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Dietary energy density and its association with the nutritional quality of the diet of children and teenagers

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Abstract
To examine the relationship between dietary energy density (DED) and the nutritional quality of the diet, using data from the Irish National Children’s Food Survey (NCFS) and the National Teens’ Food Survey (NTFS), two cross-sectional studies of food consumption were carried out between 2003 and 2006. Data from the NCFS and NTFS were used to examine the intakes of nutrients and foods among those with low- (NCFS < 7·56, NTFS < 7·65 kJ/g), medium- (NCFS 7·56–8·75, NTFS 7·66–8·85 kJ/g) and high-energy-dense diets (NCFS > 8·75, NTFS > 8·85 kJ/g). A 7-d food diary was used to collect food intake data from children (n 594) and teenagers (n 441). DED (kJ/g) was calculated including food alone and excluding beverages. Participants with lower DED consumed more food (weight) but not more energy. They also consumed less fat and added sugars and more protein, carbohydrates, starch and dietary fibre and had higher intakes of micronutrients. Participants with lower DED had food intake patterns that adhered more closely to food-based dietary guidelines. Low DED was associated with multiple individual indicators of a better nutritional quality of the diet, including higher intakes of dietary fibre and micronutrients and a generally better balance of macronutrients, as well as being associated with food intake patterns that were closer to healthy eating guidelines. Taken together, these findings support the conclusion that a low DED may be an indicator of a better nutritional quality of the diet.

Key words: Children: Teenagers: Diet quality: Energy density: Dietary guidelines

Dietary energy density (DED) is defined as the amount of available energy per unit of weight in the diet. It is generally expressed as kJ/g. Experimental studies in human subjects and a recent systematic review have shown that the consumption of high-energy-dense diets may lead to increased energy intake and weight gain(1–3) and evidence has been accumulating for an association between lower DED and better nutritional quality of the diet.

To the best of the authors’ knowledge, only one study has comprehensively examined the association between DED and the nutritional quality of the diet in children and teenagers when food is consumed ad libitum(4) and no study has examined this association using a nationally representative sample of children and teenagers. In Swedish children and teenagers, it was found that low-energy-density diets contained higher amounts of protein, carbohydrates, fibre and most of the microminerals and lower amounts of energy, fats and sucrose(5). In American children aged 2–8 years the associations between DED and food intakes and some dietary characteristics were examined. It was found that young children with lower DED consumed more food (g) and less energy, more portions of fruit and vegetables, had a lower energy intake from fat and consumed less added sugar than those with higher DED(5). In studies of adults, the intakes of protein, carbohydrates and dietary fibre decreased with increasing DED and the intakes of energy and fats and added sugar increased with increasing DED(6–9). Furthermore, more favourable eating patterns, e.g. eating patterns more in line with food-based dietary guidelines, consuming more fruit and vegetables and consuming less

Abbreviations: DED, dietary energy density; NCFS, National Children’s Food Survey; NTFS, National Teens’ Food Survey; %TE, % total energy.

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low-nutrient-dense foods, have also been reported for adults with lower DED(6,8,10), while better adherence to food-based dietary guidelines has been reported in children and teenagers with lower DED(6). It has also been proposed that DED could be used as a marker of the nutritional quality of the diet(6).

The present paper therefore examines the association of DED with the nutritional quality of the diet, using nationally representative data for Irish children and teenagers.

