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European Journal of Clinical Nutrition (2012) **66,** 765–779

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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.

European Journal of Clinical Nutrition (2012) **66,** 765–779; doi:10.1038/ejcn.2012.27; published online 4 April 2012

Keywords: young children; dietary carbohydrates; dietary intake; obesity; dental caries; cognition

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'.[1] 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.[7] The different

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Received 15 August 2011; revised 21 December 2011; accepted 22 December 2011; published online 4 April 2012

Table 1. Overview of different terms used for sugars

Term	*Description*	*Reference*
Total sugars	All monosaccharides and disaccharides in a food, whether naturally occurring or added during processing or cooking	2,4
Added sugars	Sugars and syrups that are 'added to foods during processing or preparation'	5
	According to United States Department of Agriculture: only monosaccharides and disaccharides	
	According to United States Economic Research Service: includes oligosaccharides derived from corn syrups in its definition	7
	Others: all refined sugars (e.g., sucrose, maltose, lactose, glucose and dextrin) eaten separately at the table or used as ingredients in processed foods	6
Free sugars	Traditional: any sugars in a food that were not bound, including lactose	2
	Recent: all monosaccharides and disaccharides added to foods by the manufacturer, cook and consumer, plus sugars naturally present in honey, syrups and fruit juices	39
Refined sugars	Mainly European countries: sucrose, fructose, glucose, starch hydrolysates (glucose syrup, high-fructose corn syrup) and other isolated sugar preparations such as food components used as such or added during food preparation and manufacturing	9
Non-milk extrinsic sugars (NMES)	Total sugars minus: lactose in milk and milk products and sugars present within the cellular structures of fruits and vegetables	147
Sugar (without an 's')	Appears to have a number of meanings, in some cases, referring only to sucrose, while in other cases it includes 'all monosaccharides and disaccharides', or 'any free monosaccharide or disaccharide in a food'	8
Caloric sweeteners	Sweeteners consumed directly and as food ingredients, such as sucrose, from refined cane and beet sugars, honey, dextrose, edible sugars and commercial sweeteners and including some oligosaccharides	10

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

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.

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.

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.

Table 3 provides 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 Greece[12] 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 the lowest value for 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.

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% energy[13–15] 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.[14,16]

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,[17,18] with variations from woman to woman. Final concentration is reached within 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 States[14] 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 to 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 2002[(ref. 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,

Table 3. 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
Age group 1 year or less																		
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							65	31.7		
14	United States	2002	1988/1994	2–11 months	1620	24h	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	Australia	2009	1999–2001	9 months	341	FFQ/ history	341	853	28	12.9	34	35.9	110	48.5	75	33.0	35	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	France	2008	2005	1–12 months	447	3d WR	447	701	21	11.6	29	37.1	92	52.4	59	33.6		
Age group 1 year upwards																		
147	United States	1995	1987/1988	1–3 years	402	1/3d ER	402	1174							76	24.8		
155	Netherlands	1994	1987/1988	1–3 years	303	2d ER	303	1402	45	13.1	54	33.9	184	52.9	116	32.8		
14	United States	2002	1988/1994	1–2 years	2310	24 h	2310	1310	49	15	49	33.3	175	53.6	97	27.7		
156	Italy	1991	1989	1 year	164	24 h	164	996	49	19.5	34	30.5	128	49.9	46[a]	17.2[a]	28[a]	10.7[a]
157	Netherlands	1998	1992	1–3 years	351	2d ER	351	1306	45	13.9	47	31.8	174	54.3	105	33.2		
22	United Kingdom	1995	1992/1993	1.5–4.5 years	1675	4d ER	1675	1140	37	13	46	35.9	155	51.1	87	28.6	68	22.3
158	United Kingdom	2007	1994	1.5 years	1026	3d ER	1026	1105	42	14.4	47	38.3	136	46.7	76	25.6	60	20.4
159	United States	2007	2001/1902	1–3 years	1617	3d ER	1617	1139	41	14.4	42	33.2	135	47.4	84	27.7		
15	New Zealand	2007	na	1–4 years	40	24 h	40	1379	50	13.4	48	31.7	195	54.5	114	31	88	24
153	United States	2008	na	1–2 years	77	3d WR	77	885	34	15.1	33	33.9	117	52.9	67	28.4		
160	France	2008	2005	1–3 years	259	3d WR	259	1006	41	16.4	37	32.8	128	51.0	76	30.8		
Age group 2 years upwards																		
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	21.2
12	Greece	1997	na	2–3 years	na	3d ER	na	1360	53	15.6	62	42.0	143	42	77	21.3		
162	Australia	1998	1995	2–3 years	383	24 h	383	1519	53	14.2	57	33.1	200	52.1	115	26.8		
163	United Kingdom	2002	1996	3–4 years	863	3d ER	863	1356	47	13.9	56	37.1	176	49.2	91	25.1	84	23.4
164	New Zealand	2004	1999	2–3 years	34	2d WR	34	1206	40	13.3	39	28.8	182	57.9	97	30.3		
165	Denmark	2004	2001/2002	2.5 years	121	7d ER	121	1453	42	11.9	58	36.1	185	52.1	43[b]	12[b]		
166	Belgium	2008	2002/2004	2.5–3 years	197	3d ER	197	1415	55	15.7	49	31.2	187	52.8	105	29.5	81	23.1
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 × 3.75/energy in kcal × 100, since assumed to be reported as monosaccharide equivalents. [a]Results as reported in publication, as 'complex carbohydrate' and 'sugars'. However, complex carbohydrate and sugars do not add up to total carbohydrate as given. [b]Results 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*
Age group 12 months or less															
168	Germany	1999	1985/1996	9–12 months	66	3d WR	852							9	4.1
169	Norway	2003	1998/1999	12 months	64	7d WR	794	28	14.7	26	29.1	107	56.4	17	9.1
Age group 1 year upwards															
170	Germany	1998	na	1–3 years	230	3d WR	985	32.2	13.5	39.3	37.4	118	49.1	24	9.0
171	Bulgaria	1998	1998	1–3 years	154	24 h	1400	39	11.7	55	34.7	187	53.6	32	9
Age group 2 years upwards															
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*	*NMES, % En*	*Starch, g/day*	*Starch, % En*
Age group 12 months or less																	
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
Age group 1 year upwards																	
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		
Age group 2 years upwards																	
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.

