2010

Dietary Energy Density as Marker of Dietary Quality in Swedish Children and Adolescents: The European Youth Heart Study

Emma Patterson

J. Wärnberg

E. Poortvliet

See next page for additional authors

Authors
Emma Patterson, J. Wärnberg, E. Poortvliet, John Kearney, and M. Sjöström

European Journal of Clinical Nutrition (2010) 64, 356–363

www.nature.com/ejcn

ORIGINAL ARTICLE

Dietary energy density as a marker of dietary quality in Swedish children and adolescents: the European Youth Heart Study

E Patterson[1,2], J Wärnberg[1], E Poortvliet[1], JM Kearney[2] and M Sjöström[1]

[1]*Unit for Preventive Nutrition, Department of Biosciences and Nutrition, Karolinska Institutet, Stockholm, Sweden and* [2]*School of Biological Sciences, Dublin Institute of Technology, Dublin, Ireland*

Objective: To investigate if dietary energy density is associated with measures of dietary quality (food group, micronutrient and macronutrient intakes) in children and adolescents.
Subjects/Methods: In all, 551 children (mean age 9.6 years, 52% girls) and 569 adolescents (15.5 years, 55% girls), sampled from schools in Sweden, completed a single 24-h dietary recall. Dietary energy density (kJ/g) was calculated as the energy from all food consumed divided by the weight of all food consumed. Beverages were excluded from the calculation. Food and micronutrient intakes were adjusted for energy intake. A one-way analysis of variance (ANOVA) was used to test for differences in food group and nutrient intakes across age- and gender-specific tertiles of energy density. Discriminant analysis was used to confirm the groupings formed by tertiles.
Results: Subjects with low-energy-density diets were significantly more likely to consume fruits, vegetables, pasta, rice, potatoes and cereals and less likely to consume sweetened drinks, sweets and chocolate. After energy adjustment, their intakes of many foods recommended in the Swedish food-based dietary guidelines were higher and intakes of nutrient-poor foods were lower. The macronutrient energy profile (% energy) of low-energy-density diets was closest to the recommended level. Low-energy-density diets contained greater amounts of most micronutrients. Discriminant analysis confirmed the existence of heterogeneous dietary patterns and the likelihood of correct classification by energy density in 65% of cases.
Conclusions: Lower dietary energy density is associated with better dietary quality in children and adolescents. Energy density has advantages over other whole diet analysis methods and may be suitable as a simple proxy of diet quality.
European Journal of Clinical Nutrition (2010) **64,** 356–363; doi:10.1038/ejcn.2009.160; published online 13 January 2010

Keywords: 24-h recall; dietary patterns; epidemiology; foods; nutrients

Introduction

No simple, well-accepted criteria exist that allow diets to be classified as healthy or unhealthy. Attempts to assess overall diet quality have often relied on scores or indexes (Kant, 1996) and, more recently, data-driven methods (for example, cluster or factor analyses) (Hu, 2002; Hoffmann *et al*., 2004; Kant, 2004; Newby and Tucker, 2004). These approaches attempt to capture the dietary pattern rather than focusing on certain foods or nutrients. The disadvantages are that data must be structured in a way that allows the score to be calculated or, in the case of data-driven methods that the results are sample specific. Dietary energy density has the advantage of being simply calculated and available from all types of dietary data in which food and beverage energy and intakes are available.

The energy density of a food/diet is a measure of the amount of energy provided per unit weight and is primarily determined by its water and fat content (Stubbs *et al*., 2000; Drewnowski, 2003). Dietary energy density has been associated with higher dietary quality in adults (Kant and Graubard, 2005b; Ledikwe *et al*., 2006b; Maillot *et al*., 2007; Schröder *et al*., 2008b), and also with more objective measures of health, such as the metabolic syndrome, overweight and predictors of obesity in adults and children

Correspondence: E Patterson, Department of Biosciences and Nutrition, Unit for Preventive Nutrition, Karolinska Institutet, Hälsovägen 7, Stockholm 14157, Sweden.
E-mail: emma.patterson@ki.se
Contributors: E Patterson analysed the data and wrote the initial draft of the paper. J Wärnberg, E Poortvliet, JM Kearney and M Sjöström contributed to the interpretation of results and the writing of the paper. M Sjöström was responsible for the EYHS in Sweden. All authors revised and approved the final manuscript.
Received 22 October 2009; revised 13 November 2009; accepted 19 November 2009; published online 13 January 2010

(Kant and Graubard, 2005b; Howarth *et al*., 2006; Mendoza *et al*., 2006, 2007; Ledikwe *et al*., 2006a).

The aim of this study was to examine the association of dietary energy density with dietary quality, namely food group intake, vitamin and mineral intakes and macronutrient energy profile, in Swedish children and adolescents. The ability of energy density to discriminate heterogeneous dietary patterns in the population was also tested.

Subjects and methods

Participants

Subjects were Swedish participants of the European Youth Heart Study, conducted during 1998–1999. Over 2000 ($n = 2313$) children (from grade 3 (9 years old)) and adolescents (grade 9 (15 years old)) were sampled from classes selected from 42 schools in southern Stockholm and Örebro, and 1137 students consented to participate (Wennlöf *et al*., 2003). Permission was obtained from the local ethics committees (Huddinge University Hospital no. 474/98, Örebro City Council no. 690/98). Written consent was provided by a parent or legal guardian; verbal consent was provided by the subjects. Data collection was performed at the school.

