Region-specific nutrient intake patterns exhibit a geographical gradient within and between European countries

Heinz Freisling, Michael T. Fahey, Aurelie Moskal, Marga C. Ocké, Pietro Ferrari, Mazda Jenab, Teresa Norat, Androniki Naska, Ailsa A. Welch, Carmen Navarro, Mandy Schulz, Elisabet Wirfält, Corinne Casagrande, Pilar Amiano, Eva Ardanaz, Christine Parr, Dagrun Engeset, Sara Grioni, Francesco Sera, Bas Bueno-de-Mesquita, Yvonne T. van der Schouw, Mathilde Touvier, Marie-Christine Boutron-Ruault, Jytte Halkjær, Christina C. Dahm, Kay-Tee Khaw, Francesca Crowe, Jakob Linseisen, Janine Kröger, Inge Huybrechts, Geneviève Deharveng, Jonas Manjer, Asa Agren, Antonia Trichopoulou, Kostas Tsiotas, Elio Riboli, Sheila Bingham, Nadia Slimani

Angaben zur Veröffentlichung / Publication details:

Freisling, Heinz, Michael T. Fahey, Aurelie Moskal, Marga C. Ocké, Pietro Ferrari, Mazda Jenab, Teresa Norat, et al. 2010. “Region-specific nutrient intake patterns exhibit a geographical gradient within and between European countries.” *The Journal of Nutrition* 140 (7): 1280–86. https://doi.org/10.3945/jn.110.121152.

Region-Specific Nutrient Intake Patterns Exhibit a Geographical Gradient within and between European Countries[1–3]

Heinz Freisling,[4] Michael T. Fahey,[5] Aurelie Moskal,[4] Marga C. Ocké,[6] Pietro Ferrari,[4,32] Mazda Jenab,[7] Teresa Norat,[8] Androniki Naska,[9] Ailsa A. Welch,[10,33] Carmen Navarro,[11] Mandy Schulz,[12] Elisabet Wirfält,[13] Corinne Casagrande,[4] Pilar Amiano,[14] Eva Ardanaz,[15] Christine Parr,[16] Dagrun Engeset,[17] Sara Grioni,[18] Francesco Sera,[19] Bas Bueno-de-Mesquita,[6] Yvonne T. van der Schouw,[20] Mathilde Touvier,[21,22] Marie-Christine Boutron-Ruault,[21] Jytte Halkjær,[23] Christina C. Dahm,[24] Kay-Tee Khaw,[25] Francesca Crowe,[26] Jakob Linseisen,[27] Janine Kröger,[12] Inge Huybrechts,[4] Geneviève Deharveng,[4] Jonas Manjer,[28] Asa Agren,[29] Antonia Trichopoulou,[9,30] Kostas Tsiotas,[9] Elio Riboli,[8] Sheila Bingham,[10,31,34] and Nadia Slimani[4]*

