



Basic nutritional investigation

The ω -3 and ω -6 fats in meals: A proposal for a simple new labelNigel Turner Ph.D.^{a,b,d}, Todd W. Mitchell Ph.D.^{a,b}, Paul L. Else Ph.D.^{a,b,*}, A.J. Hulbert D.Sc.^{a,c}^a Metabolic Research Centre, University of Wollongong, Wollongong, New South Wales, Australia^b School of Health Sciences, University of Wollongong, Wollongong, New South Wales, Australia^c School of Biological Sciences, University of Wollongong, Wollongong, New South Wales, Australia^d Garvan Institute of Medical Research, Darlinghurst, New South Wales, Australia

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ABSTRACT

Objective: The ω -3 and ω -6 polyunsaturated fatty acids (PUFAs) are separate essential dietary fatty acids that play a key role in many physiologic processes in higher animals. The content of these PUFAs is relatively well described for many individual food components. Our goal in this study was to analyze the PUFA content of whole meals and produce a simple measurement to estimate the intake of these fatty acids.

Methods: The fatty acid profile and macronutrient composition were determined for a range of fast food, cuisine (restaurant-prepared), and home-prepared whole meals commonly consumed by Australians.

Results: Across the different meals there was significant variation in protein (4-fold), fat (13-fold), and carbohydrate (23-fold) contents. With regard to the fatty acid profile, saturated and mono-unsaturated fatty acids made up approximately 80% of total fatty acids for most meals. The ω -6 PUFAs were substantially more abundant than ω -3 PUFAs for most meals. The balance of dietary ω -3 and ω -6 PUFAs is an important determinant of their metabolic effects within the body, and accordingly we calculated the percentage of the total PUFA comprised of ω -3 PUFAs and referred to this as the *PUFA Balance*. This parameter showed the greatest variation among the different meals (>45-fold).

Conclusion: The relative proportions of ω -3 and ω -6 PUFAs vary greatly across meals. PUFA Balance is a useful tool that will allow individuals to more easily monitor and balance their intake of ω -3 and ω -6 fats.

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Introduction

The ω -3 and ω -6 polyunsaturated fatty acids (PUFAs) are essential components of the human diet because humans are unable to synthesize these fats. In this respect these PUFAs differ from saturated fatty acids (SFAs) and monounsaturated fatty acids (MUFAs), which are not essential in the diet because humans can make these from non-lipid sources. Furthermore, because humans cannot convert one to the other, ω -3 PUFAs and ω -6 PUFAs are separate essential dietary requirements of humans. The essential requirement of humans for ω -3 PUFAs independent of the requirement for ω -6 PUFAs was first

documented for an intravenously fed young girl in 1982 [1] (also see pp. 80–3 in Allport [2]).

The most recent analysis of dietary PUFA intake by Australians provided average intakes of 10.9 g of ω -6 PUFAs and 1.4 g of ω -3 PUFAs per day [3]. These PUFA intakes are the recommended “adequate intake” by the National Health and Medical Research Council of Australia (NHMRC) [4]. However, Meyer et al. [3] showed that the median intakes of both types of PUFA were less than these average values, and consequently it can be concluded that greater than half the Australian population consume less than the recommended “adequate intake” of ω -3 and ω -6 PUFAs. This is especially the case for ω -3 PUFAs, where higher intakes are recommended by some bodies. For example, the National Heart Foundation of Australia recommends that, for cardiovascular health, all adult Australians should consume at least 2.5 g of ω -3 PUFAs daily [5]. International groups, such as the International Society for Study of Fatty Acids and Lipids (ISSFAL), have also made recommendations for adequate intake.

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Their recommendation for *adequate* intake of linoleic acid (the main ω -6 PUFA in the diet) is 2% of energy, although they suggest a *healthy* intake of α -linolenic acid (the main ω -3 PUFA in the diet) of 0.7% of energy, and they also recommend a *minimum* intake of long-chain ω -3 PUFA (eicosapentaenoic acid and docosahexaenoic acid) of 500 mg/d for cardiovascular health [6]. Assuming an individual has a relatively low metabolic rate of 8000 kJ/d, these ISSFAL recommendations are calculated to be 4.0 g of ω -6 PUFAs and 1.9 g of ω -3 PUFAs per day.

Although consumers are recommended to eat these various amounts daily, it is very difficult for them to find out what the respective contents of ω -3 PUFA and ω -6 PUFA are in the food they purchase and eat. Indeed, even for dietitians and nutritionists, let alone consumers, it is often difficult to determine the respective amounts of ω -3 PUFA and ω -6 PUFA in various foods. In Australia, food labeling specifies the total fat and the SFA contents and the MUFA and total PUFA contents in certain instances, but there is no obligation to provide the relative amounts of ω -3 and ω -6 PUFAs unless a nutritional claim regarding these fatty acid subtypes is made [7]. This is similar for most food composition tables where total PUFA content per 100 g of food is given but not the individual ω -3 and ω -6 PUFA contents. Some food databases such as the Food Standards Australia New Zealand NUTTAB 2006 [8] and the US Department of Agriculture National Nutrient Database [9] provide the composition of individual fatty acids in food items, but not the total ω -3 PUFA content or the total ω -6 PUFA content. It is possible for individuals who know their fatty acids to calculate these values from the data provided but this is quite time-consuming and it should not be necessary. Those individuals who do not know which fatty acids are ω -3 PUFAs and which are ω -6 PUFAs would not be able to determine the total ω -3 and total ω -6 PUFA contents of the food. This deficiency in information is perplexing, especially in light of the recommendations of various nutritional bodies and in view of the fact that the effects of ω -3 and ω -6 fats are often quite different and sometimes even opposing (e.g., in their effects on inflammatory processes). Therefore provision of total PUFA content of foods, without differentiating between ω -3 and ω -6 PUFAs, is essentially meaningless and may even have adverse health consequences in such a context.