Dietary assessment

All subjects completed a single interviewer-mediated 24-h recall. The younger children kept a 1-day qualitative food diary with the assistance of their parents on the day before the interview, to aid as a prompt in case of difficulties with recall. A food atlas with pictures of common foods in various portion sizes was available during the interview, along with standard household units to help estimate quantities accurately. Data from the recall were analysed using software (StorMats, version 4.02; Rudans Lättdata, Västerås, Sweden) based on the Swedish Food Administration's nutritional database (version 99.1; www.slv.se). Each food consumed was allocated to a food group on the basis of nutritional or dietary similarities and intakes are presented at the food group level. The food groups were originally based on the Swedish Food Administration's groups but were modified to allow more specific classification in some cases and less in others. The 'milk, fil, yoghurt' group includes fil, a soured-milk product similar to yoghurt, common in Nordic countries. 'Sweetened drinks' refer to carbonated or cordial-based drinks; fruit juices are concentrated or fresh juices. The 'other sweet foods' group includes desserts, ice cream, sweet soups, jams and added sugar. 'Burgers, sausages' are processed meat products and are a subsection of the 'meat, meat dishes' group. 'Cereals' refer to breakfast cereals (both sweetened and unsweetened). Fried potatoes are included in the 'chips, crisps' group. Someone who reported eating any amount of a food group was considered a consumer.

Calculation of energy density

Energy density was calculated as energy (kJ) divided by weight (g). Food was defined as solid food and liquids consumed as food (for example, soups and yoghurt). All beverages, both energy-containing (for example, milk, sweetened drinks and fruit juices) and non-energy-containing (for example, water, coffee and diet beverages), were excluded. As the energy density differed by age and gender, tertiles were created that were specific for age and gender. The diets of these groups were referred to as low-, middle- and high-energy-density diets.

Recalls of suspected poor quality or inadequate energy

On completion, the recall was immediately rated by the interviewer on the basis of the subject's perceived interest and motivation and the level of detail provided. Interviews with a score of less than three (out of five) were suspected to be of low quality. The plausibility of energy intakes reported was tested by comparing the reported intakes with a theoretical intake that is predicted from basal metabolic rate requirements, and age- and gender-specific physical activity levels, assuming weight stability. A confidence interval is constructed around the predicted intake that takes into account the number of days of diet recorded (Goldberg *et al*., 1991). Basal metabolic rate was estimated (Schofield, 1985) using weight and height that had been measured using standardized techniques, and reference physical activity levels were taken from Black (2000). Subjects with energy intakes below the lower confidence interval cutoffs were considered possible under-reporters, and these cutoffs were equivalent to a ratio of reported energy to basal metabolic rate of 0.97, 0.98, 0.98 and 1.03 in 9-year-old girls and boys, and 15-year-old girls and boys, respectively. Owing to the uncertainty in identifying under-reporters, particularly when only 1 day of dietary data were available (Black, 2000), we chose not to exclude these subjects. Instead, we considered the effect that exclusion might have on the results.

Statistical analysis

An initial correlation analysis confirmed a positive and significant association between energy intake and both food and nutrient intakes. As energy was also a component of the predictor variable—energy density—any association between foods and/or nutrients with energy density might have been attributed to the effect of increasing energy. To overcome this, food group and micronutrient intakes were regressed on total energy intakes and the residuals of these linear regressions were used as the response variables in subsequent analyses (Willett *et al*., 1997). The residuals are, by definition, uncorrelated with energy and represent the differences between the observed and predicted intakes, that is, the difference between an individual's actual food or nutrient intake and what it would be expected to be, given their energy intake.

The association of energy density tertiles with food group and micronutrient intake residuals was analysed using one-way analysis of variance (ANOVA). Differences in energy density between age and gender subgroups were analysed using one-way ANOVA with Tukey's *post hoc* test. A χ^2 test checked for differences in the frequency of food group consumers across tertiles. Energy density (after square-root transformation to normalize the distribution) was tested between under- and adequate reporters using Student's *t*-test.

To further check that the tertiles represented heterogeneous dietary patterns, we performed discriminant function analysis. This tests whether cases are classified as predicted from a set of discriminating variables (the food residuals) into predefined groups of a criterion variable (the energy density tertiles). The predicted classification was compared with the original classification. It also calculates structure coefficients of the discriminating variables, which indicate how much they predict the groups.

Before regressing the foods/nutrients on energy, the intakes were transformed (square root or natural log) so that the residuals of the regression were as homogeneous as possible across tertiles, a requirement of both discriminant analysis and ANOVA. Owing to the skewness of the data, intakes of food groups are presented in Table 2 as geometric means and 95% confidence intervals, for consumers only. The geometric mean is equivalent to the antilog of the arithmetic mean of log-transformed data. All other tables use (arithmetic) mean and s.d. All analyses were performed using SPSS for Windows, version 16 (SPSS Inc., Chicago, IL, USA) and the level of significance was set at $P<0.05$.

Results

Data were available for 551 children (52% girls, mean age 9.6 years) and 569 adolescents (55% girls, mean age 15.5 years). The prevalence of overweight was 12% (highest in 9-year-old boys at 14%; lowest in 15-year-old girls at 9%), and the prevalence of obesity was 2% (highest in 15-year-old boys at 3%; lowest in 15-year-old girls at 1%).

As the diet increased in energy density, energy intake increased, and total food intake decreased, across each tertile, in all age and gender subgroups (Table 1). These relationships were linear, except in 15-year-old boys. Only the low-energy-density diet group met the population goals for energy from macronutrients (WHO, 2003; Alexander *et al*., 2004)(Figure 1).

