

The development of food portion sizes suitable for 4-18-year-old children used in a theoretical meal plan meeting energy and nutrient requirements

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Abstract

Background: Healthy eating guidelines for school-aged children are available but without advice on portion sizes. This is a concern as consuming large portions is associated with increased risk of overweight/obesity. The study aimed to calculate recommended portion sizes for school-aged children based on weight for age and use them to develop a meal plan to meet nutritional needs within energy requirements.

Methods: Portion size data on foods consumed by school-aged children (4-18 years) were extracted from two sources 1) British National Diet and Nutrition Survey (1997) and 2) Avon Longitudinal Study of Parents and Children (1997-2006). Foods were allocated to groups based on the UK Eatwell Guide and the US My Plate Model. Portion sizes were developed for a variety of foods. A meal plan that included portion size guidance and met healthy eating guidelines was developed based on the number of portions of each food group needed to meet dietary requirements.

Results: Portion sizes were developed for 131 foods that were commonly eaten by children in age groups 4-6, 7-10, 11-14 and 15-18 years. The meal plan met requirements for energy and nutrients as specified by UK dietary reference values except for vitamin D for which there are few dietary sources.

Conclusions: Food portion sizes informed by usual intake in UK children can help inform dietary advice for a range of childhood settings and for parents. The meal plan included a wide variety of foods to encourage dietary diversity and meet energy and nutrient needs for school-aged children.

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Introduction

Optimal nutritional intake is essential to protect the health of adults and children. A balanced diet that provides sufficient energy and essential nutrients is vital to support metabolism and daily activity. Children have higher energy and nutrient requirements than adults in relation to their body size due to extra demands of growth and development ⁽¹⁾. However, excessive energy intake is associated with increased risk of overweight/obesity. This is a major public health concern as having overweight or obesity in childhood increases the risk of disease in the short- and long-term. Children who are overweight are at increased risk of potentially life-threatening illnesses such as asthma and sleep apnoea ^(2,3). Affected children have lower self-esteem and suffer more bullying compared with healthy-weight children⁽⁴⁾. They are also at increased risk of cardiovascular disease (CVD) in later life, for example, higher concentrations of CVD risk factors are present in children as early as the first decade of life ⁽⁵⁾. In recognition of this, organisations including the American Heart Association and its British equivalent, endorse dietary recommendations for children based on fruits, vegetables, whole grains, reduced-fat dairy, beans, fish and lean meat ⁽⁶⁾. To reduce the risk of obesity and related diseases, it is essential that diets for children provide adequate energy and the full range of nutrients needed to support healthy growth and development but are not excessive.

Dietary recommendations for all age groups provide guidance on energy and nutrient intakes that are adequate at a population level and protect against deficiency ^(7,8). Information about the types and quantities of foods that make a balanced diet is key to help ensure an adequate nutrient intake within a person's energy requirements.

Portion size is an important consideration when setting dietary recommendations. It is essential that portion size guidance helps achieve nutritional adequacy within an appropriate energy intake.

Sustained provision of large portion sizes, particularly of low micronutrient, energy-dense foods

leads to higher energy intake. For example, in adults consumption of large portion sizes of energy-dense foods increased overall energy intake without affecting feelings of fullness, while consumption of large portion sizes of low-energy foods reduced overall energy intake ⁽⁹⁾. Portion size also influences energy intake in children. For example, in a study of 4-5 year old children the portion size of the 10 most eaten foods explained the greatest amount of the variance in daily energy intake (19%) compared to 9% for the number of eating occasions and 6% for the number of foods consumed ⁽¹⁰⁾.

