Meeting the nutrient reference values on a low carbohydrate, high fat (LCHF) diet.

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Keywords

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Abstract

Objective

The low-carbohydrate, high-fat (LCHF) diet is becoming increasingly employed in clinical dietetic practice as a means to manage a variety of health-related conditions. Yet, it continues to remain contentious in nutrition circles due to a belief that the diet is devoid of nutrients, and concern around its saturated fat content. This work aimed to assess the micronutrient intake of the LCHF diet under two conditions of saturated fat thresholds.

Design

In this descriptive study, two LCHF meal plans were designed for each of two hypothetical cases representing the average Australian male and female weight-stable adult. National documented heights, a BMI of 22.5 to establish weight, and a 1.6 activity factor was used to estimate total energy intake using the Schofield equation. Carbohydrate was limited to <130g; protein set at 15-25% of total energy; fat supplied the remaining calories. One version of the diet aligned with the national saturated fat guideline threshold of <10% of total energy and the other included saturated fat ad libitum.

Primary outcomes

The primary outcomes included all micronutrients, which were assessed using FoodWorks dietary analysis software against national Australian / New Zealand nutrient reference value (NRV) thresholds.

Results

All of the meal plans exceeded the minimum NRV thresholds, apart from iron in the female meal plans. Saturated fat intake was unable to be reduced below the 10% threshold for the male plan.

Conclusion

Despite macronutrient proportions not aligning with current national dietary guidelines, a well-planned LCHF meal plan can be considered micronutrient-replete. This is an important finding for health professionals, consumers and critics of LCHF nutrition, as it dispels the myth that these diets are suboptimal in their micronutrient supply. As with any diet, for optimal nutrient achievement, meals need to be well formulated.

Strengths and limitations of this study

- A strength of this study is that we used an accurate, professional and local food composition database for dietary analysis.
- A strength of this study is that specialty foods, fortified foods and generally unpopular tasting food (i.e., liver and mussels) were specifically excluded from the food selection to avoid bias towards nutrient-density.
- A limitation of the study is that these results are specific to the two case studies selected, and inference to population groups cannot be made.

Introduction

The low-carbohydrate, high-fat (LCHF) diet is becoming increasingly employed in clinical practice as a dietary means to achieve a variety of health goals, from weight reduction to management of chronic disease, in particular diabetes [1-3]. This style of eating has been shown to be efficacious both short and long term for its beneficial outcomes on metabolic health [4-8]. However, LCHF continues to remain a highly contentious topic in nutrition circles. Two likely reasons for this are i. the supposition that LCHF diets are devoid of certain nutrients, and therefore increase risk of nutrient deficiencies [9,10] and ii. concern around the saturated fat content of the diets and the speculation that high intakes might increase risk of cardiovascular disease. Full-fat versions of animal fat-containing whole foods are not purposefully minimised in an LCHF diet; as a result, the saturated fat intake can exceed the maximum 10% of total energy intake threshold set by the National Australian and New Zealand Nutrient Reference Values (NRV) guidelines [11]. Recently, the science supporting the long-standing diet-heart hypothesis and the 10% threshold for saturated fat intake has been challenged; both epidemiological studies and randomised controlled trials have come under criticism for being flawed in research methodology and outcome interpretation [12 13]. This is an ongoing debate that indicates this area of public health and nutrition guidance needs further work to resolve [12 14 15].

The LCHF nutrition paradigm tend not to exclude any food groups specifically, but rather focuses on reducing intake from high load-carbohydrate foods in general; and when carbohydrate is eaten, whole-food sources are preferred to processed ones. In contrast, vegetarian and vegan diets are styles of eating that do exclude several food groups that contain vital micronutrients. Recently a lacto-ovo vegetarian diet has been shown to be nutrient-replete, if well-planned using an array of non-animal sources containing these potentially missing nutrients [16]. However, a traditional vegan diet is deficient in Vitamin B12, as this vitamin is derived only from foods of animal origin; it is also low in the fat-soluble vitamins A and D, with consumption of fortified foods and supplementation necessary for their repletion [17 18]. Despite the known nutrient deficiency risks that arise with vegan and some vegetarian eating styles, national and international nutrition organisations are not dissuasive of these diets; nutrition professionals merely address any dietary issues in clinical practice [19 20]. By contrast, carbohydrate-restricted diets are still frowned upon by many dietitians and associated national organisations [10], despite their endorsement by some organisations such as The Commonwealth Scientific and Industrial Research Organisation

(CSIRO) [21]. This study aimed to assess the micronutrient thresholds of two versions of the LCHF diet against national NRV thresholds, as set by the Australian National Health and Medical Research Council (NHMRC) and New Zealand Ministry of Health (MOH) [11] under two conditions of saturated fat thresholds.

Methods

In this descriptive study, we designed two LCHF meal plans for each of two hypothetical case studies representing the average Australian male and female as closely as possible. Using the BMI equation BMI = (weight-kg) / (height-m X height-m), we inputted actual heights recorded by the Australian Bureau of Statistics 2011-2013 [22] and used the midpoint for a healthy range BMI of 22.5 to calculate body weight. To estimate total energy expenditure, we used the Schofield equation [23], where weight and height variables and an activity factor of 1.6 (light level) were inputted. The adult age range of 19-50 years was selected from the Australian NHMRC and New Zealand MOH set of categories [11]. We used computer analysis software FoodWorks Professional, version 8 (Xyris software), which utilises an Australian and New Zealand food database. The only micronutrient NRV that varies within this age category (i.e., 19-35 years and 35-50 years) is magnesium; this was accounted for in the analysis. Total energy intake would likely change within the age groups and was accounted for in the analysis by ensuring that energy intake was met within 95% of requirements for both a 25-year old and a 45-year old male and female. We assumed weight stability and matched the energy intake with the calculated energy expenditure.

