

## Weight change before and after the introduction of solids: results from a longitudinal birth cohort

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### Abstract

We studied the association, and its direction, between the introduction of solids and weight-for-height (WFH) change between birth and 45 months. Pregnant women were asked to participate in a birth cohort during their first antenatal visit. Data from 3184 children were used. The timing of the introduction of solids was reported by the mother from a questionnaire at 12 months postpartum, and categorised into very early (0–3 months), early (3–6 months) and timely (after 6 months) introduction of solids. Anthropometric data were collected during standardised child health centre visits. WFH was converted into a *z*-score. Repeated-measurements analyses with splines positioned according to the moments of solid introduction were used to obtain estimates for WFH change before and after the introduction of solids. Analyses were adjusted for educational level, ethnicity, smoking during pregnancy, mother's BMI, breast-feeding, history of food allergy and infant's hospital admission. Before solids were introduced, weight gain was higher in children introduced to solids early ( $z = 0.65$ , 95% CI 0.34, 0.95) than in children introduced to solids very early ( $z = 0.02$ , 95% CI  $-0.03$ , 0.08) and timely ( $z = -0.04$ , 95% CI  $-0.05$ ,  $-0.03$ ). Shortly after the introduction of solids, children introduced to solids very early and early showed a relative decrease in WFH. WFH change did not differ between the solid introduction groups after 12 months, and at that time, weight change was as expected (i.e.  $z = 0$ ). We therefore conclude that differences in WFH in childhood are not the result of early introduction to solids.

**Key words:** Infant feeding: Solids: Weight change: Longitudinal studies: Epidemiology

Infant feeding (breast-feeding and complementary feeding) may be important for a healthy weight in later life. However, results on complementary feeding as a determinant of overweight are still conflicting: a recent review<sup>(1)</sup> concluded that there is not sufficient evidence for an association between the timing of introducing solids and obesity. Since then, two papers have been published that reported a clinically relevant association between the timing of the introduction of solids

and childhood obesity<sup>(2,3)</sup>. One proposed mechanism to explain the higher prevalence of obesity in children introduced early to solids is rapid infant weight gain after the introduction of solids. Results on the net increase in energy intake in children introduced to solids are controversial, but intake of fatty and sugary foods has been reported to be higher at 12 months in children introduced to solids early<sup>(4)</sup>. However, reverse causality can be the cause: an alternative explanation

**Abbreviation:** WFH, weight-for-height.

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is that infant weight gain precedes the introduction of solids. Indeed, an earlier study showed that one of the reasons for parents to introduce solids earlier than recommended is that their infant was big for their age<sup>(5)</sup>.

Most studies reporting the association between the introduction of solids and infant weight gain defined infant weight gain as the difference in weight between two time points, and did not take into account that introduction of solids may be related to weight change before and after the introduction of solids to the infant's diet, which is important to confirm or reject the proposed mechanism.

The aim of the present study was to examine the association between the very early (before 3 months), early (between 3 and 6 months) and timely (beyond 6 months) introduction of solids and weight change in infancy and early childhood. We hypothesise that infants that were introduced to solids very early and early were already heavier before introduction than infants who were introduced to solids after the age of 6 months.

## Methods

### Study design and population

The present study was embedded in the Generation R Study, an observational cohort study that follows children from fetal life onwards<sup>(6)</sup>. The Generation R Study was designed to identify early determinants of growth, development and health. Invitations to participate in the study were made to all pregnant mothers who had an expected delivery date between April 2002 and January 2006 and who lived in the study area (Rotterdam, The Netherlands) at time of delivery. The present study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the Medical Ethical Committee at Erasmus MC, University Medical Center Rotterdam. Written informed consent was obtained from all subjects.

Of the 7295 mother–infant pairs who were followed from birth, 5088 received the 12-month food questionnaire, because data collection on food started from 2003 onwards: 3643 (72%) mothers completed this questionnaire. Excluded were twins ( $n$  82), children born before 37 weeks of gestation ( $n$  158) and children with less than four measurements on weight and height ( $n$  219). Data of 3184 children were analysed.

Compared with those with missing information on the introduction of solids and those having less than four weight and height observations, mothers included in the present study were more often breast-feeding at 6 months (32.9 *v.* 26.9%), highly educated (33.4 *v.* 21.8%), more often had infants with a normal birth weight (85.0 *v.* 81.8%), were more often native Dutch (67.7 *v.* 44.2%), less often smoked during pregnancy (7.7 *v.* 12.5%) ( $P < 0.001$  for all) and more often had a normal weight, defined as a BMI  $\geq 25$  kg/m<sup>2</sup> (75.9 *v.* 72.0%,  $P < 0.01$ ).

### Measurements

**Infant feeding.** For the present study, we were interested in the age of the first introduction of any solids. At the child's age of 12 months, mothers reported in a questionnaire the age of

the first introduction of the following foods<sup>(7)</sup>: dairy products, porridge, bread, biscuits, crackers, baby cookies, pasta, meat products, vegetarian meat substitutes, fish, shellfish, vegetables, fruit, peanuts and nuts. Answer categories included 'never given', 'between 0 and 3 months', 'between 3 and 6 months', 'between 6 and 9 months' and 'older than 9 months', which was recoded into three categories: '0 to 3 months', '3 to 6 months', and '6 months or later'. The latter group adheres best to the feeding recommendations of the WHO and is therefore used as the reference group<sup>(8)</sup>.

**Anthropometrics.** Length/height and weight were measured according to a standard schedule (1, 2, 3, 4, 6, 11, 14, 18, 24, 30, 36 and 45 months of age) and procedures by well-trained staff at each visit to the child health centre. Length was measured in the supine position to the nearest millimetre until the age of 14 months using a neonatometer, after which height was measured in standing position by a Harpenden stadiometer (Holtain Limited). Weight was measured using a mechanical personal scale (SECA). Weight change was defined as the increase or decrease in weight-for-length/height (WFH) *z*-score, which was calculated from a national reference using the Growth Analyzer program (Growth Analyzer version 3.5, 2007; Dutch Growth Research Foundation)<sup>(9)</sup>.

**Covariates.** Potential confounders were maternal educational level, ethnicity, BMI, smoking during pregnancy, gestational age, child's birth weight, breast-feeding, history of (any) food allergy in the infant's first year of life and hospital admission during the first year after birth. Mother's educational level and ethnicity were asked at enrolment. Mother's BMI was calculated from self-reported pre-pregnancy weight and measured height at intake. Smoking during pregnancy was self-reported in a prenatal questionnaire. Birth weight and gestational age were obtained from medical records. Mothers reported in a postal questionnaire that was sent at 2 months after birth whether they gave breast-feeding, formula feeding or a combination of both. History of (any) food allergy in the infant's first year of life and hospital admission during the first year after birth were asked at 12 months after birth, and were taken into account because if these events took place in the first months after birth, they could have confounded the associations.

### Statistical analyses

Differences in characteristics between mothers introducing solids before 3 or 6 months were compared with those of mothers introducing solids after 6 months using the  $\chi^2$  test (categorical variables) or by ANOVA (continuous variables).

A mixed linear model (Proc Mixed in SAS) was performed with WFH *z*-score as an outcome. Linear splines for WFH change by age were created, which are useful when estimates for weight change are expected to differ between time periods. The knots for the splines were positioned according to the moments of solid introduction (i.e. 0–3, 3–6 and after 6 months), and set after the start of the introduction of solids (mid-point of each category), the following 3 months after the start point for introduction, the following period until 12 months, and after 12 months (Table 1). The four

**Table 1.** Time periods for weight change estimates

Categories of the timing of the introduction of solids	Birth until the start of the introduction of solids	Shortly after the introduction of solids	After the introduction of solids	After 12 months of age
0–3 months	0–1.5 months	1.5–4.5 months	4.5–12 months	12–45 months
3–6 months	0–4.5 months	4.5–7.5 months	7.5–12 months	12–45 months
After 6 months	0–7.5 months	7.5–11.5 months	11.5–12 months	12–45 months

periods obtained with the splines were put in the model as time variables, and the WFH development from birth to pre-school age was obtained with stratified analyses for each group of solid introduction.

Residuals of the spline model were normally distributed with a mean difference of 0.01 (95% CI –1.91, 1.89) between the actual and predicted values of WFH z-score, and residuals did not vary over time (Pearson's  $r$  0.001,  $P=0.90$ ) or for subgroups (i.e. breast-fed children, children of low socioeconomic status).

Analyses were conducted using the Statistical Package for Social Sciences for Windows version 17.0 (SPSS, Inc.) and the Statistical Analysis Software package version 9.1 (SAS Institute).

