markus, Fecych, Rhodes, & Beverly, 2018; Johnstone et al., 2008; Yang, Liu, Yang, & Jue, 2014) and nutritional ketosis (Hu et al., 2016), and a spontaneous reduction in energy intake (Johnstone et al., 2008; Weigle et al., 2005; Zinn et al., 2017). Compared to a low fat diet, low CHO diets have also shown greater efficacy in achieving short-term (six months; Brehm, Seeley, Daniels, & D'Alessio, 2003; Foster et al., 2003; Naude et al., 2014; Samaha et al., 2003) but not long-term (1-2 years; Brinkworth et al., 2009; Foster et al., 2003) weight loss.

Despite the recent and recurrent increase in public interest and following of low CHO diets, there is no evidence in New Zealand to describe how *free-living* individuals implement this diet, what foods are selected and whether and which nutritional inadequacies may be present. The aim of this study is to asses diet quality and understand the dietary practices, habits and behaviours of low CHO diet followers, aged between 20 and 45 years old, living in Auckland, New Zealand.

3.3 Materials and methods

3.3.1 Study design and participants

The larger LOCA (Low Carbohydrate diet) study, is a cross-sectional exploratory study conducted at the Human Nutrition Research Unit (HNRU) of Massey University. The aim of the LOCA study is to investigate the dietary practices, habits, behaviours and metabolic markers of low CHO diet followers, aged 20-45 years old, from Auckland, NZ. This sub-study of the LOCA study aimed to investigate the dietary intakes and practices of low CHO diet followers from both genders, aged between 20 and 45 years, living in Auckland, NZ.

Inclusion criteria for this sub-study were: having followed a self-reported low CHO diet for at least four months; an adult men or women, aged between 20 and 45 years; not pregnant or lactating; had no previous bariatric surgery; being generally healthy, and not taking medications which may affect the outcome measures (e.g. medication that changes blood lipids/cholesterol, blood sugar, or blood pressure etc.). This sub-study utilised data from all participants recruited into the study.

3.3.2 Ethics

The Declaration of Helsinki (World Medical Association (WMA), 2018), guided the ethical principles used in the LOCA Study. Ethical approval was obtained from the Massey University Human Ethics Committee (Southern A, application 18/22). Prior to the study, all participants completed consent forms and were provided with procedural information on the study.

Participants were assigned with unique number identifiers to depersonalise all data. Data was kept in locked filing cabinets and computer files were password protected. Researchers signed confidentiality agreements and only reviewed data pertinent to the task(s) at hand. Data entry and analysis were performed on de-identified data.

3.3.3 Procedures

Recruitment for the LOCA study occurred alongside data collection over a 9-month period, from 18 September 2018 to 15 June 2019. Participants were recruited, via social media platforms (Facebook and Instagram), poster advertising in local gyms and by ‘word of mouth’. Individuals who expressed interest in the LOCA study were screened using an online questionnaire.

An online information sheet specific to the LOCA study explaining requirements and procedures, were provided to persons who fulfilled the inclusion criteria. Written consent were obtained from enrolled participants using an online form and participants were invited to schedule an appointment

at the HNRU at Massy University, Albany. Participants were informed that they could withdraw from the study at any time.

3.3.4 Measures

The study was completed in two parts. Part 1, completed at home, including of a four-day weighed food record (WFR; Appendix A). Part 2, completed on site at the HNRU, including anthropometric (height and weight) measurements; two questionnaires: Health and Demographics questionnaire (HDQ) and Dietary Principles and Quality of Life (DPQOL); and a face-to-face review of the WFR to ensure incomplete information was captured (Figure 3.1).

Demographic data

Participants completed the Health and Demographics Questionnaire (HDQ) via an online electronic survey system (SurveyMonkey Inc., 2019) at the HNRU on site. Data from this questionnaire were downloaded and imported to SPSS (IBM SPSS Software, 2017), where it was coded and used for data analysis. Demographic data, including information on gender, ethnicity, income, education, employment, marital status, and health related information such as smoking status, medication and supplement use, was obtained from this questionnaire and used to describe the participant characteristics.

Anthropometric data

Trained research assistants collected anthropometric measurement data. Height was measured using the Harpenden Portable Stadiometer (Holtain Ltd., England), based on protocol from the International Society for the Advancement of Kinanthropometry (ISAK; Marfell-Jones, Olds, Stewart, & Carter, 2006). Body weight was derived from a Bioelectrical Impedance Analysis (BIA; Biospace Ltd.). Body mass index (BMI) was calculated (BMI (kg/m^2) = weight (kg)/height (m) squared). Data were entered on twice by two independent research assistants (MSc Nutrition students), cross-examined to ensure accuracy and imported into SPSS (IBM SPSS Software, 2017) for data analysis.

Dietary intake data

Prior to attending the data collection appointment at the HNRU, all participants were instructed to complete a WFR comprising all food, beverages and supplements consumed on four non-consecutive days, including at least one weekend day. Days were randomised and allocated to participants in order to have as close to equal amounts of each day of the week as possible included in the study. Participants were provided with a template, in which to complete this, and an instructional video on how to do this accurately. The completed food record was collected and

reviewed by trained research assistants, and discussed with the participant to clarify any ambiguous information.

To analyse both nutrient and food intake, food records were entered into the nutrition analysis software FoodWorks 9 (Xyris Software, 2018). All food records were entered and independently cross-checked by trained research assistants. The New Zealand Food Composition Database (NZ FOODfiles 2016) was used with preference for nutrient analysis. Where food was absent from the New Zealand database, the following Australian databases were used: AusFoods 2017 (developed by Xyris software, derived from AUSNUT 2011-13), AusBrands 2017 (developed by Xyris software, derived from nutrient data on product packaging) and AUSNUT 2013 (released by Food Standards Australia New Zealand (FSANZ) in 2014; Xyris Software, 2018). In addition, the Nutricia 2015 database (nutrition information provided by Nutricia) was used as a template for medium chain triglyceride (MCT) oil (Xyris Software, 2018).

Where necessary assumptions were made. Recipes for meals or snacks which were not present in the database (e.g. 'fat bombs', homemade 'five seed crackers') were entered into FoodWorks according to the recipes provided by participants using foods from the aforementioned databases. Where foods were not present in the databases a suitable alternative was used, for example "Ice cream, vanilla, low fat" replaced "Halo Top Ice Cream", or a recipe was created based on the product's ingredient and nutrition information panel. Furthermore, many participants consumed 'over-the-counter' supplements (e.g. multivitamins), Chinese herbal medicines and sports supplements (e.g. creatine), these were not included in the dietary analysis as the objective of the analysis is to establish intakes of nutrients from foods, not supplements. Medications e.g. ibuprofen and paracetamol were also not included, as they were not deemed to have nutritional relevance within the study. Potential supplements consumed as food i.e. an ingredient within a meal (e.g. psyllium husk used in bread, protein powder used in a smoothie) were included in the dietary analysis, while those consumed in 'pill form' (multivitamin tablet) or as a supplement (e.g. psyllium husk as a fibre supplement) were excluded from the dietary analysis. This surfeit data was tabularised (Tables A1-A4; Appendix 1) and is available on request.

The nutrient data collected was processed and analysed using SPSS software (IBM SPSS Software, 2017). To identify any over or under reporters of dietary intake, the participants energy intake was compared to their estimated energy expenditure. Energy expenditure was estimated using basal metabolic rate (BMR), estimated using each participant's own gender, age, body weight and energy intake within a modified Oxford Equation (Henry, 2005), multiplied by a physical activity level (PAL) of 1.55 (United Nations University, World Health Organization, & Food and Agriculture

Organization of the United Nations, 2001). Ten percent of energy intake was added to account for diet induced thermogenesis (DIT; Westerterp, 2004). A cut-off point of two standard deviations (SD) above and below the participant's BMR was employed to determine over- and under reporting, respectively. Two thirds (66%) of participants had energy intakes below and one participant consumed energy in excess of these cut-off points. However, the low CHO diet is known to be a popular weight loss strategy (Churuangsuk et al., 2019; Nakamura et al., 2016; Piia, Mari, Satu, & Nina, 2014; Seidelmann et al., 2018; Zinn et al., 2017), it was therefore considered inappropriate to exclude participants based energy intake alone as the low CHO diet is used to manipulate energy intake to favour weight control.

A total of 74 participants were included in the food record analysis, having completed all four days of the food record. Participants were categorised as (a) men and women; and (b) according to levels of CHO intake: very-low (VL; <50 g/day; Brouns, 2018), low (L; 50<100 g/day; Bilsborough & Crowe, 2003), moderately low (ML; 100<150 g/day; Brouns, 2018) and normal (≥150 g/day) CHO consumers.

Pivot tables were also created using the dietary data exported from FoodWorks 9 to determine the frequency of foods consumed and to determine which foods contributed the most energy to the groups intake. These values were divided by four to give the mean frequency/day and kJ/day, respectively, which is more comparable and meaningful for interpretation.

LOCA dietary practices

The DPQOL was developed by the research team to assess dietary principles and rules, altered consumption habits and quality of life related to nutrition and other aspects (e.g. sociality) of food consumption (Schünemann et al., 2010). Participants completed the DPQOL in an online format on site (SurveyMonkey Inc., 2019). Data were downloaded and imported to SPSS (IBM SPSS Software, 2017), where it was coded and used for data analysis.

3.4 Statistical analysis

All data were checked and coded prior to being exported to IBM® SPSS® software for Windows, version 25.0 (IBM SPSS Software, 2017) for data analysis.

All variables were tested for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests, with significance at $P<0.05$. Normally distributed data were presented as mean ± standard deviation (SD). Data that were not normally distributed were log transformed to improve normality, non-normal data which was normal after log transformation were presented as geometric mean and 95% confidence interval (95% CI). Where normality was not achieved after log transformation, non-

parametric statistics were applied and data were presented as median with 25^{th} and 75^{th} percentiles [25^{th}, 75^{th}].

Descriptive statistics were used to describe the participants' demographics, categorical data were presented as numbers, frequencies and percentages. Data was tested for homogeneity using the Levene's tests. Independent sample t-tests were used to compare intakes between genders for parametric data and the Mann-Whitney test for non-parametric data.

Because the differences in age, gender and total monthly income affect CHO intake, Analysis of covariance (ANCOVA) controlling for these variables (age, gender and total monthly income), was used for parametric data to determine significant differences for nutrient intake between the low CHO groups. Post hoc tests with Bonferroni adjustments were used to find the differences between groups. The sample size of 69 low CHO followers will provide 70% power at a significance level of $P = 0.0167$ to detect a large effect size f of 0.4 (G*Power 3.1.9.4) for comparing nutrient intakes between low CHO groups (Faul, 1992-2019).

A P-value of less than 0.05 was considered to be statistically significant.

3.5 Results

A total of 89 participants (23 men; 66 women) met the inclusion criteria and 74 completed the LOw CArbohydrate (LOCA) study. A flow diagram detailing participant recruitment and data collection, processing and analyses is presented in Figure 3.1.

