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PEDIATRIC REVIEW

Timing of the introduction of complementary feeding and risk of childhood obesity: a systematic review

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The World Health Organisation recommends exclusive breastfeeding until 6 months of age and continued breastfeeding until 2 years of age or beyond. Appropriate complementary foods should be introduced in a timely fashion, beginning when the infant is 6 months old. In developing countries, early or inappropriate complementary feeding may lead to malnutrition and poor growth, but in countries such as the United Kingdom and United States of America, where obesity is a greater public health concern than malnutrition, the relationship to growth is unclear. We conducted a systematic review of the literature that investigated the relationship between the timing of the introduction of complementary feeding and overweight or obesity during childhood. Electronic databases were searched from inception until 30 September 2012 using specified keywords. Following the application of strict inclusion/exclusion criteria, 23 studies were identified and reviewed by two independent reviewers. Data were extracted and aspects of quality were assessed using an adapted Newcastle–Ottawa scale. Twenty-one of the studies considered the relationship between the time at which complementary foods were introduced and childhood body mass index (BMI), of which five found that introducing complementary foods at <3 months (two studies), 4 months (2 studies) or 20 weeks (one study) was associated with a higher BMI in childhood. Seven of the studies considered the association between complementary feeding and body composition but only one study reported an increase in the percentage of body fat among children given complementary foods before 15 weeks of age. We conclude that there is no clear association between the timing of the introduction of complementary foods and childhood overweight or obesity, but some evidence suggests that very early introduction (at or before 4 months), rather than at 4–6 months or >6 months, may increase the risk of childhood overweight.

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INTRODUCTION

Obesity is associated with cardiovascular disease, type II diabetes, musculoskeletal disorders and some cancers.[1] Reducing the burden of overweight and obesity is a public health policy priority for most developed countries. The estimated direct cost of overweight and obesity in the United Kingdom was £4.2 billion in 2007, while in the United States of America, medical spending attributable to obesity only was $147 billion in 2008.[2,3] According to the most recent Foresight Report, 'the causes of obesity are extremely complex, encompassing biology and behaviour, but set within a cultural, environmental and social framework'.[2] A permissive obesiogenic environment has allowed a biological predisposition to obesity to become increasingly apparent.[2]

Children are no exception. An estimated 20% of school-aged children in the European Union and 31.8% of American children and adolescents were overweight or obese in 2010.[4,5] In the United Kingdom, the number of overweight or obese children in year 6 (aged 10–11 years) increased by 1.8% to 33.9% between 2006/7 and 2011/12.[4,6] A recent review found strong evidence of overweight tracking from childhood into adulthood, so if the number of overweight children is increasing, then so will the number of overweight adults.[7] The expectation is, therefore, that preventing excess weight gain in childhood will help to reduce adult overweight and obesity.

Early complementary feeding may be one risk factor for childhood obesity. Complementary feeding is defined as the transition from breast milk to the family diet and should occur when a baby is both developmentally ready and when breast milk is no longer enough to fulfil the nutritional requirements of the child.[8] The World Health Organisation (WHO) recommends exclusive breastfeeding until 6 months of age, after which breastfeeding should continue but appropriate complementary foods should be introduced in a timely fashion.[8] This advice has been adopted by many countries, including the United Kingdom and the United States of America.[9,10] In developing countries, early or inappropriate complementary feeding displaces breast milk and may lead to malnutrition and poor growth, resulting in stunting or wasting in childhood.[11] In developed countries, early introduction of complementary feeding has been linked to gastrointestinal problems, respiratory tract infections and an increased risk of allergy and atopy, but the relationship to growth and body composition is unclear. The consumption of specific foods may result in the epigenetic modification of metabolic programming, or there could be a hormonal link between the duration of exclusive breastfeeding and the introduction of complementary feeding on subsequent overweight and obesity.[12] The introduction of complementary food has been found to increase the secretion of the hormone ghrelin, which stimulates

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appetite and increases food consumption and a higher body mass index (BMI) in an animal model.[13]

In the United Kingdom, 75% of infants had been given complementary foods by 6 months,[14] while in the United States of America, <20% of infants were receiving only breast or formula milk at 6 months of age.[15] Signs that a baby is developmentally ready to receive complementary foods include the diminishment of the tongue-thrust reflex, being able to sit up and hold the head steady, being able to chew and control the movement of a bolus of food around the mouth and reaching and grabbing accurately.[9] Cues such as the baby watching his parents eat and not sleeping through the night are often misinterpreted as readiness to begin complementary feeding.[14]

In a recent review of the types of food given to infants during the complementary feeding period, we found that higher intakes of energy and protein in the second year of life were associated with greater BMI and percentage body fat in childhood but that more studies were needed in order to draw firm conclusions.[16,17] A systematic review, carried out in 2010, found no clear association between early or late introduction of solid foods and obesity in infancy, childhood or adolescence in developed countries.[18] The aim of the current review was to consider the relationship between the timing of the introduction of complementary feeding and BMI or body composition in children, updating the evidence presented by Moorcroft *et al.*,[18] using different inclusion criteria and including data from comparable populations in developing countries. We use the terms 'complementary foods' and 'solid foods' to describe any firm, soft or liquid food or drink other than milk (breast milk or formula milk), water or tea and 'complementary feeding' or 'weaning' to describe the period of transition from milk feeding to the family diet. Although the type of milk feeding (breast milk and formula milk) may have an independent effect on childhood overweight and obesity, the focus of this review is on the timing of the introduction of complementary foods and not on milk feeding, the effect of which has been the subject of previous reviews.[16]

MATERIALS AND METHODS

Search strategy and selection criteria

A systematic review of the literature was performed as previously reported, following the methodology originally presented by Lloyd *et al.*[17,19] Briefly, to identify published studies, which investigated the association between the timing of the introduction of complementary feeding and the risk of childhood overweight or obesity, a computerised search of the online databases PubMed (MEDLINE), ISI Web of Science and Scopus Sciverse, including all studies up to the end of September 2012 was carried out using the MeSH terms 'weaning', 'complementary food' and 'infant feeding' combined with 'obesity', 'body mass index' and 'body composition' in turn. Two investigators (JP and SCLE) independently searched for and reviewed studies for inclusion in the review, using the following inclusion/exclusion criteria.