Methods

The National Children’s Food Survey (NCFS) 2003–2004 and the National Teens’ Food Survey (NTFS) 2005–2006 were carried out to establish databases of habitual food and drink consumption in representative samples of Irish children aged 5–12 years and teenagers aged 13–17 years. A 7-d weighed food record was used to collect food intake data from 594 children (293 boys, 301 girls), while a 7-d semi-weighed food record was used to collect food intake data from 441 teenagers (224 boys, 217 girls). Participants and their parents/guardians were visited by a trained nutritionist four times, including one training visit, during the recording period. Participants with the aid of their parents/guardians (younger children requiring more aid up to 100 %) were asked to record detailed information regarding the amount and types of all foods, beverages and supplements consumed over the 7-d period and, where applicable, the cooking method used, the brand name of the food consumed, packaging size and type and details of recipes and any leftover. Data were also collected on the time and location of each eating occasion. A hierarchical method for dietary data collection and quantification was used which included weighing, photographic food atlases(11), manufacturers information and household measurements. Analyses of dietary intake data were carried out using WISP© (Tinuviel Software), which contains McCance and Widdowson’s The Composition of Foods, 6th Edition and The Irish Food Composition Database(12,13). Self-reported health and lifestyle questionnaires were completed by participants or their parents/guardians concurrent with collection of food intake data. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human participants were approved by the St. James’ Hospital and Federated Dublin Voluntary Hospitals Joint Research Ethics Committee for the NCFS and the University College Cork Clinical Research Ethics Committee of the Cork Teaching Hospitals for the NTFS. Written informed consent was given by the children, teenagers and their parents or guardians. A full description of methodologies is available elsewhere(14,15).

Sample selection

Children were selected from twenty-eight primary schools in the Republic of Ireland from a database obtained from the Department of Education and Science. The database was divided into (a) small/medium/large schools, (b) all boys/all girls/mixed, (c) disadvantage/not disadvantaged and (d) urban/rural. A random sample was selected from each category so that in the final sample the proportions of children attending each of the categories of schools reflected that of the proportions according to the database. The principal at selected schools was given detailed instructions on how to select children for participation in the survey from the school roll. Teenagers were recruited in a similar vein from thirty-two secondary schools with a divide of secondary/vocational/comprehension schools in place of the small/medium/large for children. The overall response rate was 66 % for children and 63 % for teenagers. Analysis of the demographic features of the samples has shown them to be representative samples of Irish children and teenagers with respect to age, sex, social class, socio-economic group and geographic location when compared with census data(16).

Calculation of dietary energy density

DED (kJ/g) was calculated including food only and excluding all beverages. This included all solid foods and liquid-like foods such as yoghurts and soups, and excluded all beverages: both energy-containing and non-energy-containing. This method has previously been used by other authors(4,17). As water accounts for much of the variability in DED, it was thought that the inclusion of beverages may disproportionately affect estimates in those with high beverage consumption.

Nutritional quality of the diet

The intakes of individual nutrients were used as indicators of the nutritional quality of the diet. The intakes of macronutrients were expressed as a percentage of total energy, while micronutrients were adjusted to 10 MJ/d. Each of the 1945 foods (NCFS) and 1761 foods (NTFS) consumed during the surveys were aggregated into thirty-two food groups to examine the food intake patterns associated with DED. The intakes of food groups were adjusted to 10 MJ/d. Participants who consumed a nutritional supplement at least once over the recording days were defined as supplement users.

Under-reporters for energy

Weight and height measurements were taken by researchers in the participants’ own homes. Weight was measured in duplicate using a Seca 770 digital personal weighing scale (Chasmore Ltd) to the nearest 0·1 kg. Participants were weighed having voided, wearing light clothing and without shoes. Height was measured to the nearest 0·1 cm using the Leicester portable height measure (Chasmore Ltd) with the participant’s head positioned in the Frankfurt Plane. BMR was predicted for each child and teenager from published equations(18). Minimum energy intake cut-off points, calculated as multiples of BMR, were used to identify under-reporters of energy(19). Accordingly, 32 % of children and 64 % of teenagers were classified as under-reporters. Analyses were carried out with and without under-reporters. Results presented below are those for the total population.
**Statistical analyses**

As no natural cut-offs exist and DED estimates did not vary significantly with age or sex within each study, the populations were split equally into three categories: low- (NCFS <7.56, NTFS <7.65 kJ/g), medium- (NCFS 7.56–8.75, NTFS 7.66–8.85 kJ/g) and high-DED (NCFS >8.75, NTFS >8.85 kJ/g). Analyses of the differences between low-, medium- and high-DED groups were carried out using a one-way ANOVA with a Tukey honestly significant difference (HSD) or Šidák post hoc test to test for differences in the means. Non-parametric tests, Kruskal–Wallis and Mann–Whitney U, were used when the assumptions of the ANOVA were not met and the variables could not be normalised by transformation to the natural log or square root.