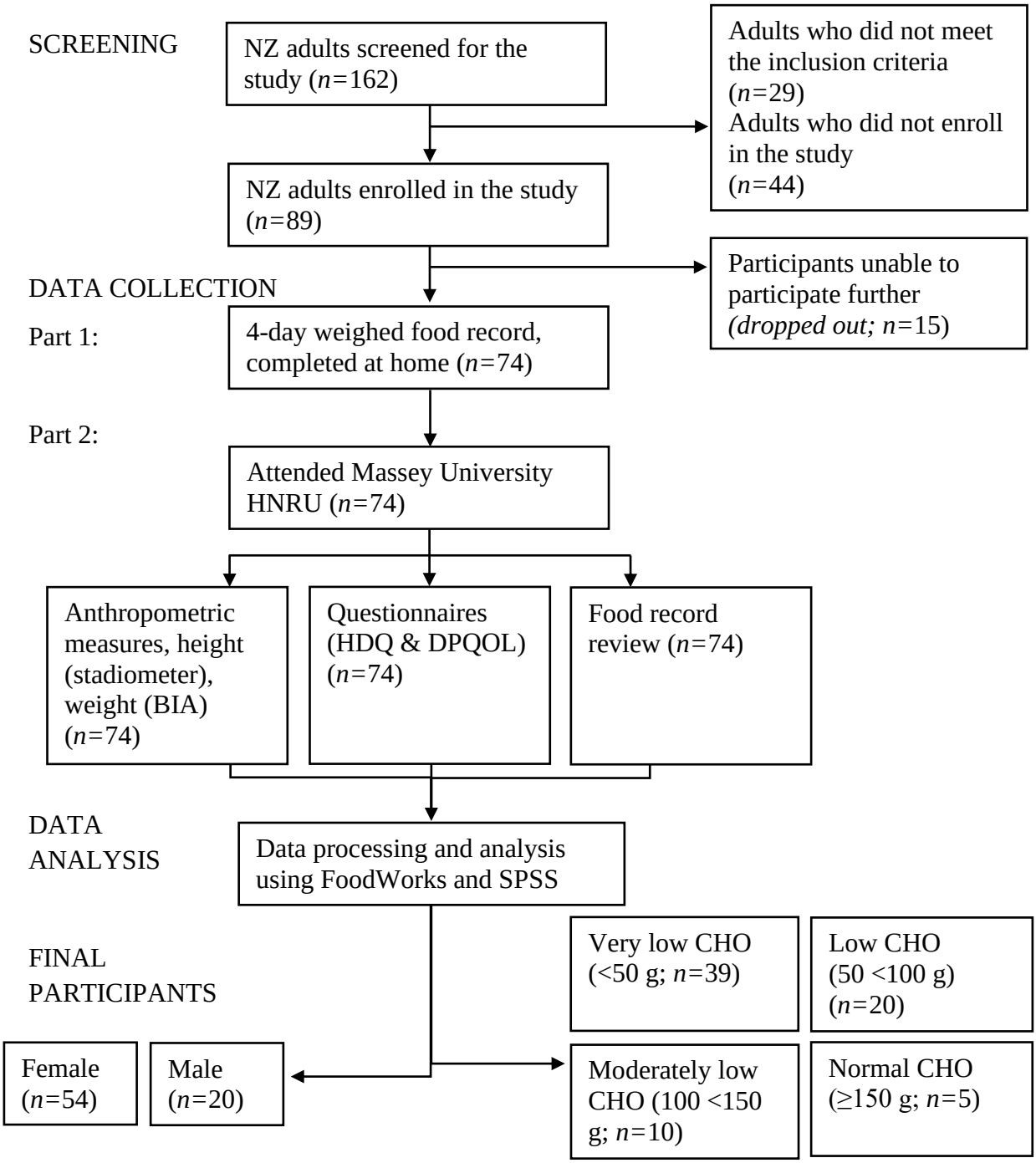

Figure 3.1 *Participant Recruitment and data collection,*

NZ: New Zealand; CHO: carbohydrate; HNRU: Human Nutrition Research Unit; BIA: Bioelectrical Impedance Analysis; HDQ: Health and Demographics Questionnaire; DPQOL: Dietary Principles and Quality of Life Questionnaire.

3.5.1 Participant characteristics

Characteristics of participants included in this study are presented in Table 3.1. The mean age of the participants was 34.7 ± 7.50 years. More women (73%) than men (27%) participated in the study. The mean BMI was 25.5 (24.5-26.5) kg/m^2 for all participants. Most participants were of NZ European ethnicity (76%), had completed a tertiary education (80%) and held regular working patterns (73%). Nearly half had a total monthly income of $3001-$8000 (47%) and never or rarely consumed alcohol (46%). Only one participant reported the low carbohydrate (CHO) diet as a dietary restriction, while two participants reported religious beliefs and practices (Table 3.1).

Table 3.1 Baseline characteristics

	All participants, *n*=74	Female, *n*=54	Male, *n*=20
Age (years), mean ± SD	34.7 ± 7.5	35.1 ± 7	33.5 ± 8.8
Age (years), median [25th, 75th%]	35.0 [28.0, 42.0]	35.0 [29.0, 42.0]	34.5 [26.0, 42.0]
Highest level of education, n (%)			
Secondary School and other Trade Certificate or diploma	15 (20.3)	9 (16.7)	6 (30.0)
Tertiary Education	59 (79.7)	45 (83.3)	14 (70.0)
Ethnicity, n (%) [a]			
New Zealand European	56 (75.7)	41 (75.9)	15 (75.0)
Maori	2 (2.70)	2 (3.7)	0 (0.00)
Other European	10 (13.5)	8 (14.8)	2 (10.0)
Asian	7 (9.50)	4 (7.4)	3 (15.0)
Other (Middle Eastern/Latin American/African)	7 (9.50)	5 (9.3)	2 (10.0)
Current working pattern, n (%) [b]			
Regular working pattern	49 (73.1)	38 (76.0)	11 (64.7)
Irregular or variable	18 (26.9)	12 (24.0)	6 (35.3)
Total monthly income, n (%) [c]			
$0-$3000	11 (17.2)	9 (19.1)	2 (11.8)
$3001-$8000	30 (46.9)	23 (48.9)	7 (41.2)
$8001 or more	23 (35.9)	15 (31.9)	8 (47.1)
Alcohol intake, n (%)			
Never or very rarely	34 (45.9)	25 (46.3)	9 (45.0)
One drink per week	14 (18.9)	11 (20.4)	3 (15.0)

	All participants, *n*=74	Female, *n*=54	Male, *n*=20
More than one drink per week	26 (35.1)	18 (33.3)	8 (40.0)
Dietary restriction, n (%) [d]			
No restriction	70 (95.9)	50 (94.3)	20 (100.0)
Restriction [e]	3 (4.1)	3 (5.7)	0.00 (0.00)
Smoking status, n (%)			
Not currently smoking	69 (93.2)	50 (92.6)	19 (95.0)
Currently smoking	5 (6.8)	4 (7.40)	1 (5.00)
Allergies, n (%)			
No allergies	56 (75.7)	39 (72.2)	17 (85.0)
Yes	18 (24.3)	15 (27.8)	3 (15.0)
Current medication use, n (%)			
No	51 (68.9)	36 (66.7)	15 (75.0)
Yes	23 (31.1)	18 (33.3)	5 (25.0)
Anthropometry			
Height (cm), mean ± SD	171 ± 9.95	168 ± 7.05	182 ± 9.77
Weight (kg), mean ± SD	75 ± 15	72 ± 13	84 ± 15
BMI (kg/m^2), mean (95%CI)	25.5 (24.5-26.5)	25.5 (24.3-26.8)	25.4 (24.0- 26.8)

SD: standard deviation;%: percentile; CI: confidence interval; BMI: body mass index; kg/m^2: kilograms/meters squared.
Continuous variables are presented as the mean ± SD, median [25th, 75th%] and geometric mean (95%CI) and categorical variables are presented as *n* and percentages.
[a]*n*=eight participants selected two ethnicities, [b]*n*=seven missing, [c]*n*=10 missing, [d]*n*=one missing, [e]*n*=one identified low carbohydrate diet.

3.5.2 Nutrient intakes of men and women

The reported intakes of macronutrients differed between men and women (Table 3.2). Male and female participants had a mean CHO intake of 65.9 (52.1-79.7) g/d which contributed to 14.0 (11.4-16.7) percent of energy intake (%EI). Participants consumed a mean of 24.4 (22.9-25.9)%EI from protein, median of 58.1 [49.1, 66.0]%EI from fat, and means of 22.0 ± 7.17 and 537 (462-612) from saturated fat (SFA) and cholesterol, respectively.

Men consumed significantly more thiamin (P<0.001), niacin (P<0.001), vitamin B6 (P=0.009), phosphorous (P=0.006), iron (P=0.019), sodium (P=0.024) and potassium (P=0.034) than women.

Table 3.2 Participant Energy and Nutrient intake by gender

	NRV female	**NRV male**	**All participants, *n*= 74**	**Female, *n*= 54**	**Male, *n*= 20**	***P*-Value ***
Age (y)	-	-	34.7 ± 7.5	35.1 ± 7.0	33.5 ± 8.8	0.401
Age (y)	-	-	35.0 [28.0, 42.0]	35.0 [29.0, 42.0]	34.5 [26.0, 42.0]	0.492
BMI (kg/m^2)	-	-	25.5 (24.5-26.5)	25.5 (24.3-26.8)	25.4 (24.0-26.8)	0.907
Energy (kJ) [^]	19-30 y: 8100-10500 31-50 y: 7900-10100 [a]	19-30 y: 10800-13800 31-50 y: 11000-16100 [a]	7451 ± 2364	6843 ± 1925	9093 ± 2694	<0.001
Protein (g)	37 [a]	52 [a]	104 (96-111)	96 (88-103)	125 (106-143)	0.002
Protein (%EI)	15-25 [b]	15-25 [b]	24.4 (22.9-25.9)	24.4 (22.9-25.9)	24.4 (20.4-28.4)	0.643
Total fat (g)	-	-	115.0 ± 46.2	105.3 ± 38.1	141.1 ± 56.4	0.003
Fat (%EI)	20-35 [b]	20-35 [b]	58.1 [49.1, 66.0]	57.9 [49.1, 65.6]	60.6 [48.1, 67.1]	0.918
SFA (g)	-	-	44.6 (39.7-49.5)	40.3 (35.9-44.7)	56.3 (43.1-69.5)	0.043
Sat Fat (%EI)	<10 [b]	<10 [b]	22.0 ± 7.17	21.9 ± 6.64	22.3 ± 8.62	0.823
MUFA (g)	-	-	43.8 ± 18.7	40.8 ± 16.4	51.8 ± 22.6	0.024
MUFA (%EI)	10-20 [c]	10-20 [c]	21.6 ± 5.50	22.0 ± 5.49	20.6 ± 5.52	0.338
PUFA (g)	-	-	15.9 (13.9, 17.9)	14.4 (12.5, 16.2)	20.0 (14.8, 25.2)	0.014
PUFA (%EI)	6-10 [c]	6-10 [c]	7.79 (7.17, 8.41)	7.70 (7.03, 7.36)	8.04 (6.53, 9.55)	0.771
Cholesterol (mg)	<200/<300 [d]	<200/<300 [d]	537 (462-612)	495 (421-568)	651 (451-851)	0.902
CHO (g)	-	-	65.9 (52.1-79.7)	61.2 (46.3-76.0)	78.6 (45.0-112.3)	0.345
CHO (%EI)	45-65 [b]	45-65 [b]	14.0 (11.4-16.7)	14.1 (10.9-17.2)	13.9 (8.5-19.4)	0.739

Sugars (g)	-	-	36.7 (30.0-43.3)	35.0 (27.3-42.7)	41.0 (26.6-55.5)	0.448
Starch (g)	-	-	28.4 (20.0-36.8)	25.4 (17.4-33.3)	36.5 (12.6-60.4)	0.470
Dietary fibre (g)	25 [e]	30 [e]	18.5 (15.6-21.4)	17.3 (14.7-19.8)	21.8 (13.2-30.4)	0.629
Alcohol (g)	-	-	0.00 [0.00, 8.44]	0.02 [0.00, 7.50]	0.00 [0.00, 12.25]	0.794
Alcohol (%EI)	<5	<5	0.00 [0.00, 2.93]	0.01 [0.00, 2.93]	0.00 [0.00, 3.25]	1.000
Thiamin (mg)	0.9 [a]	1 [a]	0.96 (0.87-1.06)	0.85 (0.77-0.92)	1.28 (1.02-1.54)	<0.001
Riboflavin (mg)	0.9 [a]	1 [a]	1.86 (1.68-2.04)	1.81 (1.58-2.04)	2.00 (1.72-2.27)	0.190
Niacin equivalents (mg)	11 [a]	12 [a]	41.5 (37.8-45.2)	37.5 (34.3-40.7)	52.5 (42.8-62.3)	<0.001
Vitamin B6 by analysis (mg)	1.1 [a]	1.1 [a]	2.27 (1.96-2.57)	1.95 (1.70-2.19)	3.12 (2.25-4.00)	0.009
Vitamin B12 (µg)	2 [a]	2 [a]	5.38 (4.61-6.15)	4.77 (4.07-5.48)	7.02 (4.91-9.13)	0.060
Folate total DFE (µg)	320 [a]	320 [a]	380 (329-431)	358 (314-402)	439 (286-593)	0.403
Vitamin A equivalents (µg)	500 [a]	625 [a]	985 (840-1129)	925 (771-1079)	1146 (792-1501)	0.159
Vitamin C (mg)	30 [a]	30 [a]	79.1 [48.5, 127.1]	75.3 [48.5, 124.2]	102.0 [49.8, 157.3]	0.289
Vitamin E (mg)	7 [e]	10 [e]	13.4 (11.6-15.1)	13.0 (10.8-15.2)	14.3 (11.3-17.3)	0.237
Calcium (mg)	840 [a]	840 [a]	802 (719-885)	814 (709-920)	769 (643-895)	0.767
Phosphorus (mg)	580 [a]	580 [a]	1462 (1358-1567)	1377 (1263-1492)	1691 (1474-1908)	0.006
Zinc (mg)	6.5 [a]	12 [a]	12.30 ± 4.21	11.3 ± 3.73	15.0 ± 4.29	<0.001
Iron (mg)	8 [a]	6 [a]	11.3 (10.26-12.38)	10.6 (9.45-11.7)	13.3 (10.9-15.7)	0.019
Magnesium (mg)	19-30 y: 255 31-50 y: 265 [a]	19-30 y: 330 31-50 y: 350 [a]	335 (300-371)	318 (281-355)	382 (293-471)	0.152

