# Association between adherence to the EAT-*Lancet* sustainable reference diet and cardiovascular health among European adolescents: the HELENA study

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## Abstract

**Background**: The EAT-*Lancet* Commission proposed a global reference diet to promote healthy diets within planetary boundaries. Studies evaluating the associations between the reference diet with health outcomes among adolescents are scarce. Thus, our aim was to assess the association between adherence to the EAT-*Lancet* diet and cardiovascular health among European adolescents. **Methods**: Data from the HELENA study were used. Usual dietary intake was assessed using two 24-hour dietary recalls and adherence to the EAT-*Lancet* diet was assessed using the Planetary Health Diet Index (PHDI), a 16-component index that ranges from 0 to 150 points. Cardiovascular health was assessed through the seven-component Ideal Cardiovascular Health (ICH) score: never smoked, eutrophic body mass index, moderate-to-vigorous physical activity, healthy dietary pattern, low blood pressure, low fasting plasma glucose, and low total cholesterol. Total ICH score was categorized into ideal (5 – 7) and non-ideal (0 – 4). **Results**: A 10-point increment in the PHDI was associated with a lower probability of a non-ideal ICH status (OR 0.84, [95% CI: 0.75, 0.94]) among European adolescents, after adjusting for age, sex, socio-economic status, and total energy intake. Furthermore, a 10-point increment in the PHDI was associated with lower probability of high blood pressure (OR: 0.87 [0.79, 0.96]) and a lower probability of high blood cholesterol (OR: 0.88 [0.78, 0.99]). **Conclusion:** Our study suggests that a higher PHDI may be associated with a better cardiovascular health status among European adolescents.


**Keywords**: sustainable diets; EAT-*Lancet* diet; cardiovascular health; adolescent’s health

## Introduction

Cardiovascular diseases (CVDs) are the leading cause of chronic disability and premature deaths worldwide [1]. Adopting health protecting lifestyle behaviours, including not smoking, regular physical activity, low-to-moderate alcohol consumption, and an energy-balanced, predominantly plant-based dietary pattern can support cardiovascular health and, subsequently, a decrease in CVDs rates [2].

The American Heart Association (AHA) proposed a seven-component score – the Ideal Cardiovascular Health (ICH) – which includes cardio-metabolic and behavioural risk factors as proxies for cardiovascular health [3]. The ICH has been widely used in epidemiological studies and the findings indicate that higher ICH scores are associated with lower rates of cardio-metabolic diseases and mortality rates in adulthood [4] and lower levels of prognostic CVD markers (e.g., vascular intima-media thickness and elasticity and inflammation biomarkers) among adolescents [5–7].

Recently, greater lifetime adherence to so-called sustainable healthy dietary patterns has been posited as a potential pathway towards the reduction of diet-related chronic non-communicable diseases, in particular CVD rates [8–10]. According to FAO/WHO, sustainable healthy diets are defined as those diets that promote all dimensions of an individual's health and well-being, have low environmental impacts, are accessible, affordable, safe and equitable, and are culturally acceptable [11].

In early 2019, the EAT-*Lancet* Commission on Healthy Diets from Sustainable Food Systems released a scientific report that promulgated a global reference diet to improve human health within planetary boundaries [8]. The EAT-*Lancet* sustainable reference diet is centred around plant-based foods (e.g., fruits, vegetables, wholegrains, nuts and peanuts, vegetable oils) and suggest a low-to-moderate consumption of animal foods (e.g., red meat, dairy foods, poultry, eggs, and seafood), added sugars, and refined cereals [8].

The global adoption of the EAT-*Lancet* reference diet would likely reduce diet-related deaths and diminish environmental impacts (e.g., greenhouse gas emission, freshwater use, land use, and nitrogen and phosphorus application) [8,10,12]. Recent observational studies among adults and elderly populations support the hypothesised effect on human health: higher adherence to the EAT-*Lancet* reference diet was associated with a lower prevalence of overweight and obesity [13], lower all-cause mortality rates [14], lower type 2 diabetes mellitus rates [15], lower blood pressure and total cholesterol levels [16], and better cardiovascular health among adults [16]. However, whether the consumption of a sustainable healthy dietary pattern at a younger age can beneficially affect prognostic markers linked to a higher later-life CVD risk is unknown. Using secondary data, we aimed to assess the relationships between adherence to the EAT-*Lancet* dietary recommendations and the ICH and its components among European adolescents enrolled in the Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA) study.

