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A Dietary Guideline Adherence Score Is Positively Associated with Dietary Biomarkers but Not Lipid Profile in Healthy Children[1,2]

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Abstract

Background: Whether dietary indexes are associated with biomarkers of children's dietary intake is unclear.

Objective: The study aim was to examine the relations between diet quality and selected plasma biomarkers of dietary intake and serum lipid profile.

Methods: The study sample consisted of 130 children aged 4–13 y (mean ± SD: 8.6 ± 2.9 y) derived by using baseline data from an intervention study. The Dietary Guideline Index for Children and Adolescents (DGI-CA) comprises the following 11 components with age-specific criteria: 5 core food groups, whole-grain bread, reduced-fat dairy foods, discretionary foods (nutrient poor; high in saturated fat, salt, and added sugar), healthy fats/oils, water, and diet variety (possible score of 100). A higher score reflects greater compliance with dietary guidelines. Venous blood was collected for measurements of serum lipids, fatty acid composition, plasma carotenoids, lutein, lycopene, and α-tocopherol. Linear regression was used to examine the relation between DGI-CA score (independent variable) and concentrations of biomarkers by using the log-transformed variable (outcome), controlling for confounders.

Results: DGI-CA score was positively associated ($P < 0.05$) with plasma concentrations of lutein (standardized β = 0.17), α-carotene (standardized β = 0.28), β-carotene (standardized β = 0.26), and n–3 (ω-3) fatty acids (standardized β = 0.51) and inversely associated with plasma concentrations of lycopene (standardized β = −0.23) and stearic acid (18:0) (standardized β = −0.22). No association was observed between diet quality and α-tocopherol, n–6 fatty acids, or serum lipid profile (all $P > 0.05$).

Conclusion: Diet quality, conceptualized as adherence to national dietary guidelines, is cross-sectionally associated with plasma biomarkers of dietary exposure but not serum lipid profile. This trial was registered with the Australia New Zealand Clinical Trial Registry (www.anztr.org.au) as ACTRN12609000453280. *J Nutr* 2015;145:128–33.

Keywords: child, validity, diet quality, dietary biomarker, cardiovascular risk factor, disease

Introduction

Dietary indexes express multiple dietary components as a single exposure, commonly termed "diet quality." They are often conceptualized as degree of adherence to prevailing dietary guidelines (1). The underlying hypothesis in dietary index research is that the combinations of foods that people eat reflect an underlying nutrient matrix that is predictive of risk factors and disease outcomes (2). The evaluation of whether diet quality indexes are associated with objective biomarkers of nutrient status is an important, but frequently missing, step in the validation of dietary indexes.

In a review of adult studies, Wirt and Collins (3) concluded that diet quality is inversely related to health outcomes, with a protective effect of a moderate magnitude after adjustment for confounders. Similar conclusions were made in an earlier review by Kant (4). One explanation for the modest relations between diet quality scores and health outcomes could be a lack of association between index scores based on assessment of dietary intake and circulating nutrient concentrations. Although studies in adults to date observed associations between dietary indexes and nutrient intake in expected directions (e.g., positive associations

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with micronutrient intakes; inverse associations with sugar, salt, and saturated fat intake) (4), this may be reflective of shared measurement error when subjective dietary assessment methods are used (3). Relatively few studies have evaluated the association between diet quality scores and objective measures of dietary intake. The range of biomarkers studied is limited, and results between studies have been conflicting, an exception being a consistent positive association between diet quality index scores and serum biomarkers of fruit and vegetable intake (5).

Similar findings exist in the pediatric literature. A 2014 review concluded that, whereas a large number of dietary indexes have been created and applied in child populations, the majority of studies are descriptive in nature (6). Of 119 studies reviewed, 56 examined associations with a health outcome, most commonly anthropometry (n = 55). Only 7 studies examined associations with serum biomarkers and 6 included cardiovascular disease risk factors. In summary, although the development of diet quality indexes is an area of intense research, their utility in terms of enhancing our understanding of diet-disease relations beyond weight status remains unestablished, particularly in children.