Significant differences between energy density tertiles were observed in both the proportion of food group consumers and in the amounts consumed (Table 2). The χ^2 tests showed that, for each of the following food groups, in at least three of the age and gender subgroups, subjects with the lowest energy density were more likely to consume fruit, vegetables, pasta, rice and potatoes, and cereals and less likely to consume sweets and chocolate, and sweetened drinks. After adjustment for energy, intakes of most food groups differed significantly across tertiles of energy density (Table 2b). The food group that differed most across tertiles, with the largest F-value, was fruit, followed by pasta, rice, potatoes, vegetables, sweets and chocolate and milk, fil and yoghurt. Low-, mid- and high-energy-density diets also differed significantly in terms of micronutrient and fibre intake (Table 3).

Table 1 Energy density, food intake and energy intake across energy density tertiles, by age and gender

			Energy density[a]		*Food only*[b]				*All food and beverages*			
			kJ/g		*MJ*		*g*		*MJ*		*g*	
	Tertile	n	*Mean*	*(s.d.)*	*Mean*	*(s.d.)*	*Mean*	*(s.d.)*	*Mean*	*(s.d.)*	*Mean*	*(s.d.)*
Girls, 9 years[c]	Low	95	5.21	(0.60)	6.57	(1.84)	1261	(319)	7.90	(1.90)	2139	(494)
	Mid	96	6.62	(0.34)	6.83	(1.76)	1034	(268)	8.29	(1.95)	2048	(562)
	High	95	8.65	(1.17)	6.93	(1.92)	817	(256)	8.49	(2.12)	1815	(448)
Boys, 9 years[c]	Low	88	5.15	(0.56)	6.70	(1.97)	1307	(387)	8.32	(2.26)	2320	(688)
	Mid	89	6.57	(0.37)	7.41	(1.99)	1133	(316)	9.12	(2.30)	2267	(624)
	High	88	8.68	(1.16)	7.92	(2.06)	930	(274)	9.44	(2.27)	1983	(543)
Girls, 15 years[c]	Low	104	5.12	(0.58)	6.64	(2.05)	1312	(438)	7.89	(2.36)	2708	(952)
	Mid	104	6.61	(0.44)	7.15	(2.27)	1082	(339)	8.63	(2.54)	2399	(723)
	High	104	9.17	(1.43)	7.78	(2.72)	870	(330)	9.28	(3.05)	2196	(810)
Boys, 15 years[d]	Low	85	5.65	(0.66)	9.72	(3.43)	1727	(587)	11.63	(3.78)	3408	(1102)
	Mid	86	7.37	(0.43)	10.70	(3.19)	1456	(439)	13.19	(3.72)	3386	(1115)
	High	86	9.43	(1.17)	9.95	(3.31)	1073	(386)	12.49	(3.72)	2916	(897)

Different superscripts c and d indicate significant differences in energy density between age and gender groups.
1 MJ = 1000 kJ = 239 kcals.
[a]Calculated from food only.
[b]All beverages excluded.

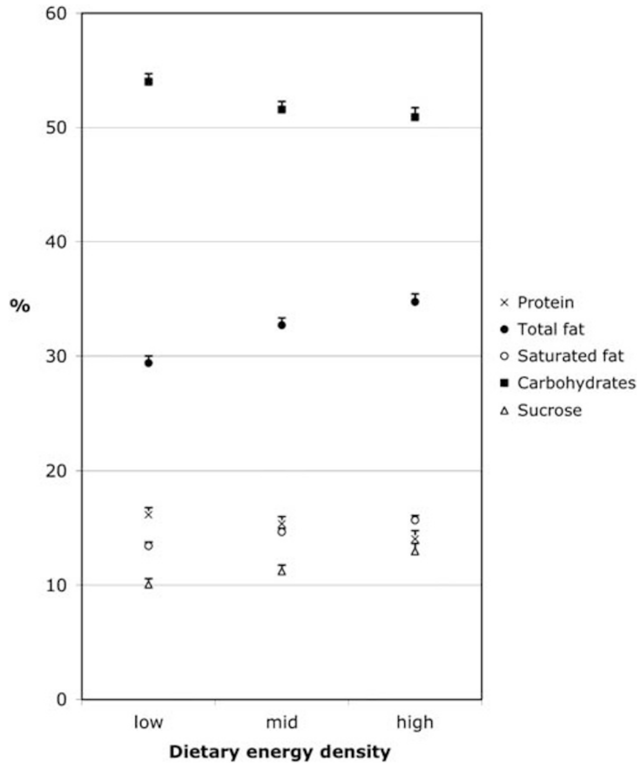

Figure 1 Mean percent energy from macronutrients across tertiles of energy density. Error bars indicate s.e.m. The s.e.m. was multiplied by a factor of two, and bars are one sided, for clarity. Recommended upper limits for saturated fat and sucrose: 10%; population goals for protein: 15%; fat: 30% and carbohydrates: 55% (Nordic Nutrition Recommendations; Nordic Council of Ministers, 2004). All means differed significantly across tertiles ($P<0.001$).

The discriminant function analysis confirmed that significant differences between energy density tertiles existed (overall Wilks' $\lambda=0.49$, $P<0.001$). The largest structure coefficients were for fruit (0.430); pasta, rice and potatoes (0.387); vegetables (0.352); sweets and chocolate (−0.275); sweetened drinks (−0.245); and milk, fil and yoghurt (0.220). The discriminant analysis was also able to classify subjects into groups that agreed well with the energy density tertiles. Using all the available food intake data, 65% of subjects were classified to the 'correct' (same) group as when only the dietary energy density variable was used, exceeding the value for classification based on chance (33%). Reanalysis with the extreme tertiles only (that is, low and high) correctly classified 89%.