Inclusion criteria:

1. Exposure variable: A measure of the age at which complementary foods were first introduced to infants, up to and including 12 months of age, regardless of the type of milk-feeding (breastfed, formula-fed or mixed-fed) given during infancy. This could be as a categorical variable (<6 months or ⩾6 months), or as a continuous variable, measured in days, weeks or months. The method by which the age at introduction of solid food was recorded should be stated (for example, infant feeding questionnaire, interview) but may be reported by the parent/carer.
2. Exposure variable: Appropriate definitions of timing and what constitutes complementary feeding should be given. Timing should refer to 'time of introduction of solids' or 'age at introduction of complementary feeding' while complementary foods should refer to food other than breast milk, formula milk, water or tea and not to the first introduction of formula milk to breastfed infants.
3. Outcome variable: Childhood measures of BMI or percentage body fat at one or more ages of childhood (4–12 years old) (The lower mean age of children was limited to 4 years to be reasonably sure that most children were beyond the adiposity rebound. The upper age of children was 12 years to reduce the risk of confounding associated with the long interval between the measurement of the exposure and the measurement of the outcome and a possible change in diet during adolescence). All measurements used to calculate BMI should have been taken by health professionals or trained investigators (not self-reported) to reduce measurement inaccuracies and reporting bias.
4. Measurements should be cross-sectional, or in the case of cohort studies, must have been carried out in the same individuals at baseline and at follow-up.
5. Childhood BMI status should be calculated using either US Centre for Disease Control (CDC) percentile charts[20] or International Obesity Task Force (IOTF) charts.[21] Childhood overweight and obese must be defined as within those criterion (CDC: >85th centile at risk of overweight, >95th centile obese; IOTF percentiles track back from the WHO Adult guidelines:[22] $\geqslant 25\,\mathrm{kg\,m^{-2}}$ overweight and $\geqslant 30\,\mathrm{kg\,m^{-2}}$ obese) or childhood BMI status should be treated as a continuous variable and association with infant feeding assessed by regression or correlation.
6. Studies must be reported in the English language.

Exclusion criteria:

1. Studies on animals.
2. Intervention studies, for example, studies where the participants were part of an obesity intervention, health promotion intervention or child feeding programme.
3. Studies where the individuals involved were at risk of abnormal growth patterns, of serious disease or suffered from conditions associated with obesity, for example, preterm babies, childhood cancer survivors or diabetes sufferers.
4. Childhood overweight or obese defined using arbitrary cutoff points.
5. Reviews or systematic reviews, rather than original data.
6. Studies where height, weight, BMI or other measures excluding time of introduction of solid food were self-reported.
7. Meeting abstracts, posters, letters or commentaries.

Agreement between reviewers was initially poor ($\kappa = 0.65$) but any differences were discussed and agreed by consensus. Figure 1 shows the searching and selection process and the number of articles that were excluded at each stage.

Data extraction and analyses

Data relating to the population characteristics, exposure and outcome variables were extracted (Table 1). Where necessary, further data or explanation of data analyses were sought from the authors of the studies. The results of studies were not combined in a meta-analysis due to the considerable heterogeneity of the methodologies and analyses presented by the different authors.

Quality assessment

The quality of the papers that were identified for inclusion in the review was assessed using an adapted 10-point Newcastle–Ottawa scale for cohort studies (Table 2) or case-control studies (Table 3). The scale was designed specifically for non-randomised studies and can be used to assess study quality against criteria relating to aspects of study design.[23] The quality of each study was assessed and awarded stars for indicators of

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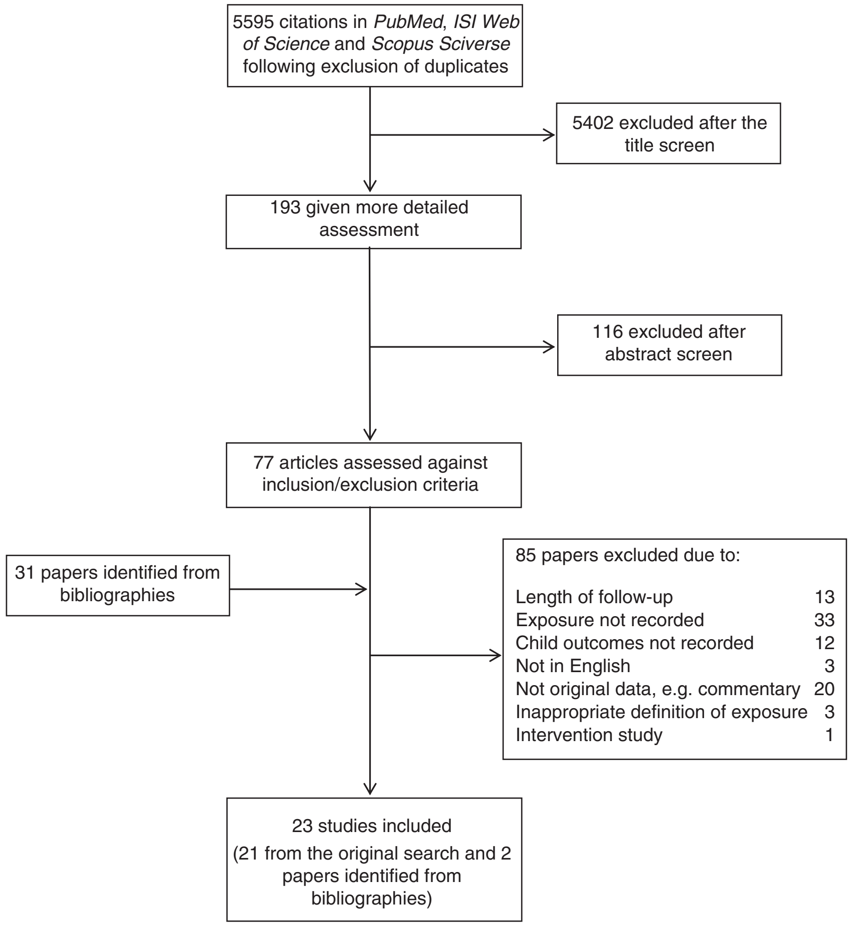

Figure 1. Flow chart of the search and selection process.

quality (Table 4), including selection of the study population, comparability to other studies and the assessment of the outcome of interest. To aid comparability between the results of different studies, the studies received a star if they adjusted for each of the following: infant weight at the start of the study, socioeconomic status (SES), breastfeeding, and maternal education.