**Results**

The mean weight of food and of food and beverages consumed decreased across tertile of DED (P < 0.001), while the mean daily intake of energy did not change significantly (Table 1).

The percentage total energy (%TE) from fat, saturated fat, monounsaturated fat and added sugars increased (P < 0.001) across tertile of DED, while the %TE from protein and dietary fibre (g/10 MJ) decreased (P < 0.001) in both populations. In teenagers alone, it was seen that as the DED increased, the %TE from both carbohydrate (P < 0.001) and starch (P < 0.001) decreased, while the %TE from polyunsaturated fats increased (P < 0.01). The %TE from total sugars and the unsaturated fats:saturated fat ratio did not change significantly, in either population, as DED increased (Table 1).

In children, as DED increased there was a significant decrease in intakes (energy adjusted) of vitamin A, vitamin D, vitamin B₁₂, folate, biotin, thiamin, riboflavin, niacin equivalents, vitamin B₆, pantothenic acid, vitamin C, Ca, Mg, P, K, Cu, Zn, Mn and Na (P < 0.001) and Fe (P < 0.05) (Table 2).

In teenagers, as DED increased there was a significant decrease in intakes (energy adjusted) of vitamin A, folate, biotin, vitamin D, thiamin, riboflavin, niacin equivalents, vitamin B₆, vitamin B₁₂, pantothenic acid and vitamin C, Mg, P, Fe, K, Cu, Zn and Mn decreased as DED increased (P < 0.001) and Ca decreased (P < 0.05). There was no significant difference in Na intakes across tertile of DED in teenagers (Table 2).

In both children and teenagers, an association was found between increased supplement use and lower DED. However, the overall association with the micronutrient density of the diet did not change when the intake from nutritional supplements was excluded.

Table 3 displays the mean daily intake of food groups (g/10 MJ/d). Fruit and vegetable intakes were inversely associated with DED in both children and teenagers (P < 0.001) as were fruit and vegetable juices intakes (P < 0.01).

In children, low DED was associated with higher intakes of wholemeal and brown bread, grains, rice, pasta, pizza and other cereals, yoghurts, potatoes, fresh meat and meat dishes, fish, soups and sauces (P < 0.001), reduced fat milks, reduced fat spread (P < 0.05), and lower intakes of butter and dairy spreads, chipped, fried and roasted potatoes, carbonated beverages, chocolate, non-chocolate confectionery, savoury snacks and biscuits and cakes (P < 0.001). In teenagers, low DED was associated with higher intakes of wholemeal and brown bread, grains, rice, pasta, pizza and other cereals, breakfast cereals, yoghurts, potatoes, fresh meat and meat dishes, soups and sauces (P < 0.001), tea and coffee (P < 0.01) and lower intakes of chips, carbonated beverages, burgers and sausages, chocolate, savoury snacks (P < 0.001), white bread (P < 0.01) and diet carbonated beverages (P < 0.05) (Table 3).

With the removal of under-reporters from the analyses, mean DED was estimated for children as 8.26 (1.39) kJ/g and for teenagers as 8.35 (1.63) kJ/g. Neither was significantly different from the total population estimates of 8.26 (1.44) kJ/g for children and 8.26 (1.51) kJ/g for teenagers. When analyses of associations were repeated excluding those children and teenagers who were classified as under-reporters, variations in the associations of DED with the nutritional quality of the diet were minimal.

**Discussion**

In these two national, detailed nutrition surveys of Irish children and teenagers, DED was inversely associated with multiple individual markers of the nutritional quality of the diet. Lower DED is generally considered to be associated with a healthier diet(4–10) and it has been proposed for use as a possible proxy of dietary quality(4). This study adds to the evidence for the use of DED as a marker of a better nutritional quality of the diet, examining the data from children and teenagers for whom there is minimal evidence and also using dietary intake data from weighed/semi-weighed 7-d food diaries, whereas previous evidence has been from FFQ and 24-h recall dietary data.