Potential energy under-reporting occurred more in the older age group (data not shown). Under-reporters had significantly lower dietary energy density compared with adequate reporters in the older age group only (1.57 vs 1.71 kJ/g, $P=0.010$); however, removing all under-reporters ($n=84$) did not change any associations between energy density and either food groups or micronutrients. Although the younger age group was more likely to have a lower quality interview, energy density did not differ between low- and high-quality recalls, and excluding these recalls ($n=149$) also had no effect on the main analysis.

Discussion

Associations between dietary energy density and diet quality

The low-energy-density diet had a macronutrient energy profile closest to the population goals and higher intakes of most micronutrients examined. In the majority of the age and gender subgroups, it was characterized by higher and more frequent intakes of many of the food groups recommended in Sweden. The discriminatory analysis confirmed that the tertiles, particularly the two extreme tertiles, were considerably different from each other. Taken together, the overall picture of a lower energy density diet is one of higher dietary quality.

To the best of our knowledge, no other studies comprehensively describing dietary quality and energy density in children under free-living conditions have been published, although Johnson *et al*. (2008a) did report a relationship between dietary energy density and percent energy from total fat (positive) and fibre (negative) in a sample of UK children. A cross-sectional association between energy density and selected predictors of obesity (Mendoza *et al*., 2006), and a longitudinal association with overweight (McCaffrey *et al*., 2008; Johnson *et al*., 2008a), have also been reported in children. In adults, low-energy-density diets have been associated with higher diet quality (based on micronutrient, macronutrient and food intakes) in two large US cohorts: the NHANES III (Third National Health and Nutrition Examination Survey) and the CSFII (Continuing Survey of Food Intakes by Individuals) 1994–1996 surveys (Kant and Graubard, 2005b; Ledikwe *et al*., 2006b). In almost 2000 French adults, dietary energy density was found to correlate with the mean adequacy ratio, an index of quality based on recommended nutrient intakes (Maillot *et al*., 2007). Cucó *et al*. (2001) defined energy density as kJ per cm^3, including beverages, and found that high energy density was associated with higher intakes of fat and certain food groups in Spanish adults. Using kJ/g and excluding beverages, Schröder *et al*. (2008a, b) also found that low-energy-density diets were of higher quality in Spanish adults, including the elderly.

Both the ANOVA and the discriminant analysis suggested that fruit, pasta, rice and potatoes, vegetables, milk, fil and yoghurt, sweets and chocolate, and sweetened drinks are the most important food groups in determining dietary energy density. Johnson *et al*. (2008b) noted in their study that fruit and vegetables (combined) had twice as heavy a loading on a dietary pattern score that included energy density than crisps and confectionary did. They propose that this should 'reinforce efforts to encourage consumption of fruit and vegetables' rather than 'focusing on the exclusion' of energy-

Table 2 Intakes of food groups across diets of low-, mid- and high-energy density in (a) 9 year olds ($n = 551$) and (b) 15 year olds ($n = 569$) by gender