RESULTS

Description of the included studies

A total of 23 studies fulfilled the selection criteria, and a summary of the characteristics and results of each study is presented in Table 1. Data were collected in Australia, Brazil (two studies), Canada, China, Denmark, India, Palestine, United Kingdom (UK) (4 studies) and the United States (US) (10 studies). One study consisted of pooled data from 22 study centres in 12 European countries. The studies were cohort (14), cross-sectional (8) or case-control studies (1). Between 54 and 17561 children were followed up from 4 to 19 years of age. Eleven of the studies were nationally or regionally representative birth cohort or cross-sectional studies. Four were locally representative (for example, all the children attending a group of schools or born in a hospital covering a specified geographical area), five studies focussed on specific populations (minority ethnic groups,[24,25] families with low SES[26,27] or children at risk of atopy[12]) and three studies relied on self-selection by participants in answer to advertisements or after being recruited by a researcher at a clinic or hospital. Data were collected between 1959 and 2009 and published between 1984 and 2011. Although most studies referred to the introduction of complementary foods as 'solid foods', all the studies defined the introduction of complementary feeding as the age at which food other than breast milk, water, tea or formula milk was first introduced.

Quality assessment

There was considerable variation in the study quality, despite the stringent inclusion and exclusion criteria applied during the selection process. Six of the cohort studies were awarded the maximum of three stars, based on the selection of the study population. Of those studies which were not awarded three stars, 11 did not demonstrate that infants were not overweight or obese at the time of exposure,[12,26–33] which made it more difficult to examine the association that the introduction of solid foods was responsible for later outcomes. Schack-Nielsen *et al.*[34] completed data collection on participants in 1959–61, which cannot be considered a contemporary population, while Agras *et al.*,[35] published in 1990, failed to report when data were collected. Of the remaining three studies, none demonstrated that infants were not overweight at the time solid foods were first introduced, and either did not report the dates of data collection[24] or were not representative of a western population of children.[36,37] Almost a quarter of the children in the study by Caleyachetty *et al.*[36] had a low weight-for-age *z*-score,[36] and in the population studied by Neutzling *et al.*,[37] babies born with a low birth weight were deliberately over-selected.[37]

The scores for comparability varied considerably, ranging from zero to four stars with seven studies attaining the maximum of four. Of those with three stars, most failed to adjust for breastfeeding (four studies), often because breastfeeding was

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considered in a separate model or was the primary focus of the article, reported after adjustment for complementary feeding, rather than vice versa. Whether or not children are breast fed is associated with growth in infancy and childhood BMI and it is of importance to control in this context.[16] Two studies, both cross-sectional and aiming to examine putative risk factors for obesity in populations of young children, collected data on infant feeding retrospectively but did not collect or adjust their data for birth weight.[26,28] A further two studies did not adjust for SES,[35,38] although Hediger et al.[38] may have used 'educational level' as a proxy for SES.[38] Wilson et al.[39] did not adjust for breastfeeding or maternal education, and the remaining five studies did not adjust for any confounding variables. Three of these studies compared categorical age brackets for the timing of the introduction of solids with later BMI using χ^2 tests,[25,31,40] two used Pearson's correlation coefficients[41,42] and Butte[43] calculated unadjusted odds ratios (ORs) for a list of putative risk factors for overweight, which included the age at introduction of solid food.

All of the cohort studies attained at least two stars for the quality of their assessment and 14 studies were awarded the maximum three stars. Six studies described differences between the cohort with complete follow-up data and those lost to follow up but did not account for any of those differences in their analysis,[12,29,34,39,42,44] while Reilly et al.[32] and Caleyachetty et al.[36] did not compare the characteristics of those with missing follow-up data to those who participated.[32,36]

Zhou et al.[45] was the only case-control study included in the review (Table 4). The study was not considered suitable for any stars for comparability as it used simple chi-squared tests to compare obese cases with normal weight controls. The selection of cases/controls and measurement of the exposure were of high quality.

Exposure measures

Across the range of papers included in the review, age at introduction of solid foods was recorded either as a continuous variable (weeks or months), as a categorical variable (for example, <3 months and ⩾3 months) or whether or not mothers followed American Academy of Paediatrics (AAP) guidelines, which recommend introducing complementary food between 4 and 6 months of age (from 2005–2012).

Outcome measures

Overweight and obesity were measured using either weight-for-height or body composition. Weight-for-height was presented as BMI (as a continuous variable), BMI *z*-scores (continuous or categorical) or BMI as IOTF,[21] US CDC[22] or WHO weight-for-height cut off values as categorical variables.[46] Body composition was measured using dual X-ray absorptiometry (DXA), bioelectrical impedance or estimated from skinfold thickness measurements taken from two or more sites (biceps, triceps, subscapular or suprailiac) using callipers. Skinfold measurements were either presented in millimetres,[27,36] used to calculate percentage of body fat using standard equations[39] or the method the authors used was not clear.[35,41]

Main results

All 23 studies measured BMI as an outcome measure, but Caleyachetty et al.[36] and Patterson et al.[41] used arbitrary cutoff values to categorise BMI and data on BMI from these studies were not included. Five of the studies, including both Caleyachetty et al.[36] and Patterson et al.,[41] measured skinfold thicknesses in addition to BMI, while two studies used DXA and Wilson et al.[39] used bioelectrical impedance as well as skinfold thicknesses to measure percentage of body fat.

BMI

Twenty-one of the studies considered the age at introduction of complementary feeding on childhood BMI (Table 1), eight of which presented unadjusted results showing that delaying the introduction of solid foods led to a significantly lower BMI during childhood. However, Reilly et al.,[32] Robinson et al.[44] and Schack-Nielsen et al.[34] found that there was no longer any association after adjustment for confounding variables. Reilly et al.[32] controlled for SES, maternal education, breastfeeding and birth weight; Robinson et al.[44] did not report which covariates were controlled for; and Schack-Nielsen et al.[34] controlled for maternal characteristics, birth weight, SES, bread winners' education and pre-term birth. Gooze et al.[40] did not present an adjusted analysis for the association between obesity and the age at solid food introduction. Four studies showed that delaying the introduction of complementary foods was associated with a lower BMI in childhood after adjusting for socioeconomic, child and/or maternal characteristics. Brophy et al.[29] found that, after adjustment for SES and ethnicity, the odds of obesity in those children who were given solid foods at 3 months or younger were 20% higher than in those fed solids later (OR; 1.2, 95% CI; 1.02–1.5). Hediger et al.[38] reported a 0.1% reduction in risk of overweight for each month of delay in the introduction of solid foods (OR; 0.9994, 95% CI; 0.9990–0.9997); Seach et al.[12] found that increasing the age at introduction of solid food from ⩽20 weeks to ⩾24 weeks reduced the odds of an above healthy BMI at 10 years of age by 10%; and Zhou et al.[45] reported a 10-fold increase in the odds of being obese at aged 3–6 years when complementary feeding was started before 4 months of age (OR; 10.96, 95% CI; 2.08–21.64). Agras et al.[35] was the only study which found that delaying complementary feeding (to beyond 5 months in this case) led to increased BMI at ages 1 and 3, but at 6 years, the difference between the early and later-weaned groups was no longer significant ($P = 0.05$).