Table 6. Dietary intakes of infants and young children where sugars information is reported as sucrose

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	Sucrose, g	Sucrose, % En
Age group 12 months or less															
14	United States	2002	1988/1994	2–11 months	1620	24 h	888	25	11.1	37	37.6	116	52.3	14	5.9
Age group 1 year upwards															
19	Finland	1992	1988	13–23 months	46	3/2d ER	1167	46	15.8	42	32.4	155	53.1	34	10.9
173	Finland	1996	1989	1–3 years	30	3d ER	1357							47	14
14	United States	2002	1988/1994	1–2 years	2310	24 h	1310	49	15	49	33.3	175	53.6	30	8.6
22	United Kingdom	1995	1992/1993	1.5–4.5 years	1675	4d ER	1140	37	13	46	35.9	155	51.1	39	12.7
174	Finland	1999	1993/1995	13 months	593	3/4d ER	973	42	17.4	29	26.6	136	56	14	5.3
15	New Zealand	2007	na	1–4 years	40	24 h	1379	50	13.4	48	31.7	195	54.5	47	12.9
Age group 2 years upwards															
148	Sweden	1986	1980/1981	2 years	82	7d ER								34	9.4
174	Finland	1999	1993/1995	3 years		3/4d ER	1217	45	14.9	43	32.1	150	49.2	31	9.5
175	Sweden	2001	1998	3–5 years	109	7d ER	1555	52	14	60	36	198	52	47	12
164	New Zealand	2004	1999	2–3 years	34	2d WR	1206	40	13.3	39	28.8	182	57.9	45	13.9
176	Sweden	2006	na	4 years	95	7dER	1494	52.2	15	54.3	33	194	54.6	45	12
24	Finland	2009	2004	3 years	471	3d ER	1246	50	16	43	31	165	53	41	13.3

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

fruit juice contributed 17% and 'soft drinks, not low calorie' 12%. Cereals and cereal products made a substantial contribution (23%), as well as 'sugars, preserves and confectionery' (23%) and milk and milk products (17%). In the 1992/1993 survey, beverage contribution was 40% of NMES intake, within which fruit juice was 7% and 'soft drinks, not low calorie' 32%.[22] The comparison of the two UK survey results for NMES confirms the findings seen with total carbohydrate on a reduction in contribution of 'soft drinks, not low calories' to carbohydrate intake. The contribution of cereals and cereal products at 21%, and 'sugars, preserves and confectionery' at 25% did not change much since the previous survey. Milk and milk products contribution was lower (7% vs 17%) in the older survey, indicating an increase over time.

