Nutrition Journal

RESEARCH

Open Access

Association between early dietary patterns and cardiometabolic health at age 8: a confirmatory analysis of the European Childhood Obesity Project

Mariona Gispert-Llauradó[1,2], Joaquin Escribano[1,2*], Natalia Ferré[1,2], Veit Grote[3,4], Berthold Koletzko[3,4], Gina Ambrosini[5], Elvira Verduci[6,7], Dariusz Gruszfeld[8], Annick Xhonneux[9] and Veronica Luque[1,2*]

Abstract

Background & Aim Metabolic and cardiovascular health outcomes are strongly influenced by diet. Dietary habits established in early childhood may persist into adulthood. This study aimed to examine the association between dietary patterns at both 2 and 8 years of age, explaining the maximum variability of high- and low-quality fats, sugars, and fibre, and cardiometabolic markers at age 8 years.

Methods This was a secondary analysis of the European Childhood Obesity Project, formerly a randomized clinical trial across five European countries performed in healthy term newborns. Children in the study were categorized at ages 2 and 8 years into two groups based on cluster analysis of dietary patterns (DP) derived from Reduction Rank Regression (RRR). A cross-sectional and prospective analysis was conducted to evaluate the associations between these DPs and cardiometabolic outcomes, including body mass index (BMI), blood pressure (BP), and biochemical markers. Triglycerides, HDL cholesterol and insulin resistance index (HOMA-IR) were also categorized as altered versus normal values. Associations between dietary patterns and health outcomes were assessed using linear and logistic regression models, adjusting for covariates based on a step-wise approach.

Results A total of 336 children were classified based on quality of nutrient intakes into either a "Poor-Quality dietary pattern" (PQ-DP) (48% and 66% of infants at 2 and 8 years, respectively) or the "Health-Conscious dietary pattern" (HC-DP) (52% and 34% of infants at 2 and 8 years, respectively). Following a PQ-DP at both ages 2 and 8 was associated with higher triglycerides ($\beta = 0.061$, $p = 0.049$), systolic and diastolic BP ($\beta = 13.019$, $p < 0.001$ & $\beta = 7.612$, $p = 0.014$, respectively) and altered levels of HOMA-IR (OR = 3.1, $p = 0.037$, 95% CI = 1.1–9.1) at 8 years, compared to children with an HC-DP at both ages, after adjusting for confounders.

Conclusion Adherence to a dietary pattern with a poorer nutritional profile in early childhood and school age is associated with worse cardiometabolic risk markers at 8 years old.

*Correspondence:
Joaquin Escribano
joaquin.escribano@urv.cat
Veronica Luque
veronica.luque@urv.cat

Full list of author information is available at the end of the article

Keywords Poor quality dietary pattern, Early childhood nutrition, Cardiometabolic health, Reduction rank regression, Cluster, Prospective analyses

Background

A high consumption of ultra-processed foods and of sweet beverages has been associated with an increasing prevalence of obesity and cardiometabolic disorders in numerous countries [1]. Dietary habits established during early childhood are likely to persist into mid-childhood, adulthood and older age [2–5].

Considering that the human diet is composed of multiple food products with complex interactions between them, studying the relationship between dietary intake and its health effects requires a more comprehensive approach beyond the focus on single foods or nutrients. Dietary patterns are a valuable approach for understanding and predicting diet-related outcomes [6, 7]. Earlier research has identified different dietary patterns associated with health. Unhealthy dietary patterns are often characterized by high consumption of processed foods, saturated fats and sugars. In contrast, healthy dietary patterns typically feature higher intakes of fruits, vegetables, whole grains, healthy fats, and fibre.

To date, index-based methods, exploratory factor analyses (EFA) and principal component analyses (PCA) are the most commonly used methods for deriving dietary patterns (DP) [6]. A valuable but less commonly used statistical approach that has emerged is Reduced Rank Regression analyses (RRR). This method offers the advantage of considering "*a priori*" knowledge about disease aetiology in combination with "*a posteriori*" methods to extract the dietary patterns. This may enhance the relevance of the extracted dietary patterns and makes it possible to explain the maximum variability in response variables and better predict the disease risk [8].

Fewer studies have explored the long-term effects of early life nutrition on cardiovascular health markers during childhood and later stages of life. Leermakers et al. found no associations between the quality of diet at the age of 1 year and its impact on cardiometabolic health at the age of 6 years in participants of the Generation R cohort Study, using RRR analyses to derive dietary patterns [9]. In a subsequent analysis, the same group reported associations between higher diet quality at 8 years and lower systolic and diastolic blood pressure at 10 years using a priori methods, although no significant associations were observed for insulin, triglycerides, HDL cholesterol, or body fat percentage [10]. Similarly, the Generation XXI birth cohort identified that an unhealthy dietary pattern at age 7 correlated significantly with systolic blood pressure (SBP) and insulin resistance index (HOMA-IR) at age 10 years, but not with other health markers [11]. A systematic review, with limited evidence, indicated that adopting a healthy dietary pattern in childhood was associated with lower blood lipid levels, triglycerides, and blood pressure (BP) later in life [12].

Using an exploratory approach, dietary patterns in the Childhood Obesity Project (EU CHOP) study were previously investigated, revealing that dietary patterns established at 2 years of age and continuing into later childhood were associated with cardiometabolic markers such as BP, triglycerides and HOMA-IR at 8 years of age [2, 3]. However, this method was not able to explain the maximum variability in response variables or to better predict disease risk.

Methods

This study aims to investigate the association between dietary patterns explaining the maximum variability of high- and low-quality fats, sugars, and fibre at both 2 and 8 years of age, and cardiometabolic markers at age 8 years, using a hypothesis driven statistical approach.

Study design and population

We used data from the randomized controlled multicentre EU CHOP study. The primary aim of EU CHOP was to investigate whether infant and follow-on formula with a lower (1.77 and 2.2 g protein/100 kcal, respectively) protein content during the first year of life reduces later obesity risk, compared to conventional infant and follow-on formula with higher (2.9 and 4.4 g protein/100 kcal, respectively) protein content [13]. The study was conducted in five European countries: Germany, Belgium, Italy, Poland and Spain, with infants recruited from birth up to a maximum of 8 weeks [median (IQR) age: 14 d (3–30 d)] between October 2002 and July 2004. Inclusion criteria were being born apparently healthy at term from a singleton pregnancy, with normal weight for gestational age, and born to mothers without health problems or taking medications that could influence intrauterine growth. Detailed information about the study is available elsewhere [13]. For the current analysis, we used data from children who participated in the 2-year visit and those who attended the 8-year visit, with dietary records available for both groups. Cross-sectional analyses included data from children who performed anthropometry, had dietary intake information and blood pressure or blood sample analyses. Prospective analyses included children who attended both visits (at 2 and 8 years) and had dietary records, along with either blood pressure measurements or blood sample analyses.

Health outcome measures

Anthropometry

Anthropometric measurements were taken in duplicate by trained nutritionists following standard operating procedures based on the manual by Lohman et al. [14]. All measurements were taken with participants wearing only underwear. Weight (kg) was measured using a SECA 702/703 digital scale (precision ± 10 g) and height was measured with a digital stadiometer SECA 242 (precision ± 1 mm). Waist circumference was measured at the midpoint between the iliac crest and the lower rib in a standing position after exhalation, according to WHO references [15]. All study centres used the same equipment for these measurements. Body Mass Index (BMI) was calculated as weight (kg)/height (m^2). BMI z-scores were calculated using WHO references [15].

Blood pressure

At the 8-years visit, blood pressure was measured using an oscillometric technique with the Digital tensiometer Dinamap ProCare 100/200 (GE Medical Systems, Freiburg, Germany). Measurements were taken in duplicate at least 20 min after the child arrived at the study centre. The measurements were performed on the left arm, while the child remained seated with the arm resting comfortably and using an appropriately sized cuff. Both measurements were separated by a slot time of 5 min, and the average of the two readings was used for statistical analysis. Systolic (SBP) and diastolic blood pressure (DBP) were standardized as percentiles based on body height using references from the American Academy of Pediatrics [16].