We have two purposes in this contribution: 1) to suggest and explain a novel measurement that we have called the *PUFA Balance* (see Abbott et al. [10] for further details on the PUFA Balance concept and the potential link between diet and membrane PUFA balance) and could be easily provided on food labeling for meals to give consumers a simple way to know the ω -3 PUFA and ω -6 PUFA contents of their food and 2) to present the results of the analysis of 23 meals commonly consumed by

Australians that demonstrate that the degree of variation in PUFA Balance of these meals is substantial and in fact for these meals it was greater than the variation in content of the other macronutrients.

Materials and methods

Sample preparation

Meals were chosen within the general groupings of fast foods, cuisine, home-cooked, and supermarket frozen meals to represent those deemed to be commonly purchased or prepared. We also prepared three home-cooked meals for comparison. These meals were roast chicken and vegetables, grilled salmon fillet and salad, and pan-fried lean steak and vegetables. A list of the components of each of the meals is presented in Table 1. Meals were prepared or purchased locally on 4 consecutive weeks. We were only able to obtain the roast pork and lamb with vegetables meals on the first week (i.e., $n = 1$), and these meals were analyzed for fatty acid composition only. To ensure homogeneity of food samples for analysis, meals were combined with dry ice and ground into a fine, frozen mince in a Breville Wizz Professional (Breville Sydney, NSW, Australia) food processor. Meals were processed within 2 h of preparation or purchase and were segregated into separate vials and stored at -80°C until further analysis, which was completed within the following 2 mo.

Macronutrient and sodium analyses

The total fat content of foods was determined using the Soxhlet method. Briefly, 2 to 4 g of dehydrated, minced food was pretreated with 1 M HCl to release lipids bound to proteins or carbohydrates [11]. Fat was then extracted with petroleum ether for a period of 3 h, which was determined in preliminary studies to be sufficient to extract all fat from the samples. Total fat content was calculated as the loss of weight in the samples after lipid extraction.

For protein measurements, foods were homogenized in distilled water (10%, w/v) using a glass/glass homogenizer. Protein concentration was determined in the homogenate using the method of Lowry et al. [12], with bovine serum albumin as a standard.

To determine the total carbohydrate content of foods, the total weight of moisture and ash in the samples was required. The moisture content of foods was determined as the loss of weight in the foods after 4 d of oven drying at 37°C . The ash content of foods was determined as the inorganic residue remaining after incineration at 550°C for 18 h in a muffle furnace. The total carbohydrate content of foods was then calculated by subtraction of the sum of the weights of protein, total fat, moisture, and ash from the total weight of the food [11].

Energy content of the meals was calculated using values (kilojoules per gram) of 17, 16, and 37 for protein, carbohydrate, and fat, respectively.

Sodium concentration was determined using a Corning 410 Flame Photometer (Sherwood Scientific Limited, Cambridge, UK). A 2- to 3-mL sample of the 10% food homogenate was used, with values determined by comparison against a standard reference curve of NaCl (5–50 mM).

Fatty acid analysis

For fatty acid analysis all solvents were of ultrapure grade and contained 0.01% (w/v) butylated hydroxytoluene as an antioxidant. Total lipid was extracted from the homogenized food matrix using 2:1 (v/v) chloroform:methanol according to the method of Folch et al. [13]. Fatty acids of the total lipid extracts were transesterified in methanol:toluene (4:1, v/v) with acetyl chloride according to the method of Lepage and Roy [14]. Fatty acid methyl esters were separated

Table 1
Australian meals tested in present study

Big Mac® and fries	Subway® low-fat (turkey, tomato, lettuce, capsicum with cheese and honey mustard dressing)	Lean heart smart steak and steamed vegetables (potato, carrot, spinach)
Filet-O-fish® and fries	Fish and chips	Roast chicken and vegetables (potato, carrot, peas)
Garden salad + French dressing	Hamburger with the lot + tomato sauce	Mexican bean burrito with rice, lettuce, tomato, corn, sour cream
Garden salad no dressing	Chicken green curry (Thai) and rice	Beef kebab
Whopper® and fries	Sweet and sour pork and rice	Lasagne (McCain)
Supreme pizza pan-fried crust—½ of large	Spaghetti bolognese	Roast pork and vegetables (pumpkin, zucchini, cauliflower, broccoli, potato, squash)
Vegetarian pizza thin and crispy crust—½ of large	Sate beef and rice (Lean Cuisine)	Lamb cutlets, bacon and vegetables (squash, zucchini, cauliflower, broccoli, carrot, potatoes, lettuce, tomatoes, rock melon)
KFC® 2-piece feed	Grilled salmon and salad (tomato, lettuce, onion, cucumber)	

by gas–liquid chromatography on a Shimadzu GC 17A (Shimadzu Scientific Instruments, Rydalmere, Australia) gas chromatograph with FAMEWAX column (Restek, PA, USA) and were identified by comparing each peak's retention time with those of external standards. Results are presented as the weight percentage of each fatty acid. Fatty acids are only presented in Table 2 if more than one of the analyzed foods contained greater than 0.5% of the particular fatty acid; however, all data were used to calculate composite parameters (e.g., sum of MUFAs, sum of PUFAs, etc.).

Results

Table 2 presents the macronutrient, energy, and sodium contents of the foods analyzed. The average meal size was 426 g, with an approximate five-fold variation observed between the smallest (garden salad) and the largest (supreme pizza) meal. Of the macronutrients, protein content was the most consistent across the meals, varying less than four-fold (2.5–9.0 g/100 g). Fat content ranged from 1.3 g/100 g in the lean steak and vegetables meal to 17.8 g/100 g in the beef kebab. Most fast food and cuisine (purchased from restaurants) meals contained greater than 10% fat, whereas all home-cooked and frozen meals contained less than 7.5% fat. Carbohydrate content was generally in the range of 20 to 35 g/100 g for most meals, whereas meals containing salads had substantially lower carbohydrate levels. Sodium levels were also determined, and because all home-cooked meals were prepared without additional salt, they showed the lowest sodium levels (60–108 mg/100 g). Most of the other meals contained sodium levels of ~400 mg/100 g or higher.