Iodine (µg)	100 [a]	100 [a]	102.8 [77.1, 151.6]	110.7 [77.1, 153.2]	101 [73.0, 138.5]	0.591
Selenium (µg)	50 [a]	60 [a]	91.9 (79.5-104)	84.5 (72.2-96.7)	112 (79.8-144)	0.054
Sodium (mg)	460-920 [e]; 2000 [c]	460-920 [e]; 2000 [c]	2241 (2038-2443)	2100 (1889-2312)	2620 (2140-3100)	0.024
Potassium (mg)	2800 [e]; 4700 [c]	3800 [e]; 4700 [c]	2943 (2657-3229)	2735 (2469-3001)	3507 (2731-4282)	0.034
Caffeine (mg)	-	-	175 [81.7, 266]	180 [99.1, 266]	125 [53.0, 307]	0.451

NRV: Nutrient Reference Values for New Zealand; y: years old; kg/m^2: kilogram/meters squared; kJ: kilojoules; g: gram;%EI: percentage of energy intake; SFA: saturated fat; MUFA: monounsaturated fat; PUFA: polyunsaturated fat; mg: milligram; µg: microgram; DFE: dietary folate equivalents. SD CI
Continuous variables are expressed as median [25th, 75th percentiles], mean ± SD and geometric mean (95%CI).
[^] EAR energy requirements, by age (years) for women (reference body weight 61 kg) and men (reference body weight 76 kg; National Health and Medical Research Council et al., 2006)
[a] EAR (Estimated Average Requirement).
[b] AMDR (Acceptable Macronutrient Distribution Range).
[c] SDT (Suggested Dietary Target; Ministry of Health, 2003).
[d] Dietary cholesterol is not an 'essential' nutrient; recommendations of <300 mg dietary cholesterol for the general adult population, and <200 mg for individuals living with or at risk for heart disease (Dietitians of Canada, 2016; U.S. Department of Agriculture & U.S. Department of Health and Human Services, 2010).
[e] AI (Adequate Intake).
*Independent sample T-tests were used for parametric data and Mann-Whitney (Exact sig.) were used for non-parametric data; a level of $P<0.05$ indicates a significant difference in intakes between men and women.

3.5.3 Nutrient intakes by carbohydrate grouping Very Low (<50 g), Low (50 <100 g) and Moderately Low (100 <150 g)

Energy intake was lower in the very low (VL) CHO group than the moderately low (ML) CHO group (P=0.001; Table 3.3). Absolute protein intake was lower in the VL CHO group than the ML CHO group (P=0.002) only, as a %EI, total fat and SFA intakes were greater in the VL CHO group versus others (VL vs low (L): total fat P=0.003, SFA P=0.003; VL vs ML: total fat P=0.003, SFA P=0.001).

The VL CHO group consumed less sugar (g) and starch (g) than the L and ML CHO groups (all P<0.001) and the L CHO group consumed less than the ML group (P<0.001 and P=0.008, respectively). The VL CHO group consumed less fibre than the L and ML CHO groups (P=0.001 and P<0.001, respectively). Compared to the L and ML CHO groups, the VL CHO group had lower intakes of thiamin (P=0.001 and P<0.001), vitamin E (P=0.004 and P=0.008), phosphorous (P=0.009 and P<0.001), magnesium (P<0.001 and P=0.002) and potassium (P=0.002 and P<0.001), and compared to the ML CHO group, the VL CHO group had lower intakes of riboflavin (P=0.008), niacin (P=0.018), folate (as DFE; P=0.006), vitamin A (P=0.005), vitamin C (P=0.007), iron (P<0.001) and iodine (P=0.028).

Table 3.3 Nutrient intake by carbohydrate intake grouping

	NRV	Very low CHO (<50 g), n=39 ǂ	Low CHO (50<100 g), n=20 ǂ	Moderately low CHO (100<150 g), n=10 ǂ	P-Value ǂ
Age (y)	-	35.8 ± 6.9 ≠	34.1 ± 7.9 ≠	34.2 ± 8.8 ≠	0.401 ≠
Age (y)	-	37.0 [29.0, 42.0] ≠	34.0 [28.0, 42.0] ≠	33.5 [27.0, 44.0] ≠	0.492 ≠
BMI (kg/m^2)	-	26.1 (24.7-27.6)	25.6 (23.4-27.7)	25.2 (22.3-28.2)	0.817
Energy (kJ) ^	Women: 19-30 y: 8100-10500, 31-50 y: 7900-10100 Men: 19-30 y: 10800-13800, 31-50 y: 11000-16100 [a]	6524 (5858-7190) [h]	7887 (6894-8880)	9499 (8148-10851) [h]	0.001
Energy (kcal)	-	1559 (1399-1718) [h]	1884 (1647-2121)	2269 (1946-2592) [h]	0.001
Protein (g)	Women: 37 Men: 52 [a]	97.6 (88.6-106.6) [h]	111 (97.8-124.7)	135 (117-153) [h]	0.002
Protein (%EI)	Women: 15-25 Men: 15-25 [b]	25.5 (23.8-27.3)	24.3 (21.9-27.0)	23.7 (20.5-27.2)	0.562
Total fat (g)	-	113 (98.1-127)	120 (98.4-142)	128 (97.8-157)	0.635
Fat (%EI)	Women: 20-35 Men: 20-35 [b]	63.1 (60.1-66) [f h]	53.9 (49.5-58) [f]	47.9 (41.9-54) [h]	<0.001
Saturated fat (g)	-	42.8 (36.6-50.1)	37.7 (29.8-47.7)	40.4 (29.3-55.6)	0.665
Sat Fat (%EI)	Women: ≤10 Men ≤10 [b]	25.9 (23.9-27.9) [f h]	19.8 (16.8-22.7) [f]	17.1 (13.1-21.1) [h]	<0.001
MUFA (g)	-	41.8 (35.8-47.8)	47.1 (38.1-56.0)	51.4 (39.3-63.6)	0.312
MUFA (%EI)	Women: 10-20 Men: 10-20 [c]	23.6 (22.2-25.0) [h]	21.1 (19.0-23.2)	19.4 (16.5-22.3) [h]	0.020
PUFA (g)	-	12.8 (11.0-14.9)	15.9 (12.6-19.9)	15.1 (11.1-20.6)	0.258
PUFA (%EI)	Women: 6-10 Men: 6-10 [c]	7.85 (7.05-8.66)	8.13 (6.93-9.33)	6.59 (4.96-8.22)	0.297
Cholesterol (mg)	Women: <200/<300 Men: <200/<300 [e]	477 (394-571)	436 (332-577)	619 (423-906)	0.326

CHO (g)	-	26.5 (22.1-30.9) [f h]	67 (60.4-73.6) [f g]	127 (118-136) [g h]	<0.001
CHO (%EI)	Women: 45-65 Men: 45-65 [b]	6.8 (5.31-8.28) [f h]	15.0 (12.8-17.2) [f g]	23.9 (20.8-26.9) [g h]	<0.001
Sugars (g)	-	17.6 (5.31-8.28) [f h]	35.3 (30.1-40.6) [f g]	65.4 (58.2-72.6) [g h]	<0.001
Starch (g)	-	6.58 (6.14-9.37) [f h]	25.7 (19.5-36.6) [f g]	60.3 (39.9-94.2) [g h]	<0.001
Dietary fibre (g)	Women: 25 Men: 30 [e]	11.0 (9.34-12.8) [f h]	18.8 (14.9-23.9) [f]	24.5 (17.7-33.8) [h]	<0.001
Alcohol (g)	-	4.41 (1.69-7.13)	7.23 (3.17-11.28)	4.26 (-1.26-9.77)	0.486
Alcohol (%EI)	Women: <5 Men: <5	1.94 (0.90-2.98)	2.36 (0.81-3.90)	1.25 (-0.85-3.36)	0.698
Thiamin (mg)	Women: 0.9 Men: 1 [a]	0.74 (0.66-0.82) [f h]	1.03 (0.90-1.17) [f]	1.26 (1.07-1.48) [h]	<0.001
Riboflavin (mg)	Women: 0.9 Men: 1 [a]	1.56 (1.36-1.76) [h]	1.98 (1.69-2.27)	2.27 (1.87-2.66) [h]	0.003
Niacin equivalents (mg)	Women: 11 Men: 12 [a]	35.8 (32.4-39.6)	43.7 (37.6-51)	49.8 (40.5-61.1)	0.008
Vitamin B6 by analysis (mg)	Women: 1.1 Men: 1.1 [a]	1.6 (1.37-1.87)	2.21 (1.75-2.78)	2.46 (1.79-3.37)	0.016
Vitamin B12 (µg)	Women: 2 Men: 2 [a]	4.97 (4.20-5.84)	4.7 (3.65-5.99)	5.78 (4.13-7.94)	0.598
Folate total DFE (µg)	Women: 320 Men 320 [a]	260 (221-305) [h]	383 (301-486)	472 (340-653) [h]	0.002
Vitamin A equivalents (µg)	Women: 500 Men: 625 [a]	730 (628-849) [h]	812 (649-1015)	1287 (949-1746) [h]	0.007
Vitamin C (mg)	Women: 30 Men 30 [a]	49 (37.2-64.4) [h]	92.9 (61.7-140)	133 (76.2-232) [h]	0.002
Vitamin E (mg)	Women: 7 Men: 10 [e]	9.43 (8.16-10.9) [f h]	14.6 (11.7-18.0) [f]	15.8 (11.8-21.2) [h]	0.001
Calcium (mg)	Women: 840 Men: 840 [a]	614 (535-705)	831 (677-1019)	887 (670-1173)	0.015
Phosphorus (mg)	Women: 580 Men: 580 [a]	1273 (1154-1393) [f h]	1607 (1429-1785) [f]	1843 (1600-2086) [h]	<0.001

Zinc (mg)	Women: 6.5 Men: 12 [a]	11.8 (10.5-13.0)	13 (11.1-14.9)	14.6 (12.1-17.2)	0.129
Iron (mg)	Women: 8 Men: 6 [a]	9.31 (8.06-10.6) [h]	12 (10.1-13.9)	15.1 (12.6-17.7) [h]	<0.001
Magnesium (mg)	Women: 19-30 y: 255 31-50 y: 265 Men: 19-30 y: 330 31-50 y: 350 [a]	240 (214-270) [f h]	372 (312-443) [f]	389 (306-494) [h]	<0.001
Iodine (µg)	Women: 100 Men: 100 [a]	96.5 (78.2-119)	96.06 (70.1-132)	185 (120-283)	0.026
Selenium (µg)	Women: 50 Men: 60 [a]	72.5 (62.3-84.3)	92.8 (74.1-116)	107 (78.6-144.89)	0.042
Sodium (mg)	Women: 460-920 Men: 460-920 [e]; Women: 2000 Men: 2000 [c]	2074 (1856-2315)	2208 (1874-2605)	2124 (1696-2657)	0.813
Potassium (mg)	Women: 2800 Men: 3800 [e]; Women: 4700 Men: 4700 [c]	2231 (2030-2453) [f h]	3032 (2633-3491) [f]	3948 (3258-4784) [h]	<0.001
Caffeine (mg)	-	210 (127-293)	261 (138-384)	177 (9.19-345)	0.681

kg/m2: kilogram/meters squared; y: years old; kJ: kilojoules; g: gram;%EI: percentage of energy intake; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid; CHO: carbohydrate; mg: milligram; µg: microgram; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid; DFE: dietary folate equivalents.

ǂ Group statistics performed using ANCOVA (P<0.0167). Covariates appearing in the model are evaluated at the following values: Age (years)=35.016, gender=1.26, total monthly income=8.21) Results are expressed adjusted marginal mean (95%CI).

≠ Group statistics performed using ANOVA (P<0.05) Results are expressed as median [25th, 75th percentiles], mean ± SD and geometric mean (95%CI).

^ EAR energy requirements, by age (years) for women (reference body weight 61 kg) and men (reference body weight 76 kg; National Health and Medical Research Council et al., 2006)

[a] EAR (Estimated Average Requirement).

[b] AMDR (Acceptable Macronutrient Distribution Range).

[c] SDT (Suggested Dietary Target; Ministry of Health, 2003).

[d] Dietary cholesterol is not an 'essential' nutrient; recommendations of <300 mg dietary cholesterol for the general adult population, and <200 mg for individuals living with, or at risk for, heart disease (Dietitians of Canada, 2016; U.S. Department of Agriculture & U.S. Department of Health and Human Services, 2010).

[e] NRV-AI (Adequate Intake).

[fgh] values with shared superscript represent significant differences according to Bonferroni post-hoc tests (P<0.0167)

3.5.4 Key food item contributors to energy intake

Table 3.4 displays the top 20 energy-providing foods, excluding tap water, salt and black pepper, consumed from the four-day food records of all 74 participants.

Processed meat, chicken and fish, consumed by 82% of participants, was the top contributor to total energy intake (1st) and was frequently consumed (4th), those who consumed this had an average of 0.9 portions or 658 kJ/day. Cheese was frequently consumed (2nd) and provided an average of 635 kJ/day to participants who consumed cheese (84%). Nuts were third; those who ate nuts (70% of participants) consumed 1.1 portions or 729 kJ/day. Pork contributed 737 kJ/day to participants who consumed pork (30%), the greatest average energy/portion/day of any of the top 20 foods. Coffee, a top 20 contributor to energy intake (20th), was the most frequently consumed food item, those consumed coffee had on average 1.7 coffees or 124 kJ/day.

All top contributing fruit and vegetables were consumed less than once per day: salad greens (0.8), tomato (0.7), capsicum (0.7) and garlic (0.7). Alcohol was consumed by 40% of participants and was a top contributor to energy intake (12th).

The most common cooking fats participants identified with were olive oil, butter and coconut oil (88%, 78% and 69%, respectively), this was reflected in the energy they provided to food records (62387 kJ, 50403 kJ, 39257 kJ, respectively). Less popular cooking fats were lard (20%), avocado oil (20%), ghee (15%) and rice bran oil (15%). Most participants also use pan frying (93%), roasting or baking (92%), grilling (75%), steaming (64%), boiling (59%) and microwaving (56%) as cooking methods.

Table 3.4 Key food item contributors to energy intake and most frequently consumed food.

Top 20 foods by energy contribution							**Top 20 foods by frequency**		
Food item	***n*** [a]	**%** [a]	**Energy/ day (kJ)** [c]	**Total energy (kJ)/4 days** [b]	**Total weight (g)/4 days** [b]	**Rank**	**Food item** [d]	***n*/day** [e]	***n*/4days** [b]
Processed beef/ lamb/ pork/ chicken/ fish, including: bacon, deli meats, sausages, deep-fried, tinned product	61	82	658	160639	16313	**1**	Coffee	1.65	390
Cheese, all varieties	62	84	635	157367	10952	**2**	Cheese, all varieties	1.04	349
Nuts, including nut meals	52	70	729	151569	5774	**3**	Nuts, including ground nuts	1.12	233
Chicken	55	74	650	143061	17322	**4**	Processed meat, chicken and fish, including: bacon, sausages & salami, tinned, sliced/ deli, deep fried	0.93	227
Beef	51	69	583	119026	15223	**5**	Cream, including reduced cream and whipped cream	1.40	224
Egg, white and/or yolk	60	81	465	111559	19386	**6**	Tea beverage, including black, green and oolong and herbal, fruit and chai teas	1.16	219
Cream, including reduced, standard & whipped cream	40	54	561	89738	5821	**7**	Eggs, white and/or yolk	0.87	209
Pork	22	30	737	64827	5803	**8**	Salad greens: lettuce, mesculun & rocket, spinach and salads: garden, Greek, green, Thai beef, Vietnamese chicken	0.82	197
Olive oil, including extra virgin olive oil	47	64	332	62387	1690	**9**	Olive oil, including extra virgin olive oil	0.90	169

Top 20 foods by energy contribution							Top 20 foods by frequency		
Food item	***n*** [a]	**%** [a]	**Energy/ day (kJ)** [c]	**Total energy (kJ)/4 days** [b]	**Total weight (g)/4 days** [b]	**Rank**	**Food item** [d]	***n*/day** [e]	***n*/4days** [b]
Avocado	37	50	392	57955	6379	**10**	Seeds, including ground seeds	1.05	156
Butter	45	61	280	50403	1651	**11**	Cow's milk, including full fat and reduced fat milks	1.20	153
Alcohol	30	41	409	49093	19129	**12**	Butter	0.83	149
Coconut oil, including extra virgin coconut oil	23	31	427	39257	1064	**13**	Chicken	0.62	137
Fish and seafood, fresh	29	39	338	39243	5259	**14**	Tomato, including whole, cherry and tinned tomatoes	0.70	135
Bread, including lower CHO and keto breads	21	28	457	38427	3266	**15**	Beef	0.58	118
Seeds, including ground seeds	37	50	251	37178	1670	**16**	Sweeteners	1.11	89
Chocolate	37	50	250	36964	1535	**17**	Chocolate	0.59	88
Nut and seed spreads	31	42	296	36758	1405	**18**	Avocado	0.58	86
Cow's milk, including full & reduced fat varieties	32	43	272	34836	16489	**19**	Capsicum, all colours	0.66	85
Coffee	59	80	124	29376	56871	**20**	Garlic, including cloves, minced and crushed	0.69	83

[a] Number of participants who recorded the food item within their food record ('food consumer'); [b] Total from the food records of 74 participants; [c] Calculated by: Energy (kJ)/ *n* [a]/4 days=energy per food consumer per day; [d] Water, tap (*n*=970), salt (*n*=190) and black pepper (*n*=108) were removed from this list as they did not contribute to energy intake; [e] Calculated by: item *n* [a] *n* [b]/4 days=*n/food consumer/*day.

3.5.5 Participant dietary principles, rationale and sources of information

The most commonly used self-imposed food rules and dietary principles included by this population were the restriction of sugars and processed foods and oils (45%), and using macronutrient targets such as 'low CHO high fat (LCHF)' or 'Keto' (43%; Table 3.5). Weight loss (4%) and other specific eating patterns of intermittent fasting (9%), flexibility (9%) and cheat meals (5%), were less-frequently listed as dietary principles. The most important reasons reported for following a low CHO diet were weight management (39%) and ease of application (19%). Further reasons included improved mental health, clarity and focus and reduced anxiety (16%), healthier eating habits (more wholefoods, avoiding empty calories, processed and 'inflammatory' foods; 14%), improved digestive health (12%), hormone balance (including: PCOS, blood sugar levels and insulin sensitivity; 11%), prevention of poor health (10%), reduced joint pain and inflammation (7%), reduced migraines/headaches (4%), clearer skin (4%) and improved sleep (3%).

Participants had most frequently heard about the low CHO diet via word of mouth from family, friends and colleagues (41%) and using the internet or own research (35%). Most participants sought low CHO dietary advice and information from the internet and podcasts (93%), social media (44%) and friends (24%). Participants were introduced to the low CHO diet and sought dietary information from low CHO diet advocates (8% and 11%, respectively), specifically: Assem Malholra, Caryn Zinn, Chris Kresser, Cliff Harvey, Deborah Murtagh, Gary Taubes, Grant Schofield, Mikki Williden, Nina Teicholz, Sarah Hallberg, Tim Noakes, Two Keto Dudes, Zoë Harcombe).

Table 3.5 Low CHO dietary principles, rationale and sources of information for this study population

Top five dietary principles or rules	**N (%)**
Avoid: all sugars (especially added sugars), processed foods, gluten and wheat, grains and legumes, seed and vegetable oils, or inflammatory foods	33 (44.6)
"LCHF" or "Keto"	32 (43.2)
CHO intake; <25 g total CHO or <10%EI	13 (17.6)
Choose minimally processed and whole foods	12 (16.2)
Include plenty of non-starchy vegetables/greens	12 (16.2)
Top five reasons for selecting a low CHO diet	
Weight management; to achieve and maintain weight loss	29 (39.2)
Easy to achieve and follow	14 (18.9)
Improved energy levels; reduced lethargy and fatigue	14 (18.9)
Lifestyle and convenience; I like the foods	13 (17.6)

General health and wellbeing; I feel good	13 (17.6)
Top five introductions to the low CHO diet	
Family, friend or colleague, Word of mouth	30 (40.5)
Internet/Own research	26 (35.1)
Social media	10 (13.5)
Unsure; dieted this way (or similarly) previously	7 (9.5)
Low carb advocates and their books	6 (8.1)
Top five sources of low CHO dietary advice or information	
Internet and Podcasts	67 (93.1)
Social media [Facebook, Instagram]	32 (44.4)
Friends	17 (23.6)
Gym or personal trainer	10 (13.9)
Family	8 (11.1)
Lifestyle/ health coach or naturopath	8 (11.1)
Dietitian or doctor	8 (11.1)
Following low CHO advocates	8 (11.1)

LCHF: low CHO high fat; CHO: carbohydrate;%EI: percent of energy intake.
Data presented as count (percent of participants).

The median diet duration at the time of data collection was 377 [179, 707] days, range 126 to 2180 days. The majority (91%) of participants stated they intended following this diet indefinitely. Since undertaking the low CHO diet, many participants reported altering their food consumption pattern (Figure 3.2),which varied by level of CHO intake (Appendix B). Low CHO participants reported consuming less starchy food (e.g. breads and cereals, potato, kumara; 99%), fruit (90%), starchy vegetables (e.g. pumpkin, beetroot, yam, carrot; 81%), lower fat dairy products (e.g. cows' milk, yoghurt; 75%), and plant-protein foods (e.g. tofu, lentils, chickpeas; 68%). And consuming more non-starchy vegetables (e.g. broccoli, cabbage, lettuce; 83%), higher fat dairy products (e.g. cheese, cream; 86%), fat (e.g. coconut oil, butter, cream, ghee (clarified butter), lard, tallow, dripping; 86%), animal-protein rich foods (e.g. eggs, meat, poultry, fish; 78%), nuts and seeds (e.g. peanut butter, walnuts, almond meal, chia seeds, cashews, almonds etc; 68%), oil (e.g. olive oil, grapeseed oil, rice bran oil, avocado oil etc; 55%), and non-dairy milk products (e.g. soy-milk, almond milk, coconut milk, coconut yoghurt etc; 52%).

Most participants also reported replacing CHO foods with non-starchy vegetables (e.g. broccoli, tomato, capsicum; 66%), fats (e.g. coconut oil, butter, cream, lard; 61%), animal protein (e.g. meat, fish, chicken, eggs; 58%), and cheese (54%).

Adoption of the low CHO diet resulted in most participants (89%) avoiding foods which they previously enjoyed eating (Figure 3.3). Avoided foods included wholefoods and discretionary foods primarily of CHO origin, most frequently breads (53%), confectionary (41%) and baked items and pastries (36%) were cited (Figure 3.3).

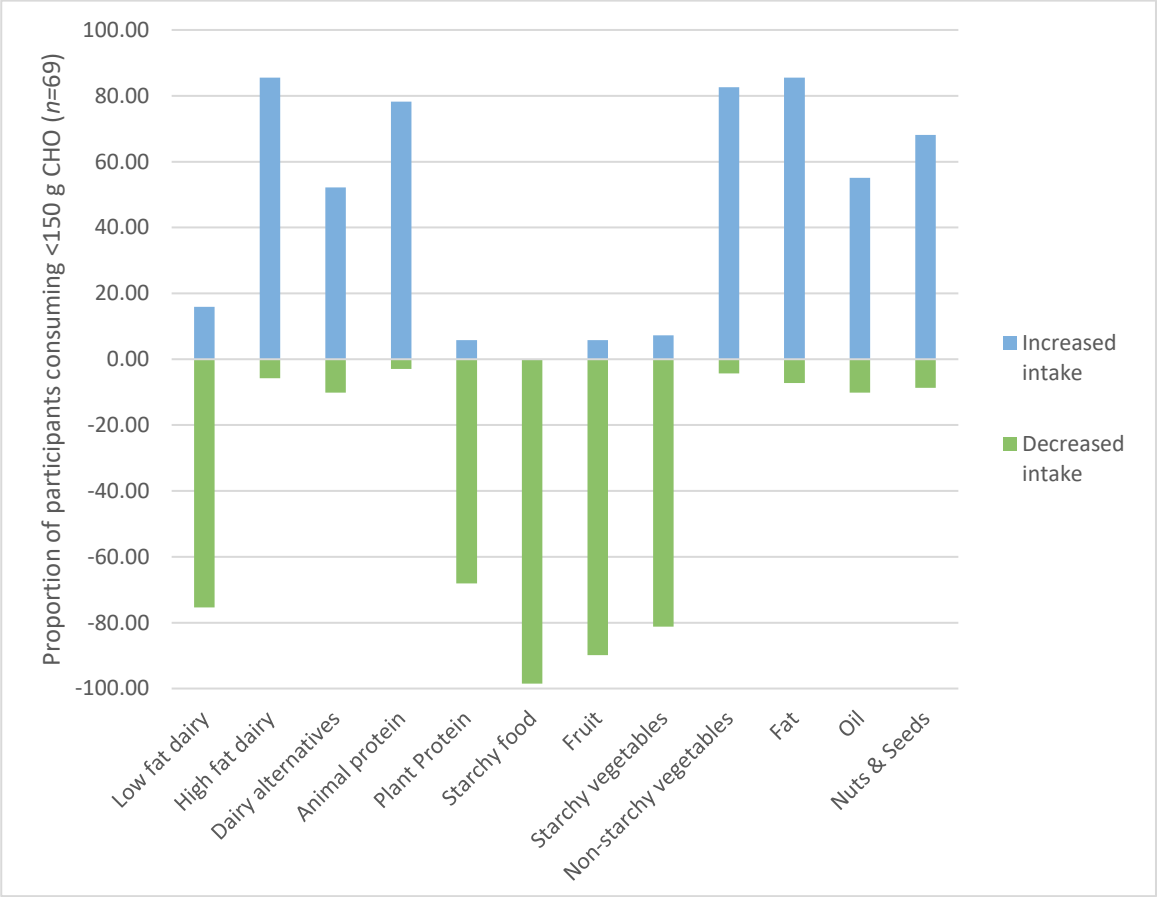

Figure 3.2 Self-reported changes in food consumption since starting the low CHO diet.

Additionally, 80% of participants have changed their meal and snack pattern, primarily by reducing meal/snack frequency and skipping meals (67%), intermittent fasting (38%) and eating to hunger (20%). Many participants consume two or three meals per day (43% or 47%, respectively) with snacks (68%). Of those who snack, most would do so two or more times a day (52%). Two thirds of the participants consumed cheat meals (68%), for the participants this means flexible eating socially, at special occasions and celebrations (48%) and eating to be polite or when there is no other food available (16%). One in four participants (26%) plan one to three cheat meals per week.

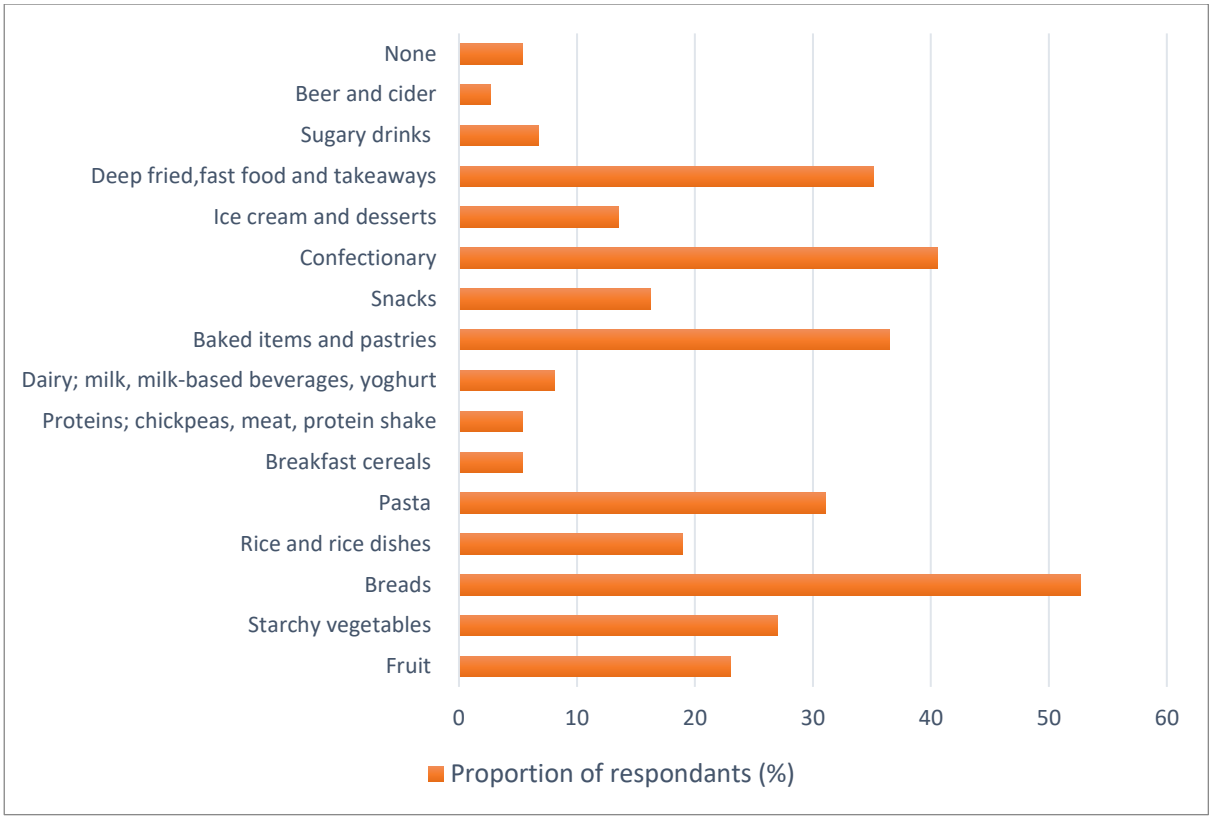

Figure 3.3 Foods avoided by low carbohydrate diet followers in New Zealand

Participant's self-reported health and energy levels (scale: poor (zero) to excellent (100)) are above average (mean: 77 ± 15 and 76 ± 16, respectively). On a scale of zero (significantly decreased) to 100 (significantly increased), participants identified an increase in their ability to perform physical activity (median: 75 [52, 91]), a decrease in hunger or appetite (median: 25 [14,38]) and an increase in thirst (median: 52 [50,68]). Nearly all participants reported a decrease in hunger or appetite (86%), however, 47% stated that thirst increased.

Participants reported that this eating pattern has impacted their family and home lives by having to prepare and consume their own food more frequently (77%), spending more time on food preparation (45%), changing the eating habits of the household (43%), spending more money on food (42%) and feeling as though they must refuse food when eating with others (42%). There was an equal proportion of participants who felt as though they needed to carry snacks in case they cannot find suitable foods when out and about (42%) to those who stated that they are easily able to locate such foods (42%; Figure 3.4).

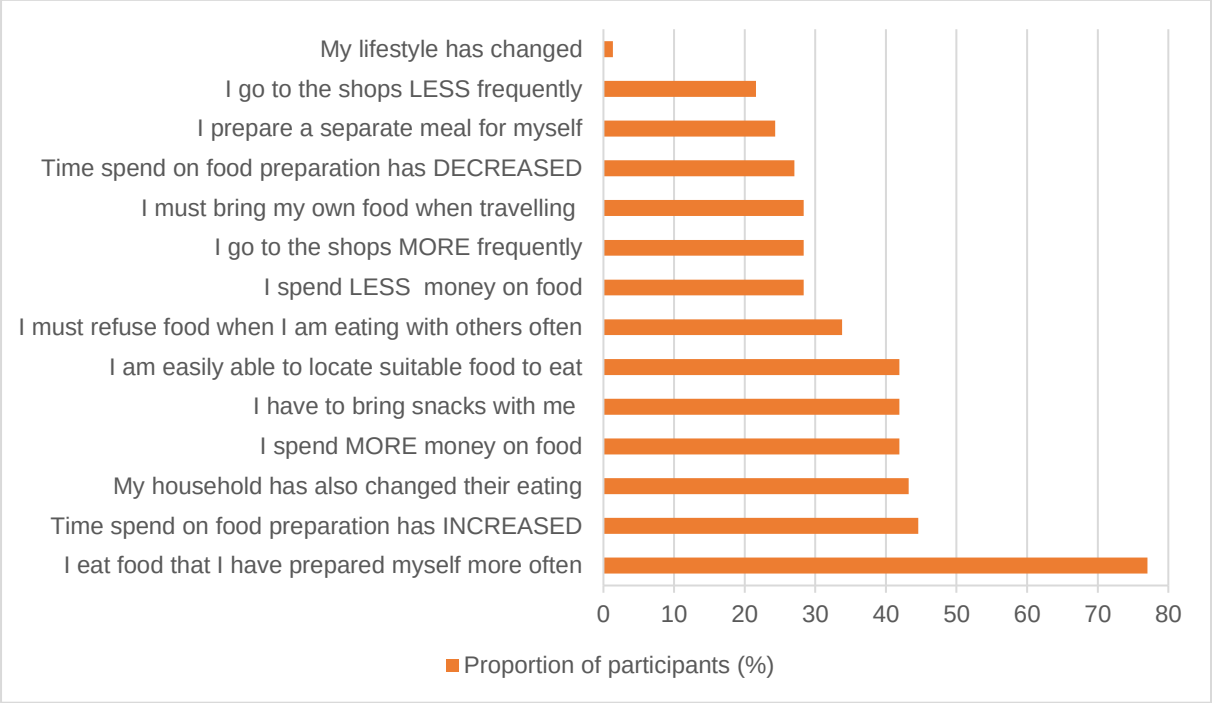

Figure 3.4 How adopting this eating pattern impacts family or home life

Many (84%) of participants report experiencing weight loss on this diet, and on a scale of 0–100 (0=reduced; 50=stayed the same; 100=improved), participants report that their quality of life has improved (median: 90 [75, 99]).

3.6 Discussion

To the best of our knowledge, this is the first New Zealand-based study to investigate the nutrient intakes and dietary practices of self-identified, *free-living* low CHO diet followers. Overall, the results show that, in principle, by avoiding CHO-foods, replacing them with animal-products and dietary fats, the low CHO diet followers consumed macronutrients outside of the AMDR. The participants who altered their food choices were motivated not only by weight management, ease and convenience, but also by perceived health benefits such as stabilized blood sugar levels and improved diet quality (more whole foods, and less processed and 'inflammatory' foods), bowel habits, energy levels, sleep, mental clarity and focus, mental health and skin conditions. Such benefits are promoted by influential low CHO advocates, and in social media success stories and may lead persons to believe a low CHO diet has significant health benefits.

Interestingly, low CHO dietary information was more frequently sourced from the internet, social media sites and even trainers than from registered health professionals. This may be relative to the ease at which information can be accessed and extracted from the former, however, these sources may provide inaccurate or incomplete dietary advice which is concerning given the impact of diet on human health.

Energy intakes for men (9093 kJ) and women (6843 kJ) were comparatively less than population intakes in the most recent Adult Nutrition Survey 2008/09 (ANS08/09; men=10683 kJ, women=7644 kJ; University of Otago & Ministry of Health, 2011) and less than a proposed LCHF meal plan by Zinn, Rush, and Johnson (2018; men=11192 kJ, women=8975 kJ). Similarly, energy intakes of the participants were less than low CHO diet followers in Iceland (8067 kJ; Elidottir, Halldorsson, Gunnarsdottir, & Ramel, 2016).

Mean CHO intakes for men (CHO=78.6 g, 14.1%EI), women (CHO=61.2 g, 13.9%EI) and all of the low CHO groups (VL CHO=26.5 g, 6.8%EI; L CHO=67 g, 15.0%EI; ML CHO=127 g, 23.9%EI) were low. As expected, it was also comparatively less than population intakes in the ANS08/09 (CHO: men=289 g, 46.0%EI, women=213 g, 47.1%EI; University of Otago & Ministry of Health, 2011) and contributed to just 14.0%EI, which is less than one-third of the AMDR for CHO intake (45-65%EI; National Health and Medical Research Council et al., 2006). Absolute CHO intake, but not as a %EI, of men and women were less than intakes of the proposed LCHF meal plan by Zinn et al. (2018; CHO: men=66 g, 10%EI, women=61 g, 11%EI; Zinn et al., 2018). Carbohydrate intake, as a %EI, was more than those reported by low CHO diet followers in Iceland (10%EI; Elidottir et al., 2016) and less than low CHO diet consumers (defined as <26%EI

(excluding alcohol) from CHO; 22.1%EI) from the UK Biobank cohort (Shafique, Russell, Murdoch, Bell, & Guess, 2018).

Sugar intakes were relatively low (men=41 g, women=35 g), approximately one-third of (sugar) intakes (men=128 g, women=103 g) reported in the ANS08/09 (University of Otago & Ministry of Health, 2011). Although neither men, women, nor any of the low CHO groups (VL CHO, L CHO and ML CHO) achieved the adequate intake (AI) for fibre, mean fibre intakes (men=21.8 g, women=17.3 g) were similar to those in the ANS08/09 (men=23 g, women=18 g; University of Otago & Ministry of Health, 2011), and more than low CHO diet followers in Iceland (12 g). As lower fibre intakes may be associated with greater incidence of total mortality, coronary heart disease incidence, T2DM and colorectal cancer (Reynolds et al., 2019), increasing the quantity of fibre consumed by low CHO dieters may yield long-term health benefits via a reduction in chronic disease risk.

Relevant to the deliberate increases in the consumption of high fat dairy, animal protein, nuts, seeds, fats and oils; total fat (men=60.6%EI, women=57.9%EI) and SFA (men=22.3%EI, women=21.9%EI) exceeded the AMDR for men, women, and all CHO groups (VL CHO; L CHO and ML CHO). Study participants consumed a lesser proportion of total fat (58.1%EI vs 66%EI) and SFA (22.0%EI vs 26%EI) than low CHO diet followers in Iceland (Elidottir et al., 2016) but more total fat (58.1%EI vs 54.8%EI) and SFA (22.0%EI vs 19.5%EI) than low CHO diet consumers from the UK Biobank cohort (24.4%EI vs 26.2%EI; Shafique et al., 2018). Total fat intake was less and SFA intake more, than those in the LCHF meal plan proposed by Zinn et al. (2018) which may incorporate more heart-healthy unsaturated fats than our participants consumed. Excessive total and saturated fat, as consumed by the LOCA study participants, may yield health ramifications such as an increased risk of cardiovascular disease. Absolute protein intakes (men=125 g, women=96 g) exceeded the EAR for men, women, and all CHO groups (VL CHO; L CHO and ML CHO), however as a %EI, protein exceeded the AMDR for the VL CHO group only. As a %EI, study participants had similar protein intakes (24.4%EI) to low CHO diet followers in Iceland (23%EI; Elidottir et al., 2016), to low CHO diet consumers from the UK Biobank cohort (24.4%EI vs 26.2%EI; Shafique et al., 2018), to the LCHF meal plan proposed by Zinn et al. (2018; men=24%EI, women=22%EI), and greater intakes than adults in the ANS08/09 (men=16.4%EI, women=16.5%EI; University of Otago & Ministry of Health, 2011) which suggests that low CHO diet followers consume more protein than the adult NZ population.

Compared to the NRV, sodium intakes for both genders and low CHO groups (VL CHO, L CHO, and ML CHO) exceeded the SDT. This is of concern as high sodium intakes may increase blood

pressure, a risk factor for cardiovascular and renal diseases, in a dose-dependent manner (National Health and Medical Research Council et al., 2006). However, population sodium intakes were previously reported to be high among adults (≥15 years old) who participated in the ANS08/09 (24-h urinary sodium excretion from spot urine samples, mean: 3035 (2990, 3079) mg. Estimated usual daily sodium intake from 24-h diet recall data (excluding salt added at the table), mean: 2564 mg (2519, 2608); McLean, Williams, Te Morenga, & Mann, 2018).

In the present study, low intakes of micronutrients were observed for thiamin among women and the VL CHO group, folate and magnesium for the VL CHO groups, vitamin E and zinc for men in the VL CHO group, calcium for men and women, and VL CHO and L CHO groups and iodine for the VL and L CHO groups. Furthermore, no group achieved the SDT for potassium. Inadequate intakes of such nutrients may contribute to a myriad of risks and potential deficiency-related illnesses (Churuangsuk et al., 2019; Desrosiers, Siega-Riz, Mosley, & Meyer, 2018; Kenig et al., 2019; National Health and Medical Research Council et al., 2006).

The present study found that with the exception of sodium, which was consumed in excess, the ML CHO group was the only group which achieved the NRV for all other micronutrients. Conversely, we found the VL and L CHO diet followers may be at risk of developing micronutrient deficiencies. This may be due to the more balanced macronutrient distribution (closer to the AMDR, which was set to allow for an adequate intake of micronutrients) consumed by the ML CHO group.

Low iodine intakes observed were most likely due to the greater restriction of CHO and consequently iodine-fortified breads. This is of particular concern in NZ, as locally grown food may be low in iodine due to low soil concentrations (National Health and Medical Research Council et al., 2006). All low CHO groups achieved the EAR for selenium which may be related to the frequent consumption of seafood, poultry and eggs, which are the greatest dietary contributors to selenium in NZ (National Health and Medical Research Council et al., 2006). Participants reported avoiding sugars and processed CHO, which was similar to another study that investigated the food choices of low CHO diet followers in Finland (Piia et al., 2014) in which butter, vegetable oils and spreads were the primary fats used, compared to our study where butter, olive oil and coconut oil were preferred.

Akin with principles of the low CHO diet, respondents frequently avoided CHO-rich foods, replacing them with foods of mostly protein and fat origin (cream, butter, cheese, coconut oil, meat and processed meat). The regular consumption of such foods is counter to the Eating and Activity Guidelines for New Zealand Adults (Ministry of Health, 2015) as such foods may contribute excess

total fat, SFA, energy and sodium. Respondents also reported reducing low-fat dairy, plant proteins, starchy food, fruit and starchy vegetable consumption. These diet patterns are concerning as inadequate calcium intakes, as observed in many groups (male, female, VL CHO and L CHO) of this present study, has been associated with osteoporosis; and low fibre intakes are associated with obesity, cardiovascular disease, diabetes and colorectal cancer (National Health and Medical Research Council et al., 2006). Furthermore, limited fruit and vegetable intake and increased intakes of processed and high fat meat, have the potential to be carcinogenic (Baghurst, Record, & Syrette, 1997; Gonzalez & Riboli, 2010).

The present study has many strengths. The WFR are valuable in ascertaining dietary information as they do not rely on memory for accurate data retrieval (Satija, Yu, Willett, & Hu, 2015), and were furthermore of optimal duration (four days; Stram et al., 1995). Rigorous dietary data assessment was performed, in which trained researchers interviewed participants to clarify any incomplete WFR diet entries. The WFR were entered into nutrition analysis software and checked for error by a second researcher, thereby limiting errors and enabling an estimation of the habitual nutrient intake of free-living low CHO diet followers.

This study investigated and compared nutrient intakes of three low CHO groups (VL, L and ML) as it allowed researchers to compare nutrient intakes, assess nutritional adequacy and identify the at-risk macro- and micronutrients at three levels of CHO intake.

The novelty of findings from this study are a strength as the information on food choices and nutrient intakes of *free-living* low CHO diet followers in NZ have not yet been explored. Results identify issues with high total fat, SFA and sodium intakes in all low CHO groups, and inadequate micronutrient intakes with VL and L CHO diets.

Comparing actual nutrient intakes of *free-living* persons to the hypothetical case study design by Zinn et al. (2018) adds strength to the study. This comparison identifies additional nutrients of concern when low CHO diets are followed by individuals than when such diets are carefully curated by dietitians and low CHO diet advocates.

Comparing actual nutrient intakes of this present study to those of low CHO diet followers in Iceland (Elidottir, Halldorsson, Gunnarsdottir, & Ramel, 2016) and from the UK Biobank cohort (Shafique, Russell, Murdoch, Bell, & Guess, 2018) identifies differences in macronutrient consumption between low CHO dieters in NZ and other countries. However, there were no further studies reporting nutrient intakes of self-reported low CHO dieters of a similar population.

The present study also has limitations. Firstly, the cross-sectional study design provides an overview of the study's participants at a point in time, and can therefore not determine causality or directionality (Setia, 2016), Due to the small sample size (*n*=74), participants are not representative of all low CHO diet followers living in Auckland, NZ. However, since there is no current data on *free-living* low CHO diet followers in NZ, this study provides valuable information on food choices and nutrient intakes. Additionally, this study relied on accurate self-reporting both in the WFR and in the questionnaires. However, since many of the participants were already self-monitoring dietary intakes via mobile health apps, we speculate that weighing and recording food may not have been such a high burden in this specific population. Furthermore, determining nutrient intakes using FoodWorks was complicated by the large proportion of specialty foods consumed by low CHO diet followers which were not routinely available in the Australia and NZ food composition databases. In such cases, care was taken to limit the variability introduced from substitution methods by choosing similar foods or ingredients from the databases as to limit the variability introduced from substitution methods. Supplements were excluded from the dietary analysis; therefore, nutrient intakes only reflect the food related nutrients consumed by participants.

Potential under-reporters of energy intake were not excluded from this study, as the low CHO diet is used to reduce energy intake, therefore energy deficits, detected by using a cut-off point of two standard deviations (SD) below the participant's BMR (estimated using a modified Oxford Equation), may have been as a result of the reduced intake related to following the low CHO diet. One over-reporter of energy intake detected by a cut-off point two SD above the participants BMR was also not excluded as low CHO diets frequently promote increased fat intakes without explicit energy restrictions.

In conclusion, this study provides valuable novel insight into food and nutrients consumed by *free-living* low CHO diet followers in NZ, as well as their motivations and food-related behaviour. Cheese, chicken, beef, cream, pork, butter, coconut oil and cow's milk, consumed by the participants, contributes excessive SFA, increased total and LDL cholesterol and the potential risk of CHD. No CHO groups achieved recommendations for total fat, SFA, fibre and sodium intakes. This, in combination with the finding that the greatest proportion of energy was from processed meats (consumed by 82% of participants), is a concern.

Nevertheless reductions in glycated haemoglobin (HbA1c), triacylglycerides, and systolic blood pressure, increases in HDL-C and insignificant changes in LDL-C have previously been reported from low CHO diets (Gjuladin-Hellon, Davies, Penson, & Baghbadorani, 2019; Huntriss, Campbell, & Bedwell, 2018) and may potentially reduce the risk of cardiovascular diseases and

T2DM. Conversely, low CHO diets may be no more effective than isoenergetic balanced weight loss diets for reducing weight and cardiovascular risk (Huntriss et al., 2018; Naude et al., 2014). However, participants of this study did not achieve recommendations for total fat, SFA, and fibre, and therefore the low CHO would not be recommended.

Unlike the VL and L CHO groups, the ML CHO group achieved recommendations for all micronutrients measured, sodium excluded, and therefore may meet the micronutrient requirements of this group.

Acknowledgements: The authors would like to thank the participants for their participation in, and the research team for their facilitation of the LOCA study.

Author Contributions: M.R. and R.K. conceived and designed the LOCA study; T.K-E., L.R., V.L., T.G., and N.B. performed data collection and data entry; T.K-E. analysed the data, T.K-E., R.K., and M.R. interpreted the results, T.K-E wrote the paper, and R.K., C.W., and M.R. reviewed and approved the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Chapter 4: Conclusion

4.1 Summary of the Study

This study was designed to understand the motives for following low CHO diets and assess the diet quality, dietary practices and food-related behaviours of self-reported low CHO diet followers aged 20 to 45 years old, from the Auckland region. A four-day WFR and the Dietary Practices & QOL (DPQOL) questionnaire were used to collect dietary information from 74 participants. To our knowledge this is the first study in NZ which has assessed the dietary intakes, food and nutrient substitution practices, and dietary practices of self-identified low CHO diet followers. Novel findings on the dietary intakes and practices of *free-living* adult low CHO diet followers in NZ are presented.

The first objective of this study was to assess the total dietary intake (macronutrients, micronutrients and energy) of low CHO diet followers, stratified by total group and gender, comparing the WFR nutrient analysis to NZ nutrient reference values (NRV) and results of the most recent NZ adult nutrition survey (Adult Nutrition Survey 2008/09 (ANS08/09)). Energy intakes (men=9093 kJ, women=6843 kJ) were comparatively less than population intakes in the ANS08/09 (men=10683 kJ, women=7644 kJ; University of Otago & Ministry of Health, 2011). Carbohydrate intakes (65.9 g/d, 14.0 percent of energy intake (%EI)), equated to less than one third of the AMDR (45-65%EI; National Health and Medical Research Council, Australian Government Department of Health and Ageing, & Health, 2006). Compensatory increases in protein (24.4%EI), fat (58.1%EI) and increases in saturated fat (SFA; 22.0%EI) and cholesterol (537 mg), were observed. Protein intakes were close to the upper-limit range, and total and saturated fat intakes exceeded their respective AMDR (15-25%EI, 20-35%EI and <10%EI, respectively; National Health and Medical Research Council et al., 2006).

As a %EI, participants in this study had lower CHO intakes compared to the ANS08/09 (14%EI vs 46.6%EI), and greater fat (58.1%EI vs 33.7%EI) and protein intakes (24.4%EI vs 16.5%EI) respectively (University of Otago & Ministry of Health, 2011). Men and women achieved the NRV for riboflavin, niacin, vitamins A, B6, B12, C, and E, folate, phosphorous, zinc, iron, magnesium, iodine, and selenium, but not for calcium and potassium, and consumed sodium above recommendations. Men but not women achieved the NRV for thiamin.

The findings of this study are novel to this population, however, compared to low CHO diet consumers (defined as <26%EI (excluding alcohol) from CHO), aged 40 to 69 years, from the UK

Biobank cohort, as a %EI LOCA participants consumed less CHO (14.0%EI vs 22.1%EI), similar protein (24.4%EI vs 26.2%EI), and more total fat (58.1%EI vs 54.8%EI) and SFA (22.0%EI vs 19.5%EI; Shafique, Russell, Murdoch, Bell, & Guess, 2018). Despite differences in the definition of a low CHO diet, this comparison indicates that the low CHO diet principles are adhered to in both countries and highlights the need for further research regarding nutrient intakes of *free-living* low CHO diet followers.

The second objective was to explore the dietary intake (macronutrients, micronutrients and energy) by level of CHO intake. Most (93%) participants consumed fewer than 150 g of CHO/day, and these participants were grouped into very low (VL), low (L) and moderately low (ML) CHO intake groups. The nutrient analyses were compared between groups and to NRV. Between-group comparisons showed significant differences in nutrient intakes between VL, L and ML CHO intake groups. Carbohydrate (g and %EI), sugar and starch intakes were significantly lower in the VL CHO group than the L and ML CHO groups, and in the L CHO group than the ML CHO group. Total fat (%EI), SFA (%EI), fibre, thiamin, vitamin E, phosphorous, magnesium and potassium intakes were significantly lower in the VL CHO group than the L and ML CHO groups. Energy, protein (g), monounsaturated fat (MUFA; %EI), riboflavin, folate, vitamin A, vitamin C and iron intakes were significantly lower in the VL than the ML CHO group. For each of these nutrients, dietary intakes were the lowest in the VL CHO group and the greatest in the ML CHO group.

Compared to the ANS08/09, the VL and L CHO group consumed less, and the ML CHO group consumed more dietary energy (ANS08/09=9103 kJ, VL=6524 kJ, L=7887 kJ, ML=9499 kJ,). The low CHO groups did not achieve the minimum AMDR (45-65%EI) for CHO intakes (VL=6.8%EI, L=15.0%EI, ML=23.9%EI). The VL CHO group consumed protein above, and the L and ML groups consumed protein within the AMDR of 15-25%EI (VL=25.5%EI, L=24.3%EI, ML=23.7%EI). All groups exceeded the AMDR of 20-35%EI for total fat (VL=63.1%EI, L=53.9%EI, ML=47.9%EI), and the AMDR of <10%EI SFA intakes (VL=25.9%EI, L=19.8%EI, ML=17.1%EI). Fibre intakes (men=21.8 g, women=17.3 g, VL=11.0 g, L=18.8 g, ML=24.5 g) were lower than recommendations for men (30 g/day) and women (25 g/day). All low CHO groups consumed sodium in excess of NRV. The VL CHO group did not achieve NRV for thiamin, folate, vitamin E, calcium, zinc, magnesium, iodine, and potassium, the L CHO group did not achieve NRV for calcium, iodine and potassium intakes, however the ML CHO group achieved all NRV for the micronutrients reported. Thus, in terms of macro- and micronutrient intakes, a ML CHO diet was more nutritionally adequate than VL and L CHO diets.

The third objective was to assess and describe food and nutrient substitution practices via the DPQOL questionnaire. Self-reported changes in food choice were corroborated by top contributors to WFR in terms of energy and frequency recorded. Generally, since undertaking the low CHO diet, participants reported replacing CHO with non-starchy vegetables, fats and oils, animal protein and cheese. Processed meats, known to be carcinogenic (Baghurst, Record, & Syrette, 1997; Gonzalez & Riboli, 2010), contributed the greatest amount of energy to the food records and were consumed by 82% of the study population. This suggests that processed meats are over-consumed by this population and pose a potential health risk. Further foods which contributed to energy intake (cheese, chicken, beef, cream, pork, butter, coconut oil and cow's milk) also contributed to the high SFA intake in this population.

The fourth objective was to explore and understand the motives for following a low CHO diet via the DPQOL questionnaire. In addition to weight management and health and wellbeing, participants also self-identified convenience and ease of application as motives for following a low CHO diet, the latter of which are novel to this study.

The fifth objective was to determine the dietary practices, food choices and 'food rules' currently employed and how they impact on participants' lives using the DPQOL questionnaire. Participants self-identified the avoidance of processed foods, the incorporation of 'cheat meals' and/or fasting, and flexibility as dietary practices. Most (80%) of the participants changed their meal and/or snack pattern since starting the low CHO diet, primarily by reducing meal/snack frequency and skipping meals; most reported consuming two to three meals/day plus snacks. The majority (68%) also consumed cheat meals, some of which are regular and/or planned. Participants reported avoiding foods which they previously enjoyed (breads, confectionary, baked goods) and reducing their intake of low-fat dairy, plant proteins, starchy food, fruit and starchy vegetables, and increasing high fat dairy, non-dairy alternatives, animal protein, non-starchy vegetables, fats and oils, and nuts and seeds. These low CHO food choices contributed to the inadequate consumption of dietary fibre (18.5 g), and excessive total fat (58.1%EI) and SFA (22.0%EI) intakes. These findings are of particular concern relative to increased risks of obesity, cardiovascular disease, type 2 diabetes and hypertension (National Health and Medical Research Council et al., 2006).

Most (84%) of the participants reported experiencing weight loss on this diet. They self-reported health and energy levels as above average, an increased ability to perform physical activity, a decrease in hunger or appetite, and an improvement in quality of life. Participants reported that this eating pattern has impacted their family and home lives by having to prepare and consume their

own food more frequently, spending more time and money on food, changing the eating habits of the household and refusing particular food when eating with others.

Some self-reported motives (health and well-being) and dietary practices (avoidance of processed foods) were contradictory to the identified key food contributors (high fat animal foods, processed meats, and coconut oil) to the energy, excess total fat and SFA intakes of participants. However, these findings may also reflect the low CHO diet followers' incorrect perception of a 'healthy' diet and highlights an area where more research is needed.

Ultimately, low CHO diet followers in NZ are consuming less than a third of the minimum CHO recommendation (45%EI), with most, in the present study, consuming <50 g CHO/day. Compensatory increases in protein and fat containing foods were reported and confirmed by the WFRs; in which protein and fat (including SFA) were consumed in excess of recommendations by this group. This pattern of macronutrient consumption did not allow for adequate micronutrient intakes and therefore, despite following this diet for improvements in health and well-being, these individuals may instead be at greater risk of micronutrient deficiencies.

The following hypotheses can be accepted:

Low CHO diet followers living in Auckland, NZ, will:

1. Be consuming less than the recommended 45-65 percent of energy intake as CHO, with concurrent increases in protein and fat intake;
2. Replace dietary CHO with foods primarily of animal origin;
3. Avoid CHO foods which they previously enjoyed eating.

4.2 Strengths and Limitations

4.2.1 Strengths

The WFR is a valuable tool in ascertaining dietary information as it does not rely on memory for accurate data retrieval (Satija, Yu, Willett, & Hu, 2015) and therefore, was a strength of this study. Food records, four to five days in length, have been found to be of optimal duration for recording dietary intakes (Stram et al., 1995). Increasing the number of days of recording may result in an increased participant burden, thus, limiting the number of recording days to four days was a further strength of this study, which may have helped with response rates.

Rigorous dietary data assessment, utilising appropriate ingredients or food substitutions as required, was a strength of the study, as it enabled an estimation of the habitual food and nutrient intake of

free-living low CHO diet followers. This study reported and compared nutrient intakes of three CHO intake groups (VL, L and ML) based on the participant's actual CHO intakes. This was a further strength of this study as it allowed researchers to investigate nutrient intakes using three ranges of CHO intake, to assess the nutritional adequacy at each range and how nutrient intakes differ between the ranges, and identifying the at-risk macro- and micronutrients at each level of CHO intake. Furthermore the novelty of findings from this study are a strength as the information on food choices and nutrient intakes of *free-living* low CHO diet followers in NZ have not yet been explored, and results highlight adverse issues with high total fat, SFA and sodium intakes in low CHO groups, and inadequate micronutrient intakes with VL and L CHO diets. Comparing actual nutrient intakes to the hypothetical case study design by Zinn, Rush, and Johnson (2018) adds strength to the study, providing a more realistic rebuttal to the proposed nutritional adequacy of the low CHO diet (Zinn et al., 2018) by using actual intakes of *free living* persons, rather than the idealistic and potentially unachievable planned low CHO diet. This comparison highlights that there may be more nutrients of concern when low CHO diets are followed by individuals using their own diet compilation, than when diets carefully curated by dietitians and low CHO diet advocates are used.

4.2.2 Limitations

Like all study designs, cross-sectional studies have limitations; they can provide an overview of the study's participants at a point in time and cannot determine causality or directionality (Setia, 2016). It is therefore difficult to generalise the results of this study to all low CHO diet followers living in NZ. The small sample size (n=74) is a limitation of the study as it increases the margin of error and is less likely to represent the population. The data collection method, requiring participants to attend the Human Nutrition Research Unit, and the requirements for blood pressure measurements, plasma and urine samples for the larger LOCA study may have discouraged persons from taking part in the study and was therefore a limitation to the study. The sample lacked diversity in gender and ethnicity as most participants were NZ European females. This was unavoidable due to the study participants who volunteered; however, it may also reflect the setting (North Shore, Auckland) and the demographic where the low CHO diet is more popular.

The process of recording one's food intake can lead to dietary changes to allow for ease of recording, thus providing dietary data atypical to usual intake (Satija et al., 2015). Under-reporting of energy intake has been observed in previous studies (Black & Cole, 2001; Gemming, Jiang, Swinburn, Utter, & Mhurchu, 2014; Johnansson, Solvoll, Bjørneboe, & Drevon, 1998), including the ANS08/09, in which 21% of men and 25% of women were classified as low energy reporters,

and for persons living with overweight and obesity, this increased to 25% and 30%, respectively (Gemming et al., 2014). However, many participants were already recording their intakes via mobile health apps, therefore this impact on intake and any time burden completing the WFR may have been negligible. Furthermore, as the low CHO diet is frequently used for weight loss, which requires an energy deficit, no participants were excluded in this study regarding concerns of under- and over- reporting (66% and 1% of participants, respectively).

Determining the participant's nutrient intakes from the WFRs was complicated by the specialty foods not routinely available in the Australia and NZ food composition databases. In such cases care was taken to choose similar foods or ingredients from the databases as to limit the variability introduced from substitution methods. Measuring dietary sodium intakes is notoriously difficult due to difficulties quantifying sodium in recipes and discretionary salt use (McLean, 2014); assessment of sodium intakes is therefore a limitation of this study. Furthermore, while 24-hour urinary collection is the gold standard method for measuring sodium intakes (McLean, 2014) it contributes a major participant burden and extra analysis cost.

4.3 Recommendations for future research

The current study provided highly valuable information related to the nutrient intakes of low CHO diet followers in NZ. Based on this study, future studies should aim to recruit a larger number of participants (≥207), as a larger study population would mean that a more detailed and accurate analysis could be carried out and provide participants of greater diversity (ethnicities and gender), from the NZ population. This may also be achieved by extending the duration of data collection, increasing advertising (e.g. radio advertising, within supermarkets, church groups etc) and by including participants from other cities/regions in the study. Efforts should also be made to recruit equal numbers of men and women, and to over-represent Māori, Pacific and Asian ethnicities to better estimate intakes of these minority groups (Vaughan, 2017). Future studies should utilise questionnaire items to assess the low CHO diet followers' perception of what constitutes a 'healthy' diet.

This study aimed to recruit *self-identified* low CHO diet followers; new research could aim to recruit equal numbers of participants who identify as following different low CHO diet variants (e.g. animal- and plant-based) to compare food choice and nutrient intakes of animal-based with plant-based low CHO diets.

This study only reported nutrient intakes from food sources only and therefore may underestimate total nutrient intakes, as many participants consumed a range of supplements. Future studies should

aim to consolidate a database which comprises the complete nutritional profile of supplements consumed in NZ, so that supplements can be analysed with dietary data to enable the full assessment of nutrient intakes of low CHO diet followers, and to compare nutritional differences with and without supplements.

Future studies could also consider an intervention (low CHO diet), which collects anthropometric, biochemical and dietary data (WFR) at baseline, six and twelve months, to identify and quantify any changes in nutrient intakes, biochemistry and body composition when a low CHO diet is consumed for one year.

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Participant ID: _____

Appendix A: Supplementary methods

An excerpt from “The Low Carb (LOCA) Study 4 Day Food Record” can be found from pages 96 to 105. This includes the cover page, instructions, an example day and a condensed template for Day 1.

Participant ID: _____

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

The Low Carb (LOCA) Study

4 Day Food Record

Thank you very much for taking part in the Low Carb Study. We are extremely grateful for your time, effort and commitment!

If you have any questions, please contact staff.

All information in this diary will be treated with the strictest confidence. No one outside the Low carb study will have access to this data.