[4]Dietary Exposure Assessment Group, International Agency for Research on Cancer, Lyon 69372, France; [5]Medical Research Council (MRC) Biostatistics Unit, University of Cambridge, Cambridge CB2 0SR, UK; [6]National Institute for Public Health and the Environment, Bilthoven 3720, The Netherlands; [7]Lifestyle and Cancer Group, International Agency for Research on Cancer, Lyon 69372, France; [8]Department of Epidemiology, Public Health and Primary Care, Imperial College, London W2 1PG, UK; [9]Department of Hygiene Epidemiology and Medical Statistics, University of Athens Medical School, Athens 11527, Greece; [10]Department of Public Health and Primary Care, University of Cambridge, Cambridge CB2 1TN, UK; [11]Epidemiology Department, Murcia Health Council, and CIBER Epidemiología y Salud Pública, Murcia 3008, Spain; [12]Department of Epidemiology, German Institute of Human Nutrition, Potsdam-Rehbrücke 14558, Germany; [13]Department of Clinical Sciences, Lund University, Malmö 20502, Sweden; [14]Public Health Division of Gipuzkoa, Basque Government, CIBERSP Ciber Salud Pública, San Sebastian 20013, Spain; [15]Public Health Institute of Navarra, Pamplona, Spain, CIBER Epidemiología y Salud Pública (CIBERESP), Pamplona 31003, Spain; [16]Institute of Basic Medical Sciences, University of Oslo, Oslo 0317, Norway; [17]Institute of Community Medicine, University of Tromsø, Tromsø 9037, Norway; [18]Nutritional Epidemiology Unit, Department of Preventive and Predictive Medicine, Fondazione IRCCS Istituto Nazionale dei Tumori, Milan 20133, Italy; [19]Molecular and Nutritional Epidemiology Unit, Cancer Prevention and Research Institute (ISPO), Florence 50139, Italy; [20]Julius Center for Health Sciences and Primary Care, University Medical Center, Utrecht 3508, The Netherlands; [21]Institut National de la Santé et de la Recherche Médicale (INSERM) ERI 20, Institut Gustave Roussy, Villejuif EA 4045, France; [22]AFSSA (French Food Safety Agency), DERNS/PASER, Maisons-Alfort 94701, France; [23]Institute of Cancer Epidemiology, Danish Cancer Society, Copenhagen 2100, Denmark; [24]Department of Clinical Epidemiology, Aalborg Hospital, Aarhus University Hospital, Aalborg 9100, Denmark; [25]University of Cambridge School of Clinical Medicine, Addenbrookes Hospital, Cambridge CB2 0SP, UK; [26]Cancer Epidemiology Unit, University of Oxford, Oxford OX3 7LF, UK; [27]Division of Clinical Epidemiology, German Cancer Research Center, Heidelberg 69120, Germany; [28]Department of Surgery, Malmö University Hospital, Malmö 20502, Sweden; [29]Department of Nutritional Research, University of Umeå, Umeå 90187, Sweden; [30]Hellenic Health Foundation, Athens 11527, Greece; and [31]Diet and Cancer Group, MRC Dunn Mitochondrial Biology Unit, Cambridge CB2 0XY, UK

Abstract

Until recently, the study of nutrient patterns was hampered at an international level by a lack of standardization of both dietary methods and nutrient databases. We aimed to describe the diversity of nutrient patterns in the European Prospective Investigation into Cancer and Nutrition (EPIC) study at population level as a starting point for future nutrient pattern analyses and their associations with chronic diseases in multi-center studies. In this cross-sectional study, 36,034 persons aged 35–74 y were administered a single, standardized 24-h dietary recall. Intake of 25 nutrients (excluding intake from dietary supplements) was estimated using a standardized nutrient database. We used a graphic presentation of mean nutrient intakes by region and sex relative to the overall EPIC means to contrast patterns within and between 10 European countries. In Mediterranean regions, including Greece, Italy, and the southern centers of Spain, the nutrient pattern was dominated by relatively high intakes of vitamin E and monounsaturated fatty acids (MUFA), whereas intakes of retinol and vitamin D were relatively low. In contrast, in Nordic countries, including Norway, Sweden, and Denmark, reported intake of these same nutrients resulted in almost the opposite pattern. Population groups in Germany, The Netherlands, and the UK shared a fatty acid pattern of relatively high intakes of PUFA and SFA and relatively low intakes of MUFA, in combination with a relatively high intake of sugar. We confirmed large variability in nutrient intakes across the EPIC study populations and identified 3 main region-specific patterns with a geographical gradient within and between European countries.

