

## Original Article

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**Address for correspondence:** Petra Vinke, Department of Epidemiology, University Medical Center Groningen, University of Groningen, (FA40) P.O. Box 30 001, 9700 RB Groningen, The Netherlands. Email: [p.c.vinke@umcg.nl](mailto:p.c.vinke@umcg.nl)

†These authors contributed equally to this work.

# Nutrition beyond the first 1000 days: diet quality and 7-year change in BMI and overweight in 3-year old children from the Dutch GECKO Drenthe birth cohort

Petra C. Vinke<sup>1</sup>†, Milou H. H. S. Luitjens<sup>1</sup>†, Karlien A. Blijleven<sup>1</sup>, Gerjan Navis<sup>2</sup>, Daan Kromhout<sup>1</sup> and Eva Corpeleijn<sup>1</sup>

<sup>1</sup>Department of Epidemiology, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands and <sup>2</sup>Department of Nephrology, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands

## Abstract

The identification of early-life determinants of overweight is crucial to start early prevention. As weight gain accelerates between 2 and 6 years, we studied the association between diet quality in children aged 3 years and the change in BMI and overweight incidence in the following 7 years. From the Dutch GECKO Drenthe birth cohort, 1001 children born in 2006 or 2007 with complete data on diet (food frequency questionnaire at the age of 3 years) and growth at the age of 3 and 10 years were included. Diet quality was estimated with the evidence-based Lifelines Diet Score (LLDS). Measured height and weight at the age of 3 and 10 years were used to calculate BMI z-scores standardized for age and sex. The associations of the LLDS (in quintiles) with BMI-z change and overweight incidence were studied with linear and logistic regression analyses. Overweight prevalence in the total study population increased from 8.3% at the age of 3 years to 16.7% at the age of 10 years. The increase in overweight prevalence ranged from 14.7% in Q1 to 3.5% in Q5. Children with a better diet quality (higher quintiles of LLDS) increased significantly less in BMI-z (confounder adjusted  $\beta_{LLDS} = -0.064$  ( $-0.101; -0.026$ )). Children with a poor diet quality at the age of 3 years had a considerably higher risk for overweight at the age of 10 years (confounder adjusted OR for Q1 vs. Q5 was 2.86 (95% CI 1.34–6.13)). These results show the importance of diet in healthy development in the early life following the first 1000 days when new habits for a mature diet composed of food groups with lifelong importance are developed, providing a relevant window for overweight prevention early in life.

## Introduction

The ongoing rise in worldwide overweight prevalence<sup>1</sup>, an important risk factor for noncommunicable diseases<sup>2</sup>, asks for better understanding of its developmental origins. Although many early-life risk factors for overweight have been identified, dietary factors are of major interest from a public health perspective, due to their lifelong modifiable character. During the first 1000 days of life, dietary factors like formula feeding<sup>3,4</sup> and the introduction of complementary foods<sup>5</sup> have been identified as potential risk factors for overweight development in later life. While such factors are highly important during a specific time window in infancy, they are usually no longer of importance after the first 1000 days, as the transition toward the family meal pattern through the introduction of complementary foods and beverages is typically concluded around the age of 2 years<sup>5</sup>. Therefore, it is of scientific interest to look further into the diet quality of young children based on dietary aspects that are of lifelong importance and study its association with future weight gain.

Dietary aspects that are generally accepted to be beneficial for health irrespective of age include the adequate intake of major food groups like fruits, vegetables, and whole-grain products, for which beneficial associations with health have been shown previously, albeit predominantly in adult study populations<sup>6–9</sup>. When scores are assigned to the quality of the overall dietary pattern, including such major food groups, many previous studies found that scores for diet quality were indeed inversely associated with the risk of overweight or obesity in adults<sup>10,11</sup>. However, in light of prevention of overweight, it is of great importance to investigate this association in childhood as well. Additionally, there is evidence for tracking of eating behavior within childhood<sup>12,13</sup> and between childhood and adulthood<sup>14</sup>, meaning that diet quality in early childhood could potentially influence both current and later health. However, scientific evidence for associations of measures of diet quality in childhood, with future weight gain or overweight, has so far led to inconclusive results.

