REVIEW
The role and requirements of digestible dietary carbohydrates in infants and toddlers

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Digestible carbohydrates are one of the main sources of dietary energy in infancy and childhood and are essential for growth and development. The aim of this narrative review is to outline the intakes of digestible carbohydrates and their role in health and disease, including the development of food preferences, as well the consequences of excess carbohydrate. Key experts in these fields provided up-to-date reviews of the literature. A search of available information on dietary intakes of children below the age of 4 years was conducted from 1985 up to 2010. Articles and reports including information about sugars and/or starch intakes were selected. A number of factors limit the ability to obtain an overall picture of carbohydrate intakes and food sources in this age group. These include small numbers of intake studies, differing approaches to analysing carbohydrate, a variety of terms used to describe sugars intakes and a dearth of information about starch intakes. Data suggest that sweet taste is preferred in infancy and later food choices. There are few established adverse consequences of high intakes of digestible carbohydrate for young children. The greatest evidence is for dental caries, although this is influenced by high intake frequency and poor oral hygiene. Evidence for detrimental effects on nutrient dilution, obesity, diabetes or cognition is limited. In infants, minimum carbohydrate (mainly lactose) intake should be 40% of total energy, gradually increasing to 55% energy by the age of 2 years.

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INTRODUCTION
The early years of life are a period of very rapid growth. Appropriate nutrition is essential during this period: children who do not receive sufficient energy and nutrients will not sustain their expected growth and development. Digestible dietary carbohydrates, primarily lactose, are one of the main sources of dietary energy in this crucial period. Additionally, other key sources are starch and sugars.

This paper provides a narrative review of the role and suggested requirements for digestible carbohydrate in the diets of infants and toddlers. It provides an overview of current intakes where available worldwide and recommendations in Europe, describing the food sources, the weaning practices and geographical and age differences. In addition, it summarises how digestible carbohydrates are absorbed, their role in the development of food preferences and food choices and in cognition. Finally, the consequences of excess carbohydrate are reviewed, in each case by providing a summary of the available literature including, where available, the results of published systematic reviews of the issue.

TERMINOLOGY
Digestible dietary carbohydrates comprising two main categories—starch and sugars. Both the total and its two components suffer from problems of variability in definition and analysis, creating challenges when examining intakes and impacts on health. In infant formula and toddlers milk, maltodextrins are also commonly used and may be an important dietary component for infants and young children. However, these are rarely reported in dietary surveys.

Carbohydrate
There are two main ways in which the carbohydrate content of foods is determined, either by analysing carbohydrate components directly and adding these together, or by calculating carbohydrate content ‘by difference’. A detailed description of those two methodologies can be found in Supplementary Appendix 1, the advantages and disadvantages of the different methods are described as well.

Sugars
There are a large number of terms used to describe sugars and their components, such as sugar(s), total sugars, total available sugars, free sugars, added sugars, refined sugar(s), simple sugars, discretionary sugar, intrinsic sugars, extrinsic sugars, non-milk extrinsic sugars (NMES) and caloric sweeteners.2–10 The existence of these many different terms and their use in different countries have resulted in a literature on intakes where studies are not comparable, thus limiting comparisons between countries and analysis of trends over time. Similarly, possibilities to compare intakes to recommendations and to establish links between intake and risk factors or disease end points are limited. The different
terms and their current definition or generally understood meaning are shown in Table 1.

Starch

Starch intake, if reported, is given only as a total. However, starch can be subdivided according to the rate and extent of its digestibility, as was first described by Englyst et al.11 in 1987. Resistant starch is not digested in the small intestine and therefore should not be considered under the label of digestible carbohydrates, but to date, this has not been separated out in any measurements of intakes of population groups. Table 2 shows the classification of starch in the diet.

### Table 2. Classification of starch in the diet

| Type of starch          | Examples                  | Digestion in small intestine |
|-------------------------|---------------------------|-----------------------------|
| Rapidly digestible starch (RDS) | Freshly cooked starchy foods | Rapid                       |
| Slowly digestible starch (SDS) | Most raw cereals, pasta | Slow but complete           |
| Resistant starch (RS)    |                           | Resistant                   |

CARBOHYDRATE COMPOSITION OF INFANT FORMULAE AND COMPLEMENTARY FOODS

The EU Directive 2006/141/EC of 22 December 2006 on infant formulae and follow-on formulae and amending Directive 1999/21/EC have established the compositional criteria of those products. Infant formulae when reconstituted as instructed by the manufacturer shall have a minimum of 9 g of total carbohydrates/100 kcal and a maximum of 14 g/100 kcal. The following carbohydrates can be used: lactose, maltose, sucrose, glucose, maltodextrins, glucose syrup or dried glucose syrup, precooked starch and gelatinised starch, the two latter naturally free of gluten. The minimum content of lactose shall be 4.5 g/100 kcal. If added, the sucrose shall not exceed 20% of the total carbohydrate content and the glucose shall not exceed 2 g/100 kcal. The maximum authorised content of precooked starch and gelatinised starch is 2 g/100 ml, and 30% of the total carbohydrate content. In follow-on formulae when reconstituted as instructed by the manufacturer, the minimum total carbohydrate shall be 9 g/100 kcal, the maximum 14 g/100 kcal and the use of ingredients containing gluten is prohibited. The minimum content of lactose shall be 4.5 g/100 kcal. Sucrose, fructose and honey can be used separately or as a whole but with a maximum of 20% of the total carbohydrate content.

The EU Directive 2006/125/EC of 5 December 2006 on processed cereal-based foods and baby foods for infants and young children has established the composition of products intended for infant weaning. For cereals, if sucrose, fructose, glucose, glucose syrups or honey are added to products mentioned, then the amount of added carbohydrates from these sources shall not exceed 7.5 g/100 kcal and the amount of added fructose shall not exceed 3.75 g/100 kcal. If sucrose, fructose, glucose syrups or honey are added to baby foods, then the amount of added carbohydrate from these sources shall not exceed 5 g/100 kcal and the amount of added fructose shall not exceed 2.5 g/100 kcal. In baby foods for infants and young children, the quantities of total carbohydrate shall not exceed 10 g/100 ml for vegetable juices and drinks based on them, 15 g/100 ml for fruit juices, nectars and drinks based on them, 20 g/100 g for fruit-only dishes, 25 g/100 g for desserts and puddings and 5 g/100 g for other non-milk-based drinks.

IN INTAKES, FOOD SOURCES, WEANING PRACTICES AND RECOMMENDATIONS

Intakes

For the purpose of this review, a search was conducted of available information on dietary intakes of infants and children below the age of 4 years. A thorough search of the literature was conducted for studies or surveys conducted in the past 25 years, that is, since 1985 where an age group <4 years was included and where information about sugars and/or starch was given. Studies or surveys that only described total carbohydrate, with no further subdivision into sugars were not included. There was no limit to study size. Studies and surveys were found through PubMed searches under ‘child’ or ‘infant’ or ‘toddler’ or ‘preschool’ and ‘intake’ or ‘diet’ or ‘dietary’ or ‘sugar’ or ‘sugars’. References in journal articles located in this manner were reviewed for secondary sources, although this was limited to 1985 onwards in an effort to report contemporary data only. Surveys known to the authors and published reports were also included. Only papers
and reports in English were included. Data for studies were reported in different tables according to the manner in which sugars were described, namely total sugars (Table 3), added sugars (Table 4), NMES (Table 5), specific monosaccharides and disaccharides (sucrose (Table 6), fructose and/or lactose) and other definitions. In each table, results were subdivided into three age groups: 1 year and under, 1 year upwards and 2 years upwards. Where the age group reported extended beyond 4 years but the category was mainly <4 years, these were also included. Studies were tabulated in chronological order, and reported for males and females together. Details of the studies including the dietary assessment method used have also been included. Most studies used a complete method of assessment, such as a 24-h recall, or an estimated or weighed record. Few studies of carbohydrate intake report the intake of lactose, in spite of its major contribution to the carbohydrate intake of infants. Breast milk contains 60–75 g/L lactose,14,15 with variations from woman to woman. Final concentrations vary with the length of time a few days of birth, rising from just over 50 g/L soon after birth.18 Mothers of premature infants have lower concentrations at birth, but these continue to rise for longer until they reach the term level.18 Lactose concentration remains constant throughout the months of lactation,17 and reductions in intake with age are a result solely of reduced milk intake. Total lactose intake has been reported in studies from Finland,19 the United States13 and New Zealand.15 According to the national data for the United States from 1988 to 1994, lactose intake decreased from 20% energy for infants aged 2–11 months, to 7% energy at 1–2 years of age and 5% at 3–5 years of age. For Finnish infants aged 13–23 months, lactose represented 23% energy, while for children aged 1–4 years from New Zealand, lactose intake was 14% energy. These later figures are in line with the American data in terms of decreases with age.

### Food sources

A small number of studies have reported intakes of fructose. Studies from the United States and New Zealand indicate total fructose intakes ranging from 4 to 8% energy13–15 and increasing with age as the infant moves to a greater contribution from complementary feeding. Few differences have been seen over three decades in the United States where fructose intake is assessed in the NHANES (National Health and Nutrition Examination Survey), in spite of seemingly increased use of High Fructose Corn Syrup (HFCS) as sweetener in that country.16,17

Few studies of carbohydrate intake report the intake of lactose, in spite of its major contribution to the carbohydrate intake of infants. Breast milk contains 60–75 g/L lactose,14,15 with variations from woman to woman. Final concentrations vary with the length of time a few days of birth, rising from just over 50 g/L soon after birth.18 Mothers of premature infants have lower concentrations at birth, but these continue to rise for longer until they reach the term level.18 Lactose concentration remains constant throughout the months of lactation,17 and reductions in intake with age are a result solely of reduced milk intake. Total lactose intake has been reported in studies from Finland,19 the United States13 and New Zealand.15 According to the national data for the United States from 1988 to 1994, lactose intake decreased from 20% energy for infants aged 2–11 months, to 7% energy at 1–2 years of age and 5% at 3–5 years of age. For Finnish infants aged 13–23 months, lactose represented 23% energy, while for children aged 1–4 years from New Zealand, lactose intake was 14% energy. These later figures are in line with the American data in terms of decreases with age.

### Food sources

A small number of studies and surveys have reported the major food sources of carbohydrate and sugars in infants. The most comprehensive is that of a national survey of 488 British infants aged 6–12 months.20 This survey indicated that the major sources of carbohydrate in this age group were commercial infant foods (24%), cereal products (23%), milk and milk products (17%) and infant formula (13%). NMES provided 29% of total sugars intake for infants 6–9 months, and 41% for those 9–12 months, indicating that the majority of sugars intake in infants <12 months is intrinsic in foods; the greatest sources being milk and milk products and infant formula. The greatest contributors of NMES in this age group were juice and other beverages, with increasing contributions from sweet grain foods and confectionery.

According to the most recent UK NDNS (National Diet and Nutrition Survey), cereal and cereal products represent 40% of total carbohydrate intake of toddlers (1.5–3 years) in the United Kingdom.21 Within this age group, ‘pasta, rice and miscellaneous cereals’ and white bread were the largest contributors, both at 9% of total carbohydrate intake. Milk and milk products contributed 16%, fruit 11% and vegetables and potatoes 10%, with smaller contributions from beverages, 4% for fruit juice and 3% from ‘soft drinks, not low calorie’. In the previous National UK Survey in 1992–1993 in toddlers (1.5–2.5 years), several food groups contributed carbohydrate intake in similar proportions as in the recent data, with cereal products the major contributor at 36%, milk and milk products 16%, and vegetables and potatoes 12%.22 Fruit contribution was lower in the earlier survey (5% vs 11%) while that of beverages was higher (14% vs 10%) with ‘soft drinks, not low calorie’ contributing to (11% vs 3%). According to the US FITS (Feeding Infants and Toddlers Study) of 2002et al.,23 for toddlers aged 12–24 months, milk, yogurt and ‘ice cream, frozen yogurt and pudding’ contributed 18% to carbohydrate intake, juice 12% and sweetened beverages 9%. Grain products made a substantial contribution, at least 27% for the figures given for individual foods in this category.

In UK’s recent data, the largest contributor to intake of NMES in toddlers 1.5–3 years was beverages, at 31%.21 Within beverages,

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**Table 3** shows the results for studies that have reported ‘total sugars’ intake, meaning all monosaccharides and disaccharides in a food, whether naturally occurring or added during processing or cooking, as described in Table 1. For infants aged 1 year or less, energy intakes were generally in the range 700–900 kcal/day, and varied with the precise age group of those included in the study. The proportion of carbohydrate was around 50% energy. Values for total sugars tended to be similar among studies at around 30–35% energy. Starch intakes, for those few studies that report it, were ~15–18% energy. These values can be explained by the major consumption in this age group being milk, either breast milk or formula, with little solid food until the second half of the first year of life. There are no obvious trends over time for the 30 years covered.

For studies reporting intakes for children aged 1 year and upwards, energy intakes ranged from 1000 to 1400 kcal/day, with carbohydrate intakes of 120–180 g/day, representing 47–55% energy, partly varying with country. Fat intakes were lower in this age group compared with the younger infants. Total sugars ranged from ~80 to 115 g/day or 25–33% energy, very similar to the younger age group. Starch intakes, however, were somewhat higher than for the younger age group, since a greater proportion of solid food is consumed by this age group. There were no changes over time from the 1980s to more recent years.

A very similar picture was seen for studies reporting intakes of children aged 2 years upwards. Energy intakes were higher than those at younger ages, from ~1200 to 1500 kcal/day. Carbohydrate intakes were 49–58% energy. The national study in Greece12 reported much lower carbohydrate and sugars intakes, and much higher fat (42% energy). This age group has yet slightly higher starch intakes for studies reporting this nutrient, representing 23% energy. There is no evidence of consistent changes over time.

Table 4 shows the five studies reporting ‘added sugars’ intake, as described by authors, irrespective of what this term included. Added sugars ranged from 4 to 13% energy. Total carbohydrate intakes were similar in these studies to those reporting ‘total sugars’.

Table 5 shows the five studies reporting NMES intake, meaning total sugars minus lactose in milk and milk products and sugars present within the cellular structures of fruits and vegetables, as described in Table 1. NMES intake represented 11–19% energy, with little variation between the youngest age group. In infants aged <1 year, NMES were also the lowest proportion of total sugars at 35%, while in the children aged >1 year NMES ranged from 47 to 65%. The proportion of NMES increases with age, so that by age 3–4 years, it is likely to be around 60% of total sugars or more.

Table 6 shows studies reporting sucrose intake. Sucrose intake ranged from 5 to 14% energy, with lower intakes in younger age groups. The only study on infants aged <12 months showed an intake of 5.9% energy. Because of the different ranges of age included in these studies, it is difficult to determine the reasons for the variability in the studies reporting from 1 year upwards, but those with wider age ranges tended to have higher values, suggesting that sucrose intakes increase with age, probably due to the increased variety of foods consumed.

**Table 6** shows studies reporting sucrose intake. Sucrose intakes were 49–58% energy. The national study in Greece12 ranged from 5 to 14% energy, with lower intakes in younger age 3–4 years, it is likely to be around 60% of total sugars or more.

Table 7 shows studies reporting sucrose intake. Sucrose intake ranged from 5 to 14% energy, with lower intakes in younger age groups. The only study on infants aged <12 months showed an intake of 5.9% energy. Because of the different ranges of age included in these studies, it is difficult to determine the reasons for the variability in the studies reporting from 1 year upwards, but those with wider age ranges tended to have higher values, suggesting that sucrose intakes increase with age, probably due to the increased variety of foods consumed.

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Digestible carbohydrates in infants and toddlers

A Stephen et al
### Table 1. Dietary Intakes of Infants and Young Children Where Sugars Information Is Reported as Total Sugars (All Monosaccharides and Disaccharides in a Food, Whether Naturally Occurring or Added During Processing or Cooking)

| Reference | Country | Publication year | Assessment year | Age, range | n | Dietary method | n | Energy kcal | Protein, g | Protein, % En | Fat, g | Fat, % En | CHO, g | CHO, % En | Total sugars, g | Sugars, % En | Starch, g/day | Starch, % En |
|-----------|---------|-----------------|-----------------|------------|---|----------------|---|--------------|------------|--------------|-------|-----------|--------|-----------|----------------|--------------|---------------|-------------|
| 148       | Sweden  | 1986            | 1979/1980       | 6-12 months | 212 | 24 h          | 212 | 901          | 37       | 16.2        | 31     | 30.2      | 114    | 51        | 60               | 25.0         |               |             |
| 20        | United Kingdom | 1992          | 1986            | 6-12 months | 488 | 7d ER         | 488 | 868          | 31       | 14.1        | 36     | 36.9      | 113    | 49        | 72               | 31.0         | 42            | 18.0        |
| 147       | United States  | 1995          | 1987/1988       | <1 year     | 100 | 1/3d ER       | 100 | 768          | 25       | 11.1        | 37     | 37.6      | 116    | 52.3      | 78               | 33.0         |               |             |
| 147       | United States  | 2002          | 1988/1994       | 2-11 months | 1620 | 24 h         | 1620 | 888          | 25       | 11.1        | 37     | 37.6      | 116    | 52.3      | 78               | 33.0         |               |             |
| 149 United Kingdom | 2001 | 1993            | 8 months        | 1131       | 3d ER | 1131 | 816          | 28       | 13.7        | 33     | 35.4      | 108    | 50.8      | 70               | 32.2         | 38            | 17.2        |
| 150 United States  | 2009 | 1999-2001       | 9 months        | 341        | FFQ/ | 341           | 853       | 28          | 12.9      | 34          | 35.9   | 110       | 48.5             | 75            | 33.0          | 15.5        |
| 151 United Kingdom | 2008 | 2001/2003       | 6 months        | 50         | 4d WR | 50            | 708        | 20          | 11.1      | 31          | 39.8   | 93        | 49.3             | 69            | 36.8         |             |
| 152 United Kingdom | 2009 | 2001/2003       | 12 months       | 50         | 4d WR | 50            | 902        | 34          | 15.3      | 37          | 36.5   | 112       | 46.6             | 65            | 27.2         |             |
| 153 United States  | 2008 | na              | 7-11 mo         | 80         | 3d WR | 80            | 740        | 18          | 9.7       | 33          | 39.9   | 94        | 51.1             | 66            | 33.4         |             |
| 154 United States  | 2008 | 2005            | 1-2 years       | 447        | 3d WR | 447           | 701        | 21          | 11.6      | 34          | 35.9   | 110       | 48.5             | 75            | 33.0          | 15.5        |
| 157 Netherlands | 1998 | 1992/1993       | 1.5-4.5 years   | 1675       | 2d ER | 1675          | 1140       | 37          | 13        | 36          | 55.9   | 155       | 51.1             | 87            | 28.6          | 22.3        |
| 161 United Kingdom | 1992 | 1988/1990       | 2-4 years       | 207        | 7d WR | 207           | 1146       | 36          | 12.5      | 45          | 35.3   | 159       | 52.2             | 90            | 29.6          | 65          |
| 12 Greece  | 1997 | 2-3 years       | 3a              | 236        | 3a ER  | 236           | 1002       | 42          | 14.4      | 47          | 38.3   | 136       | 46.7             | 76            | 25.6          | 60          |
| 162 Australia | 1995 | 2-3 years       | 3412            | 24 h       | 3412   | 1310          | 49          | 15          | 49         | 33.3    | 175       | 53.6             | 97            | 27.7          |             |
| 163 United Kingdom | 2002 | 1996            | 3-4 years       | 863        | 3d ER  | 863           | 1356       | 47          | 13.9      | 47          | 31.8   | 174       | 54.3             | 105           | 32.2         |             |
| 164 New Zealand | 2004 | na              | 1-2 years       | 77         | 3d WR | 77            | 885        | 34          | 15.1      | 33          | 33.9   | 117       | 52.9             | 67            | 28.4         |             |
| 165 Denmark  | 2004 | 2001/2002       | 2.5 years       | 121        | 7d ER  | 121           | 1453       | 42          | 11.9      | 58         | 36.1   | 185       | 52.1             | 123           | 43           |
| 166 Belgium  | 2008 | 2002/2004       | 2.5-3 years     | 197        | 3d ER  | 197           | 1415       | 55          | 15.7      | 49          | 31.2   | 167       | 52.8             | 105           | 29.5         | 81          |
| 167 Netherlands | 2007 | 2004/2005       | 2-3 years       | 640        | 2d ER  | 640           | 1342       | 44          | 13        | 45          | 29     | 192       | 58               | 122           | 34.1         |             |

Abbreviations: CHO, carbohydrate; ER, estimated record; FFQ, Food Frequency Questionnaire; WR, weighed record; % En, energy percentage. % Energy values for total carbohydrate and components are reported as published. Where % energy was not given, this was calculated as intake in g x 3.75/energy in kcal x 100, since assumed to be reported as monosaccharide equivalents. aResults as reported in publication, as ‘complex carbohydrate’ and ‘sugars’. However, complex carbohydrate and sugars do not add up to total carbohydrate as given. bResults as reported in publication, as ‘sugar’. May actually be sucrose only.
### Table 4. Dietary intakes of infants and young children where sugars information is reported as added sugars (as described by authors, definitions not usually provided)

| Reference | Country     | Publication year | Assessment year | Age, range | n  | Dietary method | Energy, kcal | Protein, g | Protein, % En | Fat, g | Fat, % En | CHO, g | CHO, % En | Added sugars, g | Added sugars, % En |
|-----------|-------------|------------------|-----------------|------------|----|----------------|--------------|------------|---------------|--------|----------|--------|-----------|------------------|---------------------|
| 168       | Germany     | 1999             | 1985/1996       | 9 - 12 months | 66 | 3d WR         | 852          | 14.7       | 26            | 29.1    | 107       | 56.4   | 17        | 4.1              |                     |
| 169       | Norway      | 2003             | 1998/1999       | 12 months   | 64 | 7d WR         | 794          | 28         | 14.7          | 26     | 29.1      | 107    | 56.4      | 17               | 4.1                 |
| 170       | Germany     | 1998             | na              | 1 - 3 years  | 230| 3d WR         | 985          | 32.2       | 13.5          | 39.3    | 37.4      | 118    | 49.1      | 24               | 9                   |
| 171       | Bulgaria    | 1998             | 1998            | 1 - 3 years  | 154| 24 h          | 1400         | 39         | 11.7          | 55     | 34.7      | 187    | 53.6      | 32               | 9                   |
| 172       | Norway      | 2004             | na              | 2 years     | 187| 7d WR         | 995          | 32.9       | 13.5          | 36.5    | 32.8      | 132    | 53.7      | 33               | 13.3                |

Abbreviations: CHO, carbohydrate; WR, weighed record; % En, energy percentage. % Energy values for total carbohydrate and components are reported as published. Where % energy was not given, this was calculated as intake in g × 3.75/energy in kcal × 100, since assumed to be reported as monosaccharide equivalents.

### Table 5. Dietary intakes of infants and young children where sugars information is reported as NMES (total sugars minus: lactose in milk and milk products and sugars present within the cellular structures of fruits and vegetables)

| Reference | Country     | Publication year | Assessment year | Age, range | n  | Dietary method | Energy, kcal | Protein, g | Protein, % En | Fat, g | Fat, % En | CHO, g | CHO, % En | NMES, g | Starch, g/day | Starch, % En |
|-----------|-------------|------------------|-----------------|------------|----|----------------|--------------|------------|---------------|--------|----------|--------|-----------|---------|---------------|-------------|
| 20        | United Kingdom | 1992             | 1986            | 6 - 12 months | 488| 7d ER         | 868          | 31         | 14.1          | 36     | 36.9      | 113    | 49         | 25      | 10.7         | 42         | 18.0          |
| 22        | United Kingdom | 1995             | 1992/1993       | 1.5 - 4.5 years | 1675| 4d ER         | 1140         | 37         | 13            | 46     | 35.9      | 155    | 51.1       | 57      | 18.7         | 68         | 22.3          |
| 158       | United Kingdom | 2007             | 1994            | 1.5 years   | 1026| 3d ER         | 1105         | 42         | 14.4          | 47     | 38.3      | 136    | 46.7       | 36      | 12.3         | 60         | 20.4          |
| 159       | United States | 2007             | 2001/2004       | 1 - 3 years | 1617| 3d ER         | 1139         | 41         | 14.4          | 42     | 33.2      | 135    | 47.4       | 45      | 14.8         |            |               |
| 163       | United Kingdom | 2002             | 1996            | 3 - 4 years | 863 | 3d ER         | 1356         | 47         | 13.9          | 56     | 37.1      | 176    | 49.2       | 58      | 17.3         | 84         | 23.4          |

Abbreviations: CHO, carbohydrate; ER, estimated record; NMES, non-milk extrinsic sugars; % En, energy percentage. % Energy values for total carbohydrate and components are reported as published. Where % energy was not given, this was calculated as intake in g × 3.75/energy in kcal × 100, since assumed to be reported as monosaccharide equivalents.
Dietary intakes of infants and young children where sugars information is reported as sucrose

Table 6.

| Reference | Year | Publication | Age, range | n | Age group | Energy, kcal | Protein, g | Fat, g | CHO, g | Sucrose, g | %E | %E | %E |
|-----------|------|-------------|------------|---|-----------|-------------|-----------|-------|--------|-----------|------|------|------|
| United States | 1988 | 1988 | 13-23 months | 46 | 2,5 | 1167 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| 1988/1994 | 6 years | 2,5 | 1167 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| Finland | 1992 | 1989 | 13-23 months | 46 | 2,5 | 1167 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| 1988/1994 | 6 years | 2,5 | 1167 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| United States | 1992 | 1989 | 13-23 months | 46 | 2,5 | 1167 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| 1988/1994 | 6 years | 2,5 | 1167 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| Finland | 1999 | 1994 | 3-5 years | 173 | 10 | 1217 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| 1994/1995 | 6 years | 2,5 | 1167 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| United States | 1999 | 1999 | 13-23 months | 46 | 2,5 | 1167 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| 1994/1995 | 6 years | 2,5 | 1167 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| Finland | 1999 | 1994 | 3-5 years | 173 | 10 | 1217 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| 1994/1995 | 6 years | 2,5 | 1167 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| United States | 2002 | 2002 | 1-3 years | 173 | 10 | 1217 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| 2002/2004 | 6 years | 2,5 | 1167 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| Finland | 1999 | 1994 | 3-5 years | 173 | 10 | 1217 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| 1994/1995 | 6 years | 2,5 | 1167 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| United States | 2002 | 2002 | 1-3 years | 173 | 10 | 1217 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |
| 2002/2004 | 6 years | 2,5 | 1167 | 30 | 15 | 20 | 33 | 43 | 37 | 27 | 33 | 24 |

Abbreviations: CHO, carbohydrate; ER, estimated record; WR, weighed record; %E, energy percentage.

Timing of introduction of weaning food and type of food given

There is very limited information on the role of eating behaviours such as eating frequency or portion sizes on the intake of carbohydrate or sugars in young children. However, there is literature on the timing of introduction of foods to infants and the type of foods that are introduced first. There is difficulty in interpreting these studies overall because of the changes in recommendations for timing of introduction of complementary feeding and the implementation of these recommendations in the different countries. Before 2001, the World Health Organisation (WHO) global recommendation was that infants be exclusively breastfed for between 4 and 6 months before the introduction of complementary foods. The same year, Kramer and Kakuma published an analysis comparing exclusive breastfeeding for 6 months vs 3-4 months. The WHO commissioned an Expert Consultation to review this work, which led to the recommendation for exclusive breastfeeding for 6 months, with introduction of complementary foods and continued breastfeeding thereafter. This recommendation has been adopted widely by countries around the globe. In 2008, the ESPGHAN (European Society for Paediatric Gastroenterology and Nutrition) issued a position statement, focussing on healthy infants in Europe, stating that while exclusive breastfeeding for ~6 months is a desirable goal, all infants should start complementary feeding by 26 weeks (but not before 17 weeks). In this analysis of different developed countries, the timing of introduction and type of food given in infants therefore vary, both according to the recommendation in...
the surveyed country at the time of survey and the degree to which it has been taken up by the population.

According to a five EU countries study, solids were introduced in 6% of formula fed infants at the age of 3 completed months, in 37.2% at 4, 96.2% at 6, and 99.3% at 7 completed months, respectively.29 The median age of introduction was 19 weeks. Among the breastfed infants only 0.6% had received solids at the age of 3 completed months, whereas 17.3%, 87.1% and 97.7% received solids at the ages of 4, 6 and 7 months, respectively, with a median age of introduction of 21 weeks.30 However, the type of foods and the main sources of carbohydrate have not yet been reported for this study.

The Euro-Growth study (11 participating countries) reported that fruit (73%) and cereals (51%) were the first foods given to infants.31 In an Italian study, similar results were found, with 73% having fruit as the first solid food introduced and 64% having cereals.31 In the ABIS (All Babies in Southwest Sweden) study, data on over 10,000 infants, the most common first foods were vegetables, specifically, potatoes, carrots and sweet corn or products containing these.32 Most of the infants in a Bavarian study received a mash of vegetable, meat and potato as their first solid food.33 In the Glasgow Longitudinal Infant Growth Study, commercially prepared cereals were the most commonly used first weaning foods, used by 82% of the mothers (n = 127), and these were subdivided into baby rice (66%), baby cereal (9%) and rusks (3%).34 Only six infants (5%) were given fruit or vegetable purées as their first weaning food. These studies show some differences between countries in terms of the type of first food introduced. However, these foods are generally high in carbohydrate and fibre, being dominated by fruit, cereals or vegetables.

Some investigations have been conducted on the contribution of meals and sizes of portions in relation to energy intake and obesity, but little literature could be found in relation to carbohydrate intake. Pearcey and de Castro35 examined meal patterns and distribution of nutrients in 29 infants aged 9–16 months. They showed that in the morning (0600–1000 h), carbohydrate made a larger contribution to energy intake than in the afternoon (1100–1400 h) or evening (1700–2100 h), with the total intake of energy similar for these three time periods.36 The French nutrition survey conducted in 1999 reported intakes of specific foods by meal occasion for 3–14 year olds and showed that sugars containing foods such as baked goods and biscuits, as well as sugars themselves were consumed more at breakfast and snacks than at other meals, while fruit was consumed more at lunch than at any other meal.37 Beverages such as fruit juice and soft drinks were consumed fairly evenly over breakfast, lunch, dinner and snacks. It was not possible to separate this analysis further by age group and to examine young children only. According to the US FITS,37,38 beverages and foods typically consumed by infants and toddlers at morning snacks were water, cow’s milk, crackers and pure fruit juice. Beverages frequently consumed at afternoon snacks were water, whole cow’s milk, fruit-flavoured drinks and pure apple juice. The most frequently consumed foods for an afternoon snack at home or day care were crackers or non-baby food cookies. Carbonated beverages consumption differed according to the consumption location: they were consumed at away lunches by 16% of toddlers, compared with 3% at home and none at day care.38 Overall, carbohydrate intake is greater at breakfast than at other meal occasions.

Current recommendations for the population and suggested recommendations for children

The Joint FAO/WHO Expert Consultation on Carbohydrates in Human Nutrition recommended an optimum diet of at least 55% of total energy from a variety of carbohydrate sources for all ages except for children under the age of 2 years as fat should not be specifically restricted below this age.10 The optimum diet should be gradually introduced beginning at 2 years of age.10 Both the 1997 FAO/WHO Expert Consultation10 and the 2002 WHO/FAO Expert Consultation39 recommended that total carbohydrate should provide 55–75% total energy, with <10% total energy for free sugars. The FAO/WHO report of 2007 updated some of the key issues related to carbohydrates in human nutrition including terminology and classification, measurement, physiology and relationship to chronic diseases such as obesity, diabetes, cardiovascular disease and cancer.40 Based on these considerations, the European Food Safety Authority panel has recently proposed 45–60% energy as the reference intake range for carbohydrates and <10% energy for sugars.51

There are scant data in infants and young children to establish adequate carbohydrate and sugars recommendations for these age groups. In infants, it could be proposed that the minimum carbohydrate intake should be close to that provided by human milk, that is, 40% of total energy, and lactose should be the main digestible carbohydrate. After the second semester and until 2 years of age, children should gradually increase the intake of digestible carbohydrates, for example, starch up to 55%, although lactose should remain the major carbohydrate. Children of later ages should have a range of digestible carbohydrates similar to that recommended for adults.52 Although there is no official recommendation, based on the adult recommendations, it would be fair to recommend that intake of added sugars should be discouraged in infants. Indeed, longitudinal follow-up studies suggest that early flavour experiences and food preferences during infancy are likely to track into childhood and adolescence.43–45 Therefore, offering complementary foods without added sugars may be advisable not only for short-term health but also to set infant’s threshold for sweet at lower levels later in life.

Since sucrose is the most cariogenic sugar, its consumption should be minimised in toddlers and preschool children. However, there is no scientific evidence to establish a specific dietary intake value for sucrose and other free sugars. Guidelines should include, avoiding frequent consumption of juice or other sugar-containing drinks in bottles or beakers, discouraging the habit of a child sleeping with a bottle, limiting cariogenic foods to mealtimes, and establishing good dental hygiene.41

ABSORPTION OF CARBOHYDRATES IN INFANTS AND YOUNG CHILDREN

In young infants, digestible carbohydrate is obtained from breast milk or formula largely in the form of lactose, which is broken down by lactase in the brush border of the small intestine to glucose and galactose, which are then absorbed via the Sodium/Glucose Transporter.46 This transporter is expressed strongly from birth and its activity capacity is well able to cope with the amount of lactose consumed.47 Fructose, which is not present in breast milk but may be present in follow-on formula, or given as fruit juice early in life, is absorbed via the GLUT5 transporter.46,48 In animals, this transporter is known to be naturally low in abundance in early life, then increasing markedly and independently of diet before weaning.49 There is evidence that fructose transport is also delayed in humans. In young children, malabsorption following fructose ingestion was found to decrease from age 1 year to age 5 years.50 High intakes of fructose may therefore not be well tolerated in infants, with malabsorption leading to discomfort and diarrhoea. Evidence from animal studies indicates that increased intakes of fructose can stimulate expression of GLUT5, thus increasing fructose tolerance,51 which suggests that graded exposure in infancy, may overcome initial malabsorption. However, increased expression of GLUT5 remains to be demonstrated in humans.

Breast milk also contains carbohydrate in the form of oligosaccharides, which are not absorbed in the small intestine,
and enter the large intestine, where they stimulate the growth on bacterial types such as bifidobacteria, resulting in potential beneficial effects on the colon and on immune responses and susceptibility to infection. As a result of growing research on the beneficial effects of oligosaccharides in breast milk, ‘prebiotic’ carbohydrates are now being added to some infant and toddler formulas. The effects of oligosaccharides on the health of infants and toddlers are currently an area of very active research, but are outside the scope of the current review that concentrates on those carbohydrates absorbed in the small intestine.

Starch is not present in breast milk, but can exist as partially hydrolysed components in infant formulas. Starch is digested through the actions of pancreatic α-amylase and brush border glucoamylase and maltase. It has long been thought that the infant pancreas is able to synthesise α-amylase, but that very little is secreted; however, newer research suggests that the pancreas cannot synthesise α-amylase in the very young. Nevertheless, infant levels of mucosal glucoamylase are similar to those for adults and these are thought to be sufficient to deal with the starch content of the diet at that stage. At weaning, the infant is exposed to more complex forms of starch, and pancreatic α-amylase is then required. It is known that in adults a proportion of starch consumed, termed as ‘resistant starch’, is not digested and amylase is then required. It is known that in adults a proportion of starch consumed, termed as ‘resistant starch’, is not digested and amylase is then required. It is known that in adults a proportion of starch consumed, termed as ‘resistant starch’, is not digested and amylase is then required. It is known that in adults a proportion of starch consumed, termed as ‘resistant starch’, is not digested and amylase is then required. It is known that in adults a proportion of starch consumed, termed as ‘resistant starch’, is not digested and amylase is then required. It is known that in adults a proportion of starch consumed, termed as ‘resistant starch’, is not digested and amylase is then required. It is known that in adults a proportion of starch consumed, termed as ‘resistant starch’, is not digested and amylase is then required. It is known that in adults a proportion of starch consumed, termed as ‘resistant starch’, is not digested and amylase is then required. It is known that in adults a proportion of starch consumed, termed as ‘resistant starch’, is not digested and amylase is then required. It is known that in adults a proportion of starch consumed, termed as ‘resistant starch’, is not digested and amylase is then required. It is known that in adults a proportion of starch consumed, termed as ‘resistant starch’, is not digested and amylase is then required. It is known that in adults a proportion of starch consumed, termed as ‘resistant starch’, is not digested and amylase is then required. It is known that in adults a proportion of starch consumed, termed as ‘resistant starch’, is not digested and amylase is then required. Starch escaping absorption is fermented and like the starch they consume, a somewhat greater proportion than in adulthood. A sweet taste in nature indicates energy, which is needed for optimal growth and development. Therefore, it would make sense for the young to consume foods with a sweet taste. Breast milk is also sweet and this would confirm the link between a sweet taste and safe energy.

In infants, the idea that the brain might be sensitive both to the fluctuations in metabolism that occur in relation to nutrient intake and to long-term nutritional status remains relatively unexplored. The only area that has been much explored in relation to carbohydrate and the brain is that of sugars and cognition. Glucose has received particular attention because it is the preferred and primary source of energy for the brain, which requires a steady supply of around 100 mg/min of glucose in adulthood and approximately twice as much in childhood. The brain is energy greedy and particularly so in infancy when it consumes around 60% of dietary energy intake. The youngest children studied seem to have been 6–7 years. Studies in these children suggest areas of cognition that might be influenced by glucose intake in younger age groups before the age of 3. Overall, the studies report selective effects, that is, on some cognitive domains but not others, demonstrated by appropriate tests but overlooked if only tests of general ability are given. Most changes are seen in the domains of attention, selective aspects of memory and information processing.
The brain appears to be sensitive to short-term variation in the availability of glucose and the degree of mental effort or cognitive demand involved in tasks is important in determining those susceptible to the effects of glucose. In one of the few areas where infants have been studied directly, the role of sugars in behaviour was investigated. In one study, four different sugars (sucrose, glucose, fructose and lactose) were shown to differ in their ability to calm infants who were crying spontaneously. While sucrose and fructose proved equally effective at calming, lactose was equivalent to water, a surprising result since lactose is the carbohydrate component of human milk. Although calming is not a cognitive outcome, brain and cognitive development may be enhanced in an infant who is calm and not suffering stress. This study also demonstrates that sugars may have distinctive effects and need to be investigated individually. Research has shown, for example, that memory for spoken words in very young infants is enhanced after a glucose feed but it is not yet known if different sugars have differential effects. Other studies investigated the role of sugars as reinforcers in early learning. Providing a sucrose solution while making eye contact with a researcher was shown to induce a face preference, an important component of infant behaviour, for that researcher. On the other hand, in very preterm infants, those <31 weeks gestational age, high repeated exposure to sucrose impaired motor development, alertness and orientation after 5 weeks, so caution and more research are required. Until we have a sound database obtained from well-designed studies we cannot determine the parameters of the effects of sugars on infant cognition.

CONSEQUENCES FOR HEALTH OF SUGARS ‘EXCESS’

Nutrient dilution

Of the adverse consequences of excess sugars consumption suggested, one of the most frequently mentioned is an effect on the intake of other nutrients, particularly micronutrients, intake of which is said to be ‘diluted’ with increasing sugars consumption. There have been a number of investigations of nutrient intakes with increasing sugars intakes in young age groups, from various countries.

In the British NDNS of children 1.5–4.5 years, NMES intakes were divided into quintiles and related to intakes of energy and a number of key nutrients. No relationship between energy, iron, vitamin D and NMES was seen. There were decreasing intakes of calcium, zinc, thiamin, riboflavin, niacin and folate with increasing NMES intakes. Vitamin C intakes increased with increasing NMES. Intakes of nutrients were compared with Dietary Reference Values, and only for zinc was the top quintile on NMES associated with mean intake below the Estimated Average Requirement for 1–4 years.

Erkkola et al. investigated the effect of increasing intakes of added sucrose in Finnish children aged 3 years. Similarly to the British study, there was no association with energy intake. Higher sucrose intake was associated with lower intakes of most micronutrients, with no associations were seen with vitamin A, vitamin C or copper.

Overby et al. examined nutrient dilution in 4-year-old Norwegian children. There were no differences in energy intake with increasing ‘added sugar’. Again, no association with vitamin C intake was found.

Similar results have been shown in surveys of older children and in studies such as the DONALD (Dortmund Nutritional and Anthropometric Longitudinally Designed) study, where the age range is wide (2–18 years). While the measure of sugars varies from study to study, there are similarities in the results in terms of effects of increasing intake on other nutrients.

Overall intakes of most nutrients remain above recommended intake levels for all intakes of sugars, and it is generally admitted that it is difficult to determine sugars intakes above which intakes of other nutrients adversely compromise health. If there would be any concerns about the effects of sugars intakes on other nutrients, it would be only for the very highest levels of sugar intake.

Hyperactivity

Sugars have been implicated in hyperactivity, more recently described as ‘attention deficit-hyperactivity disorder’ since the 1970s, when Crook observed that removal of sucrose from the diet resulted in improved behaviour, which was reversed by its reintroduction. Correlation studies also showed a relationship between sugar intake and destructive and aggressive behaviour. Many early studies had methodological problems, lacking a control group or double blind testing. More recent and better controlled studies have failed to find a relationship between sugar and activity, both in normal children and in those with attention deficit-hyperactivity disorder. In 1995, Wolraich et al. published a meta-analysis of 16 studies with good study designs and control, and concluded that sugar did not affect the behaviour of children. Of these, a small number were on very young children. Both Roshon and Hagen and Wolraich et al. studied children 3–5 years of age and found no differences between those given sugar and those given artificial sweetener in terms of behaviour and activity. Some believe that any relationships seen in the early studies may be the result of reverse causality—that is, more active children need more energy and therefore consume more sugar. It is also thought that parental perception of effects may have influenced results: In a study investigating parental expectations, different behaviours appeared when parents were told that their child had been given sugar, even though all parents were given placebo. In recent years, interest in sugar and behaviour and hyperactivity has waned.

Overweight and obesity

Excess body weight is the sixth most important risk factor contributing to the overall burden of disease worldwide and ~110 million of children are now classified as overweight or obese. The prevalence of overweight and obesity has increased dramatically in children in the past three decades in both developed and emerging developing countries and it is associated with a higher prevalence of cardiovascular and metabolic diseases, including type 2 diabetes, dyslipidemia, hypertension, atherosclerosis and non-alcoholic fatty liver disease later in life.

The role of diet composition in weight control and obesity remains controversial. Unlike positive relationships being found for both fat and protein, investigations of dietary carbohydrate or of sugars do not suggest a positive relationship between intake of these and obesity. The number of studies in children is small, partly because of small number of countries that have good sugars intake data, as indicated above. Where data do exist, the relationship between sugars and body mass index (BMI) is negative. Gibson analysed this relationship in the United Kingdom using the NDNS data. Most of these analyses are on adults or older children; those conducted on children demonstrate inverse associations between intake of either total carbohydrates or NMES and BMI, even when taking underreporting into account. The same result was found in New Zealand using national survey data obtained using a 24-h dietary recall. No relationship was found in Australia, using national survey data obtained in the same way as in New Zealand. In a large study in Norway, a negative association was found between added sugar and BMI in those 13 years old, but a positive relationship in those aged 4 years. This is one of the few studies on young children. Unfortunately, all these studies are cross-sectional; longitudinal analyses are clearly needed.

In recent years, there has been growing interest in the role of fructose in obesity and metabolic disease, particularly with the
increased use of HFCS since the 1970s in the United States in particular and the concomitant increase in obesity over the same period. Some evidence has suggested a role for fructose and HFCS in obesity, through impacts on satiety, where fructose has been found in some studies to be less satiating than glucose or to have different effects on leptin and ghrelin. Efforts on triglycerides and diabetes risk have also been shown by some investigators, but not by others. In the past few years, there have been workshops and Expert Panels reviewing the emerging literature in this new area, but to date, no compelling evidence for a specific effect of fructose on obesity or metabolic disease has been shown. Difficulties such as study design problems, dietary manipulation issues, and intake levels above normal ranges confound conclusions. Moreover, the increase in HFCS use has not altered the ratio of fructose to glucose in the diet since ratios are similar to sucrose which was used as a sweetener before HFCS introduction. There is virtually no literature on physiological effects of fructose or HFCS on these types of outcomes in the very young age group that is the focus of this review and further work is needed for this age, as well as for the population in general, to clarify a specific role for fructose, if this exists.

Overall, the sparse literature suggests little evidence of a positive relationship between sugars in general or of any particular type in relation to body weight, with many studies showing an inverse relationship between the incidences of obesity with increased sugars intake. Clearly, more research is needed on younger children, since the studies reportedly have universally been of a cross-sectional design. However, most organisations recommend limiting sugar-containing foods for infants to reduce the likelihood of high consumption later in childhood and adolescence. ESPGHAN, for example, suggests that offering complementary foods without added sugars may be advisable for both short-term health and to set a lower threshold for sweet taste for later life.

There is a substantial literature on the association between intake of soft drinks and body weight, with a number of studies on young children. Some of these investigations indicate that a greater consumption of sugar-sweetened beverages, including sugared fruit juices and drinks and carbonated beverages, is associated with weight gain and obesity, but such association has not been found in other studies. A retrospective cohort design was used to examine the association between sweet drink consumption and overweight at follow-up among 10,904 children aged 2 and 3 years. Sweet drinks included vitamin C-containing juices, other juices, fruit drinks and sodas. Children who were at risk for overweight or were obese at baseline and consumed 1 to <2 drinks/day, 2 to <3 drinks/day and ≥3 drinks/day had a significantly higher risk to become or remain overweight compared with the referent (<1 drink/day). Increased beverage consumption (milk, 100% fruit juice, fruit drinks and soda) was associated with an increase in the total energy intake of the children but not with their BMI. Among a longitudinal cohort of African-American preschool children, high consumption of sugared sweetened beverages was significantly associated with an increased risk for obesity. In addition, children’s familial predisposition to obesity may differentially affect their beverage consumption patterns and indeed the risk of overweight and obesity.

Information on persistence of early sugar-sweetened beverage patterns throughout infancy and early childhood, and their influence on long-term dietary intake is very limited. In infancy and early childhood, many other factors such as lifestyle factors, including higher dietary intake and meal portion sizes and sedentarism, are significantly associated with obesity. However, overall, there is sufficient evidence for public health strategies to discourage overconsumption of sugary drinks as part of a healthy lifestyle. ESPGHAN suggests avoidance of frequent consumption of juice or other sugar-containing drinks in bottles or beakers, discouraging sleeping with a bottle and establishing good dental hygiene.

Insulin resistance and diabetes

Quite different genetic, nutrition and environmental factors influence the development of type 1 insulin-dependent diabetes and type 2 non-insulin-dependent diabetes. However, no causal relationship has been reported for dietary carbohydrates and insulin-dependent diabetes.

Insulin resistance (IR) may be modulated by different environmental factors including dietary habits. However, there are scant data on how nutrients and other dietary components affect IR in children. The relationship between energy-dense food consumption and IR is based on observational studies. As yet it remains unclear whether this is an effect of the food per se or whether it is due to higher body weight and fat mass. The substantial reduction of overweight in children achieved by a high-carbohydrate and low-fat diet given during 1 year results in a significant decrease of IR, associated with an increase in plasma adiponectin and decreased levels of ghrelin and leptin. However, any successful body weight reduction can be expected to improve IR and this finding is not necessarily attributable to the high-carbohydrate content of the diet. There have also been a number of epidemiological studies that have attempted to determine the association between intake of dietary sugars and markers of IR. Several studies have shown an inverse relationship, others have found an opposite effect, while some further studies have revealed no association. The studies showing a positive association are for South Asian adults in the United Kingdom and for African-American children in the United States which could be explained by a genetic susceptibility to the detrimental effects of dietary sugars given the recognised high prevalence of diabetes in these ethnic groups; thus, it has been reported that both insulin clearance and insulin sensitivity inversely correlated with dietary fat/carbohydrate ratio in African-American children.

Non-insulin-dependent diabetes is characterised by IR that is complicated by impaired insulin secretion at the time of appearance of hyperglycaemia and clinical diabetes. Although diet and nutrition are widely believed to have an important part in the development of non-insulin-dependent diabetes, specific dietary factors have not been clearly defined and much controversy remains about the relationship between the amount and types of dietary fat and carbohydrate and the risk of diabetes.

High glycaemic responses to milks and foods can have negative health consequences for adults. Although there is little information on these effects in infants and young children, it can be expected that high glycaemic responses also have negative health consequences in this age group. Higher glycaemic responses are mainly due to the rate of digestion and absorption in the gastrointestinal tract. Different carbohydrates have different rates of digestion and corresponding glycaemic responses. Carbohydrates only consisting of glucose units initiate a higher glycaemic response than carbohydrates consisting of glucose with another monosaccharide unit. Additionally, carbohydrates with a shorter chain length have higher glycaemic responses than carbohydrates with longer chain lengths. Differences in rate of digestion are also known for different types of starch (with a slower rate of digestion of amylose when compared with amylpectin).

Dental caries

The WHO World Oral Health Report of 2003 indicated that dental caries remain a major oral health problem in most industrialised countries, affecting 60–90% of school children and the majority of adults. According to the DMFT (Decayed, Missing and Filled Teeth)
Index, the disease level is high in the Americas and several Asian
countries, but relatively low in Africa.

It is anticipated that the incidence of dental caries will increase
in many developing countries as a result of a growing consump-
tion of sugars and inadequate exposure to fluoride. The report
emphasises the recommendation of the WHO report on the Global
Strategy on Diet, Physical Activity and Health that free (added)
sugars should remain <10% of energy intake and the consump-
tion of foods/drinks containing free sugars should be limited to a
maximum of four times per day, suggesting that this recom-
mendation would benefit the incidence of oral disease as well as
other chronic conditions. In a recent ILSI (International Life Sciences
Institute) monograph on oral and dental disease, further detail of
the connection between sugars and dental disease was given and
the relationship between the two shown to depend on the timing
of food consumption and the extent of fluoride exposure.

Prevalence of caries-free children has been shown to be
more associated with increased use of fluoride toothpaste than
reductions in sugar intake. Oral hygiene also has an important
role. Hence, a specific sugar intake in one individual may have a
different effect in another, depending on the local environment in
the mouth, and affected by fluoride, oral hygiene and other foods
eaten.

The form of caries seen in young children is called ECC (Early
Childhood Caries), a rampant form that can affect both the front
teeth and molars. There are only a few investigations on the
association between caries and sugar intake in this young age
group. Karjalainen et al. conducted a prospective study of
sucrose consumption on plaque and caries in participants of STRIP
(Special Turku Coronary Risk Factor Intervention Project). They
assessed diet and oral health in a subset of study participants at 3
years of age, and then again at 6 years. Daily sucrose intake at 3
years of those who developed caries by 6 years were higher than
those who were caries free, with no difference between the two
groups for total carbohydrate.

While there is strength in the Finnish study in that it is
longitudinal, a difficulty is that intake of sucrose only was
assessed, and other sugars, such as fructose, maltose and glucose
are similarly cariogenic. Another major study in this age group
is the British NDNS of preschool children aged 1.5-4.5 years,
where sugars were measured as both total and NMES. It was con-
cluded that NMES consumption was related to caries incidence,
although this was influenced by frequency of brushing.

However, Gibson and Williams carried out further analysis taking
social class and tooth brushing into account and found that the
only significant relationship between NMES and caries was in
children from non-manual social class who brushed less than once
a day. In those who brushed more often and in all children in
manual class, there was no relationship between NMES and caries.
Gibson has also investigated sugars from breakfast cereals, and
he found no relationship with caries.

Other studies in this age group have focussed on sugars
containing foods, particularly beverages. About 13% of children in
the NHANES III (1988-94) aged 2-10 years had a high carbonated
soda-pop intake pattern and they also had a significantly
higher dental caries experience in the primary dentition than did
children with other fluid consumption patterns. A fluid intake
pattern comprised mainly of milk, water or juice was less likely to
be associated with dental caries. In the Iowa Fluoride Study,
beverage and nutrient intake patterns were obtained from 3-day
diaries and they were also measured as both total and NMES. It was con-
cluded that NMES consumption was related to caries incidence,
although this was influenced by frequency of brushing.

In relation to dental caries, available data suggest a positive
association with intake of added sugars, although this is also
influenced by socioeconomic position and other lifestyle factors
such as frequency of eating and use of fluoride toothpaste. An
upper limit for intake of (added) sugars on the basis of a risk
reduction for dental caries has not yet been established.

Future research needs
Much confusion remains in determining the optimal dietary
carbohydrate composition for infants and toddlers. In the future,
specific dietary recommendations in infancy and childhood might be best approached in an individualised manner, incorporating diet-gene interactions that are critical for understanding the relationships between diet and metabolic disease risk.

In the cognitive area, future studies should incorporate neurodevelopment tests as well as measuring overall cognitive level. Indications of which functions might be vulnerable can be obtained from studies with older children.

The influences of the intake of different types of carbohydrates on obesity and diabetes remain to be evaluated in prospective cohort studies covering infancy and childhood.

CONFICT OF INTEREST

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