Body composition

A total of seven of the studies considered the association between fat mass (kg) and the introduction of complementary foods, instead of, or in addition to BMI. Of the two studies which used DXA, Burdette et al.[24] categorised infants into those whose mothers had followed AAP guidelines and those who had not, while Robinson et al.[44] looked at the age of complementary food introduction as a interval variable. Neither study found any association with fat mass. Four of the five studies, which measured skinfold thickness during childhood, also found no association with the age at which complementary foods were first introduced. Wilson et al.,[39] however, reported that the percentage body fat, as measured by skinfold thicknesses determined at four sites, was greater in 7-year-old children given food other than breast or formula milk before 15 weeks of age than in those introduced to solids at ⩾15 weeks, although the data were not presented. Wilson et al.[39] also estimated body fat percentage using bioelectrical impedance and found that children who were introduced to solid food before 15 weeks of age had a higher percentage body fat than those who were introduced later (18.5% and 16.5% respectively).[39]

DISCUSSION

The transition from milk feeding to the family diet is an important milestone for every child. Our previous review found that high energy intakes and high intakes of protein, particularly animal protein, during the complementary feeding period may be associated with an increase in childhood BMI, but this finding was not conclusive and the association appeared more strongly related to nutrient intake in the second year of life.[17] The aim of this review was to consider the relationship between the timing of

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Table 1. Summary of the data presented in the selected papers

Reference	*Population*	n	*Age at follow-up (years)*	*Exposure measure*	*Outcome measure*	*Crude effect size and significance*	*Adjusted effect size and significance*
Agras *et al.*[35]	Cohort study of healthy infants, free of medical complications recruited from Stanford University Hospital, California, USA	54	6	Whether the infant was consuming solids at 2, 4, 12, 20 weeks	BMI (as a continuous variable) and skinfold thickness	Univariate correlation (correlation coefficient) found no association between delaying the introduction of solid food to >5 months and BMI at 6 years = 0.16, NS	Adjusted data not presented
Ariza *et al.*[28]	Cross-sectional study of predominantly Hispanic 5–6-year-old children attending kindergarten in inner-city public elementary schools, Chicago, USA	250	5–6	Age at introduction of solid food	BMI (NCHS CDC categories)	The age at introduction of solid food was not associated with overweight. Median age at introduction of solid foods was 7 months (overweight), 8 months (other) $P = 0.34$	Adjusted data not presented
Brophy *et al.*[29]	Sub-cohort of the Millennium Cohort study, UK; singleton children eligible to receive child benefit and born in 2000–2002, weighted to adequately represent families from disadvantaged areas and the ethnic minority groups	17 561	5	Introduction of solids < 3 months, ⩾3 months	BMI (IOTF categories)	Early introduction of solid food (< 3 months) was associated with a higher risk of obesity, particularly in white and higher income groups, OR (95% CI): Overall; 1.33 (1.13–1.55) White/European, 1.5 (1.3–1.8) Asian, 0.45 (1.3–1.8) African, 0.4 (0.2–1.1) Low income, 0.9 (0.7–1.2) Middle income, 1.7 (1.2–2.6) Higher income, 1.8 (1.2–2.7)	After adjustment for ethnicity and SES, the earlier introduction of solid food (< 3 months) was associated with obesity, using regression analysis, adjusted OR (95% CI); 1.2 (1.02–1.5)
Burdette *et al.*[24]	Prospective cohort study of full-term, healthy infants of either European or Afro-American origin, Cincinnati, USA	313	5	Follows AAP recommendations, yes or no	BMI, FM (adjusted for LBM and sex) (DXA)	Percentage of participants with high adiposity, following AAP recommendations or not, %; Yes = 26.1, No = 23.7, $P = 0.62$ (chi-squared) Mean BMI *z*-score of those following AAP recommendations or not (s.d. units); Yes = 0.44, No = 0.42, $P = 0.85$ (*t* test) Percentage of participants overweight, following AAP recommendations; Yes = 22.9, No = 28.2, $P = 0.29$ (chi-squared)	All adjusted for race, WIC, birth weight, maternal obesity, age, smoking, income, education, marital status, gestational diabetes unless otherwise stated. Percentage of participants with high adiposity, following AAP recommendations or not, %; Yes = 27.8, No = 22.3, $P = 0.29$ (multiple regression analysis) Mean BMI *z*-score of those following AAP recommendations (s.d. units); Yes = 0.49, No = 0.40, NS (ANOVA) Percentage of participants overweight, following AAP recommendations; Yes = 23.9, No = 27.6, $P = 0.46$ (Multiple regression analysis) Adjusted for LBM and sex only, mean FM (kg) of following AAP recommendations; Yes = 4.62, No = 4.47, NS Mean FM (kg) of following AAP recommendations; Yes = 4.63, No = 4.49 NS
Butte[30]	Cross-sectional study of children in Houston, Texas, USA. Families were recruited if they had one overweight child aged 4–19 years. All the child's siblings also participated in the study	1030	4–19	Age at introduction of solid food	BMI (NCHS CDC categories)	Data not presented	After adjustment for family clustering, logistic regression showed that the age at introduction of solid food was not a risk factor for obesity, OR (95% CI); 0.986 (0.935-1.04), $P = 0.6$
Caleyachetty *et al.*[36]	Prospective cohort study of pregnancy-related maternal risk factors and later infant and child health in Mysore, India. Infants were full-term and mothers did not suffer from gestational diabetes	484	5	Age at introduction of solid food (⩽3, 4, 5, ⩾6 months)	Skinfold thicknesses	There was no association between age at introduction of solids and sum of skinfold thicknesses, mm (geometric mean) (± 1 s.d.); ⩽3 months, 14.3 (11.1, 18.5) 4 months, 14.1 (11.1, 17.8) 5 months, 13.5 (10.7, 16.9) ⩾6 months, 13.6 (10.9, 16.9), $P = 0.05$ (ANOVA for linear trend)	After adjustment for age, sex, urban dwelling, SES, maternal education, birth weight, gestational age, maternal BMI and family history of diabetes and breastfeeding duration, there was no association in the estimated percentage of change in the geometric mean of sum of skinfold thickness for a one category increase in delay of introduction of solid food; − 1.7 (− 3.7 to 0.4) $P = 0.11$
Gooze *et al.*[40]	Longitudinal birth cohort study of randomly sampled births in the United States of America in 2001, weighted to adequately represent some ethnic minorities, low birth weight and twins	6750	5.5	Age at first introduction of solid food (⩽3, 4–5, ⩾6 months)	BMI (NCHS CDC categories)	The prevalence of obesity was higher among those infants whose introduction to solid food was at an earlier age, % obese (95% CI): ⩾ 6 months; 16.5 (14.5–18.6) 4-5 months; 16.2 (14.4–18.0) ⩽ 3 months; 21.8 (18.9–24.7)***	Data not presented

Table 1. (Continued)

Reference	*Population*	n	*Age at follow-up (years)*	*Exposure measure*	*Outcome measure*	*Crude effect size and significance*	*Adjusted effect size and significance*
						(Rao–Scott (design corrected) likelihood ratio chi-squared)	
Haschke and van't Hof,[51]	European longitudinal observational cohort study. European children recruited from 22 study centres in 12 countries	302	5	Time at introduction of solid food assessed at 1, 2, 3, 4, 5, 6, 9, 12 months	BMI (IOTF categories)	Data not presented	Adjusted for sex, BMI at birth and at 1 year of age, mid-parental BMI, SES, parental age, parental education, siblings, urban/rural environment, smoking and location of the study site. Prediction of BMI at 12 months**, 36 months* and at 5 years (NS). β and CI not presented
Hediger *et al.*[38]	Cross-sectional survey. Data were taken from the National Health and Nutrition Examination Survey III (NHANES III), from 1998–1994, USA	2685	3–5	Age at which solid food first introduced; <4, 4–6 or >6 months	BMI (NCHS CDC categories)	Data not presented	After adjustment for race, sex, age, maternal BMI, the timing of introduction of solid foods was associated with a 0.1% reduction in risk of overweight for each month of delay, OR (95% CI); 0.9994 (0.9990–0.9997)
Kanoa *et al.*[31]	Cross-sectional study. Random sample of pre-school children selected in Gaza Strip, Palestine, 2009	571	5–6	Age at which solid food first introduced, $\leqslant 6$, 6-12, $\geqslant 12$ months	BMI *z*-score	There was no difference in frequency of overweight between infants weaned at <6 months and those weaned $\geqslant 6$ months ($P=0.50$, chi-squared)	Not adjusted
Kuperberg and Evers[25]	All First Nations children born in 1994–5 to families living on Walpole Island, Canada	102	4	Age at introduction of solid foods	BMI (NCHS CDC categories)	There was no difference in the proportion of children with a BMI at or above the 85th percentile according to the age at introduction of solids. Data not presented	Not adjusted
Neutzling *et al.*[37]	Birth cohort study. All babies born in hospital in Pelotas, Southern Brazil in 1993 were initially recruited. All low birth weight and 20% of the remaining sample were targeted for follow-up	1204	11	Age at which semi-solid/solid food first introduced; <4 or $\geqslant 4$ months	BMI (NCHS CDC categories)	There was no difference in the proportion of overweight or obese children between the <4 and $\geqslant 4$ month groups OR (95% CI): Overweight; 0.77 (0.58–1.03) $P=0.08$ Obese; 0.93 (0.58–1.50) NP = 0.78	After adjustment for sex, skin colour, birth weight, family income, maternal education, maternal smoking and pre-pregnancy BMI. There was no difference in the proportion of overweight or obese children between the <4 and $\geqslant 4$ month groups OR (95% CI): Overweight; 0.77 (0.58-1.02) $P=0.07$ Obese; 0.88 (0.55–1.41) $P=0.60$
Obeidat *et al.*[26]	Cross-sectional study of a representative sample of parents enrolled in WIC and living in 11 public health regions in Texas, USA. All children had been overweight (non-persistent) or were overweight (persistent)	445	2–5	Age at introduction of solid food	BMI *z*-score	The age at introduction of solid food was not different between the persistent and non-persistent overweight groups (65% at 4–6 months in both cases)	Data not presented
Patterson *et al.*[41]	Cross-sectional survey. Caucasian families recruited through day-care centres, pre-schools and via birth announcements, Colombia, USA, 1983	94	2–5	Age at introduction of solid food	Triceps skinfold thickness	No significant difference between the age at introduction of solid foods and skinfold measurement. Data not presented	Not presented
Reilly *et al.*[32]	Avon Longitudinal Study of Parents and Children (ALSPAC), birth cohort study, UK, 1991–1992	7758	7	Age at introduction of solids; <1, 1–2, 2–3, 3–4, 4–6, not yet	BMI *z*-score	There was an association between the prevalence of obesity and the age at introduction of solid foods, OR (95% CI); <1 month, 1.44 (0.85–2.45) 1-2 months, 1.61 (0.83–3.01) 2-3 months, 1.78 (1.33–2.39) 3-4 months, 1.22 (0.99–1.51) 4-6 months, 1.00**	After adjustment for sex, maternal education, energy intake at aged 3 years, birth weight, maternal smoking, breastfeeding and paternal BMI, hours spent watching TV, time spent in the car, and sleep duration, OR (95% CI); <1 month, 0.88 (0.42–1.87) 1-2 months, 1.08 (0.50–2.32) 2-3 months, 1.48 (1.01–2.16) 3-4 months, 1.08 (0.83–1.39) 4-6 months, 1.00, $P=0.296$
Robinson *et al.*[44]	The Southampton Women's Study, a cohort study in United Kingdom. Women were recruited between 1998 and 2002. Any children subsequently born to study participants were followed in infancy and childhood	536	4	Age at which solid food introduced; $\leqslant 3$, up to 4, up to 5, >5 months	BMI, %BF (DXA)	There was a no association between age at introduction of solid food and childhood BMI. There was a weak association between fat mass at 4 years and age at introduction of solid foods ($P=0.034$) but this disappeared after adjustment for confounding variables	Data not presented
Schack-Nielsen *et al.*[34]	Cohort study. Individuals born at the Copenhagen University Hospital, Denmark, from 1959–1961	735 (11y)	10, 11	Age at introduction of spoon feeding (months)	BMI *z*-score	When BMI *z*-scores at various ages were regressed on age at introduction of spoon feeding and adjusted for only sex, inverse associations were seen at 7, 8, 9, 10 and 11 years (all)***	After adjustment for sex, maternal age, pre-pregnancy BMI, gestational weight gain, smoking during pregnancy, social class, bread winners' education, single mother status, prematurity, breastfeeding and birth weight Age of introduction of spoon feeding; NS in childhood

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Table 1. (Continued)

Reference	Population	n	Age at follow-up (years)	Exposure measure	Outcome measure	Crude effect size and significance	Adjusted effect size and significance
Seach *et al.*[12]	Cohort study. Children at risk of atopy, born to women attending antenatal clinics in Melbourne, Australia from 1990–1994	307	10	Age (weeks) at which solid food was first ingested (continuous)	BMI *z*-score	The earlier introduction of solid food led to an increased risk of the odds of above-healthy BMI at aged 10 years, OR (95% CI); 0.905 (0.852-0.962)**	Adjusted for maternal education, type of residence, fathers' occupational status, parental smoking, regular childcare attendance, breastfeeding and BMI at birth, the later introduction of solid foods led to a reduction in unhealthy BMI at age 10 years, OR (95% CI); 0.903 (0.841-0.970)** per week of delay
Simon *et al.*[33]	Cross-sectional study. Children enrolled in private schools, Sao Paulo, Brazil in 2004–5	566	2–6	Age at introduction of solids; 0–6, 6–12, 12–18, 18–24 months	BMI (NCHS CDC categories)	Age at introduction of water/tea, fruits, non-maternal milk, cold cuts, sugar, meat/offal/eggs had no significant effect on BMI	Adjusted for age, sex, birth weight, paternal/ maternal age and education status, no. of siblings, parents' nutritional status, exclusive or any breastfeeding, family income. 17 different foods were assessed using multiple logistic regression, but only sugar and/or honey, introduced at 6–12 months, had any significant association with childhood obesity, OR (90% CI); 1.65 (1.03-2.67), $P = 0.08$
Wilson *et al.*[39]	Prospective birth cohort study of children born 1983–1986 in Dundee, UK.	412	7.2	Age at introduction of solid food, <15, $\geqslant 15$ weeks	BMI *z*-score and %BF (bioelectrical impedance)	Crude data not presented	Adjusted for weight, body mass index and percentage body fat, children given solid foods before 15 weeks were significantly heavier than those given solid foods at 15 weeks or later Mean BMI *z*-score: <15 weeks; 0.02 (-0.02 to 0.06) $\geqslant 15$ weeks; -0.09 (-0.16 to 0.02) Mean %BF: <15 weeks; 18.5% (18.2–18.8%) $\geqslant 15$ weeks; 16.5% (16.0–17.0%)
Wolman,[42]	Longitudinal cohort study. Parents/carers were recruited in paediatric waiting rooms at a medical practice in, Maine, USA	164	4–6	Time at introduction of solids in weeks	BMI (continuous variable)	No significant association was shown between BMI and the age at introduction of solid food by a Pearson product-moment correlation coefficient, $r = -0.019$	Not adjusted
Zhou *et al.*[45]	Case-control study	162	3–6	Age at introduction of solid foods; <4, $\geqslant 4$, >6 months	BMI (IOTF categories)	No unmatched data	Age, sex and height were controlled for in the matched cases. Obese children were more likely to have been given solid foods early than non-obese children, chi-squared test for trend***
Zive *et al.*[27]	Cross-sectional survey of Anglo-American and Mexican-American families, predominately low SES, living in San Diego, California, USA	270	4	Age at introduction of solid food (months)	BMI, skinfold thickness	There was no association between age at introduction of solid food and BMI/ SUMSF using Bivariate Pearson Correlation (r): BMI; 0.02 SUMSF; 0.10	Adjusting for ethnicity, sex, birth weight, SES, maternal education, maternal BMI and SUMSF, infant feeding variables were not significantly associated with BMI or SUMSF using regression analysis, r^2: BMI; 0.015, NS SUMSF; 0.015, NS

Abbreviations: AAP, American Academy of Paediatrics; ANOVA, analysis of variance; %BF, percentage body fat; BMI, body mass index; CI, confidence interval; DXA, dual X-ray absorptiometry; FM, fat mass; LBM, lean body mass; NCHS CDC, National Centre of Health Statistics Centre for Disease Control; NS, non-significant; OR, odds ratio; SES, socioeconomic status; SUMSF, sum of skinfold thicknesses; TV, Television; WIC, Special Supplementation Nutrition Program for Women and Children. *$P<0.05$, **$P<0.01$, ***$P<0.001$.

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Table 2. Assessment of quality for a cohort or cross-sectional study; adapted from the Newcastle–Ottawa scale

Selection
1. Representativeness of the cohort (max 1 star*):
Truly representative of children in the contemporary western world
Somewhat representative of children in the contemporary western world
Selected group of infants, for example, only certain socioeconomic groups/areas
No description of the derivation of the cohort
2. Ascertainment of exposure (max 1 star*):
Measurement by a trained health professional/researcher via interview or self-reported using stated methodology (questionnaire, interview, and so on.)
Secure record
Method not reported
No description/other
3. Demonstration that outcome of interest was not present at start of study (max 1 star*):
Yes (infant weight at time of weaning using z score or percentiles)
No
Comparability
1. Comparability of cohorts on the basis of the design or analysis (max 4 stars*):
Study states that infant weight has been controlled for in statistical analysis(age and sex should have been used to calculate BMI as per study inclusion criteria)
Study states that socioeconomic status is controlled for in statistical analysis
Study states that breastfeeding has been controlled for in statistical analysis
Study states that maternal education has been controlled for in the statistical analysis
Assessment
1. Assessment of outcome (max 1 star*):
Independent assessment by trained health-care professional
Record linkage
BMI/weight/height self-reported
Other/no description
2. Was follow-up long enough for outcomes to occur (max 1 star*):
Yes, if mean child age ⩾4 years
No, if mean child age ⩽4 years
3. Adequacy of follow-up of cohorts (max 1 star*):
Complete follow-up: all subjects accounted for
Subjects lost to follow-up unlikely to introduce bias: number lost ⩽20%, or description of those lost suggesting no different from those followed
Follow-up rate <80% and no description of those lost
No statement

Abbreviation: BMI, body mass index. A star was awarded if one (in the selection and assessment sections) or any (in the comparability section) of the criteria shown in italics was met. Maximum of 10 stars*.

the introduction of complementary feeding (food other than breast milk, formula milk, tea or water) and BMI or body composition in children, updating the evidence presented by Moorcroft *et al.*,[18] and by including data from comparable populations in developing countries.

BMI

The evidence from the studies included in this review suggests that there is no clear association between the timing of the introduction of complementary foods and BMI in childhood. Thirteen out of 21 studies found no association at all and in a further three studies, any significant relationship between the age at which complementary foods were first introduced and BMI disappeared after adjustment for confounding variables. Four studies found that children introduced to complementary foods or regular feeding of complementary foods at either ⩽3 months or ⩽4 months, compared with later introduction (4–6 months, ⩾6 months), were more likely to be overweight or obese. A final study reported a 1% reduction in risk of being overweight per month when introducing complementary feeding was delayed. None of the studies examined the effect of introducing complementary foods later than recommended (for example, ⩾7 or ⩾8 months) compared with ⩽6 months.

The studies by Seach *et al.*[12] and Zhou *et al.*[45] were the only small studies to find a relationship between complementary feeding and BMI. The participants in the study by Seach *et al.*[12] were at risk of atopy, but the authors could find no reason to suggest that their results would only apply to those with atopic risk. Zhou *et al.*[45] compared 89 cases with 89 control children matched on age, sex and height only and was the only article to study putative risk factors for obesity in an obese population, compared with a similar normal weight population.

Brophy *et al.*[29] the largest study in the review, found that among children introduced to complementary feeding ⩽3 months of age, those of White/European ethnicity and from higher income groups were more likely to be obese than those from Black, Asian, middle or low income groups. The authors suggested that children from higher income families may not walk to school and that lifestyle factors seen in the ethnic groups may be protective but did not speculate on what these might be. Gooze *et al.*[40] and Hediger *et al.*[38] also deliberately oversampled certain ethnic minority groups (Chinese American, American Indian and Native Alaskan children and Black and Mexican American children, respectively), but unlike the data collected by Brophy *et al.*,[29] the effect of the timing of the introduction of complementary feeding on childhood BMI was not reported by the ethnic group. Unfortunately, no data on diet in either infancy or childhood were collected[24,40] or presented[38] to provide evidence of potential differences in complementary feeding or family eating habits.[17]

The papers by Brophy *et al.*,[29] Gooze *et al.*,[40] Reilly *et al.*[32] and Robinson *et al.*[44] were the only studies to consider the effects of weaning at very early ages, including <1, 1–2, 2–3 or ⩽3 month age brackets (Table 1). Although the differences were no longer significant after adjusting for confounding variables in the papers by Reilly *et al.*[37] and Robinson *et al.*,[44] this observation does raise the possibility that it is the very early introduction of solids (⩽3 months) that may impact on BMI, while there is little difference between introduction at 4–6 months compared with ⩾6 months.

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Table 3. Assessment of quality for a case-control study; adapted from the Newcastle–Ottawa Scale

Selection
1. Is the case definition adequate? (max 1 star*)
Independent assessment by a trained health-care professional
BMI via record linkage (for example, recent school assessment of health check)
BMI/weight/height self-reported
No description
2. Representativeness of the cases (max 1 star*):
Consecutive, all or obviously representative cases
Potential for selection biases or not stated
3. Selection of controls (max 1 star*):
Controls selected from within the same population as the cases
Controls not selected from within the same population as the cases
No description
4. Definition of controls (max 1 star*):
Normal (healthy) BMI
Not normal (healthy) BMI
No description of BMI
Comparability
1. Comparability of cases and controls on the basis of the design or analysis (max 4 stars*):
Study states that infant weight has been controlled for in statistical analysis (age and sex should have been used to calculate BMI as per study inclusion criteria)
Study states that socioeconomic status is controlled for in statistical analysis
Study states that breastfeeding has been controlled for in statistical analysis
Study states that maternal education has been controlled for in the statistical analysis
Exposure
1. Ascertainment of exposure (max 1 star*):
Secure record (for example, from health visitor visits)
Structured interview where blind to case/controls
Questionnaire self-completed by mother
Questionnaire completed by other family member
Other/no description
2. Same method of ascertainment for cases and controls (max 1 star*):
Yes
No
3. Non-response rate (max 1 star*):
Same rate for both groups
Non-respondents not described
Rate different and no designation

Abbreviation: BMI, body mass index. A star was awarded if one (in the selection or exposure sections) or any (in the comparability section) of the criteria shown in italics was met. Maximum of 11 stars*.

Given that only three of the studies collected data after the latest guidelines for complementary feeding were published by the WHO in 2001,[31,33,45] the proportion of parents waiting until 6 months to introduce solid foods would be small and more studies looking at the full range or extremes of the age at introduction of solid foods (⩽3 months and ⩾6 months) would be useful.[47]

Children who are underweight in early childhood may be more likely to be overweight adults, and upward crossing of BMI percentiles during childhood, even within the normal range of BMI, is associated with an increased risk of adult type II diabetes and metabolic syndrome.[36] Only one study considered low BMI and weight-for-age as an outcome measure. Caleyachetty *et al.*[36] found no association between the age at which complementary feeding was introduced and either underweight or stunting.

Body composition

As BMI is a surrogate measure of adiposity in children, other direct measures of body composition are useful. However, almost all of the evidence presented in this review indicates that there is little or no association between the timing of the introduction of solid food and body composition. Only the study by Wilson *et al.*,[39] using skinfold thicknesses and bioelectrical impedance, showed any differences in BMI by the age at introduction of solid food, in a small sample of children carried out in Dundee in 1990–1993. Those who started consuming solid food at or before 15 weeks of age had an increased percentage of body fat at age 7 years.[39]

Confounding

Due to the complexity of the causes of overweight and obesity in children, recording and adjusting for confounding variables are necessary, but several of the studies scored poorly in the comparability section of the Newcastle–Ottawa Scale. All of the studies recorded variables other than the age at which complementary foods were first introduced but many failed to adjust for their effect. Although it was not possible to comment on an exhaustive list, we have considered the four main confounding variables (breastfeeding, maternal education, SES and birth weight) below.

Breastfeeding

The type of milk feeding (breast milk, formula milk or mixed feeding) was found to be independently associated with the timing of the introduction of complementary feeding by Agras *et al.*,[35] Schack-Nielsen *et al.*[34] and Wolman *et al.*[42] Ten of the studies included in the review did not adjust the timing of the introduction of complementary feeding by whether the infant was breast fed and so may be confounded. This included the studies by Brophy *et al.*[29] (where breastfeeding initiation and duration was found to be associated with reduced rates of growth, when compared with formula-fed children, using the same cohort[48]), Wilson *et al.*[39] and Zhou *et al.*[45] The five studies which looked at the independent effect of breastfeeding on childhood BMI were conflicting. Agras *et al.*[35] and Gooze *et al.*[40] showed that a longer duration of breastfeeding increased childhood BMI, while Robinson *et al.*[44] found a lower fat mass in children breastfed for longer. Simon *et al.*[33] showed a protective effect of exclusive breastfeeding against the risk of obesity and Hediger *et al.*[38] found that being ever breastfed, but not breastfeeding duration, reduced the risk of being overweight in childhood. A recent systematic review found that breastfeeding has a protective effect against childhood BMI but suggested further large studies were needed.[16]