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In two systematic reviews investigating diet quality in children and adolescents, the included studies which investigated associations with anthropometric outcomes were inconsistent with regard to the significance as well as the direction of the association<sup>15,16</sup>. A major limitation identified in both reviews is that the vast majority of the studies had a cross-sectional design, which likely contributes to the inconsistency of results. Furthermore, many studies investigated dietary patterns in later childhood (10 years or older) or adolescence, while it has previously been illustrated that weight gain between the age of 2 and 6 years is pivotal. Weight gain in this period has the strongest association with adiposity, metabolic syndrome, and overweight in later life<sup>17,18</sup>, and a retrospective analysis in obese adolescents identified the greatest acceleration in BMI in this period as well<sup>19</sup>. This further identifies a gap in knowledge on the prospective association of diet quality and prospective weight change in young populations in which this critical period is captured.

It is for these reasons that we investigated whether diet quality at the age of 3 years, assessed with a contemporary, food-based diet quality score, was related to the change in BMI z-score and overweight incidence between the age of 3 and 10 years in the Dutch GECKO Drenthe birth cohort. Previous studies found evidence for tracking of dietary habits within childhood<sup>12,13</sup>, suggesting that a poor quality diet at the age of 3 years can be an indication of a cumulative exposure to poor dietary habits in subsequent years. It was therefore hypothesized that children with a poor diet quality at the age of 3 years were more prone to weight gain and incident overweight between age 3 and 10 years, than children with a better diet quality at 3 years of age.

## Methods

### *GECKO Drenthe Cohort and study population*

The GECKO Drenthe birth cohort is a Dutch population-based cohort which initially included 2,997 children born in 2006 and 2007, designed to study the determinants and development of childhood overweight. The cohort is representative of the regional population it is sampled from, for example, with regard to socioeconomic status of participating families. Further details regarding this cohort were published elsewhere<sup>20</sup>. For the current study, children were excluded if birth weight was below 2500 grams, or when data on dietary intake, BMI at the age of 3 or 10 years was missing, leaving 1001 children in the study (Supplementary Fig. S1). Written informed consent was obtained from all parents. The study was conducted according to the guidelines of the Declaration of Helsinki and was approved by the Medical Ethics Committee of the University Medical Center Groningen. The cohort is registered at [www.birthcohorts.net](http://www.birthcohorts.net).

### *Data collection*

#### *Anthropometrics*

Gestational age and birth weight rounded to the nearest 5 gram were reported by midwives. At the age of 3 and 10 years, body weight and height were measured by trained staff of the Community Health Service in the province of Drenthe. Body weight, measured using an electronic scale while wearing light clothing, was rounded to the nearest 0.1 kg and height to the nearest 0.1 cm.

#### *Parental information*

During pregnancy, questionnaires were issued to both parents to assess parental age at birth, parental pre-pregnancy BMI, maternal

smoking during pregnancy, and maternal education level. Smoking was cross-checked with midwife reports. Maternal education level was categorized as low (no education, primary school, lower vocational, or lower general secondary education), middle (intermediate vocational training or higher secondary education), or high (higher vocational or university education). A questionnaire issued 1 month after birth of the child was used to assess whether children received breastfeeding (exclusively or in combination with formula milk).

#### *Dietary assessment*

At the age of 3 years, habitual food intake over the past 4 weeks was assessed using a validated food frequency questionnaire (FFQ) for children aged 2 to 12 years, which was developed based on 2 days food record data of the Dutch National Food Consumption Survey 1997–1998<sup>21</sup>. Questionnaires were filled out by the parents. Intake frequency of 71 food products was questioned. Answer categories ranged from “never” to “6–7 times a week.” For 27 food products, additional questions were included regarding the type or brand of the product consumed. Portion size was questioned using fixed units (e.g., slices of bread) or common household measures (e.g., cups and spoons). Parents were asked to measure the volume of glasses and cups used for different beverages. Data were processed to calculate intake of each food product in grams per day, after which daily energy and nutrient intake was calculated based on the Dutch food composition database of 2011<sup>22</sup>.

The reliability of reported dietary intake was assessed using the Goldberg cutoff method and relied on the ratio of reported energy intake and basal metabolic rate<sup>23</sup>, calculated with the Schofield equation<sup>24</sup>. Children with an energy intake/basal metabolic rate ratio below 0.87 or above 2.75 were excluded to limit bias through under- or over-reporting.