Introduction

The study of dietary patterns and their relation to disease is an alternative to the traditional approach focusing on single foods

[1] Supported by the European Commission: Public Health and Consumer Protection Directorate 1993–2004; Research Directorate-General 2005; Ligue contre le Cancer (France); Société 3M (France); Mutuelle Générale de l'Education

or nutrients. Because people eat meals consisting of a variety of foods and many combinations of nutrients, the traditional approach may be inadequate for taking into account interactive effects on the bioavailability, circulating levels, and metabolism of nutrients. It is less complex from a methodological point of view and relevant from biological and physiological point of view, to analyze a small number of patterns than an array of individual foods and intakes of nutrients that are inter-correlated. Another advantage of a dietary pattern approach is a possible gain in statistical power.

Most dietary pattern analyses have been conducted on usual food consumption derived from dietary questionnaires using statistical data reduction techniques, like factor or cluster analysis, to empirically derive patterns. These approaches aim to summarize a large number of correlated dietary variables (foods, food groups, nutrients, or biomarkers) into fewer independent components explaining most of the dietary variance (so-called "dietary patterns"). Some of this work has been reviewed by Newby and Tucker (1), Kant (2), Waijers et al. (3), and Román-Vinas et al. (4).

In contrast to food pattern analyses, limited work has been done on patterns of nutrient intake. Only 3 published studies (5–7) were reported in the review by Newby and Tucker (1). More recently, 3 case-control studies (8–10) derived nutrient patterns at a national level using factor analysis and related these patterns to the risk of cancer.

Compared with food patterns, studying nutrient patterns may have several advantages, particularly in international study contexts. Nutrients are functionally not exchangeable and, despite greater differences in food patterns, the same nutrients are consumed across populations with, for most of them, no or low rates of nonconsumers, which should facilitate the use and generalization of nutrient pattern approaches across populations.

Nationale; Institut National de la Santé et de la Recherche Médicale; Institut Gustave Roussy; German Cancer Aid; German Cancer Research Center; German Federal Ministry of Education and Research; Danish Cancer Society; Health Research Fund of the Spanish Ministry of Health; Spanish Regional Governments of Andalucía, Asturias, Basque Country, Murcia and Navarra and the Catalan Institute of Oncology; and ISCIII RETIC (RD06/0020), Spain; Cancer Research UK; Medical Research Council, UK; The Stroke Association, UK; British Heart Foundation; Department of Health, UK; Food Standards Agency, UK; the Wellcome Trust, UK; Greek Ministry of Health; Hellenic Health Foundation; Stavros Niarchos Foundation; Italian Association for Research on Cancer; Italian National Research Council, Regione Sicilia (Sicilian government); Associazione Iblea per la Ricerca Epidemiologica-ONLUS (Hyblean association for epidemiological research, NPO); Dutch Ministry of Public Health, Welfare and Sports; Dutch Prevention Funds; LK Research Funds; Dutch Zorg Onderzoek Nederland; World Cancer Research Fund; Swedish Cancer Society; Swedish Research Council; Regional Government of Skane and the County Council of Vasterbotten, Sweden; Norwegian Cancer Society; the Norwegian Research Council and the Norwegian Foundation for Health and Rehabilitation.

[2] Author disclosures: H. Freisling, M. T. Fahey, A. Moskal, M. C. Ocké, P. Ferrari, M. Jenab, T. Norat, A. Naska, A. A. Welch, C. Navarro, M. Schulz, E. Wirfält, C. Casagrande, P. Amiano, E. Ardanaz, C. Parr, D. Engeset, S. Grioni, F. Sera, B. Bueno-de-Mesquita, Y. T. van der Schouw, M. Touvier, M-C. Boutron-Ruault, J. Halkjær, C. C. Dahm, K-T. Khaw, F. Crowe, J. Linseisen, J. Kröger, I. Huybrechts, G. Deharveng, J. Manjer, A. Agren, A. Trichopoulou, K. Tsiotas, E. Riboli, S. Bingham, and N. Slimani, no conflicts of interest.

[3] Supplemental Figure 1 and Supplemental Table 1 are available with the online posting of this paper at jn.nutrition.org.

[32] Present address: Data Collection and Exposure Unit (DATEX), European Food Safety Authority, Parma, Italy.