The Dietary Guideline Index for Children and Adolescents (DGI-CA) (7) measures diet quality by estimating the degree of compliance with the Australian Dietary Guidelines (8). These guidelines provide age- and sex-specific advice for types (core food groups and discretionary choices) and amounts (in servings) of food to consume to support health and well-being. With the use of this index in a national sample of children (n = 3416), higher diet quality scores were associated with lower energy, total and saturated fat, and sugar intakes and higher protein, carbohydrate, and fiber intakes, as well as higher intakes of a range of essential micronutrients (7). The validity of the DGI-CA in terms of associations with objective measures of dietary intake has not been examined. Therefore, the study aim was to examine the relations between diet quality and selected plasma biomarkers of dietary intake and serum lipids. We hypothesized that the diet quality index score is associated with a range of dietary biomarkers reflecting a better underlying nutrient matrix.

Methods

Participants and procedures

Children were recruited, with their parents, via advertisements and an established database between mid-2009 and early 2010. Data were collected at baseline as part of an intervention study targeting a change in the fat type of children's dairy food choices (9). Therefore, eligibility criteria of the primary study were healthy children (aged 4–13 y) who were regular-fat "dairy consumers" and living in the Adelaide Metropolitan area. Parents provided informed written consent and children's assent were obtained. The study was approved by the Commonwealth Scientific Industrial Research Organization (CSIRO) Animal, Food, and Health Sciences Human Ethics Committee (HREC no. 09/20) and registered in the Australia New Zealand Clinical Trials Registry (ACTRN12609000453280).

Families attended the CSIRO Clinical Research Unit for assessment. Children's age and sex were recorded and anthropometric measurements, blood sample collection, and dietary recalls conducted. Children had their height and weight measured (10) and their BMI calculated and converted to a z score, adjusted for age and sex (11). z Score calculations were based on British reference data provided as a computer program (12) and classified by using the International Obesity Task Force definition (11). Because of low numbers of underweight and obese children, weight status groups were collapsed as underweight/normal weight and overweight/obese. Sensitivity analysis excluding underweight children was performed and did not change the results observed (data not shown).

Dietary assessment and diet quality

Children's dietary intake was assessed by dietitians via 3 nonconsecutive 24-h recalls (1 as a face-to-face interview, 2 recalls via telephone) that included 1 weekend day and were scheduled within 7 d. A standardized 3-pass interview protocol was used with portion-size estimation aid (13), described in detail elsewhere (9). The 24-h recall protocol is a well-established dietary recall methodology (14, 15) that is considered to provide an accurate estimate of energy (16).

Food intake data were entered into Foodworks 7 Professional (Xyris Software) (17). Energy intake was calculated by using Australian food composition data (AusNut 2007) (18), and food groups were categorized according to the Food Standards Australia New Zealand classification system, which categorizes foods into 23 major and 122 minor groups. This hierarchy was used to allocate foods and beverages to food groups consistent with the Australian Dietary Guidelines documentation (8). Food group intake was converted to servings on the basis of the standard kilojoule value assigned to each food group (8).

With the use of children's food intake data (in servings), a diet quality index score was derived by using the DGI-CA, which represents children's compliance with the 2013 Australian Dietary Guidelines (8). The development of this index was described previously (7, 19). The DGI-CA comprises 11 components: 5 core food groups (fruit, vegetables, meat and alternatives, dairy, and breads/cereals), a measure of wholegrain bread as a proportion of total bread, reduced-fat dairy as a proportion of total dairy, discretionary foods (high in saturated fat, salt, and added sugar), healthy fats and oils, water, and diet variety. Intakes were compared with age- and sex-specific recommendations, and the sum of 11 components calculated to provide a score out of 100. The DGI-CA score represents the mean diet quality over the 3 recalled days, and a higher score reflects greater compliance with guidelines.

Blood collection, processing, and analysis

A set of biomarkers was selected on the basis of their likely association with the key index components (20, 21) and included α-carotene, β-carotene, lutein, lycopene, α-tocopherol, n–3 FAs, n–6 FAs, myristic acid (14:0), pentadecanoic acid (15:0), palmitic acid (16:0), and stearic acid (18:0). Total cholesterol, cholesterol fractions, and TGs were included as markers of cardiovascular health status.

Children provided a fasting blood sample (nothing to eat or drink other than water from midnight until sampling), with serum total cholesterol and fractions (HDL cholesterol, LDL cholesterol), TGs, FAs, fat-soluble vitamins, and carotenoids measured by the CSIRO Clinical Chemistry Laboratory. Blood samples, 6–12 mL, were collected via venipuncture using standard procedures by a pediatric phlebotomist. Samples were collected into evacuated tubes with a gel separator and allowed to clot at room temperature for 3 min. Serum was separated by centrifugation at 4° C, and aliquots stored at −80°C for lipid and FA analyses.

Lipids and FAs. TGs, total cholesterol, and HDL cholesterol were measured on a Hitachi 902 clinical analyzer with the use of appropriate diagnostic kits from Roche Diagnostics Australia. LDL cholesterol was calculated by using the Friedewald equation (22). Serum lipids were extracted by using chloroform/methanol 2:1 (22). FA composition was determined on the lipid extracts by using standard methods described in more detail elsewhere (9). The concentrations of serum FAs were expressed as the relative percentage of the total FAs analyzed.

Fat-soluble vitamins and carotenoids. Analysis of fat-soluble vitamins and carotenoids was conducted by using a standard method that uses protein precipitation of the plasma by ethanol followed by extraction of the compounds of interest into hexane with vigorous shaking (23). Fat-soluble vitamins and carotenoids were detected on a photodiode array detector with peak identification based on retention time comparison against known standards and quantification by using Shimadzu LC solutions. The CVs for all analyses were between 4.5% (lutein) and 7.8% (lycopene).

Statistical analysis

Analyses were performed with the use of SPSS 18.0. For all analyses, significance was set at $P < 0.05$. Biomarkers of dietary intake and lipid

profile were examined by child age, sex, and weight status by using unadjusted means and SDs because these variables were previously shown to vary according to these factors (24–26).

Independent-samples *t* tests and 1-factor ANOVA with Bonferroni adjustments were used to examine the differences by demographic group. Diet quality was split into 3 groups on the basis of tertile analysis to create equal groups of "low," "medium," and "high" diet quality. In most cases, biomarker data were not normally distributed and were log-transformed to improve normality. The back-transformed means and 95% CIs are presented by tertile of diet quality. ANOVA with linear trends, using the log-transformed values, was used to examine trends in biomarker of dietary intake and lipid profile between tertiles of diet quality.

Linear regression was used to examine the relation between diet quality (independent variable) and concentrations of biomarkers by using the log-transformed variable (outcome), controlling for important confounders identified a priori from previous literature (24–26). Confounders included in the regression analysis were age, sex, BMI *z* score, and energy intake. In addition, carotenoids were adjusted for total serum cholesterol because of the underlying relation between serum carotenoids and serum cholesterol (27). To examine the general level of agreement between allocation to tertile of diet quality and biomarker of dietary intake, the exact percentage agreement and κ statistics were calculated. Effect estimates are presented as unstandardized regression coefficients. To enable comparison between biomarkers, standardized regression coefficients are also presented.

Results

A total of 130 children provided an adequate blood sample to analyze the concentration of biomarkers for dietary intake ($n = 117$ for serum lipid profile). Sixty percent of children were boys, with a mean age of 8.6 ± 2.9 y. Almost half the sample (47%) was in the 4–8-y age group (34.6% aged 9–11 y, 18.5% aged 12–13 y), and approximately three-quarters (77.7%) were of a normal weight. Boys consumed more energy than girls, and children aged 4–8 y consumed less energy than the 2 older age groups. There were no differences in children's diet quality between age group or by weight status (**Table 1**).

There were no differences between boys and girls in concentrations of biomarkers of dietary intake or lipid profile, but some differences were observed by age and weight status groups. Concentrations of n–6 FAs and 16:0 were different between children aged 9–11 y and those aged 12–13 y, and the average 14:0 concentration for the oldest age group of children was significantly higher than in other age groups. The concentration of 14:0 was also higher in overweight or obese children than in normal-weight children. Lipid profile differed by weight status, with overweight or obese children having higher concentrations of serum cholesterol, LDL cholesterol, and TGs but lower serum HDL-cholesterol concentrations (Table 1).

Differences in the concentration of biomarkers of dietary intake by tertile of diet quality were observed. α-Carotene, β-carotene, lutein, and n–3 FAs increased with increasing diet quality, whereas 18:0 decreased with increasing diet quality (**Table 2**). The regression analysis showed that after controlling for covariates, overall diet quality was a significant positive predictor of α-carotene, β-carotene, and n–3 FAs ($P < 0.01$) (**Table 3**). The positive relation between diet quality and lutein and 16:0 did not reach significance ($P = 0.06$). Diet quality was inversely associated with lycopene and 18:0 concentrations ($P < 0.05$).