Please bring this food diary with you to your visit at the Nutrition Laboratory

Address: Building 27 (Oteha Rohe Campus, Albany)

Entrance: Gate 4 Albany Highway (See map attached)

Participant ID: _____

What to do?

- Record all that you eat and drink on the dates specified in the email.

- If possible record food at the time of eating or just after – try to avoid doing it from memory at the end of the day.

- Include all meals, snacks, and drinks, even tap water.

- Include anything you have added to foods such as sauces, gravies, spreads, dressings, etc.

- Write down any information that might indicate **size or weight** of the food to identify the portion size eaten.

- Use a new line for each food and drink. You can use more than one line for a food or drink. See the examples given.

- Use as many pages of the booklet as you need.

Describing Food and Drink

- Provide as much detail as possible about the type of food eaten. For example **brand names and varieties / types** of food.

General description	**Food record description**
Breakfast example – cereal, milk, sugar	1 cup Sanitarium Natural Muesli 1 cup Pam's whole milk 1 tsp Chelsea white sugar
Coffee	1 tsp Gregg's instant coffee 1 x 200ml cup of water 2 Tbsp Meadow fresh light green milk

Participant ID: _____

Pasta	1 cup San Remo whole grain pasta spirals (boiled)
Pie	Big Ben Classic Mince and Cheese Pie (170g)

- Give details of all the **cooking methods** used. For example, fried, grilled, baked, poached, boiled…

General description	**Food record description**
2 eggs	2 size 7 eggs fried in 2tsp canola oil 2 size 6 eggs (soft boiled)
Fish	100g salmon (no skin) poached in 1 cup of water for 10 minutes

- When using foods that are cooked (eg. pasta, rice, meat, vegetables, etc), please record the **cooked portion** of food.

General description	**Food record description**
Rice	1 cup cooked Jasmine rice (cooked on stove top)
Meat	90g lean T-bone steak (fat and bone removed)
Vegetables	½ cup cooked mixed vegetables (Wattie's peas, corn, carrots)

- Please specify the **actual amount of food eaten** (eg. for leftovers, foods where there is waste)

General description	**Food record description**

Apple	1 x 120g Granny Smith apple (peeled, core not eaten – core equated to ¼ of the apple)
Fried chicken drumstick	100g chicken drumstick (100g includes skin and bone); fried in 3 Tbsp Fern leaf semi-soft butter

- **Record recipes** of home prepared dishes where possible and the proportion of the dish you ate. There are blank pages for you to add recipes or additional information.

Recording the amounts of food you eat

It is important to also record the quantity of each food and drink consumed.

This can be done in several ways.

- By using household measures – for example, cups, teaspoons and tablespoons. eg. 1 cup frozen peas, 1 heaped teaspoon of sugar.

- By weight marked on the packages – eg. a 425g tin of baked beans, a 32g cereal bar, 600ml Coke

- For bread – describe the size of the slices of bread (eg. sandwich, medium, toast) – also include brand and variety.

- Using comparisons – eg. Meat equal to the size of a pack of cards, a scoop of ice cream equal to the size of a hen's egg.

- Use the food record instructions provided to help describe portion sizes.

General description	**Food record description**
Cheese	1 heaped tablespoon of grated cheese 1 slice cheese (8.5 x 2.5 x 2mm)

Participant ID: _____

	1 cube cheese, match box size Size 10B grated cheese,

- If you go out for meals, describe the food eaten in as much detail as possible.

- ***Please eat as normally as possible - don't adjust what you would normally eat just because you are keeping a diet record and be honest! Your food record will be identified with a number rather than your name.***

Participant ID: _____

Example day

Time food was eaten	**Complete description of food (food and beverage name, brand, variety, preparation method)**	**Amount consumed (units, measures, weight)**
7:55am	Sanitarium weetbix	2 weetbix
" "	Anchor Blue Top milk	150ml
" "	Chelsea white sugar	2 heaped teaspoons
" "	Orange juice (Citrus Tree with added calcium – nutrition label attached)	1 glass (275 ml)
10.00am	Raw Apple (gala)	Ate all of apple except the core, whole apple was 125g (core was ¼ of whole apple)
12.00pm	Home made pizza (recipe attached)	1 slice (similar size to 1 slice of sandwich bread, 2 Tbsp tomato paste, 4 olives, 2 rashers bacon (fat removed), 1 Tbsp chopped spring onion, 3 Tbsp mozzarella cheese)
1.00pm	Water	500ml plain tap water
3.00pm	Biscuits, chocolate covered Girl Guide biscuits	6 x (standard size)
6.00pm	Lasagne	½ cup cooked mince, 1 cup cooked Budget lasagne shaped pasta , ½ cup Wattie's creamy mushroom and

Participant ID: _____

		herb pasta sauce, ½ cup mixed vegetables (Pam's carrots, peas and corn), 4 Tbsp grated Edam cheese
6.30pm	Banana cake with chocolate icing (homemade, recipe attached)	1/8 of a cake (22cm diameter, 8 cm high), 2 Tbsp chocolate icing
" "	Tip Top Cookies and Cream ice cream	1 cup (250g)
7.30pm	Coffee	1 tsp Gregg's instant coffee 1 x 300ml cup of water 2 Tbsp Meadow fresh blue top milk 2 tsp sugar

Participant ID: _____

Date_____ **DAY 1**

Time food was eaten	**Complete description of food (food and beverage name, brand, variety, preparation method)**	**Amount consumed**

Participant ID: _____

Date_____ **DAY 1 (continued)**

Time food was eaten	**Complete description of food (food and beverage name, brand, variety, preparation method)**	**Amount consumed**

Participant ID: _____

Recipes (Day 1)

The following tables are available on request:

- Table A.1 Assumptions for entering the food records into FoodWorks
- Table A.2 Cooking yields
- Table A.3 Dietary Assumptions
- Table A.4 Items excluded from the dietary analysis

Appendix B: Supplementary results

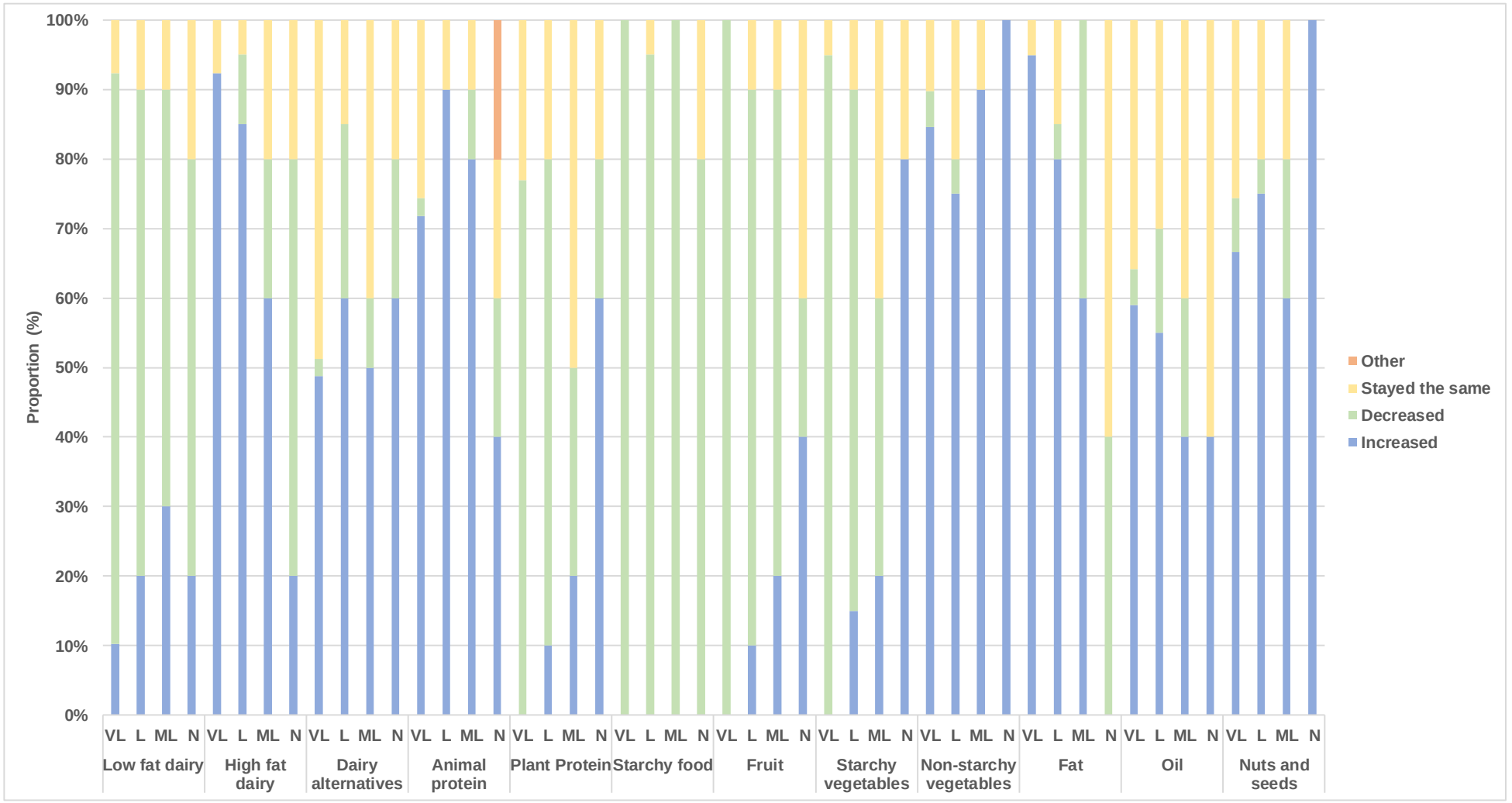

Figure B.1: Self-reported changes in food choice by CHO group.

VL: very low (<50 g CHO); L: low (50<100 g CHO); ML: moderately low (100<150 g CHO); N: normal (≥150 g CHO). Most participants of the VL CHO group reported reducing consumption of low fat dairy (82%), plant protein (77%), starchy food (100%), fruit (100%) and starchy vegetables (95%), and increasing high fat dairy (92%), animal protein (72%), non-starchy vegetables (85%), fats (95%), oils (59%) and nuts and seeds (67%). The L CHO group reported reducing consumption of low fat dairy (70%), plant protein (70%), starchy food (95%), fruit (80%) and starchy vegetables (75%), and increasing high fat dairy (85%), non-dairy alternatives (60%), animal protein (90%), non-starchy vegetables (75%), fats (80%), oils (55%) and nuts and seeds (75%). The ML CHO group reported reducing consumption of low fat dairy (60%), starchy food (100%) and fruit (70%), and increasing high fat dairy (60%), non-dairy alternatives (50%), animal protein (80%), non-starchy vegetables (90%), fats (60%) and nuts and seeds (60%).

Appendix C: Author Guidelines

The *Journal of Human Nutrition and Dietetics* is an international peer-reviewed journal that publishes high quality, peer-reviewed research, reviews, practice guidelines and discussion papers for an international readership.

The journal welcomes quantitative and qualitative human studies, high quality clinical trials, validation studies and systematic reviews.

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Journal articles

1. Steele JR, Meskell RJ, Foy J et al. Determining the osmolality of over-concentrated and supplemented infant formulas. J.Hum Nutr Diet. 2013;26:32-37.
2. Nelson M, Margetts BM & Black A. Letter to the Editor. J Hum Nutr Diet. 1993;6: 79-81.
3. Dixon N. Writing for publication- a guide for new authors. Int J Qual Health Care. 2001;13**:** 417-421.

Books and monographs

4. Kim J. Factors analysis. In: Statistical Package for the Social Sciences. pp. 468-514 [Nie K. Steinbrenner K & Brent DH, editors]. New York: McGraw-Hill; 1975.

Sources from the internet

5. Public Health England (2014) Public Health England Obesity Statistics. http://www.noo.org.uk (accessed October 2014).

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McKenzie, Y.A., Alder, A., Anderson, W., et al., British Dietetic Association evidence-based guidelines for the dietary management of irritable bowel syndrome in adults. J. Hum. Nutr. Diet. 25, 260-274.

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Swift, J.A. & Tischler, V. (2010) Qualitative research in nutrition and dietetics: getting started. J. Hum. Nutr. Dietet 23, 229-566

Pilnick, A. & Swift, J.A. (2011) Qualitative research in nutrition and dietetics: assessing quality J. Hum. Nutr. Dietet 24, 209-214

Fade, S.A. & Swift, J.A. (2011) Qualitative research in nutrition and dietetics: data analysis issues J. Hum. Nutr. Dietet 24, 108-114

Draper, A. & Swift, J.A. (2011) Qualitative research in nutrition and dietetics: data collection issues J. Hum. Nutr. Dietet 24, 3-12.

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