Surveys in the UK report that children's diets do not meet recommendations ⁽¹¹⁾. Typically, they have higher than recommended amounts of energy-dense micronutrient-poor foods. Intakes of micronutrient-rich fruits and vegetables are generally below recommendations. For example, an average intake of 3 portions of fruit and vegetables daily was reported for 11-18-year-olds rather than the 5 portions recommended. Only 9% of children sampled met this recommendation ⁽¹¹⁾. Free sugars provided around 15% of energy on average rather than 5% as recommended by the Scientific Advisory Committee on Nutrition (SACN) ^(11,12). This suggests some parents and caregivers lack the knowledge and skills needed to provide diets for children that include foods from the major food groups in appropriate amounts to meet healthy eating guidelines.

The aim of this research was to develop portion sizes for children in age groups corresponding to the UK dietary requirements for populations ⁽⁷⁾. Data on foods habitually consumed by British school-age children and portion size information was used to facilitate this work. A secondary aim was to use this information to construct a meal plan that met food-based dietary guidelines. The meal plan was designed to supply energy and nutrient amounts to comply with dietary requirements for school-aged children.

Methods

Dietary requirements and healthy eating guidelines

The UK has set age and sex specific Dietary Reference Values (DRVs) which estimate energy and nutrient requirements for healthy population groups. DRVs were set for 26 nutrients in 1991 ⁽⁷⁾. Subsequent updates were published for energy in 2011 ⁽¹³⁾, carbohydrates, free sugars and fibre in 2015 ⁽¹²⁾ and vitamin D in 2016 ⁽¹⁴⁾. The Reference Nutrient Intake (RNI) represents a level that would meet the needs of 97.5% of the population. The Lower RNI (LRNI) would meet the needs of only 2.5% of the group. For energy, the Estimated Average Requirement (EAR) represents a level adequate for 50% of the population group. The US Dietary Guidelines for Americans (2015) provide Recommended Dietary Allowances (RDAs) which are equivalent to the UK RNI and Adequate Intakes (AIs) established when evidence is insufficient to develop an RDA and are set at a level assumed to ensure nutritional adequacy ⁽⁸⁾. These recommendations provide a reference to assess the adequacy of the diet in a population.

Food-based dietary guidelines can help individuals understand how to achieve a healthy balanced diet. Plate models or food pyramids show food groups and the foods contained within them to provide a guide to healthy eating. Healthy eating guidelines including the Eatwell Guide in the UK ⁽¹⁵⁾ and My Plate in the US ⁽¹⁶⁾ show how a variety of foods within food groups combine to produce a balanced diet with adequate nutrient provision. In this study, food portion sizes to recommend were developed within the age groups addressed by the UK DRVs i.e. 4-6, 7-10, 11-14 and 15-18 years ⁽⁷⁾. The meal plan aimed to meet US as well as UK dietary guidelines to accommodate countries that base their recommendations on those from the US. The dietary content of the meal plan was calculated using these recommended portion sizes specific to each age group.

Selecting foods for portion size development

Two sources of data provided information on weights of foods consumed by different age groups of children between 4 and 18 years with relatively low obesity rates:

1. **The British National Diet and Nutrition Survey (NDNS)** collected a weighed dietary record of all food and drink consumed over 4 consecutive days from a nationally representative sample of children aged 4-18 years in 1997 (¹⁷). Children were selected using a multistage random probability design within geographical postal codes. A large database, which included portion size information, was produced from the survey. Wreiden et al. (2008) analysed this database and published portion size data for foods eaten by at least 10% of all children in the following age groups: 4-6 years, 7-10 years, 11-14 years and 15-18 years (¹⁸).
2. **The Avon Longitudinal Study of Parents and Children (ALSPAC)** collected 3-day food records from children when they were aged 5 in 1997 (n = 772), 7 in 1998/2000 (n = 7309) 10 in 2002/3 (n = 7474) and 13 years in 2004/6 (n = 6113). Dietary intake in children aged 5 and 7 years was reported by parents. Children aged 10 years and older reported their intake with parental assistance. Parents and children were asked to describe everything the child consumed in household measures and to record left-overs. The food records were analysed using DIDO nutritional analysis software (¹⁹). Food weights were entered according to the description of portion sizes. For manufactured foods, packet weights were provided. The median and inter-quartile range of portion sizes provided for foods consumed five or more times by the children was available for 573 foods at age 5, 1207 at age 7, 1175 at age 10 and 1117 at age 13 years. Full details of the methods and the nutrient and food intakes of the children are described in two previously published articles (^{20,21}). ALSPAC participants were pregnant women resident in Avon, UK with expected dates of delivery between 1st April 1991 and 31st December 1992. There were 14,541 women enrolled, resulting in a cohort of 14,062 live births with 13,988 children alive at 1 year of age (^{22,23}). Further details of ALSPAC are available at www.bris.ac.uk/alspac and the study website contains details of all the data that are available through a fully searchable data dictionary (<http://www.bris.ac.uk/alspac/researchers/data-access/data-dictionary>). Supplemental Table