## Results

In the present study, 38% of mothers introduced solids after the recommended age of 6 months. Relative to mothers who introduced solids before 3 or 6 months, mothers who

introduced solids after 6 months were more often highly educated, native Dutch, non-smokers, breast-feeding for at least 6 months and had more often an infant with a history of food allergy. Hospital admission and mother's weight were not significantly associated with the timing of the introduction of solids. The number of children with either a low or high birth weight did not differ between the groups, but the mean birth weight of children who were introduced to solids before 3 months was slightly lower than children introduced to solids after 3 or 6 months (Table 2).

Table 3 shows the growth pattern from birth to preschool age for each group of solid introduction. Children who were introduced to solids very early (before 3 months) had a WFH change as expected (i.e. WFH z-score about 0) before they were introduced to solids. This was followed by a relative decrease in WFH until 4.5 months, but after 4.5 months, they were growing as expected (i.e. WFH z-score about 0). Children who were introduced to solids early (between 3 and 6 months) had a high WFH gain before they were

**Table 2.** Characteristics of 3184 participants according to the timing of the introduction of solids\*

	Total (%)	Introduction of solids (%)			<i>P</i>
		0–3 months ( <i>n</i> 171)	3–6 months ( <i>n</i> 1808)	≥6 months ( <i>n</i> 1205)	
<b>Sociodemographic factors</b>					
<b>Educational level</b>					
Low	14.1	21.1	15.9	10.5	<0.001
Mid-low	26.8	36.0	28.1	23.6	
Mid-high	25.7	23.6	24.8	27.5	
High	33.4	19.3	31.2	38.5	
<b>Mother's ethnicity</b>					
Native Dutch	67.6	53.7	67.5	69.6	<0.001
Other Western	11.5	12.3	10.1	13.3	
Non-Western	20.9	34.0	22.3	17.0	
<b>Parental characteristics</b>					
Maternal smoking during pregnancy	7.8	13.8	9.5	4.3	<0.001
<b>Mother's BMI (kg/m<sup>2</sup>)</b>					
Normal (<25)	75.9	74.3	75.2	77.1	0.47
Overweight (25–30)	16.9	17.1	16.8	16.8	
Obese (>35)	7.2	8.6	7.9	6.0	
<b>Perinatal characteristics</b>					
<b>Birth weight (g)</b>					
Low (<2500)	1.4	1.2	1.2	1.7	0.41
Normal (2500–4000)	81.9	86.5	82.0	81.0	
High (>4000)	16.8	12.3	16.8	17.3	
<b>Birth weight (g)</b>					
Mean	3521	3422	3528	3525	0.03
SD	497	476	494	503	
<b>Postnatal characteristics</b>					
Child was breast-fed at 2 months of age	69.2	56.3	66.9	74.4	<0.001
Child was breast-fed at 6 months of age	32.8	22.2	27.3	42.6	<0.001
History of food allergy	6.4	5.6	5.1	8.6	<0.001
Hospital admission in the first year of life	6.1	7.0	5.4	7.0	0.20

\* Missing data were as follows: 99 (3.1%) for educational level; 58 (1.8%) for ethnicity; 532 (16.7%) for maternal smoking; 698 (21.9%) for mother's BMI; 3 (0.1%) for birth weight; 87 (2.7%) for breast-feeding at 2 months; 56 (1.8%) for breast-feeding at 6 months; 172 (5.4%) for history of allergy; 199 (6.3%) for hospital admission.

**Table 3.** Weight-for-height change before, shortly after and after solid introduction, and after 12 months of age for children introduced to solids very early (*n* 104), early (*n* 1120) and timely (*n* 771)

Timing of the introduction of solids	Change in weight-for-height z-score and 95% CI*			
	Before introduction	Shortly after introduction	After introduction	After 12 months of age
Very early (0–3 months)	< 1.5 month	1.5–4.5 months	4.5–12 months	12–45 months
z-score	0.02	– 0.13	0.02	– 0.01
95% CI	– 0.03, 0.08	– 0.23, – 0.04	– 0.03, 0.08	– 0.01, 0.002
Early (3–6 months)	< 4.5 months	4.5–7.5 months	7.5–12 months	12–45 months
z-score	0.65	– 0.13	0.005	– 0.004
95% CI	0.34, 0.95	– 0.18, – 0.08	– 0.01, 0.02	– 0.01, – 0.001
Timely (≥6 months)	< 7.5 months	7.5–11.5 months	11.5–12 months	12–45 months
z-score	– 0.04	0.02	– 0.05	– 0.003
95% CI	– 0.05, – 0.03	– 0.01, 0.05	– 0.10, 0.002	– 0.01, – 0.001

\* Adjustments were made for mother’s educational level, ethnicity, smoking during pregnancy, mother’s BMI, breast-feeding, history of allergy and hospital admission in the first year of life.

introduced to solids ( $z = 0.65$ , 95% CI 0.34, 0.95), but once introduced to solids, this was followed by a relative decrease in WFH ( $z = -0.13$ , 95% CI  $-0.18$ ,  $-0.08$ ). After 7.5 months, they were growing as expected with WFH  $z$ -score about 0 (Table 2; Fig. 1). Children introduced to solids according to the recommendation (after 6 months) had a small decrease in WFH before they were introduced to solids ( $z = -0.04$ , 95% CI  $-0.05$ ,  $-0.03$ ), but after the introduction of solids, they followed a growth pattern as expected (i.e. WFH  $z$ -score about 0).

At 4.5 months, children in the very early and early introduction of solid groups were on average 0.5 kg heavier than children introduced to solids timely (Table S1 and Fig. S1, available online).

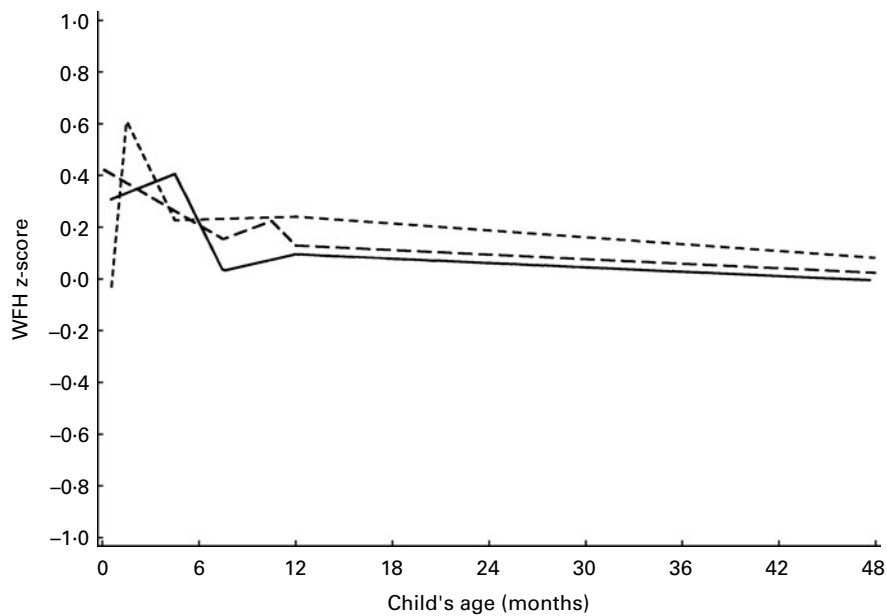
Because the exact timing of the history of food allergy and hospitalisation is unknown, these variables could be either confounders or mediators. We have therefore run the

models without these variables (Table S2, available online), but the results did not change.

Fig. 1 shows WFH  $z$ -score development from birth to preschool age, and is a graphical representation of Table 3. At the ending age (preschool age), WFH  $z$ -scores were 0.01 (95% CI  $-0.18$ , 0.19) for children introduced to solids very early, 0.11 (95% CI 0.05, 0.17) for children introduced to solids early and 0.04 (95% CI  $-0.03$ , 0.11) for children introduced to solids according to the recommendation.

### Discussion

The present study shows that children introduced early, but not very early, to solids had a higher increase in WFH before the introduction of solids than children introduced timely to solids. Differences in weight change disappeared during the first year of life. At preschool age, children



**Fig. 1.** Estimated weight-for-height (WFH)  $z$ -score for each age group of introduction to solids (this figure is a graphic presentation of the data in Table 3). —, 0–3 months; ---, 3–6 months; ···, >6 months.

introduced to solids early had a slightly higher WFH than children introduced to solids very early or timely.