	Girls									Boys									ANOVA	
	Low			Mid			High			Low			Mid			High				
	%[a]	Mean[b]	CI[b]	%	Mean	CI	%	Mean	CI	%	Mean	CI	%	Mean	CI	%	Mean	CI	F	P-value[c]
(a)																				
Food group (g)																				
Milk, fil, yoghurt[d]	97	470	394–560	96	432	380–491	94	462	404–529	99	630	551–721	99	603	527–690	92	436	377–505		
Full fat	60	377	321–443	47	264	215–324	46	299	250–357	66	420	357–494	58	331	273–402	50	247	198–310		
Reduced fat	77	294	239–363	77	371	323–427	76	385	331–448	83	361	294–444	78	507	436–589	72	376	317–445		
Cheese[d]	41	33	25–42	53	33	25–43	46	35	25–47	28	25	18–36	51	47	38–59	53	47	35–62		
Bread	93	61	52–70	97	76	65–90	98	91	77–107	89	67	56–79	94	92	78–109	97	119	103–138		
Meat, meat dishes	79	118	93–151	88	125	104–150	83	107	89–128	89	131	105–165	84	139	113–171	87	130	109–154		
Burgers, sausages	58	111	90–136	69	117	97–142	57	93	75–115	72	102	81–130	64	120	95–151	66	110	87–139		
Fish, fish dishes[d]	35	84	60–119	33	55	41–73	28	42	26–67	30	60	40–89	37	56	37–84	19	36	19–68		
Pasta, rice, potatoes[d]	80	225	194–259	84	200	174–231	74	138	118–161	91	235	204–271	84	217	185–254	72	146	124–173		
Cereals[e]	51	43	30–63	34	45	30–68	24	37	23–59	50	47	33–68	40	74	50–109	38	62	40–94		
Pizza, pies, pancakes	16	170	128–225	21	175	139–221	27	186	154–223	16	138	89–214	18	193	144–260	30	204	172–241		
Vegetables[d]	88	71	58–87	80	48	39–59	81	34	28–42	80	58	46–72	72	65	51–82	55	33	24–44		
Fruit[d,e]	83	222	189–261	63	158	133–187	42	132	111–157	75	178	144–219	51	129	100–165	43	116	94–143		
Fruit juice[e]	36	226	176–292	45	202	158–260	26	202	164–250	40	222	180–273	27	277	222–345	33	234	158–347		
Sweetened drinks[e]	39	216	173–271	54	250	193–323	58	316	269–372	43	311	264–366	35	300	252–358	52	328	267–404		
Spreads and oils[d]	89	11	10–13	90	13	11–16	91	16	13–19	80	13	11–15	91	15	12–17	94	19	16–22		
Chips, crisps	16	54	22–136	21	63	33–122	27	62	39–97	10	51	17–152	16	83	44–158	22	49	30–83		
Other sweet foods[d]	62	47	33–69	72	50	37–67	63	51	39–68	74	66	47–92	63	65	46–93	80	65	51–83		
Cakes, biscuits	42	43	32–57	50	41	32–53	50	45	34–60	39	33	23–46	32	39	27–58	39	57	43–75		
Sweets, chocolate[d,e]	55	11	8–16	74	15	12–19	83	23	18–29	53	8	6–11	72	13	9–17	65	23	17–32		
(b)																				
Food group (g)																				
Milk, fil, yoghurt	90	443	371–529	90	449	384–525	85	402	347–465	98	737	632–860	90	717	602–854	91	647	556–754	27	< 0.001 ↓
Full fat[d]	41	262	196–350	41	232	179–301	32	227	174–297	53	438	347–553	53	441	348–560	31	398	278–569	22	< 0.001 ↓
Reduced fat	77	399	337–472	79	376	316–447	71	374	321–436	76	630	541–733	74	507	404–636	84	519	439–614	2	0.113
Cheese	63	28	23–35	56	29	23–38	71	38	30–47	58	50	41–62	65	51	40–67	56	72	56–92	4	0.014 ↑
Bread	95	75	66–86	90	95	84–108	93	95	81–111	92	119	99–144	93	141	119–168	98	159	137–184	17	< 0.001 ↑
Meat, meat dishes[e]	68	135	114–159	84	106	87–130	72	102	82–129	89	190	155–231	87	244	207–287	79	159	126–199	10	< 0.001 ↓
Burgers, sausages	50	120	97–147	61	104	85–126	44	122	103–144	65	151	122–188	66	205	166–252	53	162	128–204	7	0.001 ↓
Fish, fish dishes	29	80	55–116	38	70	53–92	24	53	32–87	26	100	65–155	24	80	46–137	19	44	22–86	9	< 0.001 ↓
Pasta, rice, potatoes[d,e]	84	207	183–233	81	183	163–205	58	158	139–180	94	330	288–379	79	270	237–308	56	200	164–243	85	< 0.001 ↓
Cereals[d,e]	44	47	33–68	35	45	32–64	23	49	33–73	59	81	59–111	35	49	32–75	24	49	29–82	19	< 0.001 ↓
Pizza, pies, pancakes[e]	10	155	109–219	28	162	131–200	20	159	118–215	11	235	168–328	15	213	143–318	22	203	151–272	8	0.001 ↑
Vegetables[d,e]	91	138	119–161	80	96	80–115	70	59	49–73	81	109	88–134	77	79	67–93	53	75	60–93	69	< 0.001 ↓
Fruit[d,e]	78	244	201–297	65	139	110–175	36	116	87–154	60	190	148–244	41	144	112–185	24	133	107–166	105	< 0.001 ↓
Fruit juice	40	254	184–352	41	247	183–332	35	277	188–406	33	273	183–407	31	344	260–456	35	257	163–405	1	0.239
Sweetened drinks[d,e]	34	213	151–299	54	314	262–375	62	333	277–400	51	348	287–422	67	491	398–606	73	556	468–660	19	< 0.001 ↑
Spreads and oils[e]	74	11	9–13	81	13	11–15	89	13	11–15	81	14	11–17	90	18	15–21	93	21	18–26	19	< 0.001 ↑
Chips, crisps[e]	14	42	22–81	23	62	35–108	38	67	47–96	19	104	57–190	28	146	119–178	29	125	83–189	7	0.001 ↑
Other sweet foods	57	58	41–83	70	43	31–59	58	52	38–72	64	48	33–69	70	86	60–124	58	45	33–63	3	0.043 ↓
Cakes, biscuits[d]	30	34	24–47	34	54	41–70	39	55	41–74	22	44	27–72	40	50	37–67	38	67	51–86	6	0.004 ↑
Sweets, chocolate[e]	64	17	13–23	74	26	21–33	86	51	40–64	69	20	15–27	71	30	23–40	73	44	32–62	43	< 0.001 ↑

Arrows indicate the direction of change in residuals as dietary energy density increases from low to high.
[a]Percentage (%) consuming food group in each tertile.
[b]Mean and confidence interval (CI) is the geometric mean and 95% CI, for consumers only.
[c]One-way analysis of variance (ANOVA) for all subjects ($n = 1120$), with energy density tertiles as the independent variable, and residuals of food groups regressed on energy as dependents.
[d]χ^2 for trend in percentage of consumers across low-, mid- and high-energy-density diets significant in boys.
[e]χ^2 for trend in percentage of consumers across low-, mid- and high-energy-density diets significant in girls.