[33] Present address: School of Medicine, Health Policy and Practice, University of East Anglia, Norwich, UK.

[34] The author is deceased.

*To whom correspondence should be addressed. E-mail: slimani@iarc.fr.

In the European Prospective Investigation into Cancer and Nutrition (EPIC)[35] calibration study, a single 24-h dietary recall (24-HDR) was collected by interview from almost 37,000 participants using the same standardized computerized dietary software (EPIC-Soft) (11,12). Together with a recently compiled standardized nutrient database (13), these data allowed for the first time a reliable comparison of energy and nutrient intakes across European countries (14).

In this paper, we propose to complement these already published results on individual absolute nutrient intakes by expressing nutrient intakes graphically relative to a common denominator. Such analysis is expected to contrast and maximize the inherent heterogeneity in nutrient intakes within and between countries and may thus help to capture underlying patterns in the data. These results may then be used in the interpretation of future empirically derived nutrient patterns in the international EPIC study.

The aim of this article is to identify and describe the diversity of nutrient patterns in the EPIC study at the population level as derived from a standardized 24-HDR and a standardized nutrient database.

Participants and Methods

Study population. The EPIC calibration study was nested within the EPIC study, a multi-center cohort study that aimed at investigating the association between diet, cancer, and other chronic diseases across 10 European countries: Denmark, France, Germany, Greece, Italy, The Netherlands, Norway, Spain, Sweden, and the United Kingdom (12,15,16). The original 23 administrative EPIC centers were reclassified into 27 centers (regions) according to a geographical south-north gradient. Nineteen of the 27 EPIC centers had both female and male participants and 8 recruited only women: those in France (4 centers), Norway (2 centers), Utrecht (The Netherlands), and Naples (Italy).

The calibration study was undertaken between 1995 and 2000 to express individual dietary intakes according to the same reference scale and to partially correct the diet-disease associations for attenuation due to measurement errors (17). The calibration population sample consisted of 36,994 participants, i.e. a ~8% stratified random sample of the total EPIC cohort. The average response rate in the calibration study was 78.3% and ranged from 46.5% to 92.5% across countries (12).

A total of 36,034 participants with 24-HDR data were included in this analysis after exclusion of 960 participants aged <35 or >74 y because of low participation in these age categories. Approval for the study was obtained from the ethical review boards of the International Agency for Research on Cancer (Lyon, France) and from all local recruiting institutes. All participants provided written informed consent.

Measurements of diet and other lifestyle factors. Details of measuring diet in the calibration study have been published previously (12,18–20). In brief, each participant provided a single 24-HDR in a face-to-face interview, except in Norway where it was obtained through a telephone interview, as a validated alternative approach (21) using a computerized interview program named EPIC-Soft (11).

Energy and nutrient intakes were calculated from the 24-HDR using country-specific food composition tables that were standardized across countries in collaboration with the national compilers to allow comparisons at the nutrient level. The EPIC Nutrient Database (ENDB) project outlines in detail the methods used to standardize the national nutrient databases across the 10 countries for 25 priority nutrients (plus water and energy) (13).

[35] Abbreviations used: ENDB, European Prospective Investigation into Cancer and Nutrition Nutrient Database; EPIC, European Prospective Investigation into Cancer and Nutrition; MUFA, monounsaturated fatty acid; 24-HDR, 24-h dietary recall.

Nutrient intake from dietary supplements was not included in this analysis due to the current lack of available compositional data at the European level, but the type and frequency of use in the EPIC calibration study is described elsewhere (22).

Data on other lifestyle factors, including education level, physical activity, and smoking history considered in this analysis were collected at baseline through standardized questionnaires and have been described for the calibration sample elsewhere (12,16,23). The mean time interval between these baseline questionnaire measures and the 24-HDR interview varied by country, from 1 d to 3 y later (12). Data on age as well as body weight and height were self-reported by the participants during the 24-HDR interview (12).

Statistical analysis. To compