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Dairy product consumption, dietary nutrient and energy density and associations with obesity in Australian adolescents

T. A. O'Sullivan,[1] A. P. Bremner,[2] H. K. Bremer,[1] M. E. Seares,[1] L. J. Beilin,[3] T. A. Mori,[3] P. Lyons-Wall,[1] A. Devine[1] & W. H. Oddy[4]

[1]School of Exercise and Health Science, Edith Cowan University, Joondalup, WA, Australia
[2]School of Population Health, The University of Western Australia, Perth, WA, Australia
[3]School of Medicine and Pharmacology, Royal Perth Hospital Unit, The University of Western Australia, Perth, WA, Australia
[4]Telethon Kids Institute, The University of Western Australia, Perth, WA, Australia

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Correspondence
Dr T. O'Sullivan, Department of Nutrition and Dietetics, School of Exercise and Health Science, Edith Cowan University, 270 Joondalup Drive, Joondalup WA 6027, Australia.
Tel.: +61 8 6304 3529
Fax: +61 8 6304 5384
E-mail: t.osullivan@ecu.edu.au

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Abstract

Background: Dairy intake is likely to influence dietary energy density (ED) and nutrient density (ND), which are factors representing aspects of dietary quality. Although evidence suggests dairy intake is unlikely to contribute to obesity, intake tends to decrease over adolescence, potentially as a result of concerns around weight gain. We examined associations between dairy intake, ED and ND, and investigated relationships with obesity in adolescents.
Methods: The present study comprised a cross-sectional study of 1613 14-year-olds in the Western Australian Pregnancy Cohort (Raine) Study. Adolescents completed a 212-item food frequency questionnaire. Nutrient Rich Food index 9.3 (NRF9.3) was used to estimate ND. Age-specific body mass index (BMI) and waist–height cut-offs were used to categorise obesity risk.
Results: Mean (SD) dairy intake was: 2.62 (1.51) servings daily; ED was 4.53 (0.83) (food and beverage) and 6.28 (1.33) (food only); ND was 373 (109). Dairy intake was inversely associated with ED and positively associated with ND. The odds of being overweight (as assessed by BMI) increased by 1.24 (95% confidence interval = 1.09–1.42) with each 100-point increase in ND, after adjustment for potential confounders and energy intake. ED measures and dairy intake were inversely associated with obesity after adjustment for confounders; associations became nonsignificant after energy adjustment.
Conclusions: The NRF9.3 was originally designed to assess foods, not diets. Further research in other cohorts to determine whether similar findings exist, or investigations into alternate measures of dietary ND, may prove useful. Our findings may be the result of factors such as an excess consumption of refined but fortified foods. Although higher dairy intakes were associated with higher ND, intakes were not associated with higher obesity risk.

Introduction

Although milk and dairy products are commonly consumed by children (Australian Bureau of Statistics, 2012), Australian studies suggest that the intake of dairy products decreases during adolescence (Baird *et al.*, 2012; Parker *et al.*, 2012). Because dairy products are a good source of energy and nutrients such as calcium and potassium, this decrease is likely to affect both the energy density (ED) and nutrient density (ND) of the diet. ED and ND are measures

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that can be used to describe the quality of a food or diet. ED refers to the amount of energy provided per unit weight of food or volume of beverage and has been proposed to be a contributing factor in weight regulation and energy balance (Prentice & Jebb, 2003). Foods high in ED tend to be lower in water and higher in fat (Drewnowski, 1998), whereas foods high in ND tend to provide higher amounts of vitamins and minerals in relation to added sugar, salt and saturated fats (Drewnowski, 2009a). For example, whole milk has a higher ED than skim milk but a lower ND than skim milk as a result of the fat content.

Energy rich and nutrient poor diets have been postulated to contribute to obesity (Crowe *et al.*, 2004). Controlled studies suggest that energy dense food is linked with increased energy intake (Bell *et al.*, 1998; Rolls *et al.*, 1999), however, little is known of the relationship between ED and obesity in free-living populations, particularly in younger age groups. Foods and snacks that are relatively energy dense but nutrient poor are reported to contribute approximately one-third of the daily energy intake of American children and adolescents (Kant, 2003). Similarly, 'extra' foods, defined as those that do not fit within the five 'core' food groups of fruit, vegetables, dairy, meat and alternatives or breads and grains[1], were found to contribute over 40% of energy intake in Australian adolescents (Bell *et al.*, 2005). Although the consumption of these 'extra' foods may increase in adolescence, intake of dairy products may be reduced over the adolescent period as a result of dieting and concerns about weight gain (Neumark-Sztainer *et al.*, 1997). However, a recent systematic review and meta-analysis suggested that dairy intake was significantly inversely associated with adiposity in adolescents from developed countries (Dror, 2014).

Given the likely impact of dairy intake on ED and ND, the hypotheses around energy rich and nutrient poor diets with obesity, and concerns about dairy and weight gain in adolescents, we aimed to: (i) investigate associations between dairy intake, ED and ND and (ii) examine whether dairy, ED or ND were predictors of obesity in a cohort of Australian adolescents. We hypothesised that higher ED, lower ND and lower dairy intake would be associated with increased obesity.

Materials and methods

Study population

Participants were adolescents in the population-based Western Australian Pregnancy Cohort (Raine) Study, a longitudinal birth cohort originally comprising 2900 pregnant women enrolled through the public antenatal clinic at King Edward Memorial Hospital and nearby private clinics from 1989 to 1991 (Newnham *et al.*, 1993). The resulting 2868 live-born babies were followed up at regular intervals. The present study reports on cross-sectional associations in data collected between 2003 and 2005 at the 14-year follow-up. Ethics committees at King Edward Memorial Hospital, Princess Margaret Hospital and Edith Cowan University approved the research, and adolescents and their parents or guardians provided their informed written consent.

Dietary analysis

A 212-item semi-quantitative food frequency questionnaire (FFQ) developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) was used to assess dietary intake over the previous year (Baghurst & Record, 1984), as previously detailed (Ambrosini *et al.*, 2008). The FFQ was modified to include popular snacks and beverages typically eaten by adolescents, and was completed by the primary caregiver in conjunction with the adolescent. This tool has been shown to reasonably rank intakes when validated with a 3-day food diary in a subgroup of this cohort (Ambrosini *et al.*, 2009). A research nurse checked FFQs for any potentially missing or incorrect responses and clarified with the adolescent as required. FFQ responses were collated and analysed by the CSIRO, with data entered twice and the results checked for any intakes that appeared to be erroneous. Estimated daily intakes of foods used Australian food composition data (Lewis et al. 1995). Intake of core dairy products for each adolescent was calculated by summing daily servings of milk (including milk-based beverages such as smoothies, milkshakes and flavoured milk), yoghurt, cheese and custard (Parker *et al.*, 2012), with serving sizes based on the Australian Guide to Healthy Eating (National Health & Medical Research Council, 2011). Based on this system, a serving size was estimated to contain 300 mg of calcium (range 252–350 mg), and this calcium content was used to calculate equivalent serving sizes for noncore dairy foods (butter, cream and ice-cream) to ensure the contribution from these sources could also be assessed in the form of total dairy (core plus noncore dairy products) (Parker *et al.*, 2012). To obtain estimates of dairy content (e.g milk, butter, cheese) from mixed dishes such as mornay dishes and pizza, recipes were standardised using 'Cookery the Australian Way' (The Trustees of the Home Economics Teachers Group, 1967) and the Taste Australia Website (2012) and entered into FOODWORKS PRO 2009 dietary software (Xyris Software Pty Ltd, Highgate Hill, QLD,

[1]Core food groups refer to groups of foods that provide nutrients considered to be essential for good health; they do not include discretionary food choices high in added sugars, fats, or alcohol.

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Australia). Dairy content was then determined and added to the applicable category.

Dietary energy density

Various methods have been used to calculate dietary ED, including food only, food and all beverages, food and all beverages excluding water, and food and energy containing beverages (Ledikwe *et al.*, 2005). Calculations based only on food can be considered more meaningful (2005), although the purpose of the analysis and the outcome of interest must also be considered. Because dairy products, including milk, were important to the present study, we chose to use the weight (g day^{-1}) and energy intake (kJ day^{-1}) contributed by each food and beverage consumed to derive two ED values. These were: (i) ED food only, ED(F), calculated as total energy intake (kJ) divided by total weight (g) for all food items consumed, and (ii) ED food and beverages, ED(FB), calculated as total energy intake (kJ) divided by total weight (g) for all food items and energy containing beverages consumed. Beverages classified as non-energy containing included tea, coffee (added sugar and milk were included as separate items), artificially sweetened cordials and soft drinks, and water.

Dietary nutrient density

The calculation for ND was based on the Nutrient Rich Food index 9.3 (NRF9.3) because it has provided the best results in comparison to other ND profiling methods when validated against independent measures of a healthy diet (Drewnowski *et al.*, 2009b). The nutrient rich foods approach is conceptualised as a food guidance system that encourages consumers to make healthier food choices and improve their overall diet quality (Drewnowski *et al.*, 2009b). The NRF9.3 algorithm is composed of a positive subscore of nine key nutrients: protein, fibre, vitamin A, vitamin C, vitamin E, calcium, iron, potassium and magnesium; minus a subscore of three 'nutrients to limit': saturated fat, added sugar and sodium. To apply the NRF9.3 in our cohort, nutrient intakes were converted to percentages of recommended dietary intakes (RDI) or percentages of adequate intakes based on the Nutrient Reference Values for Australia and New Zealand for 14-year olds (National Health & Medical Research Council, 2006). Upper levels for saturated fat and added sugar were calculated as 10% of total energy (Drewnowski, 2009a) and 2300 mg was used as the upper level for sodium (National Health & Medical Research Council, 2006). Percentage RDIs were capped at 100% so that the high consumption of a single nutrient would not obtain a disproportionately high overall score, whereas 'nutrients to limit' were not capped (Drewnowski, 2005). Therefore, the maximum beneficial nutrient subscore is 900, whereas the 'nutrients to limit' subscore can be greater than 300 (Drewnowski *et al.*, 2009b).