## Methods

### *Study Design and Sample*

The HELENA study was primarily designed to obtain reliable and harmonized data on nutrition and health-related parameters from a sample of adolescents aged between 12.5 to 17.5 years from 10 European cities (Athens in Greece; Dortmund in Germany; Ghent in Belgium, Heraklion in Crete, Lille in France, Pécs in Hungary, Rome in Italy, Stockholm in Sweden, Vienna in Austria, and Zaragoza in Spain). Data collection was carried out between 2006 and 2007. The sample size was calculated using the mean body mass index (kg/m2) and variance values for each sex and age-specific strata, a 5% significance level (α), and an error of ± 0.3. Consequently, at least 300 adolescents from each country were required (300 for each country

*10 countries = 3000 participants). Exclusion criteria in the HELENA study were as follows: age <12.5 or >17.5 years, no measurement of weight and/or height, completion of less than 75% of the tests, participating simultaneously in a clinical trial, or an acute infection during the week prior to the examination. More details of the sample, objectives, and data collection methods of the HELENA study were published previously [17,18].

In total, 3,528 adolescents were recruited for participation; however, individuals from Heraklion (Crete) and Pécs (Hungary) were excluded from the current analyses, as no nutrient intake information was obtained from these two cities due to logistical problems. Blood samples were collected from a randomly selected sub-sample of the HELENA study population (*n* 1,089), of whom 637 had complete data to calculate the ICH score (**Figure 1**).

All participants and their parents gave written informed consent, and the study protocol was approved by the ethics committee of each city involved, according to the Declaration of Helsinki 1964 (revised in Edinburgh 2000) and the International Conference of Harmonization for Good Clinical Practice [19].

*Dietary Assessment*

Dietary intake data were obtained using the HELENA Dietary Assessment Tool (HELENA-DIAT), a self-administered computerized quantitative 24-h dietary recall (24H-DR) [20]. During school hours, participants were invited to complete two 24H-DR using the HELENA-DIAT on two non-consecutive days across a period of two weeks. To support the adolescents in case they required any clarifications to complete the HELENA-DIAT, a trained dietitian was present. The German Food Code and Nutrient Database (Bundeslebensmittelschlüssel, vII.3.1, Karlsruhe, Germany) was used to obtain energy and nutrient intakes [21]. The Multiple Source Method (MSM) was used to estimate the usual nutrient intakes, by accounting for intra-person variance. MSM is a statistical program available open access online: https://msm.dife.de. The

MSM first estimates the habitual nutrient intakes of individuals, which are then employed to model the usual intake distribution of the population [22,23].

*Planetary Health Diet Index Computation - Exposure*

To assess adherence to the EAT-*Lancet* sustainable reference diet, we used the Planetary Health Diet Index (PHDI). The PHDI considers all EAT-*Lancet* food groups and has a gradual scoring system (i.e., the components are scored according to the relative quantity of consumption) [24,25]. The PHDI was previously validated for usual nutrient intakes, plasma food consumption biomarkers, and adherence to the Mediterranean diet among adolescents enrolled in the HELENA study [26]. Briefly, the sub-scores are computed as a caloric intake ratio, where the sum of all foods classified in each component of the PHDI is in the numerator, while the sum of all foods that were included in the PHDI are in the denominator. The total daily energy intake (kcal/d) for the calculation of the PHDI components considered only the food groups recommended by the EAT-*Lancet* Commission.

In brief, the PHDI has 16 components divided into four categories: (i) adequacy components (nuts and peanuts, fruits, legumes, vegetables, and whole grain cereals), (ii) optimum components (eggs, dairy products, fish and seafood, tubers and potatoes, and vegetable oils), (iii) ratio components (dark green vegetables / total vegetables and red-orange vegetables / total vegetables) and (iv) moderation components (red meat, chickens and substitutes, animal fats, and added sugars). The adequacy, optimum, and moderation components are scored from 0 to 10 points, while the ratio components are scored from 0 to 5 points. For example, for adequacy components, scores were assigned the maximum score when the intake reached or exceeded the recommended intake. If not, scores would be determined by the ratio of the current intake and recommended intake as follow: *(current intake ÷ recommended value [cut-off points] * maximum score)*. Further methodological details on the

PHDI scoring criteria, cut-off points, relative validity, and reliability have been published elsewhere [25]. The total score ranges from 0 to 150 points, and higher scores indicate higher adherence to the EAT-*Lancet* reference diet (**Figure 2)**.