In Irish children and teenagers, low DED was associated with a generally better macronutrient profile: higher (energy-adjusted) intakes of protein and dietary fibre and lower intakes of total fat, saturated fat, monounsaturated fat and added sugars. In Irish teenagers (but not children), low DED was also associated with higher intakes of carbohydrates and starch and lower intakes of polyunsaturated fat. Similar results were reported in Swedish children and teenagers, finding that low DED was associated with higher (energy adjusted) intakes of carbohydrates, protein and fibre and lower intakes of total fat, saturated fat and sucrose(9). Studies in adults have also reported low DED to be associated with higher intakes of protein, carbohydrates and dietary fibre and lower intakes of fat and saturated fat(7–10).

In examining a broad range of vitamins and minerals, this study showed that lower DED was associated with a higher micronutrient density of the diet in children and teenagers. Previous studies have found that children and teenagers with low DED had higher intakes of most of the micronutrients examined than those with high DED(6). In adults, it has been reported that those with a low DED had higher, energy-adjusted intakes of vitamins A, C and B₆, folate, Fe,
Table 1. Daily intake of energy, macronutrients, dietary fibre and weight of food consumed, by tertile of energy density of diets in Irish children (n 594) and teenagers (n 441)
(Mean values and standard deviations)

<table>
<thead>
<tr>
<th></th>
<th>Children</th>
<th></th>
<th></th>
<th>Teenagers</th>
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<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Mean dietary energy density (kJ/g)</td>
<td>6.77</td>
<td>8.17</td>
<td>9.85</td>
<td>6.63</td>
<td>8.25</td>
<td>9.88</td>
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<tr>
<td>Weight of food excluding beverages (g/d)</td>
<td>845 (n=197)</td>
<td>702 (n=158)</td>
<td>603 (n=150)</td>
<td>0.000</td>
<td>1055 (n=402)</td>
<td>86.4 (n=252)</td>
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<tr>
<td>Weight of all food and beverages (g/d)</td>
<td>167.8 (n=414)</td>
<td>154.9 (n=371)</td>
<td>147.3 (n=36)</td>
<td>0.000</td>
<td>220.4 (n=791)</td>
<td>199.5 (n=617)</td>
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<td>Energy (MJ)</td>
<td>6.9</td>
<td>8.1</td>
<td>8.4</td>
<td>8.5</td>
<td>2.4</td>
<td>8.5</td>
</tr>
<tr>
<td>Protein (%TE)</td>
<td>14.6a</td>
<td>13.7b</td>
<td>12.5c</td>
<td>15.8a</td>
<td>14.7b</td>
<td>13.6c</td>
</tr>
<tr>
<td>Fat (%TE)</td>
<td>32.6a</td>
<td>34.5b</td>
<td>34.7c</td>
<td>33.8a</td>
<td>35.2b</td>
<td>37.8c</td>
</tr>
<tr>
<td>Saturated fat (%TE)</td>
<td>13.6a</td>
<td>14.5b</td>
<td>14.7c</td>
<td>13.1a</td>
<td>13.8b</td>
<td>14.9c</td>
</tr>
<tr>
<td>Monounsaturated fat (%TE)</td>
<td>10.5a</td>
<td>11.4b</td>
<td>11.6c</td>
<td>10.9a</td>
<td>11.4b</td>
<td>12.6c</td>
</tr>
<tr>
<td>Polyunsaturated fat (%TE)</td>
<td>4.6</td>
<td>4.8</td>
<td>4.9</td>
<td>5.3a</td>
<td>5.4b</td>
<td>5.9c</td>
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<tr>
<td>Unsaturated fatsaturated fat</td>
<td>1.14</td>
<td>1.13</td>
<td>1.15</td>
<td>1.28</td>
<td>1.24</td>
<td>1.27</td>
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<tr>
<td>Carbohydrate (%TE)</td>
<td>52.4</td>
<td>51.3</td>
<td>52.2</td>
<td>49.8b</td>
<td>49.2c</td>
<td>47.9d</td>
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<tr>
<td>Starch (%TE)</td>
<td>23.9</td>
<td>23.6</td>
<td>24.3</td>
<td>20.4</td>
<td>20.2</td>
<td>20.6</td>
</tr>
<tr>
<td>Added sugars (%TE)</td>
<td>12.4a</td>
<td>14.4b</td>
<td>17.0c</td>
<td>10.4a</td>
<td>12.6b</td>
<td>14.4c</td>
</tr>
<tr>
<td>Dietary fibre (g/10 MJ)</td>
<td>20.2a</td>
<td>4.1</td>
<td>17.6b</td>
<td>21.7b</td>
<td>6.3</td>
<td>18.7a</td>
</tr>
</tbody>
</table>