Of the very few other published reports of sources of specific monosaccharide and disaccharide intakes in infants and young children, a Finnish study has reported sources of added and naturally occurring sucrose in the diets of 3-year-old children.[24] Juice drinks were by far the largest contributor to added sucrose (which was 85% of sucrose intake), at 27% of intake, with yogurt and cultured milks next at 13%, chocolate and confectionery at 12% and sweet bakery at 11%. For naturally occurring sucrose, fresh fruit and berries were the largest contributor at 38%, with fruit and berry juice at 23%.[24] In the United States, where fructose is used more often as a sweetener than in Europe, Marriott *et al.*[16] have reported sources of total, added and naturally occurring fructose intake from the 1998 to 2004 NHANES. For children aged 1–3 years, added fructose represented 65% of all fructose intakes, somewhat lower than for older age groups.[16] The contributors to added fructose of 1–3 years were beverages (39%), grain products (26%), sugars and sweets (16%) and milk and milk products (14%). Naturally occurring fructose was largely from fruit and fruit products at 91% of intake. When expressed as a proportion of total fructose intake, fruit and fruit products were 38%, beverages 25%, sugars and sweets 10% and milk and milk products 9%.

All these studies indicate the major contribution of beverages (for example, fruit juices, juice drinks or soft drinks) to the intake of 'added sugars' by young children, whether that be expressed as NMES, sucrose or fructose, depending on the measure used in the country reporting.

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)[25] 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[26] 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.[27] 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).[28] 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.[29] 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 most infants.[30] 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 (5%).[34] Only six infants (5%) were given fruit or vegetable purees 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 Castro[35] 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.[35] 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.[36] 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 Consultation[10] and the 2002 WHO/FAO Expert Consultation[39] 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.[41]

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.[42] 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,[49] 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.[51] 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.[52] 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;[53] however, newer research suggests that the pancreas cannot synthesise α-amylase in the very young.[54] 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.[52] 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 absorbed in the small intestine.[11,55] The extent of malabsorption of starch in infants has been little studied but recent work using ^{13}C starch incorporated into foodstuffs and then detected in breath, suggests that infants may not absorb on average ~20% of the starch they consume, a somewhat greater proportion than in adults.[56] The starch escaping absorption is fermented and like non-digested oligosaccharides, may have a number of benefits for the colon and overall health. The effects of starch escaping digestion and absorption are, like that of undigested oligosaccharides, outside the scope of the current review.

ROLE OF CARBOHYDRATE IN DEVELOPMENT OF FOOD PREFERENCES, EFFECTS ON BEHAVIOURAL ASPECTS OF FOOD CHOICES

Taste is an important determinant of food preferences, and food preferences are crucial in infants' and children's food choices. It is generally assumed that they eat what they like and refuse the food they dislike.[57] There are two ways in which carbohydrate has an important role in the development of food preferences and, consequently, in food choice behaviour of infants and toddlers. One relates to our innate preference for sweet tastes and the other relates to our ability to learn food preferences based on the associations with the consequences of consumption (flavour-nutrient learning).

Human infants are born with an innate preference for sweet. Tasting a sweet solution elicits facial relaxation in the infant, with sucking and licking movements and an expression of enjoyment resembling a smile.[58–61] This has been shown for sucrose concentrations ranging from 0.1 to 1 M. Furthermore, most infants and toddlers prefer a sweet solution over water.[62–64] Infants can tolerate a painful stimulus, such as blood taking, with less distress if provided with a sweet solution to drink at the same time.[65] It is thought that this innate preference for sweet has an evolutionary basis. A sweet taste in nature indicates energy, which is needed for optimal growth and development.[43,66–68] Therefore, it would seem safe for the young to consume foods with a sweet taste. Breast milk is also sweet,[62,69] and this would confirm the link between a sweet taste and safe energy.

Although a sweet taste is appreciated, there are individual variations in the extent of acceptance among infants[60,64,70] and children.[71] Schwartz *et al.*[64] showed that although a sweet lactose solution was preferred over water, some infants rejected it. This inter-individual variation in sweet taste acceptance seems to increase during the first year of life.[62–64]

Two factors, genetics and sweet taste early experience, may account for these inter-individual variations. First, it is likely that genetic differences have a role.[67,72,73] In one study, children who were most sensitive to bitter tastes preferred higher levels of sweetness in sucrose solutions, cereals and beverages.[73] In contrast, other studies indicate that children and adults who are most sensitive to bitter tastes (the so-called tasters and super tasters) are often sweet dislikers.[72,74] Second, experience with sweet foods and beverages may modulate children's sweetness preference and their consumption pattern. Children who were routinely fed sugar water during infancy had a higher consumption of sucrose solutions at 6 months of age [62] and in their second year of life.[63] In all, 6- to 10-year-old children who experienced sugar water during infancy preferred solutions with higher levels of sucrose compared with children who were rarely or minimally exposed to sugar water in infancy.[71] Similarly, 4- to 7-year-old children whose mothers routinely added sugar to their children's foods were more likely to prefer apple juices with added sugar as well as cereals with higher sugar content.[75]