The fatty acid composition of the analyzed meals is presented in Table 3. There was substantial variation in the fatty acid profiles of the meals. Oleic acid (18:1 ω -9) and palmitic acid (16:0) comprised a substantial proportion of the fatty acids across all meals. Medium-chain fatty acids (8:0, 10:0, and 12:0) were highly enriched in the chicken green curry and to a lesser degree in the sate beef, likely reflecting the coconut milk used to make these meals. The slight traces of docosahexaenoic acid and eicosapentaenoic acid in these same meals are likely from the

meat sources, although the higher ratio of docosahexaenoic acid to eicosapentaenoic acid also suggests the use of fish sauces. Another meal with notable amounts of the medium-chain saturates was the Mexican bean burrito, where dairy from the sour cream (as indicated in Table 1) is the likely source. This meal also possessed some 20:5 ω -3 (eicosapentaenoic acid) presumed to be associated with some meat fillings associated with this meal. The predominant PUFA in most meals was linoleic acid (18:2 ω -6), with the sweet and sour pork and fish and chips meals containing particularly high levels (>40%) of this fatty acid. The primary ω -3 PUFA for most meals was 18:3 ω -3, which accounted for approximately 2% of the total fatty acids and about 82% of all ω -3 PUFAs in 18 of the 23 meals measured. The content of the long-chain ω -3 PUFAs 20:5 ω -3 and 22:6 ω -3 was generally less than 0.1%. The notable exception was, as expected, the salmon and salad, for which 20:5 ω -3 and 22:6 ω -3 represented 8.6% and 14.5% of the total fatty acids, respectively.

The calculated composite parameters showed that around 80% to 85% of the total fatty acids in most meals were SFAs or MUFAs (Table 4). The total PUFA content of the meals (Table 3) was predominantly a reflection of the 18:2 ω -6 and 18:3 ω -3 contents. To determine the PUFA Balance of the meals, we calculated the ω -3 PUFAs as the percentage of total PUFAs and have presented this in pie graph format in Figure 1. There was substantial variation in this parameter, with the salmon and salad meal displaying a PUFA Balance of 80%, whereas the sweet and sour pork had a PUFA Balance lower than 2%. Approximately half the meals showed a PUFA Balance in the range of 10% to 15% (Fig. 1).

Discussion

The essential nature of both types of dietary PUFA derives from the fact that they are important constituents of membrane lipids and the fatty acid composition of cell membrane bilayers has important effects on the functionality of the great variety

Table 2
Macronutrient composition and sodium content of Australian meals tested in present study*

Meal	Weight (g)	Protein (g/100 g)	Fat (g/100 g)	Carbohydrate (g/100 g)	Energy (kJ/100 g)	Sodium (mg/100 g)
Fast food						
Big Mac® and fries	314 ± 10	6.0 ± 0.1	14.8 ± 0.7	32.7 ± 1.0	1175 ± 10	423 ± 13
Filet-O-Fish® and fries	231 ± 4	5.4 ± 0.4	15.2 ± 0.7	34.8 ± 2.0	1212 ± 41	495 ± 16
Garden salad + dressing	177 ± 6	2.5 ± 0.2	5.7 ± 1.1	2.7 ± 0.6	287 ± 29	217 ± 4
Garden salad no dressing	145 ± 4	3.2 ± 0.5	6.0 ± 1.5	1.7 ± 0.2	302 ± 55	110 ± 15
Whopper® and fries	428 ± 6	4.4 ± 0.7	14.3 ± 2.4	31.9 ± 2.8	1115 ± 44	389 ± 18
Supreme pizza	694 ± 21	8.7 ± 0.6	10.1 ± 0.9	38.8 ± 2.4	1145 ± 5	466 ± 13
Vegetarian pizza	566 ± 22	7.9 ± 0.5	8.0 ± 0.3	35.0 ± 1.0	989 ± 26	552 ± 10
KFC® 2-piece feed	463 ± 16	5.1 ± 0.9	13.0 ± 0.7	26.8 ± 2.2	996 ± 34	443 ± 21
Subway® turkey and salad	222 ± 17	5.9 ± 0.2	6.5 ± 0.6	20.9 ± 1.3	675 ± 39	544 ± 15
Fish and chips	523 ± 36	4.7 ± 0.6	14.5 ± 2.8	27.4 ± 3.0	1054 ± 68	339 ± 26
Hamburger	416 ± 18	9.0 ± 0.3	14.4 ± 0.9	21.1 ± 1.0	1022 ± 38	597 ± 25
Cuisine						
Green curry chicken and rice	532 ± 13	5.3 ± 0.3	8.4 ± 1.4	23.5 ± 3.0	776 ± 92	278 ± 11
Sweet and sour pork and rice	684 ± 13	4.2 ± 0.0	11.7 ± 1.2	27.2 ± 1.6	939 ± 57	208 ± 13
Spaghetti bolognese	556 ± 55	6.0 ± 0.1	5.6 ± 0.7	21.6 ± 4.2	653 ± 57	266 ± 37
Mexican bean burrito	666 ± 51	4.6 ± 0.5	10.5 ± 0.7	19.2 ± 1.4	775 ± 26	236 ± 23
Beef kebab	328 ± 9	7.0 ± 0.1	17.8 ± 2.3	21.7 ± 0.9	1123 ± 75	543 ± 14
Home cooked						
Salmon and salad	417 ± 15	5.5 ± 1.2	7.4 ± 0.8	8.5 ± 3.0	503 ± 28	66 ± 3
Steak and vegetables	423 ± 13	6.8 ± 0.9	1.3 ± 0.3	14.4 ± 1.3	391 ± 24	108 ± 13
Chicken and vegetables	482 ± 16	6.4 ± 1.0	3.9 ± 0.5	12.5 ± 2.6	453 ± 36	81 ± 3
Frozen						
Sate beef and rice	355 ± 3	4.2 ± 0.4	4.4 ± 1.6	22.0 ± 0.9	586 ± 78	262 ± 19
Lasagne	384 ± 9	5.3 ± 0.4	6.7 ± 0.9	24.7 ± 0.8	734 ± 19	363 ± 3

* Values are presented as mean ± SEM ($n = 4$).

Table 3
Fatty acid composition of Australian meals tested in present study*

Meal	8:0	10:0	12:0	14:0	16:0	16:1 (ω-7)	18:0	18:1 (ω-9)	18:1 (ω-7)	18:2 (ω-6)	18:3 (ω-3)	20:4 (ω-6)	20:5 (ω-3)	22:6 (ω-3)
Fast food														
Big Mac® and fries	0.1 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	2.4 ± 0.1	19.3 ± 0.8	1.7 ± 0.1	10.8 ± 0.6	43.6 ± 1.8	3.8 ± 0.3	13.5 ± 0.8	2.0 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
Filet-O-Fish® and fries	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	1.6 ± 0.3	15.5 ± 1.7	1.0 ± 0.1	9.9 ± 1.0	46.7 ± 2.4	3.0 ± 0.7	17.6 ± 1.0	2.3 ± 0.1	0.0 ± 0.0	0.1 ± 0.0	0.3 ± 0.0
Garden salad + dressing	1.3 ± 0.1	3.3 ± 0.2	4.0 ± 0.2	12.7 ± 0.3	32.8 ± 0.6	1.3 ± 0.0	11.3 ± 0.2	18.4 ± 0.4	4.7 ± 0.4	3.9 ± 0.5	2.7 ± 0.3	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
Garden salad no dressing	1.3 ± 0.0	3.4 ± 0.1	4.1 ± 0.1	12.9 ± 0.1	32.9 ± 0.6	1.3 ± 0.1	11.4 ± 0.2	20.0 ± 1.9	3.4 ± 1.2	3.1 ± 0.5	2.6 ± 0.5	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
Whopper® and fries	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.9 ± 0.1	21.2 ± 0.3	2.0 ± 0.1	13.1 ± 0.5	35.9 ± 0.8	3.1 ± 0.2	18.5 ± 1.3	2.3 ± 0.2	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
Supreme pizza	0.4 ± 0.1	1.0 ± 0.2	1.2 ± 0.3	5.1 ± 0.8	24.7 ± 1.8	1.3 ± 0.2	9.9 ± 0.7	26.8 ± 1.2	3.3 ± 0.3	22.0 ± 3.6	2.5 ± 0.4	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
Vegetarian pizza	0.8 ± 0.1	2.0 ± 0.2	2.4 ± 0.3	8.8 ± 0.8	29.2 ± 1.5	1.1 ± 0.1	8.7 ± 0.3	21.7 ± 0.5	3.0 ± 0.1	18.1 ± 2.5	1.9 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
KFC® 2-piece feed	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.8 ± 0.1	36.2 ± 1.3	2.1 ± 0.2	5.3 ± 0.2	40.3 ± 0.6	2.3 ± 0.2	11.4 ± 0.4	0.6 ± 0.0	0.2 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
Subway® turkey and salad	0.4 ± 0.1	0.9 ± 0.2	1.0 ± 0.2	4.4 ± 1.0	28.3 ± 1.2	2.5 ± 0.2	6.4 ± 0.5	33.6 ± 1.3	3.8 ± 0.4	14.7 ± 1.8	2.1 ± 0.2	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Fish and chips	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.0	22.4 ± 0.2	0.7 ± 0.1	2.4 ± 0.2	17.1 ± 0.4	1.4 ± 0.3	51.6 ± 1.1	0.5 ± 0.1	0.1 ± 0.0	0.5 ± 0.1	1.3 ± 0.2
Hamburger	0.1 ± 0.0	0.3 ± 0.1	0.3 ± 0.1	1.9 ± 0.2	22.1 ± 0.6	3.1 ± 0.3	8.5 ± 0.3	42.8 ± 0.3	4.3 ± 0.4	12.8 ± 0.6	1.9 ± 0.1	0.3 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Cuisine														
Green curry chicken and rice	6.5 ± 0.2	4.9 ± 0.1	41.5 ± 0.9	14.5 ± 0.3	8.9 ± 0.2	0.2 ± 0.0	2.6 ± 0.1	13.7 ± 1.0	0.5 ± 0.2	5.4 ± 0.3	0.8 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Sweet and sour pork and rice	0.1 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.7 ± 0.09	24.2 ± 0.2	0.9 ± 0.0	4.9 ± 0.4	23.0 ± 0.9	2.0 ± 0.2	42.6 ± 1.4	0.5 ± 0.1	0.2 ± 0.0	0.0 ± 0.0	0.1 ± 0.0
Spaghetti bolognese	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	1.8 ± 0.7	20.7 ± 2.5	1.8 ± 0.3	9.1 ± 2.4	50.1 ± 6.3	3.6 ± 1.2	9.6 ± 1.0	0.8 ± 0.1	0.2 ± 0.0	0.2 ± 0.0	0.1 ± 0.1
Mexican bean burrito	0.9 ± 0.0	2.2 ± 0.1	2.6 ± 0.1	9.3 ± 0.3	29.7 ± 0.9	1.2 ± 0.1	8.1 ± 0.2	28.3 ± 0.6	4.0 ± 0.4	7.6 ± 0.5	3.2 ± 0.2	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
Beef kebab	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	1.8 ± 0.6	23.8 ± 0.2	1.0 ± 0.1	24.7 ± 0.2	36.1 ± 0.4	4.9 ± 0.3	3.4 ± 0.4	1.1 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
Roast pork and vegetables	0.0	0.0	0.07	1.41	26.7	2.0	14.8	39.5	3.6	8.4	1.1	0.5	0.08	0.10
Lamb and vegetables	0.0	0.0	0.1	2.64	24.2	1.8	16.2	39.5	5.2	5.7	2.3	0.2	0.14	0.00
Home cooked														
Salmon and salad	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	5.2 ± 0.7	16.7 ± 0.1	10.6 ± 1.2	3.8 ± 0.1	18.9 ± 2.5	5.1 ± 0.3	5.3 ± 0.8	1.3 ± 0.0	1.2 ± 0.2	8.6 ± 0.4	14.5 ± 0.2
Steak and vegetables	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 0.2	22.3 ± 0.4	2.4 ± 0.1	13.8 ± 1.2	35.5 ± 2.1	3.8 ± 0.5	10.0 ± 1.7	4.0 ± 0.6	2.0 ± 0.3	0.7 ± 0.1	0.2 ± 0.1
Chicken and vegetables	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.0	23.4 ± 0.8	6.3 ± 0.8	5.5 ± 0.7	41.0 ± 1.1	4.2 ± 0.3	15.1 ± 1.4	2.0 ± 0.5	0.8 ± 0.2	0.2 ± 0.0	0.1 ± 0.0
Frozen														
Sate beef and rice	1.4 ± 0.0	0.8 ± 0.0	8.3 ± 0.1	3.8 ± 0.1	15.8 ± 0.3	0.8 ± 0.1	6.3 ± 0.4	41.5 ± 2.0	2.0 ± 0.8	16.2 ± 1.1	0.8 ± 0.2	0.2 ± 0.0	0.2 ± 0.0	0.4 ± 0.0
Lasagne	0.3 ± 0.0	0.7 ± 0.0	1.1 ± 0.0	4.4 ± 0.1	24.6 ± 0.1	1.3 ± 0.1	15.5 ± 0.3	30.0 ± 0.8	4.5 ± 0.1	13.7 ± 0.6	1.8 ± 0.1	0.2 ± 0.0	0.1 ± 0.0	0.1 ± 0.0

* Fatty acid composition of foods was measured as the weight percentage of total fatty acids. Values are presented as mean ± SEM ($n = 4$), except for the roast pork and lamb meal ($n = 1$). Fatty acids are presented only if more than one of the analyzed foods contained more than 0.5% of the particular fatty acid; however, all data were used to calculate composite parameters (e.g., sum of monounsaturated fatty acids, sum of polyunsaturated fatty acids, etc.).

Table 4

Composite fatty acid parameters of Australian meals tested in present study*

Meal	SFA	MUFA	ω -6 PUFA (total)	ω -3 PUFA (total)	ω -6 PUFA (long-chain)	ω -3 PUFA (long-chain)
Fast Food						
Big Mac® and fries	34.2 ± 1.4	50.0 ± 1.5	13.7 ± 0.9	2.2 ± 0.1	0.1 ± 0.0	0.2 ± 0.1
Filet-O-Fish® and fries	28.3 ± 2.9	51.4 ± 1.9	17.7 ± 1.0	2.7 ± 0.1	0.0 ± 0.0	0.4 ± 0.0
Garden salad + dressing	67.6 ± 0.8	25.3 ± 0.3	4.2 ± 0.5	2.9 ± 0.3	0.0 ± 0.0	0.2 ± 0.0
Garden salad no dressing	68.2 ± 0.3	25.6 ± 0.9	3.4 ± 0.5	2.8 ± 0.4	0.1 ± 0.0	0.2 ± 0.1
Whopper® and fries	37.5 ± 0.8	41.5 ± 0.8	18.7 ± 1.3	2.4 ± 0.2	0.1 ± 0.0	0.1 ± 0.0
Supreme pizza	43.3 ± 3.6	32.0 ± 1.3	22.1 ± 3.6	2.6 ± 0.4	0.1 ± 0.0	0.1 ± 0.0
Vegetarian pizza	53.3 ± 3.0	26.5 ± 0.4	18.2 ± 2.5	2.0 ± 0.2	0.1 ± 0.0	0.1 ± 0.1
KFC® 2-piece feed	42.7 ± 1.2	44.9 ± 0.8	11.7 ± 0.5	0.7 ± 0.0	0.2 ± 0.0	0.1 ± 0.0
Subway® turkey and salad	42.2 ± 3.4	40.8 ± 1.5	14.9 ± 1.8	2.2 ± 0.2	0.2 ± 0.0	0.1 ± 0.0
Fish and chips	25.9 ± 0.3	20.0 ± 0.8	51.7 ± 1.0	2.3 ± 0.4	0.1 ± 0.0	1.9 ± 0.3
Hamburger	33.8 ± 0.8	50.8 ± 0.3	13.2 ± 0.6	2.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.0
Cuisine						
Green curry chicken and rice	79.1 ± 1.3	14.6 ± 1.0	5.5 ± 0.3	0.8 ± 0.1	0.1 ± 0.0	0.0 ± 0.0
Sweet and sour pork and rice	30.2 ± 0.4	26.1 ± 0.9	42.9 ± 1.3	0.8 ± 0.1	0.2 ± 0.0	0.2 ± 0.1
Spaghetti bolognaise	33.0 ± 5.8	55.9 ± 5.3	9.9 ± 1.0	1.2 ± 0.1	0.2 ± 0.0	0.4 ± 0.1
Mexican bean burrito	54.4 ± 0.9	34.5 ± 0.3	7.8 ± 0.5	3.4 ± 0.2	0.0 ± 0.0	0.2 ± 0.0
Beef kebab	51.7 ± 0.5	41.7 ± 0.4	5.0 ± 0.4	3.7 ± 0.3	0.1 ± 0.0	0.2 ± 0.0
Roast pork and vegetables	43.6	45.6	9.4	1.5	0.6	0.3
Lamb and vegetables	44.5	47.0	6.0	2.5	0.1	0.2
Home cooked						
Salmon and salad	26.4 ± 0.6	35.7 ± 1.1	7.4 ± 0.6	30.5 ± 1.1	1.8 ± 0.3	27.9 ± 1.1
Steak and vegetables	39.3 ± 1.9	42.1 ± 1.7	12.8 ± 2.2	5.7 ± 0.9	2.6 ± 0.4	1.7 ± 0.4
Chicken and vegetables	29.4 ± 0.7	51.8 ± 2.0	16.4 ± 1.7	2.4 ± 0.6	1.1 ± 0.4	0.4 ± 0.1
Frozen						
Sate beef and rice	37.3 ± 0.5	44.9 ± 1.3	16.4 ± 1.2	1.5 ± 0.2	0.2 ± 0.0	0.7 ± 0.1
Lasagne	48.1 ± 0.1	35.8 ± 0.8	14.0 ± 0.6	2.1 ± 0.1	0.2 ± 0.0	0.2 ± 0.0

MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; SFA, saturated fatty acid

* Values represent mean ± SEM of the weight percentage of total fatty acids ($n = 4$ except for the roast pork and lamb meals [$n = 1$]). Long-chain ω -6 and ω -3 PUFAs are fatty acids with 20 to 22 carbons.

of proteins (hormone receptors, neuroreceptors, membrane pumps, etc.) that are embedded in cellular membranes (for review, see Hulbert et al. [15]). As constituents of membrane lipids, PUFAs (especially the ω -6 PUFA arachidonic acid) are also the precursors for important signaling molecules (including eicosanoids, leukotrienes, endocannabinoids). Studies in animals have shown that membrane fatty acid composition is regulated largely by the process of constant membrane remodeling, whereby fatty acids that constitute membrane lipids are being constantly removed and replaced by a complex series of membrane-bound enzymes. These enzymes are highly selective for polyunsaturates but do not discriminate well between ω -6 PUFAs and ω -3 PUFAs [16].

In consequence, membrane fatty acid composition is highly responsive to the relative balance of ω -6 and ω -3 PUFAs in the diet. A review of studies examining dietary PUFA Balance in human health reported PUFA Balances of 20% as beneficial in the prevention of cardiovascular disease, 29% in decreasing colorectal cell proliferation and in suppressing inflammation in patients with rheumatoid arthritis, and 17% as having beneficial effects in patients with asthma, and a higher PUFA Balance as generally associated with decreased risk of breast cancer in women [17]. This review shows that, although the precise PUFA Balance may vary, there is a consistent pattern with high dietary PUFA Balance associated with improved health outcomes in humans. To understand these changes, studies in rats have shown that although membrane composition is relatively unresponsive to the SFA and MUFA contents of the diet, it is most responsive to the PUFA Balance in the diet [15]. In a recent study examining the influence of 12 isocaloric diets (differing only in fatty acid composition) on the fatty acid profile of membrane lipids of rats, we also observed a three-fold variation in arachidonic acid content of phospholipids that was better predicted by

the PUFA Balance in the diet than by the amount of the ω -6 PUFAs in the diet from which it is made, i.e., linoleic acid [10].

To investigate the degree of variation in ω -3 and ω -6 PUFA contents of commonly available meals, we analyzed the macronutrient composition and fatty acid profile of 23 meals, obtained from fast-food stores and restaurants (cuisine), and meals that would generally be consumed at home (home-cooked and frozen). The meals were diverse and differed substantially in their macronutrient composition, with a respective 4-fold, 13-fold, and 23-fold variation observed for the protein, fat, and carbohydrate content per 100 g across the meals. We also observed substantial differences in the fatty acid profile of the various meals. There were three- and four-fold variations, respectively, in SFA and MFA contents (percentage of total fatty acids) compared with 15- and 43-fold variations, respectively, in the contents of ω -3 and ω -6 PUFAs. The parameter that varied the greatest across the meals was the PUFA Balance, displaying greater than 46-fold variation from the lowest to the highest meal.

The PUFA Balance values for the meals illustrate that ω -6 PUFAs dominate ω -3 PUFAs in the modern-day food chain. Indeed, only the salmon meal had a PUFA Balance above 50%. There are different food sources of ω -3 PUFAs, with green leafy vegetables representing a good source of shorter-chain (i.e., 18 carbons) ω -3 PUFAs, and fish generally considered the best dietary source of long-chain (i.e., 20–22 carbons) ω -3 PUFAs. Given the documented health effects of long-chain ω -3 PUFAs, the consumption of fish is heavily promoted for its potential metabolic benefits. One potential negative health implication of this advice has been the potential for chemical contamination (notably mercury and dioxins, etc.) based on fish consumption. However, a recent examination of this issue has suggested there is little chance of adverse health from even long-term (70-y)

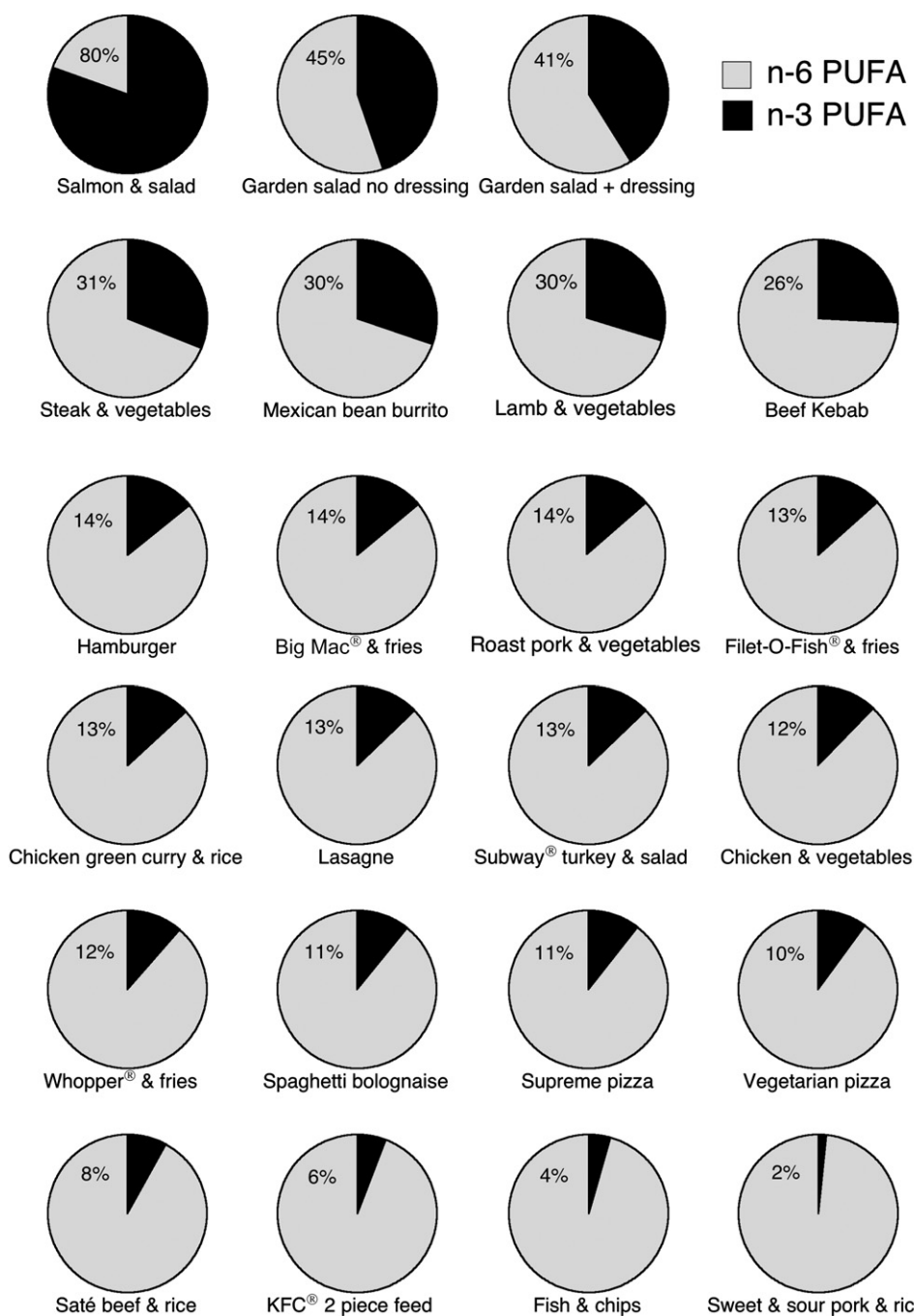


Fig. 1. PUFA Balance of 23 commonly consumed Australian meals. The value on each pie chart is the PUFA Balance for that meal calculated as n-3 PUFA as a percentage of total PUFAs. Values are means of four meals, except for the roast pork and lamb meals, where the values are the mean of one meal. n-3 PUFA, ω -3 polyunsaturated fatty acid; n-6 PUFA, ω -6 polyunsaturated fatty acid.

consumption of most fish species [18]. One striking finding from the present study was the huge variation in the PUFA Balances of the three “fish” meals. As expected, the grilled salmon and salad meal contained abundant long-chain ω -3 PUFAs, whereas the values for Filet-O-Fish (13%) and the fish and chips (4%) were ranked only 11 and 22, respectively, for the PUFA Balance. These latter two “fish” meals contained substantial amounts of ω -6 PUFAs (they had two of the highest percentage of ω -6 PUFA values; Table 3) and, although their precise PUFA Balance is likely to vary slightly based on the type of fish used, cooking time, size of “fillet,” type of batter or coating, etc., they are unlikely to show

major changes in their PUFA Balance without changes in the cooking oils used.

It has been estimated that the balance between ω -3 PUFAs and ω -6 PUFAs of hunter-gather diets was approximately equal and, in support of this suggestion, a contemporary diet based on Paleolithic food groups showed a PUFA Balance of 40% [19]. However, in recent times there has been a dramatic increase in vegetable oils (i.e., predominantly 18:2 ω -6) in the food supply of many Western nations, whereas ω -3 PUFA intake (predominantly 18:3 ω -3) has remained relatively constant (e.g., see Gerrior et al. [20] for US historical food supply data).

The Food Balance Sheets for Australia (after taking into account exports, change in stocks, processing, waste, and the amounts of food used for non-human consumption purposes) estimate the “fat consumption quantity” for the Australian food chain increased from 111 g of fat per person per day in 1962 to 132 g of fat per person per day in 2003. In 1962, this consisted of 95 g of fat from “animal products” and 16 g of fat from “vegetal products” (including 9 g from “vegetable oils”). In 2003, the total consisted of 71 g of fat from animal sources and 61 g of fat from plant sources (including 49 g from “vegetable oils”). Thus, from 1962 to 2003, on a per-capita basis, there was a 25% decrease in fat from animal sources combined with a 280% increase in fat from plant sources. The increase in the per-capita availability of “vegetable oils” for human consumption in the Australian food chain was 440% from 1962 to 2003.

The dominance of ω -6 PUFAs in the modern-day food supply is confirmed by measurement of actual dietary intake of contemporary populations. For example, the average fat intake for the Australian population in 1995 [3] had a PUFA Balance of 11%, and similarly, the average fat intake of the US population in 1999 to 2000 had a PUFA Balance of about 9% [21]. Such average PUFA Balance values for the modern human diet is of considerable concern because it indicates there are large numbers of people consuming a diet where ω -6 PUFAs dominate ω -3 PUFAs. However, consumers are provided with very little information concerning the ω -3 and ω -6 PUFA contents of the food they buy.

Based on the recommendations of the various bodies mentioned previously, the “adequate intakes” from the NHMRC of Australia can be calculated to represent a PUFA Balance of 11%, that for “cardiovascular health” is 19%, and from the international recommendations of ISSFAL a value of \sim 30% is calculated. As can be seen from Figure 1, only six meals exceed the international value, seven exceed the “cardiovascular health” value, and 18 meet or exceed the “adequate intake” value.

An increasing number of studies suggest that a diet fat profile, specifically an imbalance between ω -6 and ω -3 PUFAs, may be causal to the increasing incidence of metabolic and cardiovascular diseases and mental illness over recent times [2,15,21–25]. One such example is insulin resistance, which lies at the base of the “metabolic syndrome” (includes dyslipidemia, hypertension, inflammation, obesity, and type 2 diabetes) [26,27]. In humans, insulin action has been related to membrane fatty acid composition [28–30] and we recently measured very low PUFA Balance (\sim 3%) in tissue phospholipids of obese humans compared with non-obese humans (from A. J. Hulbert, T. W. Mitchell, S. K. Abbott, A. Zieba, and P. L. Else, laboratory measurements). Feeding high-fat diets (59% energy as safflower oil; PUFA Balance $<$ 1%) to rats causes widespread insulin resistance [31]; however, when 20% of the safflower oil is replaced with fish oil, insulin resistance does not occur [32]. This effect is not restricted to long-chain ω -3 PUFAs but is also observed when rats are fed 18:3 ω -3 [33,34]. There are a limited number of studies in humans that have also suggested that increasing ω -3 PUFA intake may be beneficial for insulin sensitivity [35,36].

With regard to cardiovascular disease, many studies have shown beneficial effects of long-chain ω -3 PUFA supplementation on risk factors and disease outcomes (as previously discussed and reviewed in Wang et al. [37] and Balk et al. [38]). Whether similar benefits are observed with 18:3 ω -3 supplementation is controversial [39]. The latest review of this research supports the role of 18:3 ω -3 as an anti-inflammatory agent, in decreasing the symptoms of attention-deficit/hyperactivity disorder, in the prevention of neuronal death, and decreasing certain autoimmune diseases in animal models,

although the role of 18:3 ω -3 in cardiovascular disease is less definitive [40].

We have used PUFA Balance (ω -3 PUFAs as percentage of total PUFAs) throughout this study instead of more common use of a ratio (e.g., ω -6/ ω -3 ratio) because PUFA Balance provides a description of the interaction between ω -3 and ω -6 PUFAs without the inherent mathematical problems of ratios. Using the ω -6/ ω -3 ratio as an example, when ω -6 PUFAs dominate in a mixture of the two, the ratio value will be 1 to infinity; however, when ω -3 is the dominant PUFA in the mixture, the range of ω -6/ ω -3 ratios will be only 0 to 1. This non-linear aspect makes it difficult to compare ratios, whereas the advantage of the PUFA Balance is that values are on a linear scale ranging from 0% to 49% when ω -6 PUFAs dominate a mixture and 51% to 100% when ω -3 PUFAs are dominant. PUFA Balance is mathematically a proportion but can also be thought of as a ratio where ω -3 PUFA and ω -6 PUFA contents add to “100.” A distinct advantage is that it is easy to combine it with the total polyunsaturated fat content (currently provided on many foods) to determine the ω -3 PUFA and ω -6 PUFA contents of the food. For example, if the PUFA Balance of a food product is 10 and the total PUFA content is 5 g, then this would simply equate to 0.5 g of ω -3 and 4.5 g of ω -6.

Another advantage of PUFA Balance is that it can be readily used to average out dietary intake. For example, if one consumed a beef kebab (meal no. 16; PUFA Balance 26%) at lunch followed by sate beef (meal no. 22, PUFA Balance 8%) for the evening meal, the averaged PUFA Balance is 17%, which corresponds to the actual value for these two meals. This is not the case if the ω -6/ ω -3 ratio is used. The averaged ω -6/ ω -3 ratio for these two meals is 7.2 (ω -6/ ω -3 ratio 2.9 for meal no. 16 and 11.4 for meal no. 22), although the actual ω -6/ ω -3 value of these two meals combined is 4.8. Such averaging is most accurate when the meals have the same total PUFA content, but using PUFA Balance also provides a more accurate average even when the total PUFA contents of meals are not the same. When specific information on the PUFA content of different foods items/meals is required, KIM2 software (available at <http://efaeducation.nih.gov/sig/kim.html> as a free download from the National Institutes of Health, based on the work of Dr. William Lands) with 12 000 different listed food items is an excellent source of data that can be used to help quantify the PUFA Balance of different meals. Although the precise PUFA Balance of a meal may vary slightly based on changes in ingredients, cooking time, size of the food items, and other facts, overall we believe the use of PUFA Balance, rather than ratios, will have future benefits in easier analysis of diets from the combinations of foods and meals, particularly because the visual pie graph representation of PUFA Balance is very easily understood.

Although the recommendations by the various bodies are for independent dietary intakes of ω -3 PUFA and ω -6 PUFA, there is some discussion in the lipid science community that intake of these two types of PUFA need to be considered together. A manifestation of this discussion is that the ISSFAL recommendations also include the statement that they recognize there may be a healthy upper limit to the intake of the ω -6 PUFA linoleic acid, but that insufficient data exist at present to set a precise value on such an upper limit. One way of approaching the interaction between dietary intake of ω -3 PUFA and ω -6 PUFA is to provide the relative proportions of ω -3 PUFA and ω -6 PUFA in the diet rather than treating the intakes of ω -3 PUFA and ω -6 PUFA separately. We think it is timely that such a discussion take place among regulatory bodies and nutrition professionals. The provision of PUFA Balance values (or a simple pie chart representation as used in Fig. 1) would be in our opinion

a valuable addition to food labels and to restaurant and takeaway food menus.

Conclusions

The relative proportions of ω -3 and ω -6 PUFAs vary greatly across meals. Imbalances in the intake of these PUFAs are associated with various diseases, and the PUFA Balance represents a simple tool that will allow consumers to more easily monitor and balance their dietary intake of ω -3 and ω -6 PUFAs.

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