%TE, % total energy.

* Mean values with unlike superscript letters were significantly different between groups. Arrows denote the direction of association with increasing dietary energy density.

* As determined by ANOVA.
### Table 2. Daily vitamin and mineral intakes (per 10 MJ energy) from all sources by tertile of energy density of diets in Irish children (n 594) and teenagers (n 441) (Mean values and standard deviations)

<table>
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<tr>
<th></th>
<th>Children</th>
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<tr>
<td>Mean dietary energy density (kJ/g)</td>
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<tr>
<td>Tertile cut-offs</td>
<td>&lt;7.56</td>
<td>7.56–8.75</td>
<td>&gt;8.75</td>
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</tbody>
</table>

**Vitamins**

- Vitamin A (µg/10 MJ per d): Mean values with unlike superscript letters were significantly different between groups. Arrows denote the direction of association with increasing dietary energy density.
- Vitamin D (µg/10 MJ per d)
- Thiamin (mg/10 MJ per d)
- Riboflavin (mg/10 MJ per d)
- Niacin equivalents (mg/10 MJ per d)
- Vitamin B6 (mg/10 MJ per d)
- Vitamin B12 (µg/10 MJ per d)
- Folate (µg/10 MJ per d)
- Biotin (µg/10 MJ per d)
- Pantothenic acid (mg/10 MJ per d)
- Vitamin C (mg/10 MJ per d)

**Minerals**

- Ca (mg/10 MJ per d)
- Mg (mg/10 MJ per d)
- P (mg/10 MJ per d)
- Fe (mg/10 MJ per d)
- K (mg/10 MJ per d)
- Cu (mg/10 MJ per d)
- Zn (mg/10 MJ per d)
- Mn (mg/10 MJ per d)
- Na (mg/10 MJ per d)

*As determined by ANOVA, unless otherwise specified.
† As determined by a Kruskal-Wallis test.
<table>
<thead>
<tr>
<th>Dietary Group</th>
<th>Mean DED (kJ/g)</th>
<th>Mean DED (kJ/g)</th>
<th>Mean DED (kJ/g)</th>
<th>Mean DED (kJ/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit and vegetables</td>
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<tr>
<td>vegetables and fruit dishes</td>
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<tr>
<td>Grains, rice, pasta, pizza and other cereals</td>
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<tr>
<td>Dairy products</td>
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<tr>
<td>Reduced fat milks</td>
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<tr>
<td>Other dairy products</td>
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<tr>
<td>Beverages</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Chopped, fried, and roasted potatoes</td>
<td></td>
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<tr>
<td>Fresh meat and meat dishes</td>
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<tr>
<td>Baked, fried, and roasted potatoes</td>
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<td>Fish and seafood</td>
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<tr>
<td>Eggs and egg dishes</td>
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**Table 3.** Mean daily food intakes (g/10 MJ) by tertile of energy density of diets in Irish children (n 584) and teenagers (n 441).
**Confectionery and savoury snacks**

<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategory</th>
<th>Mean (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugars, syrups and preserves</td>
<td></td>
<td>8.1</td>
</tr>
<tr>
<td>Chocolate confectionery</td>
<td></td>
<td>19.9</td>
</tr>
<tr>
<td>Non-chocolate confectionery</td>
<td></td>
<td>15.4</td>
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<tr>
<td>Savoury snacks</td>
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<td>14.3</td>
</tr>
<tr>
<td>Biscuits, cakes and pastries</td>
<td></td>
<td>30.4</td>
</tr>
<tr>
<td>Creams, ice creams and chilled desserts</td>
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<td>44</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Nuts, seeds, herbs and spices</td>
<td>1.2</td>
</tr>
</tbody>
</table>

**Dietary energy density**

a,b,c Mean values with unlike superscript letters were significantly different between groups. Arrows denote direction of association with increasing DED.