1 shows the median and interquartile range of the portions sizes of selected foods as consumed at each age by ALSPAC children with an indicative description in household measures and the weight of a basic portion of the food.

The median and 25th to 75th centiles of portion sizes from these two data sets were used to inform the development of the portion sizes to be recommended thus avoiding any bias from children who were overweight or obese or underreporting or misreported. The portion sizes were then adjusted to meet nutrient requirements within energy limits.

Combining foods into a theoretical meal plan

Foods that contributed most to a nutritionally adequate diet and were frequently eaten according to the NDNS and ALSPAC studies were included in the meal plan and portion size calculations.

Foods were divided into five groups based on the UK Eatwell (¹⁵) and US My Plate guides (Table 1a) (¹⁶) and expanded by three further groups to include a more complete range of foods reported as eaten by children in the NDNS and ALSPAC studies. A number of daily or weekly portions was allocated to each food group (Table 1a). An example meal plan showing how portions from each food group may be allocated over a theoretical day is shown in Table 1b.

Within each food group, a variety of foods ensured that adequate foods of medium to high nutrient density were included over an average week and lower nutrient foods (e.g. high in fat, free sugars and salt) were minimised. For example, 7 breakfast cereals were included in group 1 but those high in added sugar (e.g. sugar-coated types) were excluded to comply with recommendations on free sugars intakes (¹²). Food group 2 was split into 2 sub-groups: 2a) Fruits and 2b) Vegetables, to allow flexibility in serving frequencies (Table 1a). Fruit juices were not included in 2a) due to their free sugars content. In group 3, whole milk was included to increase the vitamin A content and help meet the requirement for 4-6-year old children (⁷). A combination of whole milk and semi-skimmed milk was included for the older children. Plant-based milk alternatives were not included because they are not all fortified with iodine. Plain and sweetened flavoured yogurts and sweetened milk

puddings were given equal weighting in the calculations. In group 4, 28 different protein-based foods were included spread across 2 weeks. This was to incorporate a variety of fish and meet recommendations to eat fish twice per week with at least one being oily fish ⁽¹⁵⁾. To increase sustainability and limit cost, several plant-based meals were included. The weekly distribution of protein-based foods was 4.5 meals based on pulses or nuts, 2.5 meals based on fish, 2.5 meals based on eggs and 4.5 meals based on meat. Group 5 included oils, butter and spreading fats to contribute to the intake and absorption of fat-soluble vitamins. Foods in group 6 were mostly complex carbohydrates with some sugars and/or fats, but included nutrient-rich ingredients such as fruits, eggs, nuts, milk and milk products and therefore contributed to nutrient intake and dietary variety. The sweet and savoury sauces and spreads in group 7 were given equal weighting in the calculations of this food group which contributes to enjoyment and palatability of the diet. Group 8 included foods and drinks that are energy-dense and low in micronutrients. These foods are frequently eaten by, and popular with children (Supplemental Table 1). They were included in the meal plan once per week in very limited quantities. Infrequent consumption of these foods in small portion sizes was necessary to maintain a nutrient adequate diet within an appropriate energy intake.

Setting average energy requirements for each age group

For each age group an estimated average energy requirement was calculated from the energy requirements of children on the 50th weight for age centiles ⁽¹³⁾. In the 3 younger age groups the mid-point energy requirement between the youngest girl and the oldest boy was calculated (Table 2). For example, in the 4-6-year age group the mid-point was between the energy requirements for a girl aged 4 and a boy aged 6, both on their 50th centile for weight. For the 15-18-year olds the estimated average energy requirement was calculated using the mid-point energy requirements for the youngest and oldest on the 50th weight for age centile for each sex separately (Table 2).

Calculation of energy and nutrient intakes for each age group

Food portion size weights for each selected food were converted to energy and nutrients using Dietplan version 7.1 (Forestville Software Ltd) which is based on McCance and Widdowson's

composition of foods Integrated data set

(<https://www.gov.uk/government/publications/composition-of-foods-integrated-dataset-cofid>) and is updated regularly. An average energy and nutrient content of each food group within each age group was produced by Dietplan. These averages were multiplied by the appropriate number of daily food group portions in the theoretical meal plan and summed to provide total daily energy and nutrient intakes within each age group.

Nutritional analysis of the theoretical meal plan was compared with UK and US dietary reference values to ascertain whether it met energy and nutrient recommendations for each age group (Tables 4a & 4b). The calculated energy content of the theoretical meal plan was compared to the estimated energy requirements for children growing along the 50th centile of the UK-1990 growth reference in each age group and to the US energy recommendations for moderately active children at the same ages (⁸). The nutrient content was compared to the UK RNI's (⁷) and the US RDAs and AIs (⁸).

Comparison was also made with public health recommendations for fibre, free sugars, saturated fats and salt intakes, as recommended by the UK SACN (^{12,24,25}) (Table 5)

Calculating portion size ranges appropriate for children in each age group

To develop portion size ranges to cover about 80% of children in each age group, a range of body weights, as a percentage of the mid-point weight in that age group was calculated. Within the 4-14-year-old children the weights of a 9th centile girl and a 91st centile boy were read from the UK Growth Charts and used for the lower and higher ends of the range respectively. For the 15-18-year olds the weight range was calculated on the weights for age from 9th to 91st centile for each sex separately (Table 2). As energy requirements are proportional to body weight, these percentage weight ranges were used in conjunction with the portion size for the child on the 50th centile to calculate the portion size range for each food (Table 3). For example, the portion size range for plain bagel in the 4-6-year age group is 46-81g which is -24% to + 35% around the portion size of 60g.

Results

Portion sizes of 131 foods appropriate for children on the 50th centile with ranges for children from the 9th to 91st centiles are shown in Table 3. Daily estimated energy and nutrient intakes from the theoretical meal plan for each age group are shown in Table 4a and 4b along with the UK RNIs and US RDAs and AIs for each age group. The energy content of the theoretical plan was within 5% of the average of the UK EARs for each age group (¹³). The US daily energy recommendations for moderately active children (⁸) vary from the UK values: higher for the 4-6-year olds and lower for the other age groups. The estimated energy content of the theoretical meal plan was 8% below the US energy requirement for 4-6-year olds and 5-12% above the requirement for the older age groups(⁸).

Daily nutrient intakes were within 95% of all the UK RNIs with the exception of vitamin D (^{7,14}). Nutrient intakes were also within 95% of the USA RDA and AIs for all age groups with the exception of vitamin D, calcium and potassium, iron for 4-6 year olds and iron and folate for 15-18 year old girls (⁸).

Both UK and US fibre recommendations could be met by the theoretical meal plan for all age groups (^{8,12}). The salt content of the theoretical plan was within the SACN recommendations for all age groups except 4-6-year olds and 15-18-year old boys where they were slightly exceeded (Tables 4a & 4b) (²⁵).