For the macronutrient thresholds, we selected a value of carbohydrate that aligned with the 'low carbohydrate' definition as per Feinman and colleagues [24] i.e., <130g per day (or <26% of total energy). The protein threshold was calculated based on the upper limit of the acceptable macronutrient distribution range (AMDR) as per the Australian NHMRC and New

Zealand MOH guidelines (i.e,. 25% of total energy intake) [11]. Fat was set as the remaining calories. The two sample meal plans differed only by saturated fat content, which was set at the threshold of 10% or less of total energy intake. All micronutrients were required to achieve at least 100% of the NRVs; where the recommended daily intake (RDI) value was not available, the adequate intakes (AI) value was used. Table 1 presents the demographic data used for the case studies.

Insert Table 1 here.

We created two different meal plans for the purpose of ensuring variety in food options, using the same macronutrient and micronutrient thresholds and targets for both set of plans. For each sample meal plan, the male and female versions differ only by portion sizes to align with personalised energy requirements. For the dual purpose of preventing duplication in Table 2 and wanting to illustrate dietary variety, we have elected to present meal plan sample 1 for females and meal plan sample 2 for males, along with their corresponding diets with saturated fat limits. All meals have been developed with a whole-food principle (i.e., using foods that have been minimally processed) as a foundation. We also opted to include foods that we considered to be, generally, popular and acceptable, rather than any specialty or unusual food that would demand an acquired taste.

Results

Tables 2 and 3 present the LCHF sample meal plans for females and males, and the nutrient analysis of the meal plans, respectively, with their corresponding plans aligning with the saturated fat threshold of <10% total energy.

Insert Table 2 here.

Insert Table 3 here.

Both of the meal plans successfully exceeded the NRV thresholds for all nutrients, apart from two instances. The first was iron intake in females, the two meal plans achieving 86-98% of the RDI threshold value for this mineral. The second instance was an inability to meet the <10% of total energy intake saturated fat threshold in the male (meal plan 2 only). In this plan, saturated fat amounted to 10.6% of total energy, exceeding the threshold by 0.6% (or 2g).

Discussion

Overall, the LCHF meal plans successfully achieved almost all of the micronutrient RDI / AI thresholds. There are several important points about iron that warrant discussion. Firstly, in our meal plan development, we specifically selected whole, unprocessed foods that were not fortified with nutrients, such as iron. We also decided to purposely exclude liver and mussels from these plans, despite their rich nutrient density, as we are aware that these foods may not be considered appealing for the majority of the population. However, it is worthwhile noting that the addition of a small amount of chicken liver (i.e., 5g and 25g, or 1-4 mussels, in meal plans 1 and 2, respectively), would have resulted in the RDI being met for iron. Our strategy differs somewhat to the work of Reid et al., who, knowing iron is a nutrient of concern for vegetarians, intentionally incorporated iron-fortified foods in their vegetarian meal plans. Hence, they were able to meet iron requirements, apart from during pregnancy, where the RDI is higher [16].

Secondly, iron bioavailability is affected by dietary composition and iron status, two aspects that are not considered comprehensively in RDI threshold generation. For industrialised counties, like Australia and New Zealand a mean iron bioavailability factor is used to generate the iron RDI for all population groups, irrespective of dietary composition [25]. Iron bioavailability is reduced by phytates, found predominantly in wholegrains, such as breads and cereals [25]. Other compounds that reduce bioavailability are polyphenols and oxalates, and while found in vegetables and fruit, are also present in wholegrains. The LCHF diet is typically very low (or devoid) in grains, which could mean higher iron bioavailability for those consuming such a diet. This, along with other factors that influence nutrient status, plus the natural variation in food intake raises caution about the use of the RDI threshold alone to assess an individual's diet at a glimpse. While not presented in this work, our nutrient analyses work on isocaloric diets aligning with the Australian NHMRC and New Zealand MOH guidelines, also indicate a failure to meet the RDI threshold for iron. As such, while the LCHF diet is often targeted for being inadequate, using NRVs as a dietary adequacy tool, one can assume a similar inadequacy for iron under mainstream dietary guidance using unfortified foods, where possible.

In the instance where the saturated fat threshold of <10% of total energy a threshold was not met in one of the male meal plans, comprehensive dietary manipulation of this meal plan for the specific purpose of meeting this target was attempted. In order to achieve carbohydrate and protein targets, the only way to achieve the energy requirements with a <10% saturated fat threshold was to add an alcoholic beverage into the meal plan, as it is the only food item that provides energy without any other macronutrient. We viewed this as being somewhat futile so decided against this option. It is also important to note that during this dietary manipulation exercise, in order to reduce the saturated fat contribution, once all the relevant animal foods were altered to low fat or non-fat versions (i.e., dairy products and meats) and coconut products were removed, the saturated fat content still slightly exceeded the 10% threshold, by 0.6%. It was only when we reduced the amount of avocados, certain seeds, olive oil and macadamia nuts, i.e., foods that contain predominantly unsaturated fats, did the thresholds align. Saturated fat guidelines exist in the form of a percentage of total energy threshold, and it is not known whether the public health caution for saturated fat relates to an amount consumed in grams or is relative to total energy only, suggesting that as a guideline it is rather arbitrary.

There are three other nutrient components that warrant discussion in the context of LCHF diets: B vitamins and fibre, protein and essential fatty acids.

B vitamins and fibre

The LCHF diet is frequency criticised for being deficient in B vitamins in particular Vitamin B1, or thiamin, and fibre, two key components of grain-based foods. We have demonstrated that these meal plans do indeed meet the RDI threshold for thiamin due to the incorporation of alternative, every day thiamin-rich foods such as animal protein, nuts and seeds, and several green vegetables. Despite RDIs met achieved for thiamin, one could call into question the minimum threshold of thiamin required in an LCHF context. A key function of thiamin is the metabolism of carbohydrate [26]; it could be speculated that with a reduced intake of carbohydrate, less thiamin is required. However, considering that in the absence of exogenous carbohydrate, glucose is still made internally through gluconeogenic precursers, research is warranted to determine whether this theory holds any truth. We also demonstrate that the AIs for fibre are surpassed in all of these meal plans, and while devoid of wholegrains, fibre, both soluble and insoluble, can be easily derived from vegetables, some fruit, nuts and seeds.

Protein

Another misconception about the LCHF diet is that it is excessive in protein. We used the protein AMDR as per the Australian NHMRC and New Zealand MOH in the development of these meal plans; however, the female meal plan 1 (<10% saturated fat threshold) exceeded the maximum AMDR protein threshold by 2% (or 7g of protein). In the dietary manipulation required to reduce saturated fat (i.e., a swap from untrimmed Sirloin steak to lean Eye fillet steak for dinner, and a swap from full-fat to non-fat dairy products) what resulted was a higher proportion of protein being derived from those foods at the same quantities so it was unavoidable. While the LCHF diet is not intended to be high in protein, by nature of the foods types consumed to replace carbohydrates, it can end up slightly exceeding the AMDR threshold.

Omega-6: omega-3 Polyunsaturated Fat (PUFA) ratio

A key characteristic of the LCHF way of eating is the discouragement of consumption of seed oils (eg. Canola, Sunflower, Soybean and Rice Brain oil), in order to minimise intake of linoleic acid (omega-6 PUFA), and consequently, to achieve an optimal omega 6:3 ratio. Evidence suggests that a high ratio is pro-inflammatory and has a role to play in promoting the pathogenesis of chronic diseases such as cardiovascular disease, cancer, inflammatory and autoimmune diseases [27 28]. Furthermore, data indicates that humans evolved on a diet with a 1:1 omega 6:3 ratio, whereas Western dietary patterns typically reflect a ratio of around 15-20:1 [28]. Along with the promotion of olive oil use, which is unanimously endorsed, NHMRC / MOH guidelines recommend the use and consumption of vegetable fats (i.e., margarine, Canola, Sunflower, Soybean and Rice Bran oil) in place of fats with a predominantly saturated fat make-up (i.e., butter, coconut oil). As a result, most packaged supermarket foods including foods recommended by the NHMRC / MOH, such as liquid breakfasts, wholegrain bread, and cereals, contain high omega-6 seed oils. This would not necessarily be problematic if omega-3 intakes were increasing on a population level. However, this is not the case; it was recently reported in the Australian 2011–2012 National Nutrition and Physical Activity Survey that 80% of the population was not meeting the NRV threshold for omega-3 [29]. In our sample meal plans, we demonstrate favourable omega-6: omega-3 ratios, i.e., less than the 10:1 NRV thresholds, and substantially closer to that of our dietary composition prior to the agricultural revolution.

Conclusion

There were two key limitations to this work. Firstly, the average height for Australian males and females, respectively, and the midpoint BMI values were used to extrapolate the weights of the two hypothetical case studies. These weights do not align with documented weights for Australian males (85.9kg) and females (71.1kg), respectively [22]. This underestimation of weight would have underestimated energy intake to a small extent. Secondly, our analyses were limited to the available values in the FoodWorks database; consequently, an accurate estimate of Vitamin D intake was not available. It is reported that due to current eating patterns, it is almost impossible to get sufficient Vitamin D (in this case 5μ□g/day) from the diet alone [30] and it is the assumption that it will be derived from sun exposure. It is likely that the LCHF diet supplies more Vitamin D than mainstream nutrition guidelines due to its greater intake of high fat, Vitamin D-rich foods, such as full-fat dairy, butter, eggs and fatty fish.

We have demonstrated that a well-formulated LCHF diet can provide sufficient intakes of all of the micronutrients profiled in the FoodWorks database, apart from iron for females. This marginal shortfall along with the acknowledged limitations of using NRVs in estimating dietary adequacy, leads us to believe that this is not a nutrient of concern for those consuming the LCHF diet. Irrespective of the ongoing saturated fat / heart disease scientific debate, it is still possible to adopt the LCHF diet while keeping saturated fat intake around the 10% of total energy threshold. Considering this way of eating provides a replete set of nutrients, and has been shown to be effective for improving metabolic health, particularly for people with diabetes, it should at least be considered a suitable dietary option for populations, alongside that of mainstream MOH guidelines.

Contributor ship statement

All authors contributed to the conception and design of the research; C. Zinn, A. Rush contributed to the diet development and analysis. All authors contributed to the interpretation of the data; C. Zinn drafted the manuscript. All authors read and approved the final manuscript.

Competing interests

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; CZ has co-authored two books called "What The Fat? - Fat's in, Sugar's out", and "What The Fat – Sports performance" which both assume an LCHF nutrition paradigm.

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Data sharing statement

Data (nutrient analysis) is unable to be placed on a data sharing system due to it being embedded in specific nutrient analysis software that is unable to be shared outside of the software programme. However, a print screen version of the data is available upon request from the author.

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Table 1: Case study demographics.

	Age range (years)	Reference Height (cm)	Reference Weight (kg)	PAL	Energy (kCal)	CHO (g)	Protein UL 25% E (g)	Saturated Fat 10% E (g)
Male	19-50	175	63-71	1.6	2820	65	165.4	30.5
Females	19-50	162	56.3	1.6	2203	65	129.4	23.8

Table 2: LCHF sample meal plans.