#### *Lifelines Diet Score*

To score overall diet quality, the food-based Lifelines Diet Score (LLDS) was calculated for all children based on their habitual dietary intake reported in the FFQ. This score is based on the scientific evidence summarized in the 29 systematic reviews of the international peer-reviewed literature regarding associations of diet and chronic diseases, which the Dutch Health Council performed in the process of the development of the 2015 Dutch dietary guidelines<sup>25</sup>. Since these guidelines are fully based on scientific evidence from international peer-reviewed literature, and not on expert opinions, they are highly suitable for use in a scientific context. The LLDS ranks the relative intake of nine food groups for which there is strong scientific evidence of positive health effects (vegetables, fruits, whole-grain products, legumes and nuts, fish, oils and soft margarines, unsweetened dairy, coffee, and tea) and three food groups for which there is strong scientific evidence of negative health effects (red and processed meat, butter and hard margarines, and sugar-sweetened beverages (SSBs)). For each of the food groups, quintiles of consumption in grams/1000 kcal are determined and awarded 0 to 4 points. For the positive food groups, higher scores are awarded to higher quintiles of consumption, whereas intake for negative food groups is scored inversely. The sum of these components leads to a LLDS between 0 and 48. As the young children in the present study did not drink coffee, this item was not included in the LLDS, resulting in a LLDS between 0 and 44. For analyses, the LLDS was categorized into quintiles, with quintile 1 representing the poorest and quintile 5 representing the best diet quality.

### Data analysis

From weight and height at the age of 3 and 10 years, age- and sex-standardized BMI z-scores were calculated with Growth Analyzer software, version 3.5, based on Dutch growth references from 1997<sup>26</sup>. Overweight and obesity were defined as a BMI z-score above 1.310 or 2.288 for boys and 1.244 or 2.192 for girls, according to Cole & Lobstein 2012<sup>27</sup>. The change in BMI-z between the age of 3 and 10 years was calculated and standardized to a period of 7 years by dividing the change in BMI-z by the age interval between measurements in months and multiplying this by 84.

Linear regression analysis was used to investigate the association of LLDS quintiles as a measure of diet quality (independent variable) with change in BMI (dependent variable). In the analyses, potential child-related confounders were added to the crude model in three steps (1A – birth weight, sex, gestational age, breastfeeding at 1 month, 1B – BMI-z at the age of 3 years, 1C – total energy intake). To investigate to what extent the association between diet quality and BMI change was explained by parental factors, parental BMI, smoking during pregnancy, parental age, and maternal education level were included in a second model (Model 2). As a sensitivity analysis, linear regression analyses were repeated with quintiles of a LLDS in which the included food groups were left out, one at a time, to investigate the contribution of the individual food groups to the association of diet quality and BMI change.

Logistic regression analysis was used to study the association between LLDS in quintiles and incidence of overweight and obesity combined (hereafter called overweight). Overweight and obesity were combined because of the low incidence of obesity alone. In these models, children without overweight at the age of 3 years were included. Models were built following the same steps as described for linear regression. Subsequently, a continuous variable containing the mean LLDS score for each quintile, replacing the categorical LLDS quintile variable, was introduced in the logistic regression models to obtain a  $P_{linear\ trend}$  for the association between diet quality and overweight incidence.

For 35 children, only data on paternal BMI were missing. These missing values were imputed with predicted values derived from a linear regression model, including maternal BMI, paternal age, and socioeconomic status estimated based on postal code<sup>28</sup>. Children for whom values were missing in multiple covariates were not included in the regression analyses ( $n = 82$ ). For regression analyses, it was checked whether assumptions were met. Furthermore, variables included in regression analyses were checked for collinearity. Paternal age was highly correlated with maternal age ( $r = 0.664, p < .001$ ) and was therefore not included in the analyses. An interaction term for sex and LLDS in quintiles was added to a crude linear regression model to test whether sex was an effect modifier of the association. Data analysis was performed in IBM SPSS 23 (SPSS, Chicago Illinois, USA). The level of significance was set to 5%.