Anthropometric assessment

We used BMI (kg m^{-2}) as an indicator of being overweight and obesity because this measure is considered appropriate for clinical and surveillance purposes in childhood and adolescence (Himes, 2009). The cohort was classified into four BMI categories (underweight, normal weight, overweight and obese) using standard criteria for this age group (Cole *et al.*, 2000, 2007). Trained researchers measured weight to the nearest 100 g using a Wedderburn Digital Chair Scale (Wedderburn, Sydney, Australia), and height to the nearest 0.1 cm with a Holtain Stadiometer (Holtain Ltd, Crymych, Dyfed, UK). We also used the waist–height ratio as an indicator of being overweight and obese because the inclusion of waist in this index considers abdominal obesity and has been shown to better predict cardiovascular disease risk factors in children than BMI (Savva *et al.*, 2000). Researchers took waist measurements to the nearest 0.1 cm at the level of the umbilicus until two readings were within a 1 cm of each other. Waist–height cut-offs for obesity based on the 85th percentile for percentage body fat have been established in the Australian population; for age 11–16 years, the cut-offs for being overweight are 0.46 for boys and 0.45 for girls (Nambiar *et al.*, 2010).

Potential confounding factors

Adolescents selected their corresponding puberty developmental stage from a set of standard drawings depicting Tanner stages of pubic hair development from two (sparse) to five (adult) (Tanner, 1962; Duke *et al.*, 1980). The primary caregiver provided sociodemographic information, including family income, highest level of education of the mother or primary caregiver, and whether or not the adolescent lived in a single-parent household. To estimate physical activity levels, adolescents reported the number of hours spent outside school hours participating in physical activity causing breathlessness or sweating, and how many hours they spent watching television/videos and using computers for school, work and recreation. This information was grouped into five classifications, ranging from very sedentary (low exercise and high television/computer use) to very active (high exercise and low television/computer screen use). The ratio of reported energy intake relative to the estimated energy requirement was used to classify participants as potential under, plausible or over-reporters, as previously described in this cohort (Ambrosini *et al.*, 2013).

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Statistical analysis

We used IBM SPSS, version 21.0 (IBM Corp, 2012) for data analysis. $P < 0.05$ was considered statistically significant. Subjects with extreme daily energy intakes (<3 000 or >20 000 kJ) were excluded (Rockett *et al.*, 1997). Baseline characteristics were summarised using the mean (SD) for continuous measures and percentages for categorical variables. We used *t*-tests and chi-squared tests to determine differences between boys and girls in baseline characteristics. Differences in dairy consumption and energy and nutrients densities between boys and girls, and across BMI categories, were compared using *t*-tests and analysis of variance. Correlations were used to examine relationships between measures of ED, ND and energy intake.

Linear regression was used to model the relationships between servings of dairy (total or core) and each of ED (FB), ED(F) and ND. Linear regression was also used to model the relationships between log (base e) BMI for each dietary predictor [servings of total dairy, servings of core dairy, ED(FB), ED(F) and ND]. Log values were used to transform the skewed distribution of BMI into one that approximated normal. To facilitate categorical comparisons of the odds of being overweight for each dietary predictor in logistic regression models, BMI was considered as a binary response variable: overweight (overweight or obese) versus not-overweight (underweight or normal weight). Logistic regression was also used to model the odds of having a waist–height ratio that indicated obesity for each dietary predictor. Hosmer–Lemeshow goodness of fit tests confirmed that logistic regression models fit the data at an acceptable level. The gamma measure of association between ordinal variables was applied to family structure and family income covariates, and *t*-tests were used to determine whether there were significant differences in the dietary intake variables between those with and without missing covariate data. Because family structure and family income were highly correlated ($\gamma = -0.871$, $P < 0.001$), only family income was included in the models, and *t*-tests confirmed that there were no significant differences in the dietary intake variables between those with and without missing covariate data (all $P > 0.41$). Within each regression analysis, models were initially unadjusted, and then adjusted for potential confounding factors of gender, family income, mother's highest school year, puberty stage and physical activity/screen use. Models were further adjusted for total daily kJ intake as a separate step to determine whether associations were independent of energy intake. Finally, models were further adjusted for potential misreporting to determine whether there were any changes to the direction and significance of the associations.

Results

At the 14-year follow-up, 1631 adolescents completed the FFQ. Those who either did not respond or did not complete the FFQ were significantly more likely to have mothers with lower levels of education, and at least one parent who smoked, compared to adolescents who completed the FFQ ($P < 0.05$) (Ambrosini *et al.*, 2008). The exclusion of 18 adolescents with implausible energy intakes resulted in a subject total of 1613, of whom 1418 had BMI measurements and 1402 had waist–height ratios. The mean (SD) age of participants was 14.0 (0.2) (range 13.0–14.9 years). Baseline characteristics and selected dietary intakes for the study cohort of 1613 adolescents are presented in Table 1. On average, boys had a BMI lower by 0.59 kg m^{-2} [95% confidence interval (CI) = 0.16–1.02; $P = 0.007$] and their Tanner puberty stage was lower by 0.19 (95% CI = 0.10–0.28; $P < 0.001$) compared to the girls. Boys consumed significantly more energy, carbohydrate, protein and fat than girls.