The percentage contributions of energy from macronutrients shown in Table 5 corresponded closely with the recommendations for healthy eating (without alcohol) in children over five years of age in the UK (^{12,13}) and the USA (⁸) for all macronutrients except saturated fat and free sugars which were slightly higher than recommended. Percentage energy from saturated fat was 1-2% above the UK

recommendation of 11% and 2-3% above the US recommendation of <10% (8,24). Percentage energy from free sugars was within the US recommendation of <10% but slightly above the UK recommendation of 5% (12).

Discussion

The findings of this research show that evidence-based recommended portion sizes for children aged 4-18 years can be used in a theoretical meal plan to provide a diet that meets UK recommendations for energy, fibre and all nutrients except vitamin D. To our knowledge, this is the first evaluation of portion sizes for children in a theoretical meal plan. The weights of the recommended portion sizes can be converted into appropriate household measures within local food supplies in which some packet and single food items come in different sizes and weights and may be adjusted by manufacturers over time. The portion sizes and meal plan provide important guidance for dietitians and nutritionists to interpret for healthcare professionals advising children and families on dietary intake; an area where evidence is currently lacking. Information can also be used to guide meal provision, for example in schools, and can be incorporated into public health guidance for parents and caregivers. Portion size advice is central in the prevention and management of childhood overweight and obesity, which is probably the most serious nutrition, related condition affecting today's children.

Importantly, the portion sizes developed here were informed by data from the UK NDNS and ALSPAC studies, which reported the foods commonly eaten by children and amounts consumed. The median and 25th-75th centile of amounts consumed were used to inform this study thus avoiding extreme intakes. The NDNS data was collected in 1997 when obesity rates were lower than today (17). Therefore, it is reasonable to assume that portion sizes reported here supported a healthy

weight. Data from ALSPAC spanned the years 1997 to 2006 (Supplemental table 1) when obesity rates were increasing⁽²⁶⁾. However, it is important to note that in this study, obesity rates were below national levels. At 7 and 13 years of age children in ALSPAC had a slightly lower prevalence of overweight and obesity than the average in England ^(26,27).

To devise the theoretical meal plan and calculate its energy and nutrient content a similar method to Karlsen et al. (2019) was used ⁽²⁸⁾, however in this study meal plans for five age groups were devised and compared to the recommendations for each age group. The calculated energy and nutrient content of each meal plan met almost all the recommendations for nutrients within an energy content that is in line with that recommended for children of each age group. However, neither the UK RNI nor the US RDA for vitamin D was met for any age groups ^(8,14). This is not unexpected as very few naturally occurring foods provide a dietary source of vitamin D and sunlight is the main source. In the US, certain foods are fortified with vitamin D (e.g. milk and spreads). A database that included nutritional values for these foods would have provided a higher estimate for the vitamin D achievable with the meal plan. It is also possible that the US recommendation is set at a higher level than is needed to prevent deficiency.

There is a disparity in the recommended intakes for calcium between the UK and US ^(7,8). In the US recommendations are higher. The meal plan exceeds the RNI in the UK and provides between 70 and 100% of the US RDA depending on the age and sex of the child.

The disparity between the UK RNIs and the US AI for potassium is wide ^(7,8). The meal plan met the UK RNI for all age groups but was below the US AI, which is based on the adult requirement of 4.7g/day. This level is associated with lower blood pressure, reduced salt sensitivity, and a lower risk of kidney stones in adults ⁽²⁹⁾. Potassium intakes in adults in the US average around 60% of the AI ⁽²⁹⁾ and children are similarly unlikely to have intakes near the AI.

The US RDA for folate in 14–18-year-old boys and girls is twice that of the UK RNI for 15-18-year olds (7,8). Within the higher energy intake of boys the folate content exceeds the US RDA but only meets 85% of the RDA for girls.