Table 3 Intakes of nutrients across diets of low-, mid- and high-energy density in (a) 9 year olds ($n=551$) and (b) 15 year olds ($n=569$) by gender

	Girls			*Boys*			*ANOVA*	
	Low	*Mid*	*High*	*Low*	*Mid*	*High*	*F*	P-*value*[a]
(a)								
Nutrient								
Vitamin C (mg)	130 (89)	92 (66)	66 (64)	122 (102)	80 (70)	72 (74)		
Folic acid (μg)	224 (79)	193 (57)	179 (65)	223 (95)	212 (81)	185 (67)		
Vitamin B12 (μg)	5.0 (2.7)	4.4 (2.0)	4.7 (2.7)	6.2 (10.3)	5.6 (2.7)	5.0 (2.8)		
Vitamin E (mg)	6.4 (2.3)	6.4 (2.5)	7.1 (3.1)	6.5 (2.5)	6.8 (2.4)	7.3 (3.0)		
Vitamin D (μg)	4.5 (2.6)	4.7 (2.9)	5.4 (3.3)	4.9 (2.9)	6.7 (9.2)	5.5 (3.5)		
Retinol equivalents (μg)	1139 (756)	931 (500)	1045 (648)	1174 (2128)	1119 (653)	1106 (933)		
Iron (mg)	8.7 (3.2)	8.7 (3.8)	8.3 (3.4)	10.5 (5.7)	11.5 (8.3)	9.6 (5.8)		
Calcium (mg)	1173 (468)	1115 (522)	1109 (500)	1224 (512)	1417 (591)	1191 (538)		
Zinc (mg)	10.3 (3.5)	10.5 (3.9)	10.1 (3.7)	11.4 (4.6)	12.2 (4.6)	11.3 (4.3)		
Selenium (μg)	32 (16)	28 (11)	28 (12)	33 (17)	37 (18)	28 (14)		
Sodium (mg)	3119 (1120)	3004 (956)	2562 (823)	3011 (1140)	3333 (1061)	3056 (1007)		
Cholesterol (mg)	269 (131)	252 (102)	282 (154)	263 (144)	310 (177)	308 (156)		
Fibre (g)	16.1 (6.2)	14.1 (5.6)	13.5 (5.4)	15.8 (5.5)	15.0 (6.2)	14.1 (5.1)		
(b)								
Nutrient								
Vitamin C (mg)	165 (131)	108 (94)	87 (89)	148 (132)	120 (114)	85 (93)	75	< 0.001 ↓
Folic acid (μg)	259 (115)	221 (95)	189 (97)	314 (121)	287 (109)	260 (121)	117	< 0.001 ↓
Vitamin B12 (μg)	4.0 (2.3)	4.7 (2.7)	4.0 (2.5)	8.1 (11.0)	7.1 (4.6)	8.3 (23.5)	16	< 0.001 ↓
Vitamin E (mg)	7.3 (3.4)	7.4 (3.6)	9.1 (15.1)	8.8 (4.0)	10.5 (4.7)	9.6 (4.1)	1	0.419
Vitamin D (μg)	4.3 (3.0)	5.3 (3.8)	4.8 (3.6)	5.9 (2.9)	6.7 (3.0)	7.1 (4.5)	2	0.096
Retinol equivalents (μg)	1043 (630)	1015 (646)	877 (594)	1548 (2191)	1374 (1075)	1605 (3128)	9	< 0.001 ↓
Iron (mg)	9.7 (3.4)	9.7 (4.4)	9.2 (4.3)	14.4 (6.3)	13.9 (5.3)	12.3 (8.1)	32	< 0.001 ↓
Calcium (mg)	1172 (575)	1168 (527)	1233 (658)	1766 (812)	1789 (854)	1732 (929)	11	< 0.001 ↓
Zinc (mg)	10.0 (4.3)	10.6 (3.9)	10.4 (4.6)	16.9 (7.5)	18.5 (10)	15.1 (6.3)	21	< 0.001 ↓
Selenium (μg)	30 (21.3)	31 (16.2)	26 (17)	42 (21)	44 (22.2)	34 (15.4)	31	< 0.001 ↓
Sodium (mg)	2924 (1315)	2925 (925)	2806 (1228)	4740 (1814)	4671 (1707)	3805 (1423)	52	< 0.001 ↓
Cholesterol (mg)	216 (129)	255 (132)	254 (187)	320 (170)	395 (177)	338 (178)	1	0.258
Fibre (g)	19.4 (9.4)	15.8 (7.1)	13.7 (7.4)	23.2 (9.7)	19.8 (8.3)	17.6 (7.3)	90	< 0.001 ↓

Results are presented as mean (s.d.).
Arrows indicate the direction of change in residuals as dietary energy density increases from low to high.
[a]One-way analysis of variance (ANOVA) for all subjects ($n=1120$), with tertiles as independent variable, and residuals of nutrients as dependents.

dense foods, but whether this would be any more effective from a public health perspective is open to debate (Verbeke, 2008). For many foods, the trend across energy density tertiles was clear, but for burgers and sausages, and crisps and chips, it was not. These foods may reflect home cooking as well as fast food consumption and hence the association with diet quality may not be as straightforward.

The mean energy density values in our study are slightly lower than those published by Johnson *et al*. (2008a) and McCaffrey *et al*. (2008), but their dietary assessment methods differed from ours and their subjects were younger. Mendoza *et al*. (2006) reported much lower values but did not exclude all beverages in their calculations. As with our younger age group, no significant gender differences in energy density were reported in these studies. Despite also consuming the most foods and beverages, 15-year-old boys had significantly more energy dense diets than either the children or 15-year-old girls. Their mean energy intake was 12.4 MJ, over 3.8 MJ more than the 15-year-old girls (data not shown). Differences of a similar magnitude have been observed in another study of Swedish 15 year olds (Sjöberg and Hulthén, 2004). Over the life course, energy density has been shown to decline after 15–17 years of age and 13–15 years in the US and Spanish adolescents, respectively (Martí-Henneberg *et al*., 1999; Drewnowski, 2000).