Summary statistics for the adolescents' dairy consumption and energy and ND values are shown in Table 2. On average, girls consumed 0.83 fewer servings of total dairy products (95% CI = 0.69–0.97; $P < 0.001$) and 0.82 fewer servings of core dairy products (95% CI = 0.68–0.96; $P < 0.001$) than boys. Consumption of dairy products did not differ significantly across BMI categories (all dairy $P = 0.63$; core dairy $P = 0.65$). On average, ED values in girls were lower than boys by 0.11 (95% CI = 0.03–0.19; $P = 0.006$) for ED(FB) and 0.28 (95% CI = 0.16–0.39; $P < 0.001$) for ED(F). The only energy or ND value that differed across BMI categories was ED(FB); compared to underweight adolescents, obese and overweight adolescents had values that were 0.34 (95% CI = 0.11–0.57; $P = 0.004$) and 0.21 (95% CI = 0.02–0.41; $P = 0.033$) lower, respectively.

There were small but significant relationships between dairy consumption and energy and nutrient densities (Table 3). Each single serving increase in total or core dairy product was associated with a decrease in mean ED (FB) of between 0.10 units (unadjusted total dairy) and 0.27 units (fully adjusted core and total dairy). Conversely, each single serving increase in total or core dairy product was associated with an increase in mean ND of between approximately 22 units (unadjusted) and 26 units (fully adjusted). Additional adjustment for potential misreporting did not change these associations.

ED(F) and ED(FB) were strongly correlated ($r = 0.74$, $P < 0.001$), whereas ND was inversely correlated with ED (F) and ED(FB) ($r = -0.50$ and -0.31, respectively; both $P < 0.001$). Daily kJ intake was positively associated with all three measures of density [ED(F) $r = 0.15$, ED(FB)

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Table 1 Characteristics for subjects in the Western Australian Pregnancy Cohort (Raine) Study, 14-year follow-up with complete and plausible food frequency questionnaires

Characteristics, mean (SD)	All (n = 1613)	Male (n = 826)	Female (n = 787)	P-value*
Total energy (MJ)	9.64 (3.01)	10.45 (3.00)	8.79 (2.84)	<0.001
Total carbohydrate (g)	276 (90)	298 (90)	253 (86)	<0.001
Total fat (g)	91.5 (33.4)	99.4 (33.5)	83.2 (31.2)	<0.001
Total protein (g)	95.6 (30.5)	104 (29.8)	86.6 (28.5)	<0.001
BMI (kg m^{-2})	21.3 (4.1)	21.0 (4.1)	21.6 (4.1)	0.01
Missing (%)	12.1	11.6	12.6	
Waist–height ratio	0.46 (0.06)	0.46 (0.06)	0.46 (0.06)	0.50
Missing (%)	12.5	12.5	13.7	
BMI classification†:				
Underweight	5.5	5.1	5.8	0.49
Normal weight	60.1	60.5	59.7	
Overweight	15.9	15.5	16.4	
Obese	6.3	7.1	5.5	
Missing (%)	12.2	11.8	12.6	
Tanner puberty stage‡(%):				
Stage 2	3.2	4.8	1.4	<0.001
Stage 3	14.2	16.1	12.2	
Stage 4	36.5	34.6	38.5	
Stage 5	13.5	12.5	14.6	
Missing	32.6	32.0	33.3	
Annual family income ($AUD) (%):				
Up to 35 000	22.9	21.1	24.9	0.11
35 001–70 000	34.7	34.4	35.1	
70 001 and over	40.0	42.1	37.9	
Missing	2.4	2.4	2.1	
Mother's highest high school year (%):				
Year 10 (or less)	36.6	35.1	38.2	0.22
Year 11	18.3	19.7	16.8	
Year 12	44.8	45.2	44.5	
Missing	0.3	0.0	0.5	
Single parent family (%):				
Yes	19.6	18.6	20.6	0.32
No	79.9	80.9	78.8	
Missing	0.5	0.5	0.6	
Physical activity/screen use§ (%):				
Low exercise/high screen use	2.5	2.4	2.7	0.71
Mod-low exercise/mod-high				
Screen use	21.9	23.2	20.5	
Mod exercise/mod screen use	29.3	28.9	29.7	
Mod-high exercise/mod-low				
Screen use	22.8	22.0	23.6	
High exercise/low screen use	9.9	9.7	10.2	
Missing	13.5	13.7	13.3	

**P*-value for comparison between boys and girls of means (*t*-tests) or proportions (chi-square tests).

†Body mass index (BMI) categories as determined using standard criteria for this age group (Cole *et al.*, 2000, 2007).

‡Tanner stages of pubic hair development ranging from stage two (sparse) to five (adult) (Tanner, 1962; Duke *et al.*, 1980).

§Based on time spent outside school hours participating in physical activity that caused breathlessness or sweating (categorised as less than once a week = low exercise; once to three times a week = moderate exercise; four times or more per week = high exercise) and time spent watching television/videos and using computers for school, work and recreation (categorised as less than 2 h day^{-1} = low screen use, 2–4 h day^{-1} = moderate screen use; >4 h day^{-1} = high screen use).

r = 0.11, ND r = 0.19; all $P < 0.001$] and there was a weak inverse correlation between kJ intake and BMI ($r = -0.09$; $P = 0.001$) and waist–height ($r = -0.08$; $P = 0.003$). Potential under-reporting was identified for 25% of adolescents, and 11% were potential over-reporters. Mean (SD) BMI was higher in the under-reporters