The agreement between the allocation to tertiles of diet quality and tertiles of biomarker of dietary intake was low to moderate, ranging from 28% to 46% (**Table 4**). The highest agreement was observed for α-carotene, β-carotene, and n–3 FAs (43–46%), where the Cohen's κ statistics were low but significant ($P < 0.05$).

TABLE 1 Dietary intake and plasma dietary biomarker and serum lipid concentrations for a sample of 4–13 y olds by demographic characteristics[1]

	Sex		Age group			Weight status[2]	
	Boys	Girls	4–8 y	9–11 y	12–13 y	Normal weight	Overweight/obese
Sample size, *n*	78	52	61	45	24	101	29
Energy intake, kJ/d	8488 ± 1707*	7617 ± 1551	7410 ± 1474[b]	8507 ± 1527[a]	8140 ± 1695[a]	8098 ± 1679*	8287 ± 1770
Diet quality index score (out of 100)	50.5 ± 14.2	48.3 ± 12.9	51.2 ± 12.9	48.4 ± 14.2	47.9 ± 14.4	50.0 ± 14.0	48.4 ± 12.6
Plasma biomarkers							
Sample size, *n*	78	52	61	45	24	101	29
α-Carotene, μg/mL	0.06 ± 0.07	0.06 ± 0.05	0.07 ± 0.06	0.05 ± 0.05	0.06 ± 0.09	0.06 ± 0.06	0.05 ± 0.05
β-Carotene, μg/mL	0.26 ± 0.17	0.27 ± 0.17	0.30 ± 0.18	0.23 ± 0.14	0.25 ± 0.17	0.28 ± 0.17	0.21 ± 0.17
Lutein, μg/mL	0.15 ± 0.06	0.16 ± 0.05	0.16 ± 0.06	0.16 ± 0.05	0.15 ± 0.05	0.15 ± 0.05	0.17 ± 0.06
Lycopene, μg/mL	0.29 ± 0.13	0.29 ± 0.11	0.28 ± 0.14	0.29 ± 0.10	0.31 ± 0.11	0.29 ± 0.13	0.30 ± 0.09
α-Tocopherol, μg/mL	7.99 ± 1.47	8.41 ± 1.22	8.07 ± 1.41	8.38 ± 1.20	7.97 ± 1.62	8.09 ± 1.36	8.38 ± 1.46
n–3, % of FAs	4.21 ± 1.44	3.91 ± 0.89	4.19 ± 1.26	4.01 ± 1.27	3.98 ± 1.25	4.12 ± 1.36	3.97 ± 0.81
n–6, % of FAs	38.5 ± 2.6	38.4 ± 3.0	38.3 ± 2.7[a]	39.2 ± 2.6[a]	37.4 ± 2.7[b]	38.5 ± 2.7	38.3 ± 2.8
14:0, % of FAs	0.8 ± 0.3	0.8 ± 0.3	0.7 ± 0.2[b]	0.8 ± 0.2[b]	0.9 ± 0.3[a]	0.7 ± 0.3*	0.9 ± 0.2
15:0, % of FAs	0.30 ± 0.06	0.29 ± 0.06	0.30 ± 0.06	0.29 ± 0.06	0.32 ± 0.05	0.30 ± 0.06	0.30 ± 0.05
16:0, % of FAs	20.4 ± 1.1	20.3 ± 1.4	20.3 ± 1.18[b]	20.1 ± 1.3[b]	21.0 ± 1.2[a]	20.3 ± 1.3	20.5 ± 1.2
18:0, % of FAs	7.2 ± 0.5	7.1 ± 0.6	7.2 ± 0.6	7.3 ± 0.6	6.9 ± 0.4	7.2 ± 0.5	7.2 ± 0.6
Serum lipids							
Sample size, *n*	68	49	53	41	23	91	26
Total cholesterol, mmol/L	4.29 ± 0.74	4.49 ± 0.67	4.29 ± 0.68	4.46 ± 0.69	4.43 ± 0.83	4.28 ± 0.65*	4.70 ± 0.85
TGs, mmol/L	0.68 ± 0.36	0.70 ± 0.30	0.62 ± 0.28[b]	0.66 ± 0.30[b]	0.88 ± 0.43[a]	0.65 ± 0.33*	0.82 ± 0.34
HDL-C, mmol/L	1.49 ± 0.32	1.45 ± 0.26	1.48 ± 0.26	1.52 ± 0.32	1.38 ± 0.31	1.51 ± 0.30*	1.34 ± 0.25
LDL-C, mmol/L	2.49 ± 0.66	2.72 ± 0.61	2.52 ± 0.66	2.64 ± 0.66	2.65 ± 0.61	2.47 ± 0.57*	2.99 ± 0.77

[1] Values are unadjusted means ± SDs. *Different from corresponding mean, $P < 0.05$. For age groups, labeled means in a row without a common letter differ, $P < 0.05$. HDL-C, HDL cholesterol; LDL-C, LDL cholesterol.

[2] The normal-weight category includes underweight children ($n = 14$); overweight ($n = 23$) and obese ($n = 6$) children were combined.

TABLE 2 Plasma dietary biomarker and serum lipid concentrations by diet quality index score tertile in a sample of 4- to 13-y-old children[1]

	Diet quality index score tertile			
	Low: median = 37.2 (range: 20.3–42.6) (n = 43)	Medium: median = 49.2 (range: 43.0–54.6) (n = 44)	High: median = 64.7 (range: 54.7–84.2) (n = 43)	P-trend
α-Carotene, μg/mL	0.02 (0.02, 0.03)	0.05 (0.04, 0.07)	0.05 (0.04, 0.07)	<0.001
β-Carotene, μg/mL	0.17 (0.14, 0.21)	0.23 (0.19, 0.28)	0.26 (0.21, 0.31)	0.005
Lutein, μg/mL	0.13 (0.12, 0.15)	0.15 (0.13, 0.16)	0.16 (0.14, 0.18)	0.031
Lycopene, μg/mL	0.28 (0.25, 0.32)	0.25 (0.22, 0.29)	0.24 (0.18, 0.32)	0.22
α-Tocopherol, μg/mL	7.96 (7.53, 8.41)	8.09 (7.68, 8.51)	8.09 (7.72, 8.48)	0.65
n–3, % of FAs	3.56 (3.34, 3.8)	3.78 (3.57, 4.01)	4.6 (4.17, 5.09)	<0.001
n–6, % of FAs	38.5 (37.7, 39.3)	38.1 (37.1, 39.0)	38.5 (37.6, 39.5)	0.98
14:0, % of FAs	0.71 (0.64, 0.79)	0.78 (0.69, 0.88)	0.73 (0.66, 0.81)	0.69
15:0, % of FAs	0.28 (0.27, 0.3)	0.30 (0.28, 0.32)	0.31 (0.29, 0.32)	0.07
16:0, % of FAs	0.32 (0.31, 0.34)	0.34 (0.32, 0.35)	0.34 (0.32, 0.35)	0.28
18:0, % of FAs	7.32 (7.16, 7.48)	7.13 (6.94, 7.32)	7.02 (6.84, 7.21)	0.022
Total cholesterol, mmol/L	4.28 (4.06, 4.51)	4.25 (4.07, 4.43)	4.45 (4.19, 4.72)	0.30
TGs, mmol/L	0.61 (0.53, 0.7)	0.67 (0.59, 0.77)	0.61 (0.53, 0.69)	0.98
HDL-C, mmol/L	1.46 (1.38, 1.55)	1.44 (1.34, 1.54)	1.44 (1.34, 1.54)	0.70
LDL-C, mmol/L	2.48 (2.29, 2.69)	2.41 (2.24, 2.6)	2.64 (2.41, 2.91)	0.27

[1] Values are back-transformed means (95% CIs). HDL-C, HDL cholesterol; LDL-C, LDL cholesterol.

Children's overall diet quality was not associated with serum lipid concentrations. There were no significant differences in the concentration of these markers by tertile of diet quality (Table 2), and diet quality was not a predictor of markers of serum lipid concentrations (Table 3). The association between diet quality score and serum LDL cholesterol was weak (β = 0.001) and only marginally significant (P = 0.08).

Discussion

In this sample of healthy Australian children, a measure of overall diet quality was positively associated with plasma concentrations of α-carotene, β-carotene, lutein and n–3 FAs and inversely associated with plasma concentrations of lycopene and 18:0 FA. No association was observed between diet quality and α-tocopherol, n–6 FAs, or serum lipid profile. These findings provide some insight that adherence to national dietary guidelines is associated with better nutrient status.

Biomarkers of fruit and vegetable intake are best represented by the group of carotenoids that can be measured in significant amounts in the blood (28). Across the analyses undertaken in the present study, positive associations were observed between the diet quality score and α-carotene, β-carotene, and lutein. To our knowledge, this is only the second examination of associations

TABLE 3 Regression coefficients for DGI-CA in predicting serum dietary biomarker and serum lipid concentrations in a sample of 4–13-y-old children[1]

	DGI-CA			
Outcome variable (log-transformed)	Unstandardized β coefficient[2]	Unstandardized SE[2]	Standardized β coefficient[3]	P
α-Carotene, μg/mL	0.096	0.031	0.28	0.003
β-Carotene, μg/mL	0.053	0.018	0.26	0.005
Lutein, μg/mL	0.022	0.012	0.17	0.059
Lycopene, μg/mL	−0.047	0.019	−0.23	0.015
α-Tocopherol, μg/mL	0.001	0.004	−0.02	0.82
n–3, % of FAs	0.042	0.007	0.51	<0.001
n–6, % of FAs	0.003	0.010	−0.11	0.27
14:0, % of FAs	0.003	0.010	0.02	0.80
15:0, % of FAs	0.011	0.016	0.17	0.07
16:0, % of FAs	0.007	0.004	0.171	0.06
18:0, % of FAs	0.006	0.002	−0.22	0.019
Total cholesterol, mmol/L	0.007	0.004	0.15	0.10
TGs, mmol/L	0.007	0.012	0.06	0.54
HDL-C, mmol/L	0.002	0.006	−0.03	0.75
LDL-C, mmol/L	0.001	0.001	0.16	0.08

[1] Biomarkers of dietary intake and serum lipids were adjusted for age, sex, BMI z score, and energy intake in the regression models. Analyses for lutein, lycopene, α-tocopherol, α-carotene, and β-carotene were also adjusted for total cholesterol. DGI-CA, Dietary Guideline Index for Children and Adolescents; HDL-C, HDL cholesterol; LDL-C, LDL cholesterol.
[2] Values were scaled (×10) to avoid zero values at 2 decimal places. Coefficient presented represents change per 10-point change in diet quality score.
[3] Unscaled coefficients are presented. Coefficient presented represents change per 1-point change in diet quality score.

TABLE 4 Exact percentage agreement between diet quality index score and biomarkers of dietary intake by allocation to tertiles in a sample of 4- to 13-y-old children

	Percentage agreement[1]	κ	*P*
α-Carotene, μg/mL	46.2	0.19	0.002
β-Carotene, μg/mL	44.6	0.17	0.006
Lutein, μg/mL	40.8	0.11	0.07
Lycopene, μg/mL	29.2	−0.06	0.32
α-Tocopherol, μg/mL	36.9	0.05	0.38
n–3, % of FAs	43.2	0.15	0.023
n–6, % of FAs	30.5	−0.04	0.51
14:0, % of FAs	31.4	−0.03	0.65
15:0, % of FAs	34.7	0.02	0.75
16:0, % of FAs	29.7	−0.05	0.39
18:0, % of FAs	28.0	−0.08	0.21

[1] Values are numbers (expressed as a percentage) of the same tertile allocation for diet quality score and biomarker measurement.

between diet quality and serum carotenoid concentrations in children. Royo-Bordonada et al. (29) observed a weak correlation between a measure of dietary variety and carotenes (r = 0.13, adjusted for energy intake) in Spanish children aged 6–7 y. The DGI-CA appears to capture variation in children's exposure to a range of vegetable (i.e., green, green leafy, orange, and red) as well as fruit intakes.

Diet quality in this sample of Australian children was inversely associated with plasma concentrations of lycopene. This finding contrasts with previous research in Spanish children that found a positive correlation between a dietary variety index and plasma lycopene concentrations (r = 0.27, adjusted for energy intake) (29). Although a high intake of tomatoes may be characteristic of dietary patterns that are rich in vegetables in Mediterranean populations, this relation may not be comparable in Australian population groups. One explanation for this discrepancy may be that tomato-rich foods, such as pizza and tomato sauce (commonly consumed as a condiment with discretionary choices such as hot chips, savory pies, and sausages), are common sources of tomato intake in Australian children's diets but contribute little to the vegetable component of the diet quality score. High intakes of these "discretionary" foods would result in a lower diet quality score. Our results are consistent with studies in U.S. adults who also commonly consumed lycopene-rich sources such as pizza and tomato soup (30, 31) over the Mediterranean-type diet sources.