Defining a healthy diet

There is no accepted way of identifying a 'healthy' diet. Defining a food or food group as healthy is also challenging (Drewnowski, 2005; Lobstein and Davies, 2009), but food-based dietary guidelines provide some direction (FAO/WHO, 1998; Becker, 1999). The Nordic Nutrition Recommendations recommend the consumption of fruits and vegetables, cereals, fish, milk and milk products (mainly lean varieties) and potatoes (Nordic Council of Ministers, 2004). They advise that the consumption of energy-dense foods should be limited. More recently, an interest in whole diet analysis has led to the development of dietary pattern methods that can be broadly classified as data-driven and knowledge-driven. The former are sample specific and require subjective interpretation of the patterns that emerge (Hu, 2002; Newby and Tucker, 2004); the latter, such as scores and indexes, are based on *a priori* assumptions about diet and health, and are not applicable in every setting. Some require information on portions, compliance with recommended daily allowances or intakes of foods or beverages (for example, alcoholic), which may not be appropriate in all countries or age groups (Kant, 1996, 2004; Kant and Graubard 2005a). Energy density has the advantage of being easy to calculate in every dietary study in which energy and weight of food and beverages consumed are available. If these results are replicated in other studies, using different dietary assessment methods and in other populations, the use of energy density as a simple proxy marker for a diet of better quality might be supported. It could be used to identify upper and lower quantiles within a population and to thereby discriminate between diets that are generally of lower and higher quality, respectively.

Methodological considerations
The most appropriate method of calculating dietary energy density remains to be defined. Not only are beverages much less energy-dense than most foods, but the regulation of beverage intake is different to that of food (Rolls *et al*., 2005). We chose to exclude all beverages from the calculation, and this has been recommended to enhance comparability with other studies (Ledikwe *et al*., 2005; Johnson *et al*., 2009). We repeated the analysis using energy density calculated with milk, and with milk and other energy-containing beverages included. The association with 3–6 food groups (out of 20) and 2–3 micronutrients (out of 13) changed; some became associated, some lost association (data not shown), but our overall conclusion did not change.

It should be noted that high energy-dense foods are not nutritionally equal. For example, a person with a high intake of 'healthy' fats would be as likely to be in the high energy-dense diet category as someone with a high intake of saturated fats, and this is one limitation of dietary energy density. The relatively large sample size and the use of both an objective and subjective method of identifying recalls of potentially lower quality are strengths of this study. The limitations of 24-h recalls in capturing habitual intake at the individual level are well known (Bingham, 1991; Beaton *et al*., 1997), because of the large day-to-day variation in intake that exists. However, for the purpose of this study, a 24-h recall on a reasonably large group, with no obvious bias, was deemed appropriate to show an association with energy density and dietary quality.

Conclusions

The use of dietary energy density to categorize the diets resulted in groups characterized by quite different dietary patterns. Subjects with lower energy density diets are more likely to consume recommended food groups, have higher intakes of micronutrients and recommended food groups and have the most favourable macronutrient energy profile. Replication of these findings in other studies could support the use of dietary energy density as a simple marker of dietary quality.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

We thank Associate Professor Olle Carlsson and Professor Juni Palmgren for their suggestions regarding the statistical analysis. We also thank the participants of this study and colleagues who collected the data. This work was funded and supported by the Stockholm County Council.

References

Beaton GH, Burema J, Ritenbaugh C (1997). Errors in the interpretation of dietary assessments. *Am J Clin Nutr* **65**, 1100S–1107S.
Becker W (1999). Dietary guidelines and patterns of food and nutrient intake in Sweden. *Br J Nutr* **81** Suppl 2), S113–S117.
Bingham SA (1991). Limitations of the various methods for collecting dietary intake data. *Ann Nutr Metab* **35**, 117–127.
Black AE (2000). The sensitivity and specificity of the Goldberg cut-off for EI:BMR for identifying diet reports of poor validity. *Eur J Clin Nutr* **54**, 395–404.
Cucó G, Arija V, Martí-Henneberg C, Fernández-Ballart J (2001). Food and nutritional profile of high energy density consumers in an adult Mediterranean population. *Eur J Clin Nutr* **55**, 192–199.
Drewnowski A (2000). Sensory control of energy density at different life stages. *Proc Nutr Soc* **59**, 239–244.
Drewnowski A (2003). The role of energy density. *Lipids* **38**, 109–115.
Drewnowski A (2005). Concept of a nutritious food: toward a nutrient density score. *Am J Clin Nutr* **82**, 721–732.
FAO/WHO (1998). Preparation and use of food-based dietary guidelines. Report of a Joint FAO/WHO consultation. Technical Report Series, No. 880. WHO: Geneva.
Goldberg GR, Black AE, Jebb SA, Cole TJ, Murgatroyd PR, Coward WA *et al*. (1991). Critical evaluation of energy intake data using fundamental principles of energy physiology: 1. Derivation of cut-off limits to identify under-recording. *Eur J Clin Nutr* **45**, 569–581.
Hoffmann K, Schulze MB, Schienkiewitz A, Nöthlings U, Boeing H (2004). Application of a new statistical method to derive dietary patterns in nutritional epidemiology. *Am J Epidemiol* **159**, 935–944.
Howarth NC, Murphy SP, Wilkens LR, Hankin JH, Kolonel LN (2006). Dietary energy density is associated with overweight status among 5 ethnic groups in the multiethnic cohort study. *J Nutr* **136**, 2243–2248.
Hu FB (2002). Dietary pattern analysis: a new direction in nutritional epidemiology. *Curr Opin Lipidol* **13**, 3–9.
Johnson L, Mander AP, Jones LR, Emmett PM, Jebb SA (2008a). A prospective analysis of dietary energy density at age 5 and 7 years and fatness at 9 years among UK children. *Int J Obes (Lond)* **32**, 586–593.
Johnson L, Mander AP, Jones LR, Emmett PM, Jebb SA (2008b). Energy-dense, low-fiber, high-fat dietary pattern is associated with increased fatness in childhood. *Am J Clin Nutr* **87**, 846–854.