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Table 2 Mean (SD) daily dairy intake and energy and nutrient density variables for adolescents participating in the Raine Study 14-year follow-up

	n	Total dairy (servings)†	Core dairy‡ (servings)	Energy density (FB), kJ g^{-1}	Energy density (F), kJ g^{-1}	Nutrient density
All	1613	2.62 (1.51)	2.56 (1.51)	4.53 (0.83)	6.28 (1.33)	373 (109)
Median		2.40	2.35	4.46	6.16	381
Range		0–10.4	0–10.4	2.30–10.8	3.16–12.7	−164 to 674
Boys	826	3.03 (1.60)*	2.96 (1.59)*	4.59 (0.83)*	5.93 (1.21)*	371 (109)
Girls	787	2.19 (1.29)*	2.14 (1.28)*	4.47 (0.83)*	5.65 (1.13)*	381 (108)
Underweight	88	2.58 (1.55)	2.52 (1.52)	4.69 (0.83)*	5.95 (1.18)	357 (113)
Normal weight	970	2.67 (1.55)	2.61 (1.54)	4.54 (0.80)*	5.81 (1.18)	373 (111)
Overweight	257	2.53 (1.41)	2.48 (1.41)	4.48 (0.83)*	5.68 (1.08)	384 (107)
Obese	102	2.62 (1.58)	2.58 (1.57)	4.35 (0.92)*	5.74 (1.34)	380 (95.1)

FB, food and beverage; F, food only.
*Indicates that there was a statistically significant difference ($P < 0.05$) between genders, or across body mass index groups.
†Dairy servings are defined by a serving that contains 300 mg of calcium (range 252–350 mg).
‡Core dairy is limited to milk, yoghurt, cheese and custard.

Table 3 Relationship between dairy servings per day (explanatory variable) and energy and nutrient density variables (response variables) in unadjusted and adjusted linear regression models ($n = 1613$)

Explanatory variable	Response variable	Unadjusted (95% CI)	Adjusted 1 (95% CI)	Adjusted 2 (95% CI)
Total dairy	ED(FB)	−0.10 (−0.13, −0.07)	−0.14 (−0.17, −0.11)	−0.27 (−0.31, −0.23)
	ED(F)	−0.13 (−0.18, −0.09)	−0.17 (−0.21, −0.12)	−0.37 (−0.42, −0.31)
	ND	23.2 (19.0, 27.4)	25.7 (21.5, 29.9)	24.7 (19.4, 30.1)
Core dairy	ED(FB)	−0.11 (−0.13, −0.08)	−0.14 (−0.18, −0.11)	−0.27 (−0.31, −0.23)
	ED(F)	−0.12 (−0.16, −0.08)	−0.17 (−0.22, −0.13)	−0.37 (−0.42, −0.31)
	ND	23.7 (19.5, 27.9)	26.2 (22.0, 30.4)	25.1 (19.8, 30.4)

CI, confidence interval; ED(FB), energy density (food and beverage); ED(F), energy density (food only); ND, nutrient density.
All total and core dairy coefficients: $P < 0.001$.
Adjusted models: 1, Adjusted for sex, family income, maternal education, puberty stage and physical. activity/screen use; 2, Further adjusted for total daily kJ intake.

compared to the over-reporters [23.2 (5.0) versus 19.0 (2.1), respectively; $P < 0.01$].

The odds of being overweight as determined by BMI category for each dietary predictor are presented in Table 4. The only dietary predictor that had a significant univariate association with being overweight was ED(FB). Each unit increase in ED(FB) was associated with a factor change in the odds of being overweight of 0.84 (95% CI = 0.72–0.98) in that the odds of being overweight decreased by 16% per 1 kJ g^{-1} increase in ED(FB). This remained significant after adjustment for gender, family income, mother's highest school year, puberty stage and physical activity/screen use, although it was no longer significant when further adjusted for total daily kJ intake. When BMI was modelled as a continuous variable, on average, log BMI decreased by 0.02 (95% CI = 0.01–0.03; $P = 0.001$), which is equivalent to a factor change in (untransformed) BMI of 0.98 (95% 0.97–0.99), with each increase of 1 kJ g^{-1} of ED(FB), after adjustment for all covariates. ND was significantly associated with being in an overweight BMI category after adjustment for all covariates including energy intake (odds ratio for 100-point increase in ND = 1.24; 95% CI = 1.09–1.42; $P = 0.001$). In analyses that modelled BMI as a continuous variable with ND, log BMI increased by 0.01 (95% CI = 0.002–0.020; $P = 0.013$) after adjustment for all covariates, which is equivalent to a factor change of 1.011 (95% CI = 1.002–1.020) in BMI, with each 100-point increase in ND. Dairy intake was not significantly associated with risk of being overweight as determined by BMI. These

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Table 4 Odds of being overweight/obese as determined by body mass index categories* associated with each explanatory variable in logistic regression models (n = 1418)

Explanatory variable	Unadjusted odds ratio (95% CI)	Adjusted odds ratio 1 (95% CI)	Adjusted odds ratio 2 (95% CI)
Total dairy	0.93 (0.85, 1.02) P = 0.13	0.92 (0.84, 1.02) P = 0.12	1.02 (0.90, 1.16) P = 0.71
Core dairy	0.96 (0.89, 1.04) P = 0.32	0.94 (0.85, 1.03) P = 0.20	1.04 (0.92, 1.17) P = 0.56
ED(FB)	0.84 (0.72, 0.98) P = 0.03	0.83 (0.70, 0.99) P = 0.04	0.85 (0.71, 1.01) P = 0.07
ED(F)	0.91 (0.82, 1.01) P = 0.08	0.87 (0.77, 0.99) P = 0.04	0.90 (0.80, 1.02) P = 0.08
ND scaled† (ND/100)	1.10 (0.98, 1.23) P = 0.10	1.18 (1.03, 1.34) P = 0.02	1.24 (1.09, 1.42) P = 0.001

CI, confidence interval; ED(FB), energy density (food and beverage); ED(F), energy density (food only); ND, nutrient density.
Adjusted models: 1, Adjusted for sex, family income, maternal education, puberty stage and physical. activity/screen use; 2, Further adjusted for total daily kJ intake.
*Risk of being overweight/obese as classified by standard age specific criteria (Cole *et al.*, 2000, 2007).
†ND scaled (per 100 units) as reported.

Table 5 Odds of being overweight/obese as determined by waist–height ratio* associated with each explanatory variable in unadjusted and adjusted logistic regression models (n = 1402)

Explanatory variable	Unadjusted odds ratio (95% CI)	Adjusted odds ratio 1 (95% CI)	Adjusted odds ratio 2 (95% CI)
Total dairy	0.85 (0.78, 0.93) P < 0.001	0.88 (0.80, 0.97) P = 0.01	0.96 (0.85, 1.07) P = 0.45
Core dairy	0.87 (0.81, 0.93) P < 0.001	0.89 (0.81, 0.97) P = 0.01	0.96 (0.86, 1.08) P = 0.50
ED(FB)	0.87 (0.77, 1.00) P = 0.05	0.86 (0.74, 1.01) P = 0.06	0.88 (0.75, 1.03) P = 0.12
ED(F)	0.93 (0.85, 1.02) P = 0.12	0.88 (0.79, 0.99) P = 0.03	0.90 (0.80, 1.01) P = 0.08
ND scaled† (ND/100)	0.98 (0.88, 1.08) P = 0.61	1.07 (0.95, 1.21) P = 0.28	1.13 (1.00, 1.28) P = 0.05

CI, confidence interval; ED(FB), energy density (food and beverage); ED(F), energy density (food only); ND, nutrient density.
*Risk of being overweight/obese as classified by Australian age and gender specific cut-off points (Nambiar *et al.*, 2010).
†ND scaled (per 100 units) as reported.
Adjusted models: 1, Adjusted for sex, family income, maternal education, puberty stage and physical. activity/screen use; 2, Further adjusted for total daily kJ intake.

results did not change with additional adjustment for potential dietary misreporting.

The odds of being overweight, as determined by waist–height ratio cut-offs, are presented in Table 5. The unadjusted odds of being overweight reduced by a factor of 0.85 (95% CI = 0.78–0.93; P < 0.001) with each additional serving of any dairy product, and a factor of 0.87 (95% CI = 0.81–0.93; P < 0.001) with each additional serving of a core dairy product. These associations remained significant after adjustment for gender, family income, mother's highest school year, puberty stage and physical activity/screen use, although they were nonsignificant when total daily kJ intake was included in the models. ED(F) was also significantly inversely associated with the risk of being overweight as determined by waist–height by a factor of 0.88 (95% CI = 0.79–0.99; P = 0.03) after adjusting for confounding factors, although it was no longer significant after further adjustment for energy intake. These results did not change with additional adjustment for potential dietary misreporting, with the exception of ND, which went from borderline significance to significance in the same direction of effect) (odds ratio for 100-point increase = 1.15; 95% CI = 1.02–1.28; P = 0.024).

Discussion

Intakes of energy density and nutrient density

We observed that boys consumed more energy-dense diets than girls and that higher milk consumption was

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associated with lower ED. These findings are in accordance with data previously reported in a nationally representative sample of US children and adolescents (Mendoza *et al.*, 2006). National Health and Nutrition Examination Surveys (NHANES) data suggest that overall ED of the diet including food and beverages drops from a peak of 5.0 kJ g^{-1} in childhood and adolescence to a low of 3.1 kJ g^{-1} for adult women (Drewnowski, 2000). Our reported mean (SD) ED(FB) of 4.5 (0.8) kJ g^{-1} is towards the upper end of this range, supporting the concept that ED is comparatively high during childhood and adolescence. The change in ED with increasing age may be related to changes in taste preferences and eating habits, potentially as a resuilt of increased acceptance of vegetables, salad greens and more bitter flavours (Drewnowski, 2000). A study of 569 Swedish 15-year-olds found that ED (F) averaged 7.0 kJ g^{-1} in girls and 7.5 kJ g^{-1} in boys (Patterson *et al.*, 2010) compared to our values of 5.7 and 5.9 kJ g^{-1}, respectively. In both studies, boys consumed more energy dense diets, which we speculate may be explained in part by a subconscious preference for more energy dense food as a result of growth spurts and increased nutrient needs during adolescence.

To our knowledge, there are few published studies that report daily ND values using the NRF9.3 on an individual dietary (not food) level. This is likely to be because the NRF was originally designed to be used for ranking and/or classifying foods based on their nutrient composition, rather than being used to assess individual diets. One study reported NRF9.3 values in an adult Dutch population, although this was calculated by adding NRF9.3 scores for each food consumed, instead of on an individual nutrient level and used an energy adjustment per 100 kcal (Streppel *et al.*, 2012). We chose not to adjust our data for energy directly but rather to include it as an additional covariate in the final model to allow comparisons between models.