* As determined by ANOVA, unless otherwise specified.
† As determined by Kruskal-Wallis test.

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**Soups and sauces**

<table>
<thead>
<tr>
<th>Category</th>
<th>Mean (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>49.9</td>
<td></td>
</tr>
</tbody>
</table>

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**Vitamin and mineral intake**

Some exceptions to the association of low DED with better nutritional quality of the diet were noted in this study. Firstly, children and teenagers with low DED, compared with those with high DED, consumed more fruit and vegetables, wholemeal bread, grains, rice, nuts, and vegetables. This better nutritional quality associated with lower DED may be explained by differences in food intake patterns and dietary recommendations established by the Spanish Society of Community Nutrition.

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**Micronutrient and energy intake**

The lack of association observed between lower DED and micronutrient intakes was also examined. The intake of vitamin A was lower in children and teenagers with low DED, compared with those with high DED. This finding is consistent with previous studies reporting a trend towards a healthier lifestyle, as characterised by more leisure-time physical activity, lower prevalence of smoking and alcohol consumption, and better compliance with dietary recommendations for micronutrient intake. However, the association of lower DED with increased micronutrient intake was not replicated in this analysis. The lack of association shown in this study suggests that the lower micronutrient intakes observed in children and teenagers with low DED cannot be attributed to a lower dietary intake of these nutrients. Instead, lower DED may be associated with other factors, such as increased use of nutritional supplements, which were more likely to consume fruit, vegetables, and other micronutrients.

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**Conclusions**

In conclusion, the association of low DED with better nutritional quality, lower micronutrient intakes, and lower use of nutritional supplements was observed in this study. These findings highlight the importance of promoting healthy eating habits and dietary recommendations, especially among children and teenagers, to improve the nutritional status of the population.
in the associations of DED with food intakes were noted between children and teenagers, no differences in the direction of the association of macro- and micronutrients with DED were shown, in keeping with the notion of DED as an indicator of overall dietary quality.

DED is a useful marker of the nutritional quality of the diet as it is easy to calculate, is applicable to most data and can be used in the place of multiple individual markers of dietary quality or cumulative scores. One difficulty with its use is the determination of cut-off points: at what level does DED begin to reflect a less healthy diet? This study categorised individuals according to tertile of DED but these are sample specific cut-off points and do not represent healthy and unhealthy ends of the spectrum but rather less and more healthy within the study group. This does not undermine the usefulness of DED as a marker as it can be readily used in a continuous form.

The limitations of the study merit consideration here. The cross-sectional nature of the data collection prevents the determination of the direction of associations. The percentages of under-reporters for energy in the study populations were high, particularly in teenagers; however, upon repeating the analyses without their inclusion, the associations with a better nutritional quality of the diet remained significant. No well-accepted method for calculating the DED exists, limiting the findings of this study to the method of ‘food only’. The food-only method for calculating DED was used, as water contributes to the weight of the diet but not energy intake; it was thought that the inclusion of beverages may have a disproportionate effect on DED and misclassify high beverage consumers; this also allowed for comparisons with other publications. Strengths of these analyses include the detailed level in which dietary intake data were collected, making use of 7-d weighed/semi-weighed diaries collected by trained nutritionists, and the use of a sample which was nationally representative of age, sex, social class, socio-economic group and geographic location.

This study shows that in children and teenagers in Ireland, low DED was associated with multiple individual indicators of a better nutritional quality of the diet, including higher intakes of dietary fibre and micronutrients and a generally better balance of macronutrients. Low DED was also associated with food intake patterns that were generally closer to healthy eating guidelines, as well as with supplement use. Taken together, these findings support the conclusion that a low DED may be a useful indicator of a better nutritional quality of the diet.

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