Across the analyses undertaken in the present study, a consistent relation was observed between diet quality and serum concentrations of n–3 FAs (positive association) and 18:0 FA concentrations (inverse association), but no associations were observed for n–6 FAs or other FA concentrations. Similar results were reported in a small American study that used a diet quality index composed of nutrient- and food-based components (21). In that sample of postmenopausal women, diet quality was positively associated with 16:0 and inversely associated with 18:0, but no association was observed for EPA or DHA. Others have observed a positive association between concentrations of n–3 FAs and an index of diet quality relating to compliance with dietary recommendations for prevention of cardiovascular disease in adults in southern France (32). To our knowledge, the present study is the first to examine the relation between diet quality and serum concentrations of n–3 FAs in children. Our findings suggest that diet quality, as conceptualized here, has some ability to distinguish underlying dietary exposure in terms of type or quality of fat intake.

However, no associations were observed between diet quality and the serum lipid profile. In adult populations, associations between diet quality and lipid profile have been observed in the expected direction (3). However, in child populations, no studies observed significant associations between diet quality and serum lipid profile (29, 33). There may be a number of reasons why the validation of diet quality indexes in relation to markers of disease status or risk in children is particularly difficult. For example, a lack of available data (i.e., blood rarely collected from children), limitations in study design (i.e., tend to be cross-sectional), less variation in serum lipids in children than in adults, and the time lag in the development of risk factors or chronic disease. More longitudinal studies are needed to assess the association between diet indexes, risk factors, and disease outcomes in children.

Although the Australian diet quality index used in this study has shown no association with health outcomes, e.g., lipid profile here or BMI in previous research (7), evaluation of a wider range of biomarkers along with investigation of the longitudinal association with health outcomes such as lipid profile, adiposity, and blood pressure are areas for further evaluation. Such research would strengthen our ability to make evidence-based whole-diet recommendations for the population.

This study has a number of strengths and limitations. First, the biomarkers measured reflected a number of dietary components including fruit, vegetables, and fat quality; however, not all of the components of the diet quality index were represented. For example, currently no biomarkers exist for whole grains or added sugars (20), and urinary nitrogen or sodium was not collected in this study. Second, dietary intake was assessed by using 3 scheduled 24-h recalls, which perform adequately as an assessment of current intake against doubly labeled water in this age group (16, 34). A limitation of this method is that within-subject variation (random error) was not accounted for, particularly for infrequently consumed foods (35, 36). However, the inclusion of a weekend day improves the estimates because consumption is known to vary over weekends and weekdays (35, 36). There was also a limitation in the time window of exposure of the dietary intake assessment (3 d over a 1-wk period) compared to the dietary biomarkers and lipids, which reflect intake over the previous several weeks. Third, the biomarkers evaluated are concentration biomarkers that reflect dietary exposure and are influenced by factors such as endogenous synthesis, nutritional status, and processes affecting absorption and availability (20).

The study limitations are all likely to attenuate the correlations observed (36). Therefore, it is likely that the relations observed are real and may in fact be stronger than observed. The statistical analysis was undertaken in a number of ways and included adjustment for potential confounders. This provides some confidence in the results observed because they were consistent across the type of analyses performed and independent of sex, age, weight status, and energy intake. We are mindful that the magnitudes of the differences in biomarker concentrations across tertiles of diet quality are small, as are the regression coefficients, although this is the effect size per 10-point increase in a diet quality score that ranges from 0 to 100. Finally, the variation in the diet quality index can reflect differences in any of the 11 indicators, not just the indicator that the biomarker reflects; therefore, it might be unrealistic to expect perfect agreement.

To conclude, in this sample of healthy Australian children, a dietary quality index score reflecting greater adherence to the national dietary guidelines was associated with a dietary

biomarker profile consistent with better nutritional status but not serum lipid profile. Together with previous research (7, 19), the associations between DGI-CA score and sociodemographic characteristics, reported food and nutrient intake, objective measures of nutrient intake, cross-sectional BMI, and lipid profile were evaluated. The agreement between several measures of food and nutrient intake provides evidence of convergent validity for the DGI-CA and a measure of diet quality (37). The results of this study suggest that adherence to dietary guidelines is associated with better biochemical nutrient profile, but whether this predicts better health outcomes longitudinally in childhood and adolescence needs to be explored in future research.

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