*Ideal Cardiovascular Health – Outcome*

The ICH score and its components were calculated as described by the AHA, using the proposed thresholds for adolescents [3]. A detailed description of the classification of ICH behaviours and factors, as either ideal or non-ideal, has been previously published in the HELENA study [27,28]. In brief, the ICH score considers four components as health behaviours (smoking, body mass index, healthy diet, and physical activity) and three as health factors (cholesterol, glucose, and blood pressure). Data on smoking status were collected using a self-reported questionnaire. Body weight was measured to the nearest 0.1 kg with an electronic scale and height was measured with a telescopic stadiometer to the nearest 0.1 cm [29]. Body mass index (BMI) was calculated as weight divided by height squared and subsequently expressed in *z*-scores using the 2007 WHO reference [30]. Physical activity was assessed by a questionnaire validated among adolescents [31]. Serum total cholesterol and glucose were measured in venous blood samples obtained after an overnight fast (Dade Behring, Schwalbach, Germany) [32]. Blood pressure were measured twice in a sitting position with a 10 min interval in-between and the lowest reading was recorded, using the same type BP device approved by the European Hypertension Society (Omron M6, Japan) [33].

In brief, the seven ideal ICH components are: (i) never smoked (i.e., non-smokers); (ii) an eutrophic body mass index (BMI; ≥ -2 to < +1 *z*-score, according to WHO); (iii) physical activity ≥60 min/d of moderate-to-vigorous intensity; (iv) healthy diet: achieving ≥4 of the following components daily: 1) ≥400 g/d of fruits and vegetables, 2) ≥28 g/d of fish, 3) ≥3 28 g/d equivalent servings of fibre rich grains (1.1 g of fiber per 10 g of carbohydrates), 4) ≤1500 mg/d sodium, and 5) ≤145 mL/d of sugar-sweetened beverages; (v) systolic blood pressure

<120 mmHg and diastolic blood pressure <80 mmHg; (vi) fasting serum glucose concentrations <5.6 mmol/L (<100 mg/dL), and (vii ) total cholesterol <4.40 mmol/L (<170 mg/dL) [3]. Thereafter, the ICH score was categorized as either non-ideal ICH (0–4 points) or ideal ICH (5–7 points).

*Socioeconomic Status*

The socio-economic disadvantage and vulnerability score considers the mother and father's education, family affluence scale, family structure, origin of parents, and employment status, as described in previous papers [34,35]. Education status was categorized as follows: low education or medium-to-high education (i.e., higher secondary education or university degree). The family affluence scale was based on the number of cars and computers owned by the household, the presence or absence of an internet connection, and whether the enrolled adolescent had his own bedroom. A score of 0-3 was defined as low family affluence and 4-8 as medium-to-high affluence. Family structure was categorised as follows: adolescents from "traditional families" lived with both parents or with one parent and his/her partner while others were categorised as "single-parent/shared-care families" [36]. Origin of parents: a migrant background was assumed if one or both parents were born in a country different from the one where the study took place. Employment status: children with unemployed parents were those whose mother or father was unemployed, or those living on social assistance or welfare. We calculated a total socioeconomic disadvantage/vulnerability score by summing the number of indicators of socioeconomic disadvantage a child was exposed to (low maternal education, low paternal education, low family affluence) and of social vulnerability indicators (single-parent/shared-care families, migrant parent, and unemployed parent) [34]. This score ranged from zero to six and was divided into two categories (no disadvantages/vulnerability and ≥1 disadvantages/vulnerability).

*Statistical Analyses*

Descriptive analyses were performed with categorical variables expressed as frequency and percentage (*n*, %) and continuous variables expressed as mean (standard deviation) or median (interquartile range). Student's *t*-test, Pearson's chi-square tests, or Mann-Whitney U-test were used to test differences among variables, by ICH status.