Therefore, we suggest that amounts of calcium, potassium and folate provided by the theoretical meal plan are likely to meet UK recommendations for almost all children but there will be a need to provide other sources of vitamin D including in fortified foods, supplements and through careful sun exposure. Some or most of a child's vitamin D needs can be met by synthesis in skin that is adequately exposed to sunlight. In the UK, due to its northerly latitude, this is possible only during the spring and summer months. During the autumn and winter months, cutaneous synthesis of vitamin D does not occur in the UK and since 2016 the Department of Health has recommended that a dietary supplement of 10µg/day be taken in autumn and winter. A supplement is also recommended during the spring and summer months for children who do not spend much time outside or cover most of their skin when outside (14,30).

Across the age groups 63-70% of iodine comes from Food Group 3 (milk, cheese and yogurt) and we would have been unable to meet the UK RNIs for iodine if we had included in this food group the plant-based alternatives to dairy milk drinks which are not usually fortified with iodine. Iodine is important for growth and development via the thyroid hormones and for normal cognitive and neurological function (31).

The recommendations are made for salt in the UK and sodium in the US. The salt content of the theoretical meal plan slightly exceeds the UK SACN (2003) salt intake recommendations for the 4-6 age group and the 15-18-year old boys (25). However, many manufacturers have reduced levels of salt in foods in recent years and this is an ongoing process (25). The sodium content of the meal

plan is below the US upper limit for younger children (4-10 years) but slightly exceeds that for the 9-18-year groups (⁸). It is likely that a balanced diet using foods available today will always exceed the UK recommendation for salt unless the use of processed food is limited or more pressure is put on manufacturers to reduce salt levels in everyday foods.

The energy-dense, micronutrient-poor foods in food group 8 (Table 2) have been limited in the theoretical meal plan in order to maximise nutrient density within energy requirements. If more foods in food group 8 were used to feed children, they would either replace some nutrient-dense foods, thus compromising nutrient intake, or be an addition thus increasing energy intake to exceed the EAR for the age group (¹³). Including fruit juice in Food Group 2 rather than Food Group 8 would have increased the total free sugars content beyond 6-7% energy (¹²).

Limitations

Portion sizes and foods in this study were informed by records of foods commonly eaten by children in the UK therefore the foods chosen were not necessarily typical of other countries. However, they were kept relatively uncomplicated to allow local interpretation. UK food composition tables were used, and these do not represent nutrient content of foods fortified with nutrients at different levels in other countries.

Composite dishes, which contain a mixture of foods from more than one food group were not included in this meal plan. This would require analysis of dishes to separate into their constituent foods. For example: in 'pizza' the main ingredients are a bread base, tomato sauce, vegetables and cheese. Thus, the dish would contribute a portion each to groups 1 and 3 and half a portion to group 2b and the portion size would be an addition of all of these. This was beyond the scope of the current research.

Conclusions

To provide adequate nutrient intakes within guidelines on energy intake, nutrient-dense foods must be used. Using the suggested portion size ranges and a typical variety of foods/drinks within each of the recommended food groups a diet can be provided for 4-18-year old children containing adequate levels of all nutrients except vitamin D. It is not possible to provide adequate levels of vitamin D from the diet without including fortified foods or supplements. Energy-dense, high free sugars and micronutrient-poor foods should be limited to a small portion once a week. The portion sizes and ranges developed here together with the theoretical meal plan serve as a guide for dietitians and nutritionists to interpret with appropriate household measures for other health care professionals, parents, caterers, caregivers and policy makers on the amounts and types of foods that constitute a healthy meal. They are a practical aid for use in the prevention and management of childhood overweight and obesity that can help to achieve nutritional adequacy in childhood diets.

Ethics approval

Ethical approval for ALSPAC was obtained from the ALSPAC Law and Ethics Committee and the Local Research Ethic Committees. Informed consent for the use of data collected in ALSPAC via questionnaires and clinics was obtained from participants following the recommendations of the ALSPAC Ethics and Law Committee at the time.

Transparency Declaration

The lead author affirms that this manuscript is an honest, accurate, and transparent account of the study being reported, that no important aspects of the study have been omitted and that there are no discrepancies from the study as planned.

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(<http://www.bristol.ac.uk/alspac/external/documents/grant-acknowledgements.pdf>);

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