LCHF meal plan 1 (females)	**LCHF meal plan 1 (females) (saturated fat <10% of total energy)**	**LCHF meal plan 2 (males)**	**LCHF meal plan 2 (males) (saturated fat <10% of total energy)**
Breakfast ¾ cup frozen mixed berries, 150g plain, unsweetened, full-fat yoghurt, 2 T each sunflower and pumpkin seeds, 3 macadamia nuts, 2 Brazil nuts, 6 almonds	*Breakfast* ¾ cup frozen mixed berries, 150g plain, *unsweetened low-fat yoghurt*, 2 T each sunflower and pumpkin seeds, 3 macadamia nuts, 2 Brazil nuts, 6 almonds	*Breakfast* Omelette: 3 eggs, 60g mushrooms, 100g tomato, 1 cup baby spinach, cooked in 2 tsp butter. Coffee made with 200ml full-fat milk	*Breakfast* Omelette: 3 eggs, 60g mushrooms, 100g tomato, 1 cup baby spinach, cooked in *3 tsp olive oil* Coffee made with *200ml low-fat milk*
Lunch Tuna salad: 95g tin tuna, canned in brine (drained), 1 cup baby spinach leaves, 60g English cucumber, 5 cherry tomatoes, 30g cheddar cheese, 2T linseeds, 1 tsp basil pesto, 3 tsp olive oil	*Lunch* Tuna salad: 95g tin tuna, canned in brine (drained), 1 cup baby spinach leaves, 60g English cucumber, 5 cherry tomatoes, *30g low fat cottage cheese*, 2T linseeds, 10 green olives, 5 tsp avocado oil	*Lunch* Beef salad: 120g Eye fillet, 1 cup spinach leaves, ½ red capsicum, 60g English cucumber, 5 cherry tomatoes, ½ large avocado, 5 walnuts, 1T linseeds, 30g parmesan cheese, 2T olive oil	*Lunch* Beef salad: 150g Eye fillet, 1 cup spinach leaves, ½ red capsicum, 60g English cucumber, 5 cherry tomatoes, ½ large avocado*, 3 T sunflower seeds, 12 green olives, 30g low fat cottage cheese, 2T olive oil, 2 tsp avocado oil*
Dinner 150g Sirloin steak, fat not trimmed, grilled, roasted vegetables: 8 florets cauliflower, 1 medium sized beetroot, 1 medium courgette, 1 medium carrot, coated in 2T olive oil	*Dinner* *150g Beef eye fillet, grilled*, roasted vegetables: 8 florets cauliflower, 1 medium sized beetroot, 1 medium courgette, 1 medium carrot, coated in 2T olive oil	*Dinner* 130g grilled Salmon, 100g green beans, 150g broccoli, 200g grilled pumpkin, ½ cup peas, 1 T olive oil	*Dinner* 150g grilled Salmon, 100g green beans, 150g broccoli, 200g grilled pumpkin, ½ cup peas, 1 T olive oil
Snacks 10 medium strawberries 3Tpistachio nuts Coffee made with 200ml full fat milk	*Snacks* 10 medium strawberries 3Tpistachio nuts *100g low fat plain, unsweetened yoghurt* Coffee made with *200ml low-fat milk*	*Snacks* 20 macadamia nuts Smoothie made with 200ml full fat milk, 10 medium strawberries, crushed nuts (20g almonds, 2T linseeds)	*Snacks* 20 macadamia nuts Smoothie made with *200ml low-fat milk*, 10 medium strawberries, crushed nuts (20g almonds, 2T linseeds, *100g low fat plain, unsweetened yoghurt*)

Table 3: Nutrient analysis of LCHF meal plans.

	Female meal plans			Male meal plans		
Nutrient	Meal plan 1	Meal plan 1 (saturated fat <10% TE) NRV / goal	NRV / goal	Meal plan 2	Meal plan 2 (saturated fat <10% TE)	NRV / goal
Energy (Cal)	2145	2053	2203	2675	2758	2820
Carbohydrate (g) **% TE**[†]	61 11	67 13	248-358 45-65	66 10	69 10	303-439 45-65
Protein (g) **% TE**	115 22	135 26	83-138 15-25	149 22	164 24	106-176 15-25
Fat (g) **% TE**	153 63	129 57	49-86 20-35	194 65	195 64	63-110 20-35
Saturated fat (g) **% TE**	40 28	21 9.6	24 10	46 15	33 10.6	31 10
Trans fats (g) **% TE**	2.2 0.9	0.7 0.3	<2.4 <1%[‡]	1.4 0.4	0.8 0.3	<3g <1%[‡]
Monounsaturated fat (MUFA) (g) **% total fat**	75 53	71 59	-	101 56	117 65	-
Polyunsaturated fat (PUFA) (g) **% total fat**	27 19	28 23	-	32 18	31 17	-
Linoleic acid (O6 PUFA) (g)	20.4	18.6	8*	19.1	18.5	13*
α-linoleic acid (O3 PUFA) (g)	5.8	5.5	0.8*	9.3	6.2	1.3*
Omega 6: omega 3 ratio	3.5	3.4	10	2.1	3.0	10
Fibre (g)	38	39	25*	45	44	30*
Thiamin (mg)	1.4	1.4	1.1	1.6	1.8	1.2
Riboflavin (mg)	2.4	2.4	1.1	3.3	3.5	1.3
Niacin (mg)	23.4	18.8	14	16.2	17.5	16
Vitamin C (mg)	371	370	45	394	398	45
Vitamin A (µg)	2247	2095	700	2374	2047	900
Vitamin E (mg)	23	22	7*	32	41	10*
Vitamin B12 (µg)	3.9	6.4	2.4	11.6	12.8	2.4
Folate, total (µg)	568	583	400	788	757	400
Calcium (mg)	1093	1224	1000	1216	1251	1000
Iron (mg)	16	16	18	20	21	8
Magnesium (mg)	553	589	310	582	598	400
Zinc (mg)	16	22	8	23	24	14

Sodium (mg)	2183	2250	460*	1554	2032	460*
Potassium (mg)	4639	5154	2800*	5585	6107	3800*
Phosphorous (mg)	1848	2076	1000	2478	2644	1000
Selenium (µ g)	166	169	60	113	117	70
Iodine (µ g)	225	190	150	223	207	150

† TE: Total energy

*AIs were used as RDIs were unavailable

‡ World Health Organisation recommendation for trans fats

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Assessing the nutrient intake of a low carbohydrate, high fat (LCHF) diet; a hypothetical case study design.

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Assessing the nutrient intake of a low carbohydrate, high fat (LCHF) diet; a hypothetical case study design.

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Abstract

Objective

The low-carbohydrate, high-fat (LCHF) diet is becoming increasingly employed in clinical dietetic practice as a means to manage many health-related conditions. Yet, it continues to remain contentious in nutrition circles due to a belief that the diet is devoid of nutrients, and concern around its saturated fat content. This work aimed to assess the micronutrient intake of the LCHF diet under two conditions of saturated fat thresholds.

Design

In this descriptive study, two LCHF meal plans were designed for two hypothetical cases representing the average Australian male and female weight-stable adult. National documented heights, a BMI of 22.5 to establish weight, and a 1.6 activity factor was used to estimate total energy intake using the Schofield equation. Carbohydrate was limited to <130g; protein set at 15-25% of total energy; fat supplied the remaining calories. One version of the diet aligned with the national saturated fat guideline threshold of <10% of total energy and the other included saturated fat ad libitum.

Primary outcomes

The primary outcomes included all micronutrients, which were assessed using FoodWorks dietary analysis software against national Australian / New Zealand nutrient reference value (NRV) thresholds.

Results

All of the meal plans exceeded the minimum NRV thresholds, apart from iron in the female meal plans, which achieved 86-98% of the threshold. Saturated fat intake was logistically

unable to be reduced below the 10% threshold for the male plan but exceeded the threshold by 2g (0.6%).

Conclusion

Despite macronutrient proportions not aligning with current national dietary guidelines, a well-planned LCHF meal plan can be considered micronutrient-replete. This is an important finding for health professionals, consumers and critics of LCHF nutrition, as it dispels the myth that these diets are suboptimal in their micronutrient supply. As with any diet, for optimal nutrient achievement, meals need to be well formulated.

Strengths and limitations of this study

- A strength of this study is that we used an accurate, professional and local food composition database for dietary analysis.
- A strength of this study is that specialty foods, fortified foods and generally unpopular tasting food (i.e., liver and mussels) were specifically excluded from the food selection to avoid bias towards nutrient-density.
- A limitation of the study is that these results are specific to the two case studies selected, and inference to population groups cannot be made.

Introduction

The low-carbohydrate, high-fat (LCHF) diet is becoming increasingly employed in clinical practice as a dietary means to achieve a variety of health goals, from weight reduction to management of chronic disease, in particular diabetes [1-3]. This style of eating has been shown to be efficacious both short and long term for its beneficial outcomes on metabolic health [4-8]. However, LCHF continues to remain a highly contentious topic in nutrition circles. Two likely reasons for this are i. the supposition that LCHF diets are devoid of certain nutrients, and therefore increase risk of nutrient deficiencies [9 10] and ii. concern around the saturated fat content of the diets and the speculation that high intakes might increase risk of cardiovascular disease. Full-fat versions of animal fat-containing whole foods are not purposefully minimised in an LCHF diet; as a result, the saturated fat intake can exceed the maximum 10% of total energy intake threshold set by the National Australian and New Zealand Nutrient Reference Values (NRV) guidelines [11]. Recently, the science supporting the long-standing diet-heart hypothesis and the 10% threshold for saturated fat intake has been challenged; both epidemiological studies and randomised controlled trials have come under criticism for being flawed in research methodology and outcome interpretation [12 13]. This is an ongoing debate that indicates this area of public health and nutrition guidance needs further work to resolve [12 14 15].

The LCHF nutrition approach tends not to exclude any food groups specifically, but rather focuses on reducing intake from high load-carbohydrate foods in general; and when carbohydrate is eaten, whole-food sources are preferred to processed ones. In contrast, vegetarian and vegan diets are styles of eating that do exclude several food groups that contain vital micronutrients. Recently a lacto-ovo vegetarian diet has been shown to be nutrient-replete, if well-planned using an array of non-animal sources containing these potentially missing nutrients [16]. However, a traditional vegan diet is deficient in Vitamin B12, as this vitamin is derived only from foods of animal origin; it is also low in the fat-soluble Vitamins A and D, with consumption of fortified foods and supplementation necessary for their repletion [17 18]. Despite the known nutrient deficiency risks that arise with vegan and some vegetarian eating styles, national and international nutrition organisations are not dissuasive of these diets; nutrition professionals merely address any dietary issues in clinical practice [19 20]. By contrast, carbohydrate-restricted diets are still frowned upon by many dietitians and associated national organisations [10], despite their endorsement by some organisations such as The Commonwealth Scientific and Industrial Research Organisation (CSIRO) [21]. This study aimed to assess the micronutrient thresholds of two versions of the LCHF diet against national NRV thresholds, as set by the Australian National Health and Medical Research Council (NHMRC) and New Zealand Ministry of Health (MOH) [11] under two conditions of saturated fat thresholds.

Methods

In this descriptive study, we designed two LCHF meal plans for each of two hypothetical case studies representing the average Australian male and female as closely as possible. Using the BMI equation BMI = (weight-kg) / (height-m X height-m), we inputted national average heights recorded by the Australian Bureau of Statistics 2011-2013 for male and female adults [22] and used the midpoint for a healthy range BMI of 22.5 to calculate body weight. To estimate total energy expenditure, we used the Schofield equation [23], where weight and height variables and an activity factor of 1.6 (light level) were inputted. The adult age range category of 19-50 years was selected from the Australian NHMRC and New Zealand MOH set of categories [11]. We used computer analysis software FoodWorks Professional, version 8 (Xyris software), which utilises an Australian and New Zealand food database. The only NRV that varies within this age category is magnesium, which is slightly higher, for both males and females, in the 35-50 years age sub-category, than in the 19-35 year age sub-category; this was accounted for in the analysis. Total energy intake would likely change within the age groups and was accounted for in the analysis by ensuring that energy intake was met within 95% of requirements for both a 25-year old and a 45-year old male and female. We assumed weight stability and matched the energy intake with the calculated energy expenditure.

For the macronutrient thresholds, we selected a value of carbohydrate that aligned with the 'low carbohydrate' definition as per Feinman and colleagues [24] i.e., <130g per day (or <26% of total energy). The protein threshold was calculated based on the upper limit of the acceptable macronutrient distribution range (AMDR) as per the Australian NHMRC and New Zealand MOH guidelines (i.e,. 25% of total energy intake) [11]. Fat was set as the remaining calories. The two sample meal plans differed only by saturated fat content, which was set at the threshold of 10% or less of total energy intake. All micronutrients were required to achieve at least 100% of the NRVs. The NRVs are a set of recommendations for nutritional intake based on currently available scientific knowledge. NRVs include Recommended Dietary Intakes (RDIs), a term used to represent the average daily micronutrient level sufficient to meet the requirements of almost all (97–98%) healthy individuals of a certain gender and life stage, and Adequate Intakes (AIs), where the nutrient intake level is based on observed or experimentally-determined nutrient estimates of apparently healthy people and are assumed to be adequate [11]. Where the RDI value was not available, the AI value was used. Table 1 presents the demographic data used for the case studies.

Insert Table 1 here.

We created two different meal plans for the purpose of ensuring variety in food options, using the same macronutrient and micronutrient thresholds and targets for both sets of plans. For each sample meal plan, the male and female versions differ only by portion sizes to align with personalised energy requirements. For the dual purpose of preventing duplication in Table 2 and wanting to illustrate dietary variety, we have elected to present meal plan sample 1 for females and meal plan sample 2 for males, along with their corresponding diets with saturated fat limits. All meals have been developed with a whole-food principle (i.e., using foods that have been minimally processed) as a foundation. We also opted to include foods that we considered to be, generally, popular and acceptable, rather than any specialty or unusual food that would demand an acquired taste.

Results

Tables 2 and 3 present the LCHF sample meal plans for females and males, and the nutrient analysis of the meal plans, respectively, with their corresponding plans aligning with the saturated fat threshold of <10% total energy.

Insert Table 2 here.

Insert Table 3 here.

Both of the meal plans successfully exceeded the NRV thresholds for all nutrients, apart from two instances. The first was iron intake in females, the two meal plans achieving 86-98% of the RDI threshold value for this mineral. The second instance was an inability to meet the <10% of total energy intake saturated fat threshold in the male (meal plan 2 only). In this plan, saturated fat amounted to 10.6% of total energy, exceeding the threshold by 0.6% (or 2g).

Discussion

Overall, the LCHF meal plans successfully achieved almost all of the NRV thresholds. There are several important points about iron that warrant discussion. Firstly, in our meal plan development, we specifically selected whole, unprocessed foods that were not fortified with nutrients, such as iron. We also decided to purposely exclude liver and mussels from these plans, despite their rich nutrient density, as we are aware that these foods may not be considered appealing for the majority of the population. However, it is worthwhile noting that the addition of a small amount of chicken liver (i.e., 5g and 25g, or 1-4 mussels, in meal plans 1 and 2, respectively), would have resulted in the RDI being met for iron. Our strategy differs somewhat to the work of Reid et al., who, knowing iron is a nutrient of concern for vegetarians, intentionally incorporated iron-fortified foods in their vegetarian meal plans. Hence, they were able to meet iron requirements, apart from during pregnancy, where the RDI is higher [16].

Secondly, iron bioavailability is affected by dietary composition and iron status, two aspects that are not considered comprehensively in RDI threshold generation. For industrialised countries, like Australia and New Zealand a mean iron bioavailability factor is used to generate the iron RDI for all population groups, irrespective of dietary composition [25]. Iron bioavailability is reduced by phytates, found predominantly in wholegrains, such as breads and cereals [25]. Other compounds that reduce bioavailability are polyphenols and oxalates, and while found in vegetables and fruit, are also present in wholegrains. The LCHF diet is typically very low (or devoid) in grains, which could mean higher iron bioavailability for those consuming such a diet. This, along with other factors that influence nutrient status, plus the natural variation in food intake raises caution about the use of the RDI threshold alone to assess an individual's diet at a glimpse. While not presented in this work, our nutrient analysis work on isocaloric diets aligning with the Australian NHMRC and New Zealand MOH guidelines, also indicate a failure to meet the RDI threshold for iron. As such, while the LCHF diet is often targeted for being inadequate, using NRVs as a dietary adequacy tool, one can assume a similar inadequacy for iron under mainstream dietary guidance using unfortified foods, where possible. It is worthwhile to note that this point can also be applied to other micronutrients, in that it is unlikely that any diet will achieved over 100% of the NRV thresholds each day; hence the reason why dietitians encourage the consumption of a varied diet.

In the instance where the saturated fat threshold of <10% of total energy was not met in one of the male meal plans, comprehensive dietary manipulation of this meal plan for the specific purpose of meeting this target was attempted. In order to achieve carbohydrate and protein targets, the only way to achieve the energy requirements with a <10% saturated fat threshold was to add an alcoholic beverage into the meal plan, as it is the only food item that provides energy without any other macronutrient. We viewed this as being somewhat futile so decided against this option. It is also important to note that during this dietary manipulation exercise, in order to reduce the saturated fat contribution, once all the relevant animal foods were altered to low-fat or non-fat versions (i.e., dairy products and meats) and coconut products were removed, the saturated fat content still slightly exceeded the 10% threshold, by 0.6%. It was only when we reduced the amount of avocados, certain seeds, olive oil and macadamia nuts, i.e., foods that contain predominantly unsaturated fats, did the thresholds align. In New Zealand and Australia, saturated fat guidelines exist in the form of a percentage of total energy threshold, and it is not known whether the public health caution for saturated fat relates to an absolute amount consumed in grams or is relative to total energy only, suggesting that as a guideline it is rather arbitrary.

There are three other nutrient components that warrant discussion in the context of LCHF diets: B vitamins and fibre, protein and essential fatty acids.

B vitamins and fibre

The LCHF diet is frequency criticised for being deficient in B vitamins in particular Vitamin B1, or thiamin, and fibre, two key components of grain-based foods. We have demonstrated that these meal plans do indeed meet the RDI threshold for thiamin due to the incorporation of alternative, every day thiamin-rich foods such as animal protein, nuts and seeds, and several green vegetables. Despite RDIs met for thiamin, one could call into question the minimum threshold of thiamin required in an LCHF context. A key function of thiamin is the metabolism of carbohydrate [26]; it could be speculated that with a reduced intake of carbohydrate, less thiamin is required. However, considering that in the absence of exogenous carbohydrate, glucose is still made internally through gluconeogenic precursers, research is warranted to determine whether this theory holds any truth. We also demonstrate that the AIs for fibre are surpassed in all of these meal plans, and while devoid of wholegrains, fibre, both soluble and insoluble, can be easily derived from vegetables, some fruit, nuts and seeds.

Protein

Another misconception about the LCHF diet is that it is excessive in protein. We used the protein AMDR as per the Australian NHMRC and New Zealand MOH in the development of these meal plans; however, the female meal plan 1 (<10% saturated fat threshold) exceeded the maximum AMDR protein threshold by 2% (or 7g of protein). In the dietary manipulation required to reduce saturated fat (i.e., a swap from untrimmed Sirloin steak to lean Eye fillet steak for dinner, and a swap from full-fat to non-fat dairy products) what resulted was a higher proportion of protein being derived from those foods at the same quantities so it was unavoidable. While the LCHF diet is not intended to be any higher in protein than current dietary recommendations, in this case protein only exceeded the AMDR when saturated fat was restricted. .

Omega-6: omega-3 Polyunsaturated Fat (PUFA) ratio

A key characteristic of the LCHF way of eating is the discouragement of consumption of seed oils (eg. Canola, Sunflower, Soybean, Corn oil and Rice Bran oil), in order to minimise intake of linoleic acid (omega-6 PUFA), and consequently, to achieve an optimal omega 6:3 ratio. Evidence suggests that a high ratio is pro-inflammatory and has a role to play in promoting the pathogenesis of chronic diseases such as cardiovascular disease, cancer, inflammatory and autoimmune diseases [27 28]. Furthermore, data indicates that humans evolved on a diet with a 1:1 omega 6:3 ratio, whereas Western dietary patterns typically reflect a ratio of around 15-20:1 [28]. Along with the promotion of olive oil use, which is unanimously endorsed, NHMRC / MOH guidelines recommend the use and consumption of vegetable fats (i.e., margarine, Canola, Sunflower, Soybean, Corn oil and Rice Bran oil) in place of fats with a predominantly saturated fat make-up (i.e., butter, coconut oil). As a result, most packaged supermarket foods including foods recommended by the NHMRC / MOH, such as liquid breakfasts, wholegrain bread, and cereals contain omega-6-rich seed oils. This would not necessarily be problematic if omega-3 intakes were increasing on a population level. However, this is not the case; it was recently reported in the Australian 2011–2012 National Nutrition and Physical Activity Survey that 80% of the population was not meeting the NRV threshold for omega-3 [29]. In our sample meal plans, we demonstrate favourable omega-6: omega-3 ratios, i.e., less than the 10:1 NRV thresholds, and substantially closer to that of our dietary composition prior to the agricultural revolution.

Finally, it is important to note that LCHF eating is frequently adopted for weight loss purposes. In this context it would be highly likely that energy intakes would be lower than that of these hypothetical healthy weight case studies for a certain period of time, while weight is being lost. This poses a risk to achieving 100% of all NRVs on a daily basis; however, this would not be unique to the LCHF approach, but would apply to any energy-restricted eating style, including mainstream national nutrition guidelines. During the active weight loss period, nutrient density should be a priority and if suboptimal nutrient status becomes a concern, this could be addressed by the inclusion of nutrient-fortified foods or supplementation.

Conclusion

There were two key limitations to this work. Firstly, the average height for Australian males and females, respectively, and the midpoint BMI values were used to extrapolate the weights of the two hypothetical case studies. These weights do not align with documented weights for Australian males (85.9kg) and females (71.1kg), respectively [22]. This underestimation of weight would have underestimated energy intake to a small extent. Secondly, our analyses were limited to the available values in the FoodWorks database; consequently, an accurate estimate of Vitamin D intake was not available. It is reported that due to current eating patterns, it is almost impossible to get sufficient Vitamin D (in this case 5μ□g/day) from the diet alone [30] and it is the assumption that it will be derived from sun exposure. It is likely that the LCHF diet supplies more Vitamin D than mainstream nutrition guidelines due to its greater intake of high fat, Vitamin D-rich foods, such as full-fat dairy, butter, eggs and fatty fish.

We have demonstrated that a well-formulated LCHF diet can provide sufficient intakes of all of the micronutrients profiled in the FoodWorks database, apart from iron for females. This marginal shortfall along with the acknowledged limitations of using NRVs in estimating dietary adequacy, leads us to believe that this is not a nutrient of concern for those consuming the LCHF diet. Irrespective of the ongoing saturated fat / heart disease scientific debate, it is still possible to adopt the LCHF diet while keeping saturated fat intake around the 10% of total energy threshold. Considering this way of eating provides a replete set of nutrients, and has been shown to be effective for improving metabolic health, particularly for people with diabetes, it should at least be considered a suitable dietary option for populations, alongside that of mainstream MOH guidelines.

Contributorship statement

C. Zinn, A. Rush and R. Johnson contributed to the conception and design of the research; C. Zinn, A. Rush contributed to the diet development and analysis. C. Zinn, A. Rush and R. Johnson contributed to the interpretation of the data; C. Zinn drafted the manuscript. C. Zinn, A. Rush and R. Johnson read and approved the final manuscript.

Competing interests

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; CZ has co-authored two books called "What The Fat? - Fat's in, Sugar's out", and "What The Fat – Sports performance" which both assume an LCHF nutrition approach.

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Data sharing statement

Data (nutrient analysis) is unable to be placed on a data sharing system due to it being embedded in specific nutrient analysis software that is unable to be shared outside of the software programme. However, a print screen version of the data is available upon request from the author.

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Tables

Table 1: Case study demographics.

	Age range (years)	Reference Height (cm)	Reference Weight (kg)	PAL	Energy (kCal)	CHO (g)	Protein UL 25% E (g)	Saturated Fat 10% E (g)
Male	19-50	175	63-71	1.6	2820	65	165.4	30.5
Females	19-50	162	56.3	1.6	2203	65	129.4	23.8

Table 2: LCHF sample meal plans.

LCHF meal plan 1 (females)	**LCHF meal plan 1 (females) (saturated fat <10% of total energy)**	**LCHF meal plan 2 (males)**	**LCHF meal plan 2 (males) (saturated fat <10% of total energy)**
Breakfast ¾ cup frozen mixed berries, 150g plain, unsweetened, full-fat yoghurt, 2 T[†] each sunflower and pumpkin seeds, 3 macadamia nuts, 2 Brazil nuts, 6 almonds	*Breakfast* ¾ cup frozen mixed berries, 150g plain, *unsweetened low-fat yoghurt*, 2 T each sunflower and pumpkin seeds, 3 macadamia nuts, 2 Brazil nuts, 6 almonds	*Breakfast* Omelette: 3 eggs, 60g mushrooms, 100g tomato, 1 cup baby spinach, cooked in 2 tsp butter. Coffee made with 200ml full-fat milk	*Breakfast* Omelette: 3 eggs, 60g mushrooms, 100g tomato, 1 cup baby spinach, cooked in *3 tsp olive oil* Coffee made with *200ml low-fat milk*
Lunch Tuna salad: 95g tin tuna, canned in brine (drained), 1 cup baby spinach leaves, 60g English cucumber, 5 cherry tomatoes, 30g cheddar cheese, 2T linseeds, 1 tsp* basil pesto, 3 tsp olive oil	*Lunch* Tuna salad: 95g tin tuna, canned in brine (drained), 1 cup baby spinach leaves, 60g English cucumber, 5 cherry tomatoes, *30g low fat cottage cheese*, 2T linseeds, 10 green olives, 5 tsp avocado oil	*Lunch* Beef salad: 120g Eye fillet, 1 cup spinach leaves, ½ red capsicum, 60g English cucumber, 5 cherry tomatoes, ½ large avocado, 5 walnuts, 1T linseeds, 30g parmesan cheese, 2T olive oil	*Lunch* Beef salad: 150g Eye fillet, 1 cup spinach leaves, ½ red capsicum, 60g English cucumber, 5 cherry tomatoes, ½ large avocado, *3 T sunflower seeds, 12 green olives, 30g low fat cottage cheese, 2T olive oil, 2 tsp avocado oil*
Dinner 150g Sirloin steak, fat not trimmed, grilled, roasted vegetables: 8 florets cauliflower, 1 medium sized beetroot, 1 medium courgette, 1 medium carrot, coated in 2T olive oil	*Dinner* *150g Beef eye fillet, grilled,* roasted vegetables: 8 florets cauliflower, 1 medium sized beetroot, 1 medium courgette, 1 medium carrot, coated in 2T olive oil	*Dinner* 130g grilled Salmon, 100g green beans, 150g broccoli, 200g grilled pumpkin, ½ cup peas, 1 T olive oil	*Dinner* 150g grilled Salmon, 100g green beans, 150g broccoli, 200g grilled pumpkin, ½ cup peas, 1 T olive oil
Snacks 10 medium strawberries 3Tpistachio nuts	*Snacks* 10 medium strawberries 3Tpistachio nuts	*Snacks* 20 macadamia nuts Smoothie made with 200ml	*Snacks* 20 macadamia nuts Smoothie made with *200ml*

Coffee made with 200ml full fat milk	*100g low fat plain, unsweetened yoghurt* Coffee made with *200ml low-fat milk*	full fat milk, 10 medium strawberries, crushed nuts (20g almonds, 2T linseeds)	*low-fat milk*, 10 medium strawberries, crushed nuts (20g almonds, 2T linseeds, *100g low fat plain, unsweetened yoghurt*)

[†] T = tablespoon; * tsp = teaspoon

Table 3: Nutrient analysis of LCHF meal plans.

	Female meal plans			**Male meal plans**		
Nutrient	Meal plan 1	Meal plan 1 (saturated fat <10% TE) NRV / goal	NRV / goal	Meal plan 2	Meal plan 2 (saturated fat <10% TE)	NRV / goal
Energy (Cal)	2145	2053	2203	2675	2758	2820
Carbohydrate (g) **% TE**[†]	61 11	67 13	248-358 45-65	66 10	69 10	303-439 45-65
Protein (g) **% TE**	115 22	135 26	83-138 15-25	149 22	164 24	106-176 15-25
Fat (g) **% TE**	153 63	129 57	49-86 20-35	194 65	195 64	63-110 20-35
Saturated fat (g) **% TE**	40 28	21 9.6	24 10	46 15	33 10.6	31 10
Trans fats (g) **% TE**	2.2 0.9	0.7 0.3	<2.4 <1%[‡]	1.4 0.4	0.8 0.3	<3g <1%[‡]
Monounsaturated fat (MUFA) (g) **% total fat**	75 53	71 59	-	101 56	117 65	-
Polyunsaturated fat (PUFA) (g) **% total fat**	27 19	28 23	-	32 18	31 17	-
Linoleic acid (O6 PUFA) (g)	20.4	18.6	8*	19.1	18.5	13*
α-linoleic acid (O3 PUFA) (g)	5.8	5.5	0.8*	9.3	6.2	1.3*
Omega 6: omega 3 ratio	3.5	3.4	10	2.1	3.0	10
Fibre (g)	38	39	25*	45	44	30*
Thiamin (mg)	1.4	1.4	1.1	1.6	1.8	1.2
Riboflavin (mg)	2.4	2.4	1.1	3.3	3.5	1.3
Niacin (mg)	23.4	18.8	14	16.2	17.5	16
Vitamin C (mg)	371	370	45	394	398	45
Vitamin A (μg)	2247	2095	700	2374	2047	900
Vitamin E (mg)	23	22	7*	32	41	10*
Vitamin B12 (μg)	3.9	6.4	2.4	11.6	12.8	2.4

Folate, total (μg)	568	583	400	788	757	400
Calcium (mg)	1093	1224	1000	1216	1251	1000
Iron (mg)	16	16	18	20	21	8
Magnesium (mg)	553	589	310-320	582	598	400-420
Zinc (mg)	16	22	8	23	24	14
Sodium (mg)	2183	2250	460*	1554	2032	460*
Potassium (mg)	4639	5154	2800*	5585	6107	3800*
Phosphorous (mg)	1848	2076	1000	2478	2644	1000
Selenium (μg)	166	169	60	113	117	70
Iodine (μg)	225	190	150	223	207	150

† TE: Total energy

*AIs were used as RDIs were unavailable

‡ World Health Organisation recommendation for trans fats