Because a sweet taste is highly liked, children can learn to like initially neutral or new foods by adding sweetness to these foods. This process is called flavour-flavour learning, as an association is established between a new or neutral food and the liked sweet taste resulting in an increased liking for that food.[67,76–78]

Besides the innate preference for sweetness, carbohydrate has an important role in the development of food preferences and behaviour. This is the process of flavour-nutrient learning, where an association is established between the flavour of a food and the pleasantly satiating effects of energy. Due to this principle, humans are predisposed to learn to like high-energy foods.[66,67,76,77] Flavour-nutrient learning has been effectively used in children below the age of 5 years.[79–81] In these studies, fruity flavours and new tastes such as orange chocolate, bubblegum and maple almond were associated with fat or carbohydrate in yoghurt drinks. Various studies indicate that flavour-nutrient learning influences children's food consumption patterns. Observations of food choices during lunchtime among 2-year-old children reveal that the children choose foods that are relatively high in energy. Meat and starchy products were mainly chosen, whereas vegetables–which are low in energy–were least chosen.[82] Moreover, within the low-energy food category of fruit and vegetables, children prefer the fruits and vegetables that are more energy dense.[83]

Carbohydrate influences food preferences and food choices of infants and toddlers via our innate preference for sweet and our ability to learn to like foods that are relatively energy dense through the process of flavour-nutrient learning.

ROLE OF CARBOHYDRATE ON COGNITION

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[84] and approximately twice as much in childhood.[85] 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.[86] 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.[86,87]

The brain appears to be sensitive to short-term variation in the availability of glucose[88] and the degree of mental effort or cognitive demand involved in tasks is important in determining those susceptible to the effects of glucose.[89]

In one of the few areas where infants have been studied directly, the role of sugars in several aspects of behaviour was investigated. In one study,[90] 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 calming agents, 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[91] 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.[92] 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.[93] Until we have a sound data base 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.[94] 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.[94] 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.*[24] 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, while no associations were seen with vitamin A, vitamin C or copper.

Overby *et al.*[95] 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.[95]

Similar results have been shown in surveys of older children[96] and in studies such as the DONALD (Dortmund Nutritional and Anthropometric Longitudinally Designed) study, where the age range is wide (2–18 years).[6] 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[97] 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 behaviours.[98] Many early studies had methodological problems, lacking a control group or double blind testing.[85] 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.*[99] 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[100] and Wolraich *et al.*[101] 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.[100,101] 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.[102] 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.[103] 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 $\sim$110 million of children are now classified as overweight or obese.[104] The prevalence of overweight and obesity has increased dramatically in children in the past three decades in both developed and emerging developed 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.[105]

The role of diet composition in weight control and obesity remains controversial.[106] Unlike positive relationships being found for both fat and protein,[28] 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 the 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.[107] 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.[108] No relationship was found in Australia, using national survey data obtained in the same way as in New Zealand.[109] 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.[95] 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.[110-112] Effects on triglycerides and diabetes risk have also been shown by some investigators, but not by others.[111,113-115] 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.[116,117] 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.[116] 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.[28]

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.[116,118-120] 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.[121] 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 $\geqslant 3$ 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.[122] Among a longitudinal cohort of African-American preschool children, high consumption of sugar-sweetened beverages was significantly associated with an increased risk for obesity.[123] In addition, children's familial predisposition to obesity may differentially affect their beverage consumption patterns and indeed the risk of overweight and obesity.[124]

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.[125] 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.[126] 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.[28]

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.[127] 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.[128] 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.[127]

There have also been a number of epidemiological studies that have examined the association between intake of dietary sugars and markers of IR.[129] 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 Unites 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.[130]

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.[131]

High glycaemic responses to milks and foods can have negative health consequences for adults.[132-134] 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.[135] 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.[136] Differences in rate of digestion are also known for different types of starch (with a slower rate of digestion of amylose when compared with amylopectin).[137,138]

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 consumption of sugars and inadequate exposure to fluoride.[139] 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 consumption of foods/drinks containing free sugars should be limited to a maximum of four times per day,[42] suggesting that this recommendation 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.[140]

Prevalence of caries-free children has been shown to be more associated with increased use of fluoride toothpaste than reductions in sugar intakes. 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.[140]

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.*[141] 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 intakes 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.[141]

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.[140] 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 concluded that NMES consumption was related to caries incidence, although this was influenced by frequency of brushing.[142] 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[143] 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 soft drink consumption 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.[144] In the Iowa Fluoride Study, beverage and nutrient intake patterns were obtained from 3-day food and beverage diaries completed at 1, 2, 3, 4 and 5 years of age; primary dentition was examined and weight and height measured at 4.5–6.9 years of age.[145] Children with caries had lower family incomes, less educated parents, heavier mothers and higher soda-pop intakes at 2, 3 and 1–5 years than children without caries.

The relationship between sugars and dental caries is therefore complex. While sugars make some contribution to caries, this is confounded by socioeconomic status, frequency of food consumption and oral hygiene, particularly the use of fluoride containing toothpaste and frequency of brushing. It has been suggested that the sugar/caries relationship is sigmoid in nature, with western societies on the upper flattened area, implying that a large reduction in sugars intake would be required for a small change in caries incidence.[146] Reducing frequency of consumption and improving oral hygiene may have a much more noticeable impact.

CONCLUSION

There are four major factors that limit the amount of comparable information about carbohydrate intakes in infants and young children. These are

(a) the limited number of studies performed in infants and young children worldwide;
(b) the differing approaches to the analysis of carbohydrate, giving different figures in food composition databases;
(c) the wide variety of terms used to describe intakes of sugar components in the diet;
(d) the dearth of information about starch intakes in the world, due in part to lack of interest in this nutrient, and in part to lack of information about starch content of foods in food composition databases in many countries.

In contrast to the large literature on breast and formula feeding, relatively little attention has been paid to the complementary feeding period, and there are a very limited number of studies for infants <1 year of age examining sources of carbohydrate, starch and sugars. There are also very few studies in toddlers.

Data suggest that sweet taste is preferred in early infancy and later food choices, but a clear association cannot be established yet.

It is no surprise, therefore, that the literature relating carbohydrate intake to the development of brain and to cognition is sparse and, for the age group under consideration here, almost non-existent.

Nutrient dilution consecutive to high-carbohydrate intakes seems to be a concern only for the very highest levels of intake.

In relation to obesity, there is no clear evidence that altering the proportion of total carbohydrate in the diet is an important determinant of energy intake and therefore BMI. Only a few studies have found a relationship between consumption of sugars or added sugars and obesity, with those positive studies limited to beverages and foods containing sugars. However, many other lifestyle factors, including the higher dietary intake, meal portion sizes and sedentarism, are significantly associated with obesity, therefore it would be wise for public health strategies to discourage overconsumption of sugary drinks as part of a healthy lifestyle.

Results are controversial on the relationship of intake of dietary sugars to IR, glucose intolerance and diabetes, and there is insufficient evidence on which to make recommendations in relation to digestible carbohydrate intakes. There is a lack of information on the different glycaemic responses of carbohydrates in children and their relationships with later life health have not been established.

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 type of carbohydrates on obesity and diabetes remain to be evaluated in prospective cohort studies covering infancy and childhood.

CONFLICT OF INTEREST

Dr Christophe Matthys is employed by ILSI Europe. Dr Stephen, Professor de Graaf, Dr Isaacs, Professor Maffeis and Professor Gil received an honorarium from ILSI Europe for their participation in this publication and/or reimbursement of their travel and accommodation costs for attending the related meetings.

ACKNOWLEDGEMENTS

All authors wrote, read and approved the final manuscript. AS and AG had primary responsibility for final content. This work was commissioned by the Nutrient Requirements Task Force of the European Branch of the International Life Sciences Institute (ILSI Europe). Industry members of this task force are Barilla G and R Fratelli, Coca-Cola Europe, Danone, DSM, Kellogg Europe, Nestle, Royal FrieslandCampina, Südzucker/BENEO Group, Ulker Bisküvi, Unilever. This publication was coordinated by Ms Evangelia Grammatikaki and Dr Christophe Matthys, scientific project managers at ILSI Europe. The ILSI Europe expert group on Role of Dietary Carbohydrates in the Diet of Infants and Toddlers would like to thank the past scientific project managers from ILSI Europe involved in this expert group: Ms Agnès Le Carré and Dr Stéphane Vidry. Further, the expert group would like to thank Ms Ria Dewit, Mr Sergi Migallon and Mr Frederic Timmermans for all the administrative support. For further information about ILSI Europe, please call +32 2 771 00 14; E-mail: info@ilsieurope.be or http://www.ilsi.eu. The opinions expressed herein are those of the authors and do not necessarily represent the views of ILSI Europe nor those of their companies.

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