Advice to limit the consumption of energy-rich foods is based on the assumption that ED and ND are inversely linked (Drewnowski, 2005). We observed significant inverse associations between ND and ED measures, with a stronger association with ED(F) than ED(FB). This is probably the result of a dilution effect of the beverages because water provides weight to food products but no energy.

Dairy association with energy density and nutrient density

Intakes of both core and total dairy were significantly negatively associated with ED and positively associated with ND, suggesting the dairy products consumed tended to be more nutrient rich but less energy dense compared to other foods and beverages eaten. Our findings are supported by previous work that compiled definitions of food described as healthy or nutrient rich, and included milk, cheese, yoghurt and the dairy group as a whole (Drewnowski, 2005). This is likely to be the result of dairy being a source of essential micronutrients including vitamin A, vitamin B_{12}, calcium, riboflavin, phosphorus, potassium, magnesium and zinc (Shils, 2006).

Associations between diet and obesity measures

In accordance with our hypothesis, dairy intake was inversely associated with measures of obesity, with this relationship being moderated by energy intake. Dairy product consumption may affect weight gain or loss through dietary calcium because increasing calcium may promote lipolysis through the suppression of calcitriol (the hormonally active form of vitamin D), resulting in decreased adipocyte lipid accumulation (Zemel & Miller, 2004). In addition, other bioactive compounds in dairy, such as angiotensin-converting enzyme inhibitors, may act synergistically with calcium to reduce adiposity (Premaratna *et al.*, 2012). Beneficial bacteria found in yoghurt may also play a role in weight control (Kootte *et al.*, 2012). In our findings, adjustment for energy resulted in the association becoming nonsignificant, indicating the association was moderated by energy intake. A recent meta-analysis of dairy intake and weight in adults concluded that inclusion of dairy products leads to a greater loss of fat mass than usual weight loss diets when diets were energy restricted, although this was less likely to lead to a significant weight change without energy restriction (Abargouei *et al.*, 2012). However, some research suggests that diets that include three or more daily servings of dairy products can result in significant loss of fat mass tissue mass for overweight people, even without energy restriction (Zemel, 2004). In our cohort, only 22% of girls and 40% of boys consumed at least three servings of dairy per day (Parker *et al.*, 2012).

In contrast to our hypothesis, a higher ND was positively associated with measures of obesity in our cohort of adolescents. This was unexpected given the previously reported positive association between junk food, generally considered to be low in ND, and childhood obesity (Gillis & Bar-Or, 2003). Similar findings to ours were reported in a Dutch study that also examined ND using the NRF9.3 score (Streppel *et al.*, 2012). Adults with higher NRF9.3 index scores had a higher BMI, body weight, waist circumference and waist–height ratio compared to those with a low NRF9.3 index scores after adjustment for a range of factors including energy intake. It was suggested that this was a result of under-reporting by overweight subjects, although it was not possible to test this theory. Notably, we found that ND was still significantly

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associated with odds of obesity (for BMI $P = 0.001$, waist–height ratio $P = 0.05$) after adjustment for energy, indicating that the association was independent of kJ intake. However, although significant, these associations were small, with a one-point increase on the ND scale associated with 0.2% increase in odds of being overweight/obese, where the average ND in our cohort was 373 units. These findings suggest that some nutrient dense foods may be associated with a small increased risk of obesity in adolescence. Refined grains, including white bread and puffed grain-based ready-to-eat breakfast cereals, are often fortified with nutrients such as B group vitamins, iron and zinc. Many studies suggest that a higher intake of more refined or processed carbohydrates (reflected by increased dietary glycaemic load) is associated with a greater risk of obesity and chronic disease (Bell & Sears, 2003; Ebbeling *et al.*, 2003; Barclay *et al.*, 2008; O'Sullivan *et al.*, 2010), possibly because of higher increases in blood glucose and insulin concentrations after consumption. Similarly, fruit juice as a good source of vitamin C can be considered nutrient dense but excess consumption has been linked with obesity in children (Dennison *et al.*, 1997) and adults (Mozaffarian *et al.*, 2011), potentially because of the rapid hepatic metabolism of fructose (Stanhope *et al.*, 2013). However, a review suggests that the ingestion of fructose in normal amounts by healthy weight people does not cause relevant changes in body weight (Dolan *et al.*, 2009). Additionally, although foods higher in saturated fat result in a lower NRF9.3 score, fat intake may not necessarily be a determinant of obesity (Willett, 1998). Because our study was cross-sectional, it may be that adolescents who are overweight are more likely to select more nutrient dense foods. In a previous study of teenage food choice, health and dieting were among the primary food choice criteria, along with taste, habit and satiety (Contento *et al.*, 2006).