Logistic regression models were fitted to evaluate the association between the PHDI (exposure) and ICH score (outcome). First, crude models included the continuous PHDI and binary variables of each individual ICH component [i.e., above (reference) or below cut-off]. Second, a crude model included the PHDI score and the dichotomous ICH status [i.e., ideal (reference) or non-ideal]. Third, adjusted models included potential confounders, including age (years), sex (female, male), socioeconomic disadvantage/vulnerability score (yes, no), and total energy intake (kcal/d).

To assess effect modification, an interaction term was tested between the PHDI score and sex, age, socioeconomic disadvantage/vulnerability score, and countries. As a sensitivity analysis, the 'diet' component was excluded from the ICH computation, to assess potential overestimation of the odds of achieving an ideal ICH status due to a higher PHDI score.

Two-sided statistical significance was considered at alpha $<0.05$, except for our exploratory interaction test (alpha $< 0.10$). All statistical analyses were performed using Stata version 14.2 (College Station, Texas, USA).

## Results

In our HELENA sub-sample study (*n* 637), adolescents with non-ideal cardiovascular health were more likely to be older and have lower total dietary energy intakes (**Table 1**).

Furthermore, the mean (SD) PHDI was significantly lower (*P*=0.003) among adolescents with a non-ideal [43.3 (1.3)], as compared to ideal ICH status [46.5 (1.4)] (**Figure 3**).

A 10-point increment in the PHDI (i.e., greater adherence to the EAT-*Lancet* reference diet) was associated with 16% lower probability of having a non-ideal cardiovascular health status [adjusted odds ratio (OR): 0.84, 95% CI: 0.75, 0.94], after adjusting for age, sex, socio-economic status and total energy intake (**Figure 4**).

Moreover, our findings indicated that a 10-point increase in the PHDI was associated with 13% lower odds of high blood pressure (OR: 0.87, 95% CI: 0.79, 0.96), 12% lower probability of high blood cholesterol (OR: 0.88, 95% CI: 0.78, 0.99), 7% lower probability of being a smoker (OR: 0.93, 95% CI: 0.87, 0.98), 13% lower odds of a poor physical activity level (OR: 0.87, 95% CI: 0.82, 0.93), and 56% lower probability of a poor diet (OR: 0.54, 95% CI: 0.35, 0.85) (**Figure 4**). No association was observed for BMI and fasting plasma glucose. Unadjusted odds ratio between total ICH and components with PHDI is described in **Supplementary Figure 1**.

Lastly, sex, age, socioeconomic disadvantages/vulnerability score, and country did not modify the association between PHDI score and ICH status, nor did removing the 'diet' component from the ICH score alter the magnitude of our primary (un)adjusted regression coefficients (data not shown).

## Discussion

In the HELENA study, we found that higher adherence to the EAT-*Lancet* reference diet was positively associated with better cardiovascular health status among European adolescents. Furthermore, adolescents with a higher PHDI were less likely to be smokers and have a high blood pressure and cholesterol, while they were more physically active and consumed healthier diets.

To the best of our knowledge, only one other study evaluated the relationships between the EAT-*Lancet* diet and cardio-metabolic risk markers among adolescents. After three years of follow-up, Montejano Vallejo *et al.* reported inverse associations between greater adherence to an 18-point dietary index and anthropometric measures (e.g., body mass index, fat-free body mass) among young adulthood in Dortmund in Germany. However, non-significant associations were observed with plasma cholesterol, LDL, HDL, triglycerides, and blood pressure [37].

Similarly, a prospective cohort study, among 62,382 French participants aged over 18 years, did not find lower rates of CVD among adults with higher adherence to the EAT-*Lancet* sustainable reference diet [38]. Moreover, in a Danish prospective cohort study of 55,016 adults aged 50 to 64 years, adherence to the EAT-*Lancet* reference diet was significantly associated with a lower subarachnoid haemorrhage stroke subtype, but not overall risk of stroke [39]. In contrast, in a prospective cohort study among 46,069 UK participants aged over 20 years, a high adherence to the EAT-*Lancet* score was associated with lower rates of ischaemic heart disease [40]. In addition, in a prospective cohort study of 23,877 Swedish adults aged 44-73, higher adherence to the EAT-*Lancet* diet score was associated with lower risk of coronary events [41].

Likewise, other research among adult and elderly populations have associated greater adherence to the EAT-*Lancet* diet with lower rates of overweight, obesity, and better cardiovascular health among Brazilians [13,16], lower rates of type II diabetes mellitus in the UK [15], and lower rates of all-cause mortality in Sweden [14].

It is noteworthy that these aforementioned studies used different metrics to assess adherence to the EAT-*Lancet* diet, which may partly explain the divergent results. As an example, studies in the Danish and British population used a binary scoring system that can range from 0 to 14 points, while studies in Sweden (EAT-*Lancet* diet score: 0 – 42 points) and

Brazil (PHDI: 0 – 150 points) used metrics with gradual scoring systems, which can more sensitively capture levels of adherence of populations. Literature reviews suggest that diet scores should consider gradual scoring systems [42,43], but there is still no consensus when it comes to diet scores based on the EAT-*Lancet* diet. In the present study, we used the PHDI, which was previously validated among Brazilian adults [25] and, more recently, among European adolescents participating in the HELENA study [26].

At present, a dearth of studies has assessed adherence to the EAT-*Lancet* diet among children and adolescents. Using the validated PHDI, Marchioni *et al.* reported poor adherence to the EAT-*Lancet* reference diet among Brazilian adolescents aged 10 to 19 years [44]. Likewise, among Finnish pre-schooler children aged 3 to 6 years, Bäck *et al.* found that the consumption of plant-based foods, such as legumes, nuts, wholegrain cereals, and vegetables was very low, while the consumption of red meat and dairy was about fivefold higher than the EAT-*Lancet* reference diet targets [45], and tubers and starchy vegetable, and added sugar were over two- and one-half times higher, respectively, than the EAT-*Lancet* reference diet [45].

Although the EAT-*Lancet* Commission provided a seminal report for discussions pertaining to healthy diets from sustainable food systems, it has received criticism from the global research community [46–48]. Importantly, the EAT-*Lancet* reference diet exceeds the household per capita income for at least 1.58 billion people, predominantly from low-and middle-income countries (LMICs) [49]. Moreover, if all countries adopted the EAT-*Lancet* diet it is suggested that global greenhouse gas emissions (GHGE) [50] and water footprint would fall [51], while increasing in LMICs.

The current study has several key strengths. First, we used a culturally diverse, multi-country sample of European adolescents with standardized data collection procedures and strict research protocols in each country. Second, quantitative dietary intakes were assessed using HELENA-DIAT and usual intakes were modelled using MSM software. Third, we computed a diet index that was previously associated with overall dietary quality and lower GHGE in a Brazilian adult cohort and validated against usual nutrient intake, food consumption biomarkers and adherence to a Mediterranean dietary pattern among European adolescents.

Nonetheless, our study is also subject to certain limitations. First, no interpretation of causality can be derived from our research due to the cross-sectional nature of our data, to the lack of temporality between exposure and outcome and to the potential confounding by omitted variables. Second, although random intra-person error was accounted for by repeated 24H-DRs, self-reported dietary assessment methods remain prone to measurement error (e.g., social desirability bias). Of note is that, at the time of data collection, sustainable diets and planetary health were little discussed topics, which might explain the poor adherence to the EAT-*Lancet* recommendations. Lastly, the generalizability of our study findings is limited to adolescents from European countries, not from LMICs.

In conclusion, our results provide first evidence showed that a higher PHDI is associated with a better cardiovascular health status among European adolescents. In conjunction with previous research on the PHDI, our findings warrant prospective analyses of the EAT-*Lancet* sustainable reference diet and diet-related health outcomes among adolescents, including biomarkers of CVD risk.

**Data Availability Statement:** The data described in the manuscript can be made available upon request pending application and approval by the chair of the steering committee for the HELENA study. The analytic code of the PHDI computation will be made available upon request pending to the corresponding author.

**Author Contributions:** LTC, DMM, and LAM designed the research; IH advised on the data curation; LTC carried out the data analyses; LTC developed the first draft and revised the

manuscript; GTH-C supported with writing the draft. GTH-C, SDH, CL, and LAM advised on statistical analyses. LAM supervised LTC. GTH-C, SV, CL, SDH, AMS-P, YM, NM, LEDP, MG-G, KW, DM, PS, AK, FG, MK, MJC, CL, DMM, IH, and LAM critically reviewed and revised the manuscript. All authors read and approved the final manuscript.

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**Ethical Approval:** All participants and their parents gave written informed consent, and the study protocol was approved by the ethics committee of each city involved according to the Declaration of Helsinki 1964 (revision of Edinburgh 2000) and the International Conference of Harmonization for Good Clinical Practice.

**Competing Interests:** The authors declare no conflict of interest.

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**Figure 1.** Flowchart of adolescents in the Healthy Lifestyle in Europe by Nutrition in Adolescence study included in the present study. ICH, Ideal Cardiovascular Health.

**Figure 2.** Overview of the Planetary Health Diet Index's components, cut-off points (i.e., % kcal/d), and calculation of the total score.

**Figure 3.** Planetary Health Diet Index (PHDI) of the adolescent enrolled in the HELENA study, by Ideal Cardiovascular Health (ICH) status.

**Figure 4.** Adjusted odds ratios between a 10-point increase in the Planetary Healthy Diet Index score and Ideal Cardiovascular Health components. CI, confidence interval.

**Table 1.** Descriptive characteristics of the adolescent enrolled in the HELENA study, by Ideal Cardiovascular Health (ICH) status.

| | ICH[a] | | | | |
|---|---|---|---|---|---|
| | Ideal (5 – 7) | | Non-ideal (0 – 4) | | *P*-value |
| Sex, *n* – % | | | | | 0.072[1] |
| Boys | 165 | 57.3 | 123 | 42.7 | |
| Girls | 175 | 50.1 | 174 | 49.9 | |
| Age (years), median – IQR | 14.4 | 13.7 – 15.4 | 14.9 | 14.0 – 15.9 | <0.001[2] |
| Disadvantage/vulnerability score[b], *n* – % | | | | | 0.100[1] |
| 0 | 118 | 58.1 | 85 | 41.9 | |
| ≥1 | 222 | 51.2 | 212 | 48.8 | |
| Smoking status, *n* – % | | | | | <0.001[1] |
| Never | 276 | 69.7 | 120 | 30.3 | |
| Already smoked[c] | 64 | 26.6 | 177 | 73.4 | |
| Physical activity level (min/w), median – IQR | 1,162 | 740 – 1,888 | 685 | 371 – 1,350 | <0.001[2] |
| Body Mass Index (*z*-score), mean – SD | 0.13 | 1.0 | 0.71 | 1.2 | <0.001[3] |
| Systolic blood pressure, median – IQR | 118 | 110 – 124 | 121 | 114 – 133 | <0.001[2] |
| Diastolic blood pressure, median – IQR | 66 | 61 – 71 | 70 | 64 – 76 | <0.001[2] |
| Total cholesterol (mg/dL), median – IQR | 152 | 135 – 166 | 171 | 151 – 186 | <0.001[2] |
| Fasting plasma glucose (mg/dL), median – IQR | 89 | 86 – 93 | 91 | 85 – 96 | 0.034[2] |
| Total energy intake (kcal/d), mean – SD | 2,274 | 811 | 2,078 | 718 | 0.001[3] |

[1]Pearson's Chi-squared test. [2]Mann-Whitney U-test. [3]Student's *t*-test. [a]The ICH score comprises seven-components: never smoked, eutrophic body mass index, moderate-to-vigorous physical activity, healthy dietary pattern, low blood pressure, low fasting plasma glucose and low total cholesterol. [b]The score was calculated by adding up the scores (1 vs. 0) of the six indicators (low education of the mother, low education of the father, low family affluence (FAS), single-parent/shared-care families, migrant background, parents unemployed). [c]Already smoked includes adolescents who have smoked at least one or more cigarettes. HELENA, Healthy Lifestyle in Europe by Nutrition in Adolescence. SD, standard deviation. IQR, interquartile range.