Maternal education

The majority of studies controlled for maternal education. Maternal education (time spent in education) was associated with an increase in breastfeeding duration[37,49] and compliance with AAP guidelines. Four studies found that an increase in maternal education lowered the risk of childhood obesity[29,40,50,51] while nine studies found no association.[24–28,33,35,36,45]

SES

Similarly, most studies controlled for SES. Three studies found that SES was independently associated with BMI[29,39,40] while five studies found no association.[26,27,33,41,45]

Birth weight

All the studies which examined the association between birth weight and BMI found that it was positively associated with increased BMI in childhood.[25,27,30,32,33,35,39,45,51] Seach *et al.*[12] did not report on the nature of the association.[12]

Table 4. Summary of the associations between the time at which complementary foods are introduced and the risk of childhood overweight or obesity and study scores (*) for three quality criteria

Reference	*Adjusted association with delayed introduction of complementary food*	*Adapted Newcastle–Ottawa scale*		
		Selection (maximum 3)*	*Comparability (maximum 4*)*	*Assessment (maximum 3*)*
Cohort studies				
Agras *et al.*[35]	↔	**	***	***
Ariza *et al.*[28]	↔	**	***	***
Brophy *et al.*[29]	−	**	***	**
Burdette *et al.*[24]	↔	*	***	***
Butte[30]	↔	**		***
Caleyachetty *et al.*[49]	↔	*	****	**
Gooze *et al.*[40]	−	***		***
Haschke and van't Hof[51]	↔	***	****	***
Hediger *et al.*[38]	−	***	***	***
Kanoa *et al.*[31]	↔	**		***
Kuperberg and Evers[25]	↔	***		***
Neutzling *et al.*[37]	↔	*	***	***
Obeidat *et al.* [26]	↔	**	***	***
Patterson *et al.*[41]	↔	**		**
Reilly *et al.*[32]	↔	**	****	**
Robinson *et al.*[44]	↔	***	***	**
Schack-Nielsen *et al.*[34]	↔	**	****	**
Seach *et al.*[12]	−	**	****	*
Simon *et al.*[33]	↔	**	****	***
Wilson *et al.*[39]	↔, −	***	**	**
Wolman[42]	↔	**		**
Zive *et al.*[27]	↔	**	****	***
		Selection (maximum 4*)	Comparability (maximum 4*)	Exposure (maximum 3*)
Case-control studies				
Zhou *et al.*[45]	−	****	*	***

+, increased risk of overweight and/or obesity; ↔, no significant association; −, decreased risk of overweight/obesity, multiple annotations reflect differing associations within the paper, e.g., for body mass index or skinfold thickness.

Methodological limitations

The aim of this paper was to perform a systematic review of the literature using a pre-defined methodology, and some studies were omitted as they failed to meet the inclusion/exclusion criteria, for example; children were too young at follow up. Some older studies were not included as they were carried out before the current agreed definition of overweight or obese.[21] As is always the case with the systematic review methodology, a review with different inclusion/exclusion criteria may have produced a different result.

Other limitations

The age at introduction of complementary feeding is a simple exposure measure and ignores the complex dynamics of nutrition during the first 2 years of a child's life. The transition from milk feeding to the family diet potentially spans 6–24 months, and although many of the studies included in this review examined milk feeding, only the studies by Robinson *et al.*,[44] Reilly *et al.*[32] and Simon *et al.*,[33] considered food or nutrient intake during infancy or childhood. It is assumed that net energy intake is consistent during the transition from a milk-based diet to the family diet, but this may not be the case.[12] A baby should be developmentally ready to take mashed and/or finger foods at 6 months of age. Overly cautious feeding of low-nutrient density food such as pureed fruit, pureed vegetables or baby rice (low in energy, protein and fat with varying levels of carbohydrate), which would be advised at 4 months but are not suitable at 6 months when more nutritionally dense foods are required, could lead to underweight in childhood and should be avoided. Robinson *et al.*[44] found that children from families who followed infant feeding recommendations, had a greater lean mass and lean mass index at 4 months of age. Further studies are needed to assess the relationship between the types of food given during complementary feeding, timing and childhood BMI to ascertain whether certain foods or nutrients, given at certain times, impact on growth.

The four largest studies in the review (Reilly *et al.*,[32] Brophy *et al.*,[29] Gooze *et al.*[52] and Hediger *et al.*[25]) found that the later introduction of solid food resulted in a lower childhood BMI (before adjustment), but the majority of the other studies were small and possibly lacked sufficient power to detect a meaningful association between the effects of the timing of introduction of complementary food and BMI/body composition in childhood. Data on complementary feeding, collected retrospectively, may have been subject to recall bias, and parents who are aware of current recommendations are more likely to tell the researcher/health professional that they acted in accordance to guidelines (current guidelines being ⩾4 or 4–6 months at the time of data collection in most studies).

Although weight for height is an accepted method of measuring overweight and obesity, it does not measure body fat and does not determine fat mass or distribution. Few of the studies used measures of body composition, possibly because of the expense and practicalities of using DXA and the measurement errors associated with using skinfold thickness. Ethnic minorities may also have less subcutaneous fat, and a higher measurement error may exist in these populations.[24] Children given

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complementary food later may be shorter but have the same BMI as taller children introduced to complementary foods earlier, and height was not considered in addition to BMI.

Finally, of the studies which reported an association between BMI or body composition and the timing of complementary food introduction, none considered the age of adiposity rebound, and data between pre- and post-adiposity rebound may not be comparable. In the studies that found a significant association, the ages at outcome measurement were 3–5, 5, 5.5, 3–6, 7.5 and 10 years.[12,29,38–40,45] Only the study by Reilly *et al.*[32] considered the adiposity rebound and found an independent association with BMI at 7 years of age.

CONCLUSIONS

The timing of the introduction of complementary foods has no clear association with childhood obesity, although very early introduction of solid foods (⩽4 months of age) may result in an increase in childhood BMI. The current increasing rates of obesity are the result of a complex array of genetic, environmental and social factors, and with so many variables affecting any individual, identifying single risk factor is difficult. Recent evidence shows that fewer children in developed countries are being introduced to complementary feeding ⩽4 months of age, but avoidance of very early introduction of food other than breast milk, formula milk or water needs to be further promoted.[14] The average age at which complementary foods are introduced may have increased in recent years and relaxing the guidelines to 4–6 months may see a reversion to parents introducing solid foods at ⩽4 months of age. Finally, the reasons for the early introduction of complementary feeding should be more closely examined and used to help promote comprehensive and consistent guidelines that promote a healthy, balanced diet throughout infancy and childhood.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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