### Results

Mean age at dietary assessment was  $3.1 \pm 0.2$  years and 50.7% of children were boys. Mean change in BMI z-score between the age of 3 (mean age  $3.2 \pm 0.3$ ) and 10 (mean age  $10.6 \pm 0.4$ ) years was  $0.11 \pm 0.85$  SD, meaning that overall, children were gaining more weight than expected based on normal growth. At the age of 3 years, 8.3% of children were overweight, of which 1.2% had obesity. At the age of 10 years, overweight prevalence was doubled to 16.7%, including an obesity prevalence of 3.3% (Table 1).

Supplementary Table S1 shows the intake of food groups of the LLDS in grams per day, for the total study population and stratified by quintiles of the LLDS.

### Association LLDS and weight parameters

From the age of 3 to 10 years, change in BMI-z was higher in lower quintiles of the LLDS (Q1:  $0.26 \pm 0.84$ , Q2:  $0.20 \pm 0.86$ , Q3:  $0.13 \pm 0.86$ , Q4:  $0.02 \pm 0.86$ , and Q5:  $-0.03 \pm 0.79$ ) (Fig. 1). In the two highest quintiles of the LLDS, those with a relatively good diet quality, the BMI-z change was close to zero. This illustrates that BMI change in these groups approximated what was predicted based on the growth curve. In lower quintiles of the LLDS, those with poorer diet quality, the positive mean BMI-z change represents an excess change in BMI between the age of 3 and 10 years. Fig. 2 illustrated that cross-sectionally at the age of 3 years, no clear trend in overweight prevalence was observed over quintiles of the LLDS. Prospectively, however, the higher changes in BMI-z from the age of 3 to 10 years in the lower quintiles of the LLDS did result in greater increases in overweight prevalence (Fig. 2). This increased prevalence was the result of both a higher incidence and a lower remission of overweight in lower LLDS quintiles (Supplementary Fig. S2).

### Regression analyses

After adjustment for potential confounders in linear regression analyses, children in a lower quintile of the LLDS gained 0.064 SD in BMI more than children in the adjacent, higher quintile ( $\beta = -0.064$ , 95% CI:  $-0.101; -0.026$ ) (Table 2). This means that for children with the poorest diet quality (Q1), BMI-z change was  $4 \times 0.064 = 0.256$  SD higher than for children with the highest diet quality (Q5). Further adjustment for parental factors (model 2) attenuated this association by approximately 33%. This was mainly the result of the addition of parental BMI. Smoking of the mother during pregnancy was not significantly associated with the outcome ( $\beta = 0.132, p = 0.119$ ) and did not majorly attenuate the association of diet quality and change in BMI. The child's sex was not an effect modifier of the association (Supplementary Table S2).

To translate these findings into a more clinically relevant outcome, we investigated the association of diet quality with the incidence of overweight. A lower diet quality was related to higher odds for developing overweight ( $P_{linear\ trend} = 0.012$ ). Also in this approach, further adjustment for parental factors attenuated the association ( $P_{linear\ trend} = 0.044$ ) (Table 3).

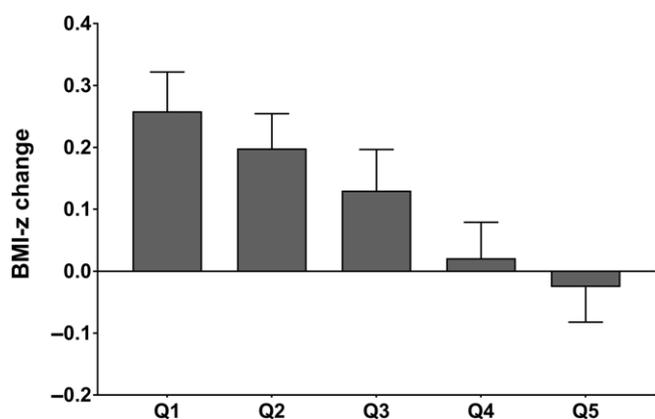
In sensitivity analyses, it was investigated whether the effect of the LLDS could be attributed to specific food groups included in the score. After adjustment for confounding and parental factors, the association of the LLDS and BMI change was most strongly attenuated when “unsweetened dairy” (model 1C  $\beta = -0.46$ , 95% CI:  $-0.083; 0.009$ , 28.1% attenuation) or “whole-grain products” (model 1C  $\beta = -0.056$ , 95% CI:  $-0.093; 0.019$ , 12.5% attenuation) was left out of the score (Supplementary Table S3). Both food groups were categorized as positive for health, meaning that higher intake led to higher diet quality scores.

### Discussion

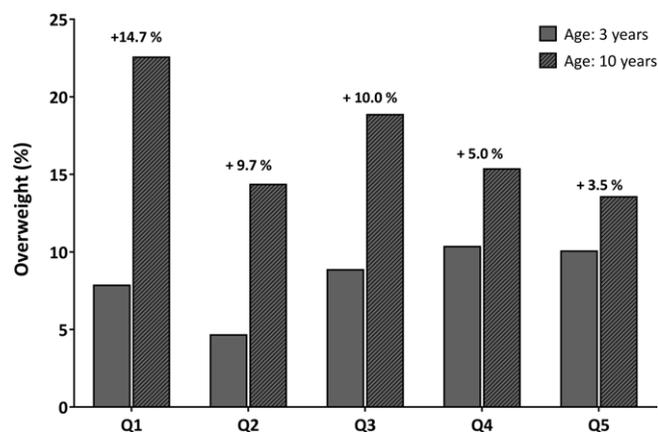
This prospective study in the contemporary GECKO Drenthe cohort showed that diet quality at the age of 3 years is strongly predictive of the degree of BMI change, and the incidence of overweight between the age of 3 and 10 years. While diet quality at the age of 3 years did not yet show a clear association with weight status at the age of 3 years, the strong association with prospective change in BMI and weight

**Table 1.** Characteristics of study population. For total study population and stratified by quintile of the Lifelines Diet Score

Child characteristics	Total (n = 1001)	Q1 (n = 177)	Q2 (n = 236)	Q3 (n = 169)	Q4 (n = 221)	Q5 (n = 198)
<b>Sex, n(%)</b>						
Boy	508 (50.7)	90 (50.8)	123 (52.1)	87 (51.5)	110 (49.8)	98 (49.5)
Girl	493 (49.3)	87 (49.2)	113 (47.9)	82 (48.5)	111 (50.2)	101 (50.5)
Birth weight (gram)	3605 ± 494	3586 ± 478	3612 ± 517	3670 ± 467	3560 ± 507	3607 ± 486
Gestational age (weeks)	39.9 ± 1.4	39.9 ± 1.4	40.0 ± 1.4	40.0 ± 1.2	40.0 ± 1.5	39.9 ± 1.5
Breastfeeding at 1 month, n (%)	651 (65.8)	100 (56.8)	152 (64.7)	98 (58.7)	156 (70.9)	145 (75.5)
BMI z-score age three (SD)	0.10 ± 0.89	0.16 ± 0.85	0.01 ± 0.81	0.04 ± 0.96	0.15 ± 0.93	0.17 ± 0.91
Overweight at the age of 3 years, n (%)	83 (8.3)	14 (7.9)	11 (4.7)	15 (8.9)	23 (10.4)	20 (10.1)
BMI z-score at the age of 10 years (SD)	0.22 ± 1.05	0.44 ± 1.07	0.22 ± 0.98	0.17 ± 1.15	0.17 ± 1.04	0.15 ± 0.99
Overweight at the age of 10 years, n (%)	167 (16.7)	40 (22.6)	34 (14.4)	32 (18.9)	34 (15.4)	27 (13.6)
Energy intake (kcal/day)	1387 ± 293	1447 ± 325	1413 ± 299	1389 ± 290	1362 ± 282	1329 ± 257
Boy	1430 ± 293	1482 ± 328	1456 ± 292	1450 ± 304	1394 ± 281	1375 ± 254
Girl	1342 ± 289	1410 ± 319	1365 ± 301	1325 ± 263	1330 ± 281	1285 ± 254
Lifelines Diet Score	21.2 ± 6.1	12.4 ± 2.6	17.5 ± 1.1	20.9 ± 0.85	24.4 ± 1.1	30.0 ± 2.5
<b>Parental characteristics</b>						
Maternal age at birth (years)	31.2 ± 4.1	30.3 ± 4.5	31.7 ± 4.2	31.4 ± 3.8	31.3 ± 4.1	31.1 ± 3.9
Paternal age at birth (years)	33.8 ± 4.6	33.2 ± 4.7	33.9 ± 4.8	34.1 ± 4.0	34.1 ± 4.8	33.8 ± 4.7
Maternal BMI before pregnancy (kg/m <sup>2</sup> )	24.8 ± 4.8	25.6 ± 5.1	24.8 ± 4.2	24.8 ± 4.4	24.8 ± 5.1	24.3 ± 4.9
Paternal BMI before pregnancy (kg/m <sup>2</sup> )	25.4 ± 3.2	25.6 ± 3.3	25.6 ± 3.0	25.3 ± 3.4	25.5 ± 3.1	25.1 ± 3.4
<b>Maternal education level, n(%)</b>						
Low	248 (24.9)	64 (36.4)	63 (26.9)	38 (22.8)	42 (19.2)	41 (20.7)
Middle	337 (33.9)	67 (38.1)	84 (35.9)	57 (34.1)	78 (35.6)	51 (25.8)
High	409 (41.1)	45 (25.6)	87 (37.2)	72 (43.1)	99 (45.2)	106 (53.5)
Smoking during pregnancy, n(%)	100 (10.1)	31 (17.7)	25 (10.7)	19 (11.2)	15 (6.9)	10 (5.1)

**Figure 1.** Change in BMI z-score between the age of 3 and 10 years in different quintiles of the LLDS. Mean ± SEM, n = 1001.

status at the age of 10 years illustrates that the assessment of diet quality at this young age can identify children at risk for excess weight change in the future. This emphasizes that diet is of major importance early in life, following the first 1000 days.

**Figure 2.** Overweight prevalence (%) at the age of 3 and 10 years in different quintiles of the LLDS. n = 1001.

This study showed that an increase in 1 quintile of the LLDS at the age of 3 years was associated with a 0.064 SD lower augmentation in BMI between the age of 3 and 10 years. Further adjustment showed that parental factors explained approximately 33% of this association.

**Table 2.** Linear regression analyses to investigate the association between LLDS (in quintiles) and change in BMI-z between the age of 3 and 10 years.  $\beta$  for estimated difference in change in BMI-z corresponding to an increase in 1 quintile of LLDS,  $n = 919$ .

Model	$\beta$	95% CI	P-value
Crude	-0.072	-0.111 ; -0.033	<.001
1A	-0.067	-0.107 ; -0.028	.001
1B	-0.062	-0.099 ; -0.024	.001
1C	-0.064	-0.101 ; -0.026	.001
2	-0.043	-0.079 ; -0.007	.019

Crude model LLDS (in quintiles).

Model 1A) crude + birth weight, sex, gestational age, and breastfeeding at 1 month.

Model 1B) 1A + BMI z-score at the age of 3 years.

Model 1C) 1B + total energy intake.

Model 2) 1C + BMI father, BMI mother, smoking during pregnancy, age mother, and education level mother.

Additionally, the higher change in BMI-z in children with lower diet quality resulted in larger increases in the prevalence of overweight in the lower quintiles of the LLDS. This increase was 14.7% in Q1 (poor diet) and only 3.5% in Q5 (healthy diet). Although not clearly dose-dependent, the odds for overweight incidence in Q1 was 2.86 times higher than in Q5. The absence of a clear cross-sectional association between diet quality and BMI-z or overweight at the age of 3 years emphasizes the importance of prospective studies in childhood. Even if at a young age, no cross-sectional association is observed between poor diet quality and weight, this may become apparent after a longer period of exposure.

So far, literature on associations of diet quality in early childhood and future weight gain has been inconsistent and surprisingly limited for this young age group<sup>15,16</sup>. For example, the Australian Raine study showed small but significant associations between a better diet quality at the age of 1 year, expressed by the Raine Eating Assessment in Toddler score, and lower BMI at the age of 5, 8, and 10 years. However, these associations were not found for diet quality at the age of 2 and 3 years<sup>29</sup>. In the second Australian study that investigated the bidirectional associations between diet quality and body composition from the age of 2 to 15 years, diet quality scores in early childhood did not predict BMI in subsequent bi-annual assessments<sup>13</sup>. A study including children from the UK birth cohort showed that children with higher adherence to a healthy dietary pattern identified through principal component analyses, assessed at 6 months, 1, 3, and 6 years, had lower fat-mass z-scores at the age of 6 years, but no independent associations were found between the healthy dietary pattern and BMI z-score<sup>30</sup>. We hypothesize that differences in diet quality assessment methods and tools to assess diet quality contributed to the inconclusiveness on this topic. Associations in previous studies could have been more pronounced when a more comprehensive dietary assessment method, like a validated FFQ, was used instead of a single 24-h recall<sup>29</sup> or a short, non-validated dietary screener<sup>13</sup>. Also, the use of a food-based diet quality score instead of data-driven pattern score to assess diet<sup>30</sup> may yield more robust insight in the association as well.

At the food group level, unsweetened dairy and whole-grain products were the strongest contributors to the inverse association of diet quality and change in BMI-z, meaning that children with higher intakes of these foods may be less likely to gain weight or become overweight. In line with our results, a previous meta-analysis on prospective cohort studies also illustrated that high dairy intake was associated

with lower body fat percentages and lower overweight/obesity risk in childhood<sup>31</sup>. A meta-analysis of prospective cohort studies in adults also reported a lower risk for abdominal obesity and overweight for high dairy consumers, although this meta-analysis did not find a significant association for servings of dairy and body weight change<sup>32</sup>. Additionally, a recent randomized cross-over trial in adults showed that a high versus low dairy diet reduces both systolic and diastolic blood pressure<sup>33</sup>, which further underlines that dairy intake can favorably influence the metabolic profile throughout the life course. With regard to whole-grain intake, the evidence for an association with weight outcomes in childhood is limited, but our results are in line with two previous observational studies. The first study found a cross-sectional association in 10-year-old children, for whom higher whole-grain intake was associated with lower BMI z-score and obesity prevalence<sup>34</sup>. The second showed that lower intake of whole-grain products at the age of 6 to 7 years was predictive of increases in BMI up until the age of 10 to 11 years<sup>35</sup>. The influence of whole-grain consumption on obesity measures later in life is uncertain, as a recent meta-analysis of randomized controlled trials in adults could not identify significant associations between whole-grain intake and various anthropometric measurements<sup>36</sup>.

Another important food group considered to be of importance in the prevention of childhood weight gain are SSBs<sup>37</sup>. In a meta-analysis of prospective cohort studies investigating this association in children, the pooled estimate for the change in BMI during the time period specified in each study, associated with each daily serving increment of SSBs, was 0.07 SD. However, SSB intake did not strongly contribute to the association of diet quality and BMI-z change in our study. Our young age of dietary assessment may offer a possible explanation. The two studies included in the meta-analysis with children of a similar age did not find an association between SSB and BMI change either<sup>38,39</sup>. The absence of this association in young children may be related to a lower overall consumption or to the type SSB consumed. For example, young children in the Netherlands predominantly consume instant lemonade made from cordial, for which the parent is in control of the dilution.

The dietary intake of children is not just a characteristic of the children themselves, but it is in large part influenced by decisions of the parents. The role of the parents was investigated by adjusting the analyses for parental factors. Indeed, approximately a third of the association of children's diet quality and change in BMI-z was explained by parental factors, especially parental BMI. At the age of 3 years, parental choices and associated availability of foods within the household determine a child's dietary intake, but also the dietary intake of the parent, which leads to nesting of both diet quality and BMI within families. Although it has previously been argued that prevention of overweight in childhood holds much more potential than treatment later on<sup>40</sup>, at a young age children cannot be targeted without their parents. Together, this suggests that public health interventions focusing on parents of young children aiming to improve the diet quality of parents as well as their children should be considered. In the design of such interventions, upstream determinants of a household's dietary habits such as parental education level and the disposable household's income should be considered, since these factors can be limiting the interventions' efficacy.

From a behavioral point of view, higher diet quality in early childhood may be associated with anthropometric outcomes in later childhood due to tracking of established dietary habits<sup>12,13</sup>, which makes that it can exert its influence on body weight throughout childhood in a cumulative way. From a physiological point of view, the risk of an early adiposity rebound may serve as an explanation for the importance of a healthy diet early in life. The adiposity

**Table 3.** Logistic regression analyses to investigate the association between LLDS (in quintiles) and overweight incidence between the age of 3 and 10 years. OR (95% CI),  $n = 843$ .

Model	Q1	Q2	Q3	Q4	Q5	$P_{\text{logistic}}$	$P_{\text{linear trend}}$
Crude	2.57 (1.25 – 5.31)	1.66 (0.81 – 3.42)	2.68 (1.30 – 5.54)	1.65 (0.79 – 3.46)	1.00 (REF)	0.044	0.020
1A	2.41 (1.16 – 5.00)	1.60 (0.77 – 3.31)	2.52 (1.21 – 5.23)	1.64 (0.78 – 3.44)	1.00 (REF)	0.081	0.037
1B	2.73 (1.28 – 5.81)	1.98 (0.94 – 4.19)	3.26 (1.52 – 6.99)	1.88 (0.888 – 4.04)	1.00 (REF)	0.029	0.017
1C	2.86 (1.34 – 6.13)	2.06 (0.97 – 4.39)	3.34 (1.56 – 7.18)	1.93 (0.90 – 4.15)	1.00 (REF)	0.024	0.012
2	2.55 (1.13 – 5.76)	1.82 (0.81 – 4.09)	3.14 (1.39 – 7.10)	1.72 (0.75 – 3.92)	1.00 (REF)	0.060	0.044

Crude LLDS (in quintiles).

Model 1A) crude + birth weight, sex, gestational age, and breastfeeding at 1 month.

Model 1B) 1A + BMI z-score at the age of 3 years.

Model 1C) 1B + total energy intake.

Model 2) 1C + BMI father, BMI mother, smoking during pregnancy, age mother, and education level mother.

rebound generally occurs between the age of 3 and 7 years, and earlier adiposity rebound has been found to be associated with higher adiposity in adulthood<sup>41,42</sup>. Although not yet frequently studied, there are indications that dietary factors, such as higher energy intake<sup>43</sup> or protein intake<sup>44</sup>, can increase the risk of early adiposity rebound, although these associations could not be replicated in a third study<sup>45</sup>. In the current study, higher overall diet quality was associated with a lower energy intake. This suggests that adherence to a high quality diet in early childhood might exert its influence on anthropometry in later childhood by the prevention of an early adiposity rebound. However, since the addition of energy intake to our regression analyses did not attenuate the association of diet quality and weight change or overweight, this explanation seems less likely. Further research is needed to elucidate whether an influence of dietary factors on timing of adiposity rebound is involved in the association of early childhood diet quality and anthropometry later in childhood.

A major strength of this study is the follow-up of 7 years, in which objectively measured BMI-z changes could be investigated. Furthermore, we used the contemporary, food-based LLDS to assess diet quality. However, the LLDS is based on population-specific cutoffs, and the type of food products consumed may be specific to our population. This could attenuate the generalizability of our results. Furthermore, dietary intake data were collected via a parent-reported FFQ. Although a validated FFQ was used, this assessment method is prone to recall and reporting bias. A specific type of reporting bias that is important in dietary assessment is social desirability bias, leading participants to report slightly healthier dietary habits than are true. The risk for this type of bias is greater for participants with higher BMI<sup>46</sup>. Since not many children in our study population were overweight at the time of dietary assessment, the risk for this type of bias is limited. Furthermore, some dropout bias may be present in this study as it was illustrated that parents of children who were lost to follow-up had slightly higher BMIs, and mothers had slightly lower education levels (Table S4). Finally, the potential for residual confounding is also a limitation of this study. For example, models could not be adjusted for physical activity since data were not available. However, as there is no consensus on the prospective association of (moderate to vigorous) physical activity and changes in BMI in early childhood<sup>47</sup>, the residual confounding by physical activity may be limited. In summary, despite the well-established association between diet and overweight in adults, surprisingly little was known about this association in very young children. The current study showed that diet quality at the age of 3 years, measured with the

LLDS, was significantly and relevantly associated with changes in BMI z-score and overweight incidence between the age of 3 and 10 years. This illustrates that already at a very young age, a poor quality diet, for example, low in unsweetened dairy and whole-grain foods, can identify children who are prone to excess weight gain and overweight in subsequent years. Addressing diet in the first years of life is therefore crucial to start early prevention of childhood overweight. Additionally, when children get accustomed to healthy eating early in childhood, their behaviors may track into adulthood and therefore diminish excessive weight gain over the life course.

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**Conflict of Interest.** None.

**Ethical standards.** The authors assert that all procedures contributing to this work comply with the ethical standards of the Netherlands Code of Conduct for Research Integrity and with the Helsinki Declaration of 1975, as revised in 2008, and have been approved by the Medical Ethics Committee of the University Medical Center Groningen.

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