Blood sample analyses

Fasted venous blood samples were collected by trained nurses when the child were 8 years old. Serum samples were stored at -80 ºC and transported in dry ice to the central laboratory. Glucose, high-density lipoprotein cholesterol (HDL cholesterol) and triglyceride levels were analysed at the respective local study laboratories using routine methods [17]. Insulin levels (μIU/ml) were quantified using immunoradiometric assays. Fasting insulin and glucose levels were used to calculate insulin resistance (HOMA-IR) using the Homeostasis Model Assessment of Insulin resistance [18, 19]. Serum insulin levels were measured using an immunoradiometric assay (DiaSource, Nivelles, Belgium) following the manufacturer's instructions. HDL cholesterol ≤ 10th percentile, and triglycerides and HOMA-IR ≥ 90th percentile, based on the age- and sex-specific references from the IDEFICS study [20, 21], were considered altered.

Cardiometabolic risk score

To assess the children's cardiometabolic risk, we computed a continuous cardiometabolic risk score variable (Cmet Risk) following the method proposed by Eisenmann et al. [22]. This score was calculated as the sum of standardized variables: waist circumference, SBP, DBP, triglycerides, HOMA-IR and HDL cholesterol internal z-scores, this last one multiplied by -1 (as HDL cholesterol is inversely related to cardiometabolic risk). A higher score in this Cmet Risk indicates a less favourable cardiometabolic profile.

Predictors of health outcome measures

Assessment of dietary intake

Dietary intake was assessed using three-day estimated and weighed food diaries completed by the child's parent or caregiver at ages 2, 3, 4, 5, 6, and 8. For these analyses we used the initial and final intakes (2 and 8 years). Parents were instructed on how to record all food and beverages consumed over two weekdays and one weekend day. Energy and macronutrient intakes were estimated using a database derived from the German BLS II.3 [23]. Food items and recipes not available in the database were incorporated at each study center based on information from manufacturers, other databases, or ingredient lists. Detailed information on standard operating procedures for assessing dietary intake has been previously published [24, 25]. A total of 7444 individual foods and beverages were categorized into 105 groups, which were subsequently reduced to 27 major food groups based on similarities in their nutrient profile and processing levels. Additional information on this process of combining food groups has been previously published [2].

Covariates

Sociodemographic and other characteristics, including sex (male vs. female), country of origin (Germany, Belgium, Italy, Poland, and Spain), maternal education level (high, medium or low), maternal smoking during pregnancy at any time (yes vs. no), maternal BMI, feeding group during the first year of life (lower protein vs. higher protein formula or exclusive breastfeeding for at least 3 months), mean energy intake at 8 years (kcal/day) and BMI z-score at 8 years (not included in BMI outcome measures nor in the cardiometabolic risk score variable) were included as covariates. All categorical variables with more than two levels were converted into dummy variables.

Statistical analyses

Descriptive data were reported as median and interquartile range (IQR) for continuous variables and as frequency and percentage for categorical variables. Normal distribution of variables was assessed visually, and

non-normally distributed variables (triglycerides, HDL cholesterol and HOMA-IR) were transformed into a logarithmic scale [20, 21].

Major factors were extracted using RRR analyses, as previously described by Hoffmann et al. [26]. The 27 food groups (g/day) were considered as predictor variables, and low-quality fats, healthy fats, fibre and total sugars (g/total daily energy intake [kcal]) were selected as response variables based on evidence of a relationship with metabolic and cardiovascular problems both in childhood and adulthood. Low-quality fats were defined as fats from meat, eggs, milk, saturated spreads, processed products, cakes and confectionary; healthy fats were defined as fats from olive oil, nuts and fish.

Four extracted factors were obtained in accordance with the number of response variables included. Factor loadings were also obtained to quantify the contribution of each food group to the extracted factors. Food groups with a factor loading of 0.2 or higher were considered as significant for interpreting and labelling the extracted factor.

In a first step we explored the extracted factors obtained at all ages (2 to 8 years) to confirm the consistency of the patterns. The extracted factors obtained at 4 years were the most independent of each other and explained the greatest variability in intake. To track predictor scores for exactly the same extracted factor from 2 to 8 years, we use the scoring coefficients produced by the 4-year analysis for both 2 and 8 years. In this way, adherence to the 4 extracted factors was fully comparable at both 2 and 8 years of age. Each participant received a z-score quantifying their adherence to each extracted factor at both 2 and 8 years.

Since the quality of the diet for each participant depended on combinations of four different factor z-scores, we grouped the subjects using cluster analyses. This approach allows for a simplified and clearer interpretation of diet quality in each participant, following the methodology proposed by Shang, X [27]. This clustering procedure used Ward's method with squared Euclidean distances in a hierarchical cluster analysis to categorize subjects into two distinct clusters, each representing a dietary pattern group (DP).

Differences between dietary patterns (DP) and nutrient intakes adjusted for energy were analysed using the Mann–Whitney U test. Linear regression models were applied to assess the association between these two DP groups, identified through cluster analyses, and the main outcome measures (BMI z-score, triglycerides, HDL cholesterol, HOMA-IR, systolic and diastolic blood pressure and Cmet Risk score) at 8 years of age. Two regression models were constructed: the first model included DP groups at age 8 years, and the second model included DP groups at age 2 years. Additionally, children were classified into groups based on their consistency in remaining within the same dietary pattern (DP) cluster across different time points.

The association of persistent dietary patterns with cardiometabolic health markers was analysed using linear regression model.

Logistic regression analyses were conducted to examine the relationship between classification into different dietary pattern groups and the presence of altered values in triglycerides, HDL cholesterol and HOMA-IR at ages 2 and 8 years, in both cross-sectional and prospective analyses.

In all the linear and logistic regression models, dietary pattern group was introduced as the main predictor using the enter method, while other covariates were included using the step forward method. All models were adjusted for the following possible confounders: sex, country of origin, maternal education level, maternal smoking during pregnancy, maternal BMI, feeding during the first year of life, mean energy intake at 8 years and BMI z-score at 8 years (not included as covariate in models with BMI or cardiovascular risk score as outcome).

Statistical significance was accepted at the level $p < 0.05$. The statistical analyses were performed using SPSS (Statistical Package for the Social Sciences) version 29.0 (IBM Corp., Armonk, NY, USA) and SAS version 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

Study participant characteristics

At 2 years, 1009 infants completed the follow-up visits. Among them, 726 participants had both anthropometry measurements and information on nutrient intake. At age 8, 653 children attended the visit. We collected completed 3-day food diaries and anthropometry data from 396 participants. Additionally, 385 participants had their blood pressure parameters measured, and 274 participants had anthropometry, dietary intake, and biochemical parameters measured under fasting conditions at 8 years of age. At both ages, 336 participants had dietary intake information, while 322 also had anthropometry and measured blood pressure. Finally, 228 participants had dietary intake, anthropometry, and biochemical parameters measured under fasting conditions at both time points. Additional File 1 shows the study flowchart. Detailed descriptions of anthropometric, biochemical parameters, dietary intake, and blood pressure measurements for the children included in the analyses at ages 2 and 8 years are shown in Table 1. The descriptive characteristics of the entire study sample are shown in Additional File 2. Further details about the sociodemographic characteristics of the study sample were previously published [3].

Table 1 Descriptive of the study sample of children included in the analyses

	2 years		8 years	
	Median	**[25th ;75th centiles]**	**Median**	**[25th ;75th centiles]**
Anthropometry parameters	*n* = 336		*n* = 336	
Weight [kg]	12.4	[11.6;13.2]	27.5	[24.4;31.1]
Height [cm]	88.0	[86.1;90.2]	129.7	[125.7;133.1]
Waist circumference [cm]	47.9	[45.6;50.4]	57.4	[54.5;62.4]
Body Mass Index [kg/m^2]	16.1	[15.3;17.0]	16.4	[15.1;18.2]
Body Mass Index [z-score]	0.29	[-0.41;0.94]	0.37	[-0.43;1.26]
Nutrient intake	*n* = 336		*n* = 336	
Energy intake [kcal/day]	1105	[940;1264]	1610	[1383;1770]
Protein intake [g/day]	44.0	[36.3;54.1]	59.3	[50.4;70.3]
Carbohydrate intake [g/day]	135.8	[115.3;156.0]	192.1	[166.6;221.3]
Fat intake [g/day]	41.9	[33.7;50.7]	63.7	[53.5;74.9]
Dietary fibre [g/day]	6.9	[5.2;9.1]	11.8	[9.6;14.0]
Sugars [g/day]	67.4	[55.1;85.5]	79.3	[65.6;99.8]
Protein intake by energy [g/1000 kcal]	40.8	[34.9;46.0]	37.1	[33.2;42.1]
Carbohydrate intake by energy [g/1000 kcal]	123.9	[112.0;135.0]	121.1	[110.4;132.0]
Fat intake by energy [g/1000 kcal]	38.0	[34.1;41.8]	40.6	[36.4;44.3]
Dietary fibre by energy [g/1000 kcal]	6.2	[4.8;8.1]	7.3	[6.2;8.9]
Sugars by energy [g/1000 kcal]	62.0	[53.6;72.2]	51.6	[43.1;59.6]
Blood Pressure parameters			*n* = 385	
Systolic BP [mmHg]	-		100	[93;107]
Systolic BP percentile [AAP 2017]	-		61	[34;81]
Diastolic BP [mmHg]	-		57	[52;61]
Diastolic BP percentile [AAP 2017]	-		44	[25;60]
Biochemical parameters			*n* = 274	
Total cholesterol [mg/dl]	-		166	[146;185]
HDL cholesterol [mg/dl]	-		58	[49;68]
Triglycerides [mg/dl]	-		53	[42;69]
Glucose [mg/dl]	-		84	[78;89]
Insulin [µiu/ml]	-		8.3	[6.5;10.6]
HOMA-IR	-		1.72	[1.31;2.22]
Cardiometabolic Risk	-		*n* = 257	
Cardiometabolic Risk Score	-		-0.75	[-2.54;1.26]

Dietary patterns

The four major extracted factors and their respective loadings for each food group are depicted in Fig. 1. The first extracted factor was characterized by high positive loadings for saturated spreads, added sugars, confectionary products and fruit juices and negative loadings of fish, olive oil and olives. Thus, it was labelled as "poor quality fats and sugar". It explained the greatest variation (34.8%) in all four response variables low-quality fats, healthy fats, fibre and total sugars; the second factor (labelled as "fibre"), the third factor (labelled as "poor quality fats without sugar") and fourth extracted factor (labelled as "high quality fats") explained each 16%, 13%, and 5%, respectively.

The two dietary clusters/patterns at 2 and 8y that discerned those predictor scores from each extracted factor best is displayed in Fig. 2. As expected, the predicted score of Factor 1, which explained the highest variation, differed significantly between the two dietary pattern groups.

The first group of children had negative predicted scores for Factor 1: -0.67 (± 0.77) at 2 years and − 2.12 (± 1.0) at 8 years (mean ± SD). Conversely, the second dietary pattern group had positive scores for Factor 1: 0.71 (± 0.62) at 2 years and 0.49 (± 1.1) at 8 years. These differences between the dietary pattern groups were statistically significant at both timepoints ($p < 0.001$).

The other predictor scores also differed between groups at both timepoints, except at 8 years, where the predictor score from the second extracted factor did not differ significantly between the two groups of children. (Fig. 2).

Figure 3 shows the nutrient intakes by dietary pattern group. Significant differences were observed between the groups for healthy fats, processed fats, other non-healthy fats, and sugar intake adjusted for energy at both ages ($p < 0.001$ for all associations at 2 and 8 years). For fibre intake, the first dietary pattern (DP) group had a lower

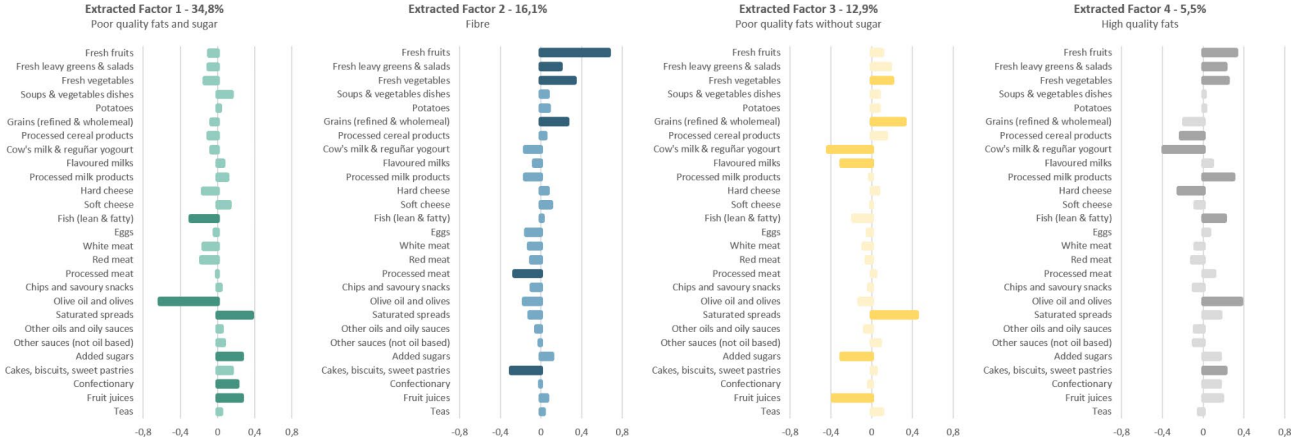

Fig. 1 Loading factors of the four major extracted factors at 4 years

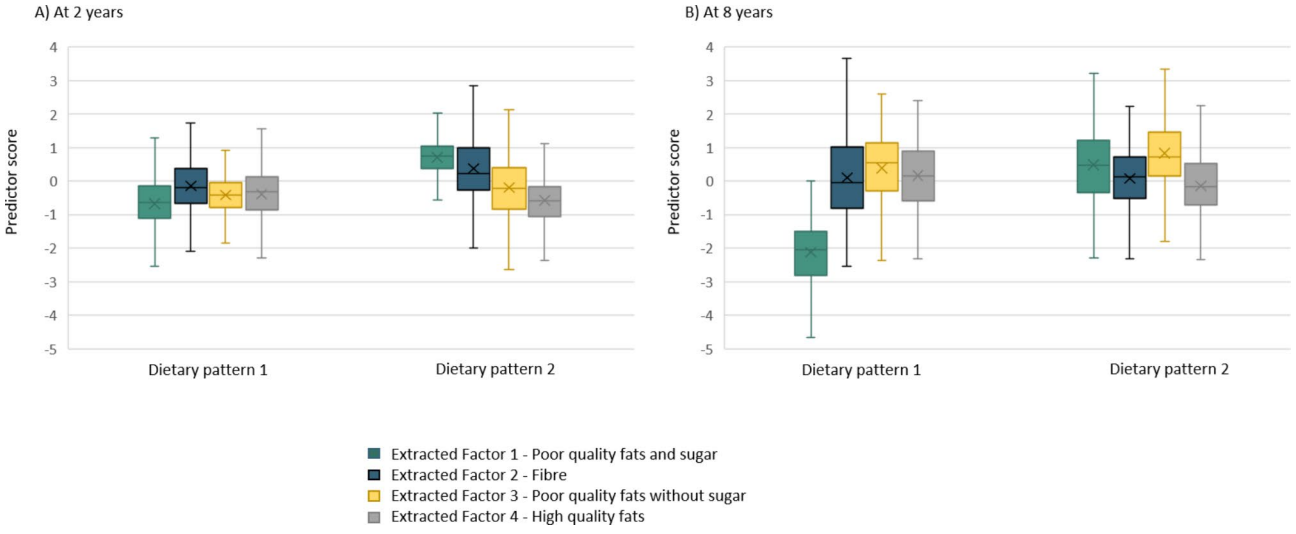

Fig. 2 Differences in predictor scores from each extracted factor between dietary patterns groups at 2 **(A)** and 8 **(B)** years old. Note: "Median (centre line)", "Mean (cross)", "Interquartile Range (Q1-Q3 box)", "Whiskers (range of acceptable values)"

intake than the second group at 2 years ($p < 0.001$), but no differences were observed at 8 years. Similarly, no differences in energy intake were observed between groups at any timepoint (data not shown). Based on this dietary intake information, the two dietary patterns were labelled as follows: "Poor-Quality dietary pattern" (PQ-DP) and "Health-conscious dietary pattern" (HC-DP). At 2 years, 362 infants (48%) were classified into the PQ-DP group and 385 infants (52%) into the HC-DP group. At 8 years, 262 children (66%) were classified into the PQ-DP group and 134 children (34%) into the HC-DP group.

Association between dietary patterns and cardiometabolic markers

Multiple linear regression models for each health outcome variable in relation to dietary patterns are shown in Table 2.

The first model examined the association between the diet type at 8y and health markers at the same age. Overall, we did not find significant associations between the type of diet and the health outcomes variables, except for BMI z-score, which was inversely associated with the poor-quality dietary pattern group at 8 years (β=-0.260, $p = 0.049$) (Table 2).

The second model shows the association between diet at 2 years and health outcomes at 8 years. Belonging to the PQ-DP at 2 years was associated with higher blood triglycerides (β = 0.056, $p = 0.017$), lower HDL cholesterol (β=-0.034, $p = 0.032$), and higher systolic (β = 11.400, p = < 0.001) and diastolic blood pressure percentiles (β = 4.950, $p = 0.049$). Consistently, we found that infants in the poor-quality dietary pattern had significantly higher cardiometabolic risk score at 8 years (β = 1.086, $p = 0.020$). No significant associations were found

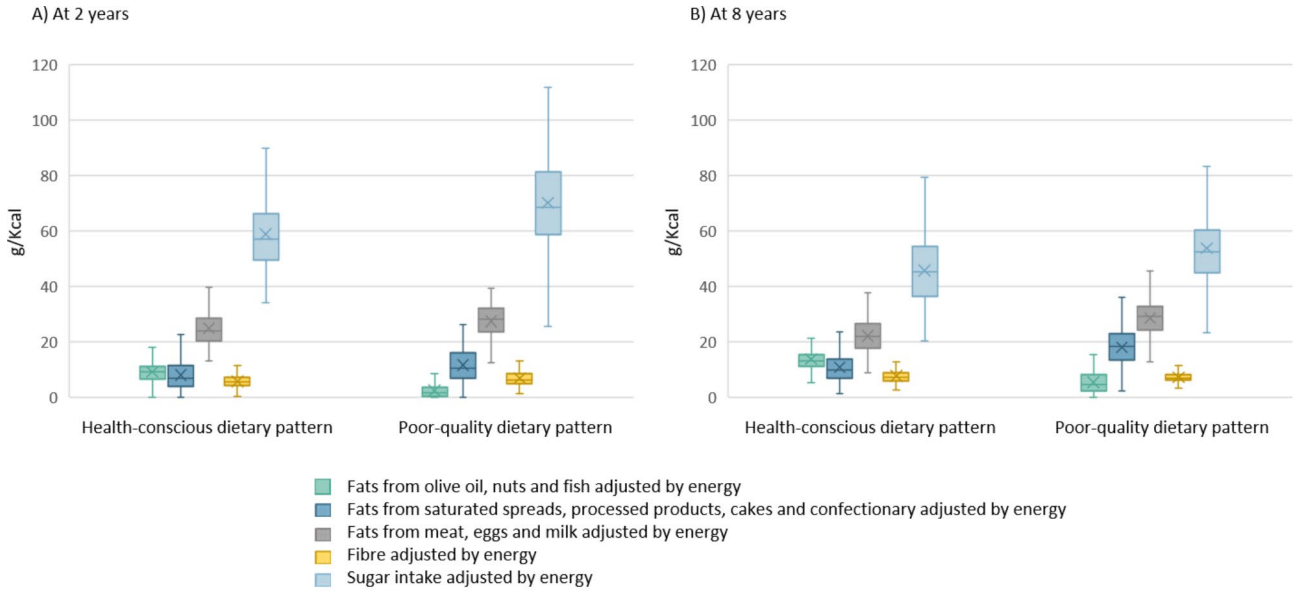

Fig. 3 Differences in nutrient intake adjusted by energy between dietary patterns groups at 2 **(A)** and 8 **(B)** years old. Note: P value for Mann-Whitney U test between dietary pattern clusters. At 2 years, $p < 0.001$ in all cases; at 8 years, $p < 0.001$ in all cases except for fibre. "Median (centre line)", "Mean (cross)", "Interquartile Range (Q1-Q3 box)", "Whiskers (range of acceptable values)"

between the PQ-DP at 2 years and the BMI z-score and HOMA-IR at 8 years.

The third model examined the association between remaining in a diet group over time, at 2 and 8 years, and health outcomes at 8 years. Based on their consistency in remaining within the same dietary pattern (DP) cluster across different time points, children were classified in four different groups: (1) PQ-DP at both 2 and 8 years: 145 children (43.2%); (2) PQ-DP at 2 years and HC-DP at 8 years: 19 children (5.7%); (3) HC-DP at 2 years and PQ-DP at 8 years: 76 children (22.6%), and; (4) HC-DP at both 2 and 8 years: 96 children (28.6%) (Table 3). We observed that children adhering to the PQ-DP at both 2 and 8 years had significantly higher blood triglycerides ($\beta = 0.061$, $p = 0.049$) and higher systolic and diastolic blood pressure ($\beta = 13.019$, $p < 0.001$ and $\beta = 7.612$, $p = 0.014$, respectively), compared with children who followed the HC-DP at both ages. Furthermore, we did not find significant differences in the cardiometabolic risk score, HOMA-IR, HDL cholesterol, and BMI between children who followed the PQ-DP at both 2 and 8 years, compared with those who followed the HC-DP at both ages (Table 2). To be classified either in the PQ-DP at 2 years and then a HC-DP at 8 years or vice versa (HC-DP at 2 years and a PQ-DP at 8 years) was not associated with any of the health outcomes at 8 years (Table 2).

We also performed logistic regression analyses to observe the association between being classified in different dietary patterns and altered levels of triglycerides, HOMA-IR and HDL cholesterol. Children in the PQ-DP at 2 years had increase odds of 2.5 for having a high HOMA-IR at 8 years ($p = 0.021$). Moreover, children with a PQ-DP at both 2 and 8 years had increased odds of 3.1 for having a high HOMA-IR at 8 years ($p = 0.037$) compared with children with a HC-DP at both timepoints (Table 4). No significant associations were observed between DPs and altered levels of triglycerides and HDL cholesterol at any timepoint (Table 4).

Discussion

Here, we describe associations between dietary patterns at 2 and 8 years reflecting the quality of dietary nutritional profiles and cardiovascular health markers at 8 years, delivering a hypothesis-driven analysis. Our findings confirm that adhering to dietary patterns characterized by the intake of poor-quality fats, sugars, and low fibre, along with low intake of high-quality fats during childhood, is associated with worse cardiometabolic risk indicators, independent of BMI. Specifically, we observed that children consistently adhering to a poor-quality diet, labelled as "PQ-DP", at both 2 and 8 years were more likely to have higher concentrations of triglycerides, systolic and diastolic blood pressure and an increased risk of having an altered HOMA-IR, compared to children adhering to a health-conscious dietary pattern at both ages.

Our results are consistent with previously published findings in early childhood. For instance, the Generation XXI birth cohort identified that an unhealthy dietary pattern at age 7 was significantly associated with DBP

Table 2 Linear regression models on the associations of dietary patterns during childhood on health outcomes at 8y

	Body Mass Index (z-score)	Triglycerides (lg10)	HDL Cholesterol (lg10)	HOMA-IR (lg10)	Systolic Blood Pressure (*P*)	Diastolic Blood Pressure (*P*)	Cardiometabolic Risk Score
	β (95% CI), *P* value and R^2	**β (95% CI), *P* value and R^2**	**β (95% CI), *P* value and R^2**	**β (95% CI), *P* value and R^2**	**β (95% CI), *P* value and R^2**	**β (95% CI), *P* value and R^2**	**β (95% CI), *P* value and R^2**
Model 1: Cross-sectional: association of the diet at 8y on health outcome at 8 years							
PQ-DP at 8y	-0.260 (-0.519, -0.001) **0.049**, 13%[a]	0.010 (-0.035, 0.054) 0.666, 18.6%[b]	0.016 (-0.013, 0.045) 0.286, 17%[c]	0.025 (-0.012, 0.062) 0.183, 32.4%[d]	-0.525 (-6.435, 5.385) 0.861, 27.3%[e]	4.122 (-0.387, 8.631) 0.073, 18%[f]	-0.582 (-1.423, 0.258) 0.174, 18.6%[g]
Model 2: Prospective: association of the diet at 2y on outcome at 8 years							
PQ-DP at 2y	0.037 (-0.239, 0.313) 0.794, 12%[h]	0.056 (0.010, 0.101) **0.017**, 18.7%[i]	-0.034 (-0.065, -0.003) **0.032**, 17.7%[j]	0.014 (-0.026, 0.054) 0.483, 34.9%[k]	11.400 (5.810, 16.990) **<0.001**, 26.4%[l]	4.950 (0.014, 9.885) **0.049**, 16.4%[m]	1.086 (0.173, 1.999) **0.020**, 21.6%[n]
*Model 3: Prospective: association of the diet at 2y and 8y on outcome at 8 years**							
PQ-DP at 2y and PQ-DP at 8y	-0.247 (-0.553, 0.059) 0.113	0.061 (0.000, 0.121) **0.049**	-0.014 (-0.054, 0.027) 0.515	0.025 (-0.026, 0.075) 0.337	13.019 (6.115, 19.924) **<0.001**	7.612 (1.574, 13.650) **0.014**	0.733 (-0.462, 1.928) 0.228 .
PQ-DP at 2y and HC-DP at 8y	0.258 (-0.297, 0812) 0.362	0.042 (-0.040, 0.124) 0.315	-0.044 (-0.100, 0.012) 0.120	0.012 (-0.067, 0.091) 0.758	7.374 (-4.583, 19.331) 0.226	2.546 (-7.470, 12.562) 0.617	0.996 (-0.627, 2.619) 0.228
HC-DP at 2y and PQ-DP at 8y	-0.249 (-0.595, 0.097) 0.158 12.3%[o]	0.000 (-0.057, 0.057) 0.991 18%[p]	0.023 (-0.014, 0.060) 0.225 17.8%[q]	0.016 (-0.036, 0.068) 0.548 34.4%[r]	1.572 (-5.957, 9.102) 0.681 26.2%[s]	3.719 (-2.547, 9.985) 0.244 16.5%[t]	-0.601 (-1.684, 0.482) 0.275 21.3%[u]

HOMA-IR: Homeostasis Insulin Resistance Index. PQ-DP: Poor-quality dietary pattern group, HC-DP: Health-consious dietary pattern group. All models adjusted by sex, country (reference category: Spain), energy intake at 8y, diet during the first year of life (reference category: Low protein formula), maternal education level (reference category: Low), maternal smoking during pregnancy, maternal BMI and BMI z-score at 8y (except when it was the outcome measure and in the Cardiometabolic Risk Score outcome due to collinearity). The R^2 for the goodness of fit is provided for each model. Bold numbers: statistically significant. Reference dietary pattern group: HC-DP at 2 years and HC-DP at 8 years. Confounders with effect on the outcome variable: [a] Belgium (β=-0.630, $p=0.006$), maternal BMI (β=0.080, $p<0.001$), smoking during pregnancy (β=0.330, $p=0.012$). [b] Poland (β=0.166, $p<0.001$), Belgium (β=0.098, $p=0.008$), Italy (β=0.069, $p=0.005$), maternal education level: medium (β=-0.048, $p=0.012$), maternal BMI (β=0.005, $p=0.018$). [c] Poland (β=-0.097, $p<0.001$), BMI z-score at 8y (β=-0.018, $p<0.001$).[d] Italy (β=-0.162, $p<0.001$), BMI z-score at 8y (β=0.060, $p<0.001$). [e] Italy (β=-12.560, $p<0.001$), Germany (β=20.611, $p<0.001$), Poland (β=9.524, $p<0.001$), BMI z-score at 8y (β=7.634, $p<0.001$), smoking during pregnancy (β=8.957, $p=0.001$), maternal BMI (β=0.743, $p=0.019$). [f] Germany (β=18.658, $p<0.001$), Italy (β=-9.335, $p=0.001$), sex: female (β=5.153, $p=0.013$), diet during the first year of life: breastfed (β=-4.804 $p=0.027$). [g] Poland (β=2.326, $p<0.001$), maternal BMI (β=0.191, $p<0.001$), diet during the first year of life: breastfed (β=-1.029, $p=0.009$). [h] Belgium (β=-0.764, p0.003), smoking during pregnancy (β=0.386, $p=0.005$), maternal BMI (β=0.076, $p<0.001$). [i] Poland (β=0.105, $p<0.001$), maternal education level: medium (β=-0.056, $p=0.006$), mean caloric intake at 8y (β=-0.000, $p=0.016$), maternal BMI (β=0.006, $p=0.023$). [j] Poland (β=-0.074, $p<0.001$), BMI z-score at 8y (β=-0.015, $p=0.009$), diet during the first year of life: breastfed (β=-0.032, $p=0.029$). [k] Italy (β=-0.167, $p=0.001$), BMI z-score at 8y (β=0.063, $p<0.001$). [l] Italy (β=-17.154, $p<0.001$), BMI z-score at 8y (β=7.340, $p<0.001$), maternal BMI (β=0.880, $p=0.012$), smoking during pregnancy (β=7.471, $p=0.014$). [m] Germany (β=17.753, $p<0.001$) Italy (β=-8.170, $p=0.008$). [n] Poland (β=1.658, $p=0.002$), maternal BMI (β=0.188, $p<0.001$), mean caloric intake (β=0.002, $p=0.036$), smoking during pregnancy (β=0.886, $p=0.041$). [o] Belgium (β=-0.597, $p=0.018$), maternal BMI (β=0.075, $p<0.001$), smoking during pregnancy (β=0.430, $p=0.002$). [p] Poland (β=0.101, $p<0.001$), maternal education level: medium (β=-0.055, $p=0.007$), mean caloric intake (β=0.000, $p=0.025$), maternal BMI (β=0.006, $p=0.026$). [q] Poland (β=-0.083, $p<0.001$), BMI z-score at 8y (β=-0.013, $p=0.022$), diet during the first year of life: breastfed (β=-0.032 $p=0.029$). [r] Italy (β=-0.165, $p<0.001$), BMI z-score at 8y (β=0.064, $p<0.001$). [s] Italy (β=-16.419, $p<0.001$), BMI z-score at 8y (β=7.497, $p<0.001$), maternal BMI (β=0.889, $p=0.011$), smoking during pregnancy (β=7.332, $p=0.016$). [t] Germany (β=16.992, $p<0.001$), Italy (β=-7.485, $p=0.017$). [u] Poland (β=2.066, $p<0.001$), maternal BMI (β=0.210, $p<0.001$), smoking during pregnancy (β=1.024, $p=0.018$), maternal education level: medium (β=-0.969, $p=0.019$)

Table 3 Classification of children into dietary pattern groups based on cluster membership over time

		Dietary pattern at 8 years	
		Health-consious DP	**Poor-quality DP**
Dietary pattern at 2 years	Health-consious DP	96 participants	76 participants
	Poor-quality DP	19 participants	145 participants

DP: dietary pattern

Table 4 Logistic regression models on the associations of dietary patterns during childhood on health outcomes at 8y

	Triglycerides ≥ 90th pct	**HDL Cholesterol ≤ 10th pct**	**HOMA-IR ≥ 90th pct**
	OR (95% CI) ***P* value and R^2**	**OR (95% CI)** ***P* value and R^2**	**OR (95% CI)** ***P* value and R^2**
Model 1: Cross-sectional: association of the diet at 8y on health outcome at 8 years			
PQ-DP at 8y	0.533 (0.147, 1.934) 0.339, 11.2%[a]	0.828 (0.236, 2.897) 0.767, 7.9%[b]	1.276 (0.647, 2.517) 0.482, 21.6%[c]
Model 2: Prospective: association of the diet at 2y on outcome at 8 years			
PQ-DP at 2y	1.501 (0.465, 4.851) 0.497, 15.7%[d]	2.714 (0.750, 9.817) 0.128, 14.2%[e]	2.513 (1.152, 5.480) **0.021**, 29.2%[f]
*Model 3: Prospective: association of the diet at 2y and 8y on outcome at 8 years**			
PQ-DP at 2y and PQ-DP at 8y	0.583 (0.105, 3.229) 0.536	3.752 (0.586, 24.026) 0.163	3.115 (1.072, 9.052) **0.037**
PQ-DP at 2y and HC-DP at 8y	1.711 (0.261, 11.218) 0.576	1.273 (0.115, 14.113) 0.844	3.454 (0.911, 13.100) 0.068
HC-DP at 2y and PQ-DP at 8y	0.328 (0.056, 1.927) 0.217 17.8%[g]	0.966 (0.173, 5.404) 0.969 15.1%[h]	1.499 (0.624, 3.602) 0.365 29.6%[i]

HOMA-IR: Homeostasis Insulin Resistance Index, PQ-DP: Poor-quality dietary pattern group, HC-DP: Health-consious dietary pattern group, pct: percentile. All models adjusted by sex, country (reference category: Spain), energy intake at 8y, diet during the first year of life (reference category: Low protein formula), maternal education level (reference category: Low), maternal smoking during pregnancy, maternal BMI and BMI z-score at 8y. The R^2 for the goodness of fit is provided for each model. Bold numbers: statistically significant. Reference dietary pattern group: HC-DP at 2 years and HC-DP at 8 years. Confounders with effect on the outcome variable: [a] Belgium (OR = 6.288, $p = 0.034$), Poland (OR = 6.323, $p = 0.010$), maternal BMI (OR = 1.102, $p = 0.032$). [b] Poland (OR = 5.599, $p = 0.015$). [c] Italy (OR = 0.300, $p = 0.002$), BMI z-score at 8y (OR = 2.003, $p < 0.001$). [d] Poland (OR = 4.189, $p = 0.044$), maternal education level: medium (OR = 0.367, $p = 0.047$), maternal BMI (OR = 1.141, $p = 0.008$). [e] Diet during the first year of life: breastfed (OR = 3.183, $p = 0.027$). [f] Italy (OR = 0.245, $p = 0.001$), Poland (OR = 0.392, $p = 0.037$), smoking during pregnancy (OR = 2.093, $p = 0.031$), BMI z-score at 8y (OR = 2.038, $p < 0.001$). [g] Poland (OR = 7.694, $p = 0.018$), maternal education level: medium (OR = 0.355, $p = 0.044$), maternal BMI (OR = 1.150, $p = 0.005$). [h] Diet during the first year of life: breastfed (OR = 3.386, $p = 0.022$). [i] Italy (OR = 0.233, $p = 0.001$), Poland (OR = 0.360, $p = 0.039$), smoking during pregnancy (OR = 2.111, $p = 0.031$), BMI z-score at 8y (OR = 2.071, $p < 0.001$)

and HOMA-IR at 10 years, although no statistically significant associations were found for SBP, triglycerides, HDL and LDL cholesterol at that age [11]. Similarly, the Generation R study reported significant associations between higher diet quality at 8 years and lower systolic and diastolic blood pressure at 10 years, but no statistically significant associations with insulin, triglycerides, HDL cholesterol, or body fat percentage as individual factors [10]. To our knowledge, this is the first confirmatory analyses (as dietary patterns are hypothesis driven) describing the association between diet and cardiovascular effects at such an early age.

Dietary patterns derived from exploratory methods are population-specific and may differ between different research studies. Nevertheless, the dietary patterns identified in our study share similarities with and can be compared to other studies. Unhealthy patterns have been commonly described and labelled as processed dietary pattern [28], snacky dietary pattern [11], western dietary pattern [27] and sweet & processed dietary pattern [29], among others. Conversely, healthy patterns have been described as Mediterranean dietary pattern [30], healthy dietary pattern [27] and health-conscious dietary pattern [29], among others.

Interestingly, following a PQ-DP was not associated with an increase in BMI z-score at 8 years. In fact, we found an inverse association between following a poor-quality dietary pattern and BMI z-score at 8 years in the cross-sectional analysis. However, this association disappeared when we analysed the persistence of this dietary pattern over time. It's important to consider that parents of children with overweight or obesity might be more likely to under-report their child's intake or omit unhealthy foods, compared to parents of children with normal weight, as shown in a previous study [31]. Additionally, the observed associations could also be influenced by reverse causation, where children with higher BMI may alter their dietary patterns. Moreover, we studied a population of healthy children with a low prevalence of overweight and obesity [32, 33], thus the overall goodness of fit for that model was low. The relationship between obesity and healthy dietary patterns in children

has been extensively studied, with controversial results, as indicated in a recently published systematic review [34]. Conversely, the fact that dietary patterns were associated with cardiometabolic health outcomes adjusted for energy intake highlights the importance of diet quality independently of the amount consumed. In fact, the adjustment for BMI further reinforces the importance of diet quality, also in thin children.

In early childhood, few studies have analysed the long-term longitudinal effects of diet on cardiometabolic health indicators. Our cross-sectional and prospective findings indicate that the type of diet at 2 years influences cardiometabolic health markers in school-age children and may impact disease risk later in life. Therefore, our results highlight the importance of promoting a healthy diet from an early age onwards. Diet during early years can influence later cardiometabolic health through metabolic programming of body functions during the first 1000 days of life and also through the tracking of dietary patterns established in early life [2, 35]. Dietary patterns acquired at 2 years of age tend to persist into later childhood, particularly unhealthy patterns [3]. In our study, of all the children classified in the PQ-DP group at 2 years, only a very small percentage were classified in the HC-DP group at 8 years. These findings highlight the importance of promoting healthy eating habits early in life, which may be achievable by implementing targeted family education programs.

This study has several limitations. First, the sample size and loss to follow-up which may introduce bias, after several years of participation in the study, some families did not diligently complete the food diaries, and other declined to participate in blood sampling. Second, this is a secondary analysis of data from a study not originally designed for this specific purpose. Third, the Cmet Risk variable does not diagnose existing pathology but instead reflects a less favourable cardiometabolic profile normalised for population, age and sex. Additionally, we are aware that there are different approaches for calculating the cardiometabolic risk score, but we are unsure whether the score we have used is the most appropriate for our population [36]. Lastly, the covariate adjustment strategy, based on a stepwise approach, may have led to the inclusion of variables potentially lying on the causal pathway, which could influence the interpretation of the effect estimates.

Important strengths of our study include the methodological approach applied and the independence of results from BMI. The prospective analyses conducted in a multicentric sample with five different countries in Europe in pre-school children, enhances the robustness and transferability of the findings.

Conclusion

Adherence to a dietary pattern with poor nutritional quality in early childhood and at school age is associated with worse cardiometabolic risk markers at 8 years, independent of body mass index. Promoting healthy dietary habits during early ages of life could be an important preventive strategy to reduce later cardiometabolic disease risks.

Abbreviations

BMI	Body Mass Index
BP	Blood pressure
CHOP	European Childhood Obesity Project
Cmet Risk	Cardiometabolic risk score
DBP	Diastolic blood pressure
DP	Dietary pattern
EFA	Exploratory factor analyses
HC-DP	Health-Conscious dietary pattern
HDL	High-density lipoprotein cholesterol
HOMA	IR-Insulin resistance index
IQR	Interquartile range
PCA	Principal component analyses
PQ-DP	Poor-Quality dietary pattern
RRR	Reduced Rank Regression analyses
SBP	Systolic blood pressure

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12937-025-01080-1.

Additional File 1. Flow chart of participation in CHOP study.

Additional File 2. Descriptive of all study sample.

Acknowledgements

CHOP study group: J. Beyer, M. Fritsch, G. Haile, U. Handel, I. Hannibal, B. Koletzko, S. Kreichauf, I. Pawellek, S. Schiess, S. Verwied-Jorky, R. von Kries, M. Weber (Children's University Hospital, University of Munich Medical Center, Munich, Germany); R. Closa-Monasterolo, J. Escribano, N. Ferré, V. Luque, M. Gispert-Llauradó, C. Rubio-Torrents, M. Zaragoza-Jordana (Pediatrics, Nutrition and Development Research Unit, Universitat Rovira i Virgili, IISPV, Reus, Spain); A. Dobrzańska, D. Gruszfeld, R. Janas, A. Wierzbicka, P. Socha, A. Stolarczyk, J. Socha (Children's Memorial Health Institute, Warsaw, Poland); C. Carlier, E. Dain, P. Goyens, J.N. Van Hees, J†. Hoyos, J.P. Langhendries, F. Martin, P. Poncelet, A. Xhonneux (ULB, Bruxelles, Belgium, and CHC St. Vincent, Liège-Rocourt, Belgium); E. Perrin (Danone Research Centre for Specialised Nutrition, Schiphol, The Netherlands), and C. Agostoni, M. Giovannini, A. Re Dionigi, E. Riva, S. Scaglioni, F. Vecchi, E. Verducci (University of Milan).

Author contributions

VL designed research; VL, GA and MG analysed data and performed statistical analysis; MG drafted the manuscript and had primary responsibility for final content. JE, NF, VG, BK, GA, EV, DK, AX and VL reviewed, edited, and agreed with the published version of the manuscript.

Funding

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under the ERA-NET Cofound action Number 727565, JPI-HDHL-INTIMIC 2021; Instituto de Salud Carlos III (ISCIII) and Next Generation EU funds for actions of the Recovery, Transformation and Resilience Plan (PRTR) under grant agreement AC21_2/00010 (IISPV); Bundesministerium für Bildung und Forschung (BMBF) under grant agreements 01EA2203A (LMU) and 01EA2203B (HMGU); and Österreichische Forschungsförderungsgesellschaft mbH (FFG) and the MissionERA program under grant agreement FO999890543 (MUW). The Childhood Obesity Project was funded by the 5th Framework Program [QLRTe2001e00389 & QLK1-CT-2002-30,582], the 6th Framework Program (contract number

FOOD-CT-2005-007036), the 7th Framework Program (FP7-KBBE-2007-1, ref. nº 212,652; and FP7- 289346-EarlyNutrition) and the European Union's Horizon 2020 research and innovation programme under the ERA-NET Cofound action (no 727565) - JPI Call PREPHOBES (PCI2020-120,697-2, EndObesity Project) of the European Commission. This manuscript does not necessarily reflect the views of the Commission and in no way anticipates the future policy in this area. VL holds a Serra Hunter Fellowship from Generalitat de Catalunya. The work of VG and BK has been supported by the European Commission, H2020 Programmes Lifecycle-733,206 and CoreMD, the Erasmus Plus Programmes Early Nutrition Academy Southeast Asia-573651-EPP-1- 2016-1-DE-EPPKA2-CBHE-JP and Capacity Building to Improve Early Nutrition and Health in South Africa-598488-EPP-1-2018-1-DEEPPKA2- CBHE-JP, and the European Joint Programming Initiative Projects NutriPROGRAM, EndObesity and BiomarKids co-funded by the German Ministry of Education and Research (01EA1904, 01EA2101 and 01EA2203A), and the German Federal Ministry of Education and Research as part of the German Center for Child and Adolescent Health (DZKJ), 01GL2406A. BK is the Else Kroner- Seniorprofessor of Paediatrics co-funded by the Else Kroner-Fresenius-Foundation, Bad Homburg, Germany, LMU and LMU University Hospitals, Munich, Germany.

Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study was performed following the principles of the Helsinki Declaration [37]. The project was accepted by the corresponding Ethics committees responsible in each study centre: Ethik-Kommission der Bayerishen Landersäzrtekammer, Comité d'Ethique d'Hopital Universitarie des Enfants Reine Fabiola, Brussels (CEH 1402), Comité d'Ethique du Clinique Saint Vincent (0905/DrMM/IS), Comitato Etico Azienda Ospedaliera San Paolo Polo Universitario (1172), Komiscja Bioetyczna Pomnik-Centrum Zdrowia Dziecka ((Code/ID: n°11/2009), Comitè d'Ètica d'Investigació Clínica de l'Hospital Universitari Sant Joan de Reus (09-12-17/12obs1), Comitè d'Ètica d'Investigació Clínica de l'Hospital Universitari de Tarragona Joan XXIII (4/2002). All parents or legal guardians received written information and provided signed consent for their child to participate in the study at recruitment and in the following visits.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Paediatrics, Nutrition and Development Research Unit, Universitat Rovira i Virgili. Reus, Tarragona, Spain
[2]Paediatrics, Nutrition and Development Research Unit, Institut d'Investigació Sanitària Pere Virgili. Reus, Tarragona, Spain
[3]Department of Paediatrics, Dr. von Hauner Children's Hospital, LMU - Ludwig Maximilians Universität Munich, LMU University Hospitals, München, Germany
[4]German Center for Child and Adolescent Health, site Munich, Lindwurmstraße 4, 80337 München, Germany
[5]School of Population and Global Health, University of Western Australia, Clifton Street Building, Clifton St, 6009 Nedlands, Perth, WA, Australia
[6]Metabolic Diseases Unit, Department of Paediatrics, Vittore Buzzi Children's Hospital, University of Milan, Via Lodovico Castelvetro, 32, 20154 Milano, MI, Italy
[7]Department of Health Sciences, University of Milan, Via di Rudini 8, 20146 Milan, Italy
[8]Neonatal Department, Children's Memorial Health Institute, Al. Dzieci Polskich 20, 04-730 Warsaw, Poland
[9]Groupe Santé CHC, bd Patience et Beaujonc 2 - (B), 4000 Liège, Belgium

Received: 25 September 2024 / Accepted: 8 January 2025
Published online: 29 January 2025

References

1. Dinu M, Martini D, Ultra-Processed, Foods. Diet Quality and Human Health. Vol. 15, nutrients. Multidisciplinary Digital Publishing Institute (MDPI); 2023.
2. Luque V, Escribano J, Closa-Monasterolo R, Zaragoza-Jordana M, Ferré N, Grote V, et al. Unhealthy dietary patterns established in infancy track to mid-childhood: the EU childhood obesity project. J Nutr. 2018;148(5):752–9.
3. Luque V, Closa-Monasterolo R, Grote V, Ambrosini GL, Zaragoza-Jordana M, Ferré N, et al. Dietary patterns acquired in early life are associated with cardio-metabolic markers at school age. Clin Nutr. 2021;40(7):4606–14.
4. Northstone K, Emmett PM. Are dietary patterns stable throughout early and mid-childhood? A birth cohort study. Br J Nutr. 2008;100(5):1069–76.
5. Emmett PM, Jones LR, Northstone K. Dietary patterns in the Avon Longitudinal Study of parents and children. Nutr Rev. 2015;73(Suppl 3):207.
6. Wingrove K, Lawrence MA, McNaughton SA. A systematic review of the methods used to assess and report dietary patterns. Front Nutr. 2022;9:1034.
7. Jacobs DR, Steffen LM. Nutrients, foods, and dietary patterns as exposures in research: a framework for food synergy. Am J Clin Nutr. 2003;78(3):S508–13.
8. Ambrosini GL. Childhood dietary patterns and later obesity: a review of the evidence. Proc Nutr Soc. 2014;73(1):137–46.
9. Leermakers ETM, van den Hooven EH, Franco OH, Jaddoe VWV, Moll HA, Kiefte-de Jong JC, et al. A priori and a posteriori derived dietary patterns in infancy and cardiometabolic health in childhood: the role of body composition. Clin Nutr. 2018;37(5):1589–95.
10. Siddiqui NZ, Nguyen AN, Santos S, Voortman T. Diet quality and cardiometabolic health in childhood: the Generation R Study. Eur J Nutr. 2022;61(2):729–36.
11. Pinto A, Santos AC, Lopes C, Oliveira A. Dietary patterns at 7-year-old and their association with cardiometabolic health at 10-year-old. Clin Nutr. 2020;39(4):1195–202.
12. 2020 Dietary Guidelines Advisory Committee DPS. Dietary Patterns and Risk of Cardiovascular Disease: A Systematic Review. 2020;1–15.
13. Koletzko B, Von KR, Closa R, Escribano J, Scaglioni S, Giovannini M, et al. Lower protein in infant formula is associated with lower weight up to age 2 y: a randomized clinical trial. Am J Clin Nutr. 2009;89(Electronic):1938–3207.
14. Lohman TG, Roche AF, Martorell R. Anthropometric standardization reference manual. Human Kinetics Books; 1988.
15. de Onis M, Onyango AW, Borghi E, Siyam A, Nishida C, Siekmann J. Development of a WHO growth reference for school-aged children and adolescents. Bull World Health Organ. 2007;85(9):660–7.
16. Flynn JT, Kaelber DC, Baker-Smith CM, Blowey D, Carroll AE, Daniels SR et al. Clinical practice Guideline for Screening and Management of High Blood pressure in children and adolescents. Pediatrics. 2017;140(3).
17. Miller WG, Myers GL, Sakurabayashi I, Bachmann LM, Caudill SP, Dziekonski A, et al. Seven direct methods for measuring HDL and LDL Cholesterol Compared with Ultracentrifugation Reference Measurement procedures. Clin Chem. 2010;56(6):977–86.
18. McLaughlin T, Abbasi F, Cheal K, Chu J, Lamendola C, Reaven G. Use of metabolic markers to identify overweight individuals who are insulin resistant. Ann Intern Med. 2003;139(10):802–9.
19. Matthews DR, Hosker JR, Rudenski AS, Naylor BA, Treacher DF, Turner RC. Homeostasis model assessment: insulin resistance and fl-cell function from fasting plasma glucose and insulin concentrations in man. Diabetologia. 1985;28:412–9.
20. De Henauw S, Michels N, Vyncke K, Hebestreit A, Russo P, Intemann T, et al. Blood lipids among young children in Europe: results from the European IDEFICS study. Int J Obes (Lond). 2014;38(Suppl 2):S67–75.
21. Peplies J, Jiménez-Pavón D, Savva SC, Buck C, Günther K, Fraterman A, et al. Percentiles of fasting serum insulin, glucose, hba1c and homa-ir in pre-pubertal normal weight European children from the idefics cohort. Int J Obes. 2014;38:S39–47.
22. Eisenmann JC. On the use of a continuous metabolic syndrome score in pediatric research. Cardiovasc Diabetol. 2008;7:17.
23. Dehne LI, Klemm C, Henseler G, Hermann-Kunz E. The German Food Code and Nutrient Data Base (BLS II.2). Eur J Epidemiol. 1999;15(4):355–8.
24. Verwied-Jorky S, Schiess S, Luque V, Grote V, Scaglioni S, Vecchi F, et al. Methodology for longitudinal assessment of nutrient intake and dietary habits in early childhood in a transnational multicenter study. J Pediatr Gastroenterol Nutr. 2011;52(1):96–102.
25. Luque V, Escribano J, Mendez-Riera G, Schiess S, Koletzko B, Verduci E, et al. Methodological approaches for dietary intake assessment in formula-fed infants. J Pediatr Gastroenterol Nutr. 2013;56(3):320–7.

26. Hoffmann K, Schulze MB, Schienkiewitz A, Nöthlings U, Boeing H. Application of a New Statistical Method to derive dietary patterns in Nutritional Epidemiology. Am J Epidemiol. 2004;159(10):935–44.
27. Shang X, Li Y, Liu A, Zhang Q, Hu X, Du S et al. Dietary pattern and its association with the prevalence of obesity and related cardiometabolic risk factors among Chinese children. PLoS ONE. 2012;7(8).
28. Bull CJ, Northstone K. Childhood dietary patterns and cardiovascular risk factors in adolescence: results from the Avon Longitudinal Study of parents and children (ALSPAC) cohort. Public Health Nutr. 2016;19(18):3369–77.
29. Latorre-Millán M, Rupérez AI, González-Gil EM, Santaliestra-Pasías A, Vázquez-Cobela R, Gil-Campos M et al. Dietary patterns and their association with body composition and cardiometabolic markers in children and adolescents: Genobox Cohort. Nutrients. 2020;12(11).
30. Pérez-Rodrigo C, Gil Á, González-Gross M, Ortega RM, Serra-Majem L, Varela-Moreiras G, et al. Clustering of dietary patterns, lifestyles, and overweight among Spanish children and adolescents in the ANIBES Study. Nutrients 2016. 2015;8(11):11.
31. Gomes D, Luque V, Xhonneux A, Verduci E, Socha P, Koletzko B, et al. A simple method for identification of misreporting of energy intake from infancy to school age: results from a longitudinal study. Clin Nutr. 2018;37(3):1053–60.
32. Weber M, Grote V, Closa-Monasterolo R, Escribano J, Langhendries JP, Dain E, et al. Lower protein content in infant formula reduces BMI and obesity risk at school age: follow-up of a randomized trial. Am J Clin Nutr. 2014;99(5):1041–51.
33. Totzauer M, Escribano J, Closa-Monasterolo R, Luque V, Verduci E, ReDionigi A et al. Different protein intake in the first year and its effects on adiposity rebound and obesity throughout childhood: 11 years follow-up of a randomized controlled trial. Pediatr Obes. 2022;17(12).
34. Teixeira B, Afonso C, Rodrigues S, Oliveira A. Healthy and sustainable dietary patterns in children and adolescents: a systematic review. Adv Nutr. 2022;13(4):1144–85.
35. Aguayo VM, Britto PR. The first and next 1000 days: a continuum for child development in early life. Lancet. 2024;404(10467):2028–30.
36. Ahrens W, Moreno LA, Mårild S, Molnár D, Siani A, De Henauw S, et al. Metabolic syndrome in young children: definitions and results of the IDEFICS study. Int J Obes [Internet]. 2014;38:4–14. Available from: www.nature.com/ijo.
37. World Medical Association Declaration. Of Helsinki: ethical principles for medical research involving human subjects. JAMA: J Am Med Association. 2000;284(23):3043–5.

Publisher's note