Johnson L, Wilks DC, Lindroos AK, Jebb SA (2009). Reflections from a systematic review of dietary energy density and weight gain: is the inclusion of drinks valid? *Obes Rev* **10**, 681–692.
Kant AK (1996). Indexes of overall diet quality: a review. *J Am Diet Assoc* **96**, 785–791.
Kant AK (2004). Dietary patterns and health outcomes. *J Am Diet Assoc* **104**, 615–635.
Kant AK, Graubard BI (2005a). A comparison of three dietary pattern indexes for predicting biomarkers of diet and disease. *J Am Coll Nutr* **24**, 294–303.
Kant AK, Graubard BI (2005b). Energy density of diets reported by American adults: association with food group intake, nutrient intake, and body weight. *Int J Obes (Lond)* **29**, 950–956.
Ledikwe JH, Blanck HM, Khan LK, Serdula MK, Seymour JD, Tohill BC *et al.* (2005). Dietary energy density determined by eight calculation methods in a nationally representative United States population. *J Nutr* **135**, 273–278.
Ledikwe JH, Blanck HM, Kettel Khan L, Serdula MK, Seymour JD, Tohill BC *et al.* (2006a). Dietary energy density is associated with energy intake and weight status in US adults. *Am J Clin Nutr* **83**, 1362–1368.
Ledikwe JH, Blanck HM, Khan LK, Serdula MK, Seymour JD, Tohill BC *et al.* (2006b). Low-energy-density diets are associated with high diet quality in adults in the United States. *J Am Diet Assoc* **106**, 1172–1180.
Lobstein T, Davies S (2009). Defining and labelling 'healthy' and 'unhealthy' food. *Public Health Nutr* **12**, 331–340.
Maillot M, Darmon N, Vieux F, Drewnowski A (2007). Low energy density and high nutritional quality are each associated with higher diet costs in French adults. *Am J Clin Nutr* **86**, 690–696.
Martí-Henneberg C, Capdevila F, Arija V, Pérez S, Cuco G, Vizmanos B *et al.* (1999). Energy density of the diet, food volume and energy intake by age and sex in a healthy population. *Eur J Clin Nutr* **53**, 421–428.
McCaffrey TA, Rennie KL, Kerr MA, Wallace JM, Hannon-Fletcher MP, Coward WA *et al.* (2008). Energy density of the diet and change in body fatness from childhood to adolescence; is there a relation? *Am J Clin Nutr* **87**, 1230–1237.
Mendoza JA, Drewnowski A, Cheadle A, Christakis DA (2006). Dietary energy density is associated with selected predictors of obesity in US Children. *J Nutr* **136**, 1318–1322.
Mendoza JA, Drewnowski A, Christakis DA (2007). Dietary energy density is associated with obesity and the metabolic syndrome in US adults. *Diabetes Care* **30**, 974–979.
Newby PK, Tucker KL (2004). Empirically derived eating patterns using factor or cluster analysis: a review. *Nutr Rev* **62**, 177–203.
Alexander J, Anderssen S, Aro A, Becker B, Fogelholm M, Lyhne N *et al.* (2004). Nordic Nutrition Recommendations 2004. Nordic Council of Ministers: Copenhagen.
Rolls BJ, Drewnowski A, Ledikwe JH (2005). Changing the energy density of the diet as a strategy for weight management. *J Am Diet Assoc* **105**, S98–S103.
Schofield WN (1985). Predicting basal metabolic rate, new standards and review of previous work. *Hum Nutr: Clin Nutr* **39C**, 5–41.
Schröder H, Covas M, Elosua R, Mora J, Marrugat J (2008a). Diet quality and lifestyle associated with free selected low-energy density diets in a representative Spanish population. *Eur J Clin Nutr* **62**, 1194–1200.
Schröder H, Vila J, Marrugat J, Covas MI (2008b). Low energy density diets are associated with favorable nutrient intake profile and adequacy in free-living elderly men and women. *J Nutr* **138**, 1476–1481.
Sjöberg A, Hulthén L (2004). Assessment of habitual meal pattern and intake of foods, energy and nutrients in Swedish adolescent girls: comparison of diet history with 7-day record. *Eur J Clin Nutr* **58**, 1181–1189.
Stubbs J, Ferres S, Horgan G (2000). Energy density of foods: effects on energy intake. *Crit Rev Food Sci Nutr* **40**, 481–515.
Wennlöf AH, Yngve A, Sjöström M (2003). Sampling procedure, participation rates and representativeness in the Swedish part of the European youth heart study (EYHS). *Public Health Nutr* **6**, 291–299.
Verbeke W (2008). Impact of communication on consumers' food choices. *Proc Nutr Soc* **67**, 281–288.
WHO (2003). Diet, nutrition and the prevention of chronic diseases. A Joint WHO/FAO Expert Consultation. WHO Technical Report Series no. 916. WHO: Geneva.
Willett WC, Howe GR, Kushi LH (1997). Adjustment for total energy intake in epidemiologic studies. *Am J Clin Nutr* **65**, 1220S–1228S; discussion 1229S-1231S.