Also in contrast to our hypothesis, we observed an inverse relationship between ED and obesity measures, although this association was attenuated by energy intake. Some studies in the literature suggest a positive relationship between ED and body weight (Pérez-Escamilla *et al.*, 2012), although the results are not consistent (Drewnowski *et al.*, 2004). A US study in children and adolescents found that ED was associated with predictors of obesity such as energy intake and lower household income, although they did not directly evaluate obesity measures (Mendoza *et al.*, 2006). High ED foods typically contain less water and more fat. Restricted dietary fat intake has traditionally been recommended for weight loss, based on the concept that fat is high in energy (Bray & Popkin, 1998). However, there is currently controversy in this area, with some randomised trials showing that subjects who consume moderate or high-fat diets lose just as much weight, if not more, than those who follow low-fat diets (Shai *et al.*, 2008; Sacks *et al.*, 2009). This may partially explain the associations that we observed with ED.

Age is likely to be an important factor when comparing our results with other studies. In a small study of 49 children aged 3–6 years, no significant differences were observed in dietary ED and obesity status, as determined by BMI, waist circumference or total body fat using dual-energy X-ray absorptiometry (Kral *et al.*, 2007a). Furthermore, the results of a small prospective study of children followed to adolescence suggested that the relationship between ED and obesity varies depending on the accuracy of the methods used to determine obesity status (McCaffrey *et al.*, 2008). The study by McCaffrey et al. (2008) found an association with ED(F), but not ED(FB), when obesity was measured using body fat from total body water by isotope dilution, normalised for height but not with BMI or waist circumference. In a free-living environment, young children have been shown to adjust their daily food intake to maintain a similar daily energy intake (Kral *et al.*, 2007b). This energy compensation ability may decrease as children grow (Kral *et al.*, 2007b), perhaps influenced by genetics, hormones, environmental or psychological factors, such as emotional eating or pressure to eat. In a controlled study, adolescents given the opportunity to eat fast food over-consumed it regardless of body weight (Ebbeling *et al.*, 2004). However, compared to their lean peers, overweight adolescents were less likely to compensate for the additional energy provided by the fast food by adjusting energy intake throughout the day. Energy compensation ability may decrease leading into adulthood, and may differ by existing body size.

There is evidence for (Drewnowski, 1998; Tey *et al.*, 2012) and against (Rolls *et al.*, 1988) the hypothesis that energy dense foods are more filling and result in higher satiety. It has been suggested that satiety depends on gastric emptying rather than specific ED of food intake (Carbonnel *et al.*, 1994). A review of childhood obesity reported that there was limited evidence to suggest a positive association between energy intake and obesity in these younger age groups, and obese children may not overeat to a great extent (Newby, 2007). Mean energy intakes have been reported to be similar or lower in overweight children than normal weight children (Newby, 2007). Similarly, we found small inverse correlations between energy intake and measures of obesity. This may be related to those with higher BMIs being more likely to potentially under-report energy intake, although factors other than energy balance may also affect obesity risk. Weight control is often focused on the simple model of energy in, energy out, although homeostatic feedback mechanisms can effect weight loss success, with numerous

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neural and hormonal factors operating to regulate body weight (Hafekost *et al.*, 2013). For example, high consumption of carbohydrates over the long term, particularly refined carbohydrates, fructose, and sugar-sweetened beverages, has been linked with low satiation, poor appetite control, and a lack of compensation for calories consumed (Hafekost *et al.*, 2013).

The strengths of the present study include a relatively large sample size and a dietary assessment tailored to (and validated in) our adolescent population (Ambrosini *et al.*, 2011). We have also used waist–height measures in conjunction with BMI to allow consideration of weight distribution. Because the present study is cross-sectional, we are not able to infer cause and effect relationships in the data and so care must be taken with the interpretation of results. In addition, the generalisability of our study to other populations may be limited because adolescents who completed the dietary assessment were also more likely to have older mothers, a higher family income or a lower BMI than the nonrespondents (O'Sullivan *et al.*, 2011). However, families who were involved in the study were more likely to be of middle to lower socioeconomic status initially (Li *et al.*, 2008), which may improve applicability to the general adolescent population.

The findings of the present study add to the existing literature by describing ED and ND measures in a large free-living adolescent population and investigating the association between these factors and dairy intake. The findings from the present study suggest that the ND of the diet rather than the ED is positively associated with measures of obesity; however, the association is small. We are not advocating that adolescents try to reduce the ND of their diets. Our findings may be the result of factors such as the high glycaemic impact of some refined but fortified foods classified as nutrient dense, or overweight adolescents being more likely to select more nutrient dense foods. Given that the NRF9.3 was originally designed to assess foods, the application to overall diets is a new approach and further research in other cohorts would be useful to determine whether similar findings exist. Alternatively, there may be the need for a different approach to assess dietary ND that can also consider intake on a food basis to account for potential health implications of processed fortified items or fruit juice. Although an increased intake of dairy foods was associated with increased ND in the present study, dairy was inversely associated with being overweight or obese, with the association attenuated by energy. Our results support dairy consumption in adolescents, particularly because there was a shortfall in the mean intake of dairy in our group compared to recommendations (Parker *et al.*, 2012). A similar inverse association was observed for ED, suggesting adolescent obesity may be more complicated than the hypothesis proposing that a low ED causes overeating and weight gain.

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Conflict of interests, source of funding and authorship

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TOS, MES and HEB were responsible for the development of the research question. LJB, TAM and WHO obtained data. MES, HEB, TOS, PLW and AD were involved in derivation of variables. APB analysed the data. TOS drafted the manuscript. LJB, TAM, WHO, PLW and AD critically reviewed the manuscript. All authors approved the final version submitted for publication.

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