Studying the association between the early introduction of solids and weight gain is quite a methodological challenge. First, the association between the early introduction of solids and weight gain may be subject to reverse causality: infants experiencing rapid weight gain may be earlier, or later, introduced to solids. Therefore, some studies adjusted the analyses for birth weight. However, this does not take the rate of weight gain shortly after birth into account. The present results revealed no significant differences in birth weight *z*-score among the subgroups, but showed that infants who were introduced early to solids were already heavier before the introduction of solids. Second, the association between the early introduction of solids and weight gain may be confounded by several factors. Although the associations were adjusted for the most important confounders, no detailed information was available on breast-feeding exclusivity, i.e. breast-feeding with no other fluids or solids at all. We also did not have detailed information on the exact amount of formula feeding and solid intake, and therefore not on exact energy and protein intake. This may have caused bias in any direction, but is most likely to affect weight change after the introduction of solids. However, this may not change our conclusion that children introduced to solids early were heavier before any solids were introduced. The timing of the introduction of solids was based on the 12-month FFQ. This could have induced some recall bias. However, there is no reason to assume that the recall differed according to weight change. Lastly, 72% of participants returned the 12-month FFQ. Although this response rate is relatively high, mothers included in the analyses were generally healthier and wealthier, which was also reflected in the mean *z*-scores being above 0. However, we think it is unlikely that this has led to selection bias as we assume the missing data being 'missing at random', which means that the missing data depend on covariates in the model only. Selection bias would, for example, occur when children of less healthy or wealthy families had more often missing data but were also introduced to solids earlier than recommended and had a higher WFH after the introduction of solids.

Despite the use of different cut-off points to define the early introduction of solids, the present findings that solid introduction is associated with weight during the first months of life are consistent with other studies. Baker *et al.*<sup>(10)</sup> reported that infants introduced to solids before 4 months of age had a higher weight gain from birth to 1 year. Baird *et al.*<sup>(11)</sup> found that children introduced to solids after 6 months were lighter and shorter than children introduced to solids before that age. One study included several measurement points and used a similar cut-off point as in the present study (at 3 months), making this study best comparable to ours. Infants receiving solids before 12 weeks were heavier at 4, 8, 13 and 26 weeks of age, but not at 52 weeks or later<sup>(12)</sup>. There is also one trial that found no weight differences at 3, 6 and 12 months in children introduced to solids at 3–4 months of age compared with children introduced to solids at 6 months<sup>(13)</sup>. Wright *et al.*<sup>(14)</sup> found that babies who were

heavier at 6 weeks and 3 months were weaned earlier, but that infant weight gain between birth and 6 weeks was a stronger predictor. Also, Wright *et al.* in their study asked mothers for their reasons starting introduction of solids, and 'my baby seems hungry' was a predictor of early weaning. Thus, our hypothesis that infants are heavier before the introduction of solids, making mothers believe it is necessary to introduce solids, fits well in the present findings and the findings from the current literature.

After 1 year of age, we found no differences in weight change between children introduced to solids very early or early and children introduced to solids timely. However, as a result of differences in weight change during the first year of life, children introduced to solids early had a slightly higher WFH *z*-score compared with children introduced to solids according to the recommendation. This result is consistent with a study describing that early introduction of solids before 4 months of age is not associated with weight change adjusted for height between birth and age 3 years<sup>(15)</sup>. However, associations between the early introduction of solids (defined either as continuous variables or before the age of 4 months) and weight status after 1 year of age have been reported at several ages, ranging between 3 and 40 years old<sup>(2,3,16,17)</sup>. In two of these studies, an association was not found between the introduction of solids before 4 months of age and weight in the same cohort at an earlier age<sup>(16,17)</sup>. Huh *et al.*<sup>(2)</sup> adjusted their analyses for weight gain between 0 and 4 months of age, and this hardly influenced the association between the early introduction of solids and overweight at age 3 years. They also reported that the association was only present in formula-fed children. We have stratified our analyses according to the type of milk feeding to reveal possible effect modification, but our conclusions do not change (Tables S3(a)–(c), available online). We hypothesise that the early introduction of solids may therefore be associated with characteristics that determine later overweight. These characteristics may be related to lifestyle or may be related to biological programming. Grummer-Strawn<sup>(4)</sup>, for example, found that children introduced to solids before the age of 4 months were more likely to have a higher intake of fatty and sugary food at 1 year of age.

In conclusion, although prior size may be related to the introduction of solids, we have found no evidence that early introduction of solids increases WFH. Infant weight change may therefore not be one of the underlying causal mechanisms for the association between the early introduction of solids and later overweight.

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J. C. K.-d. J., H. A. M. and H. R. had a role in the conception and design of the study; L. v. R., J. C. K.-d. J. and C. W. N. L. performed the statistical analysis and wrote the manuscript; J. P. M., V. W. V. J., A. H. and A. C. S. H.-K. provided comments and consultations regarding the analyses and manuscript; H. A. M., H. R., J. P. M., V. W. V. J. and A. H. had a role in the acquisition of the data. All authors read and approved the final manuscript.

Supplementary tables and figure are available online at <http://www.journals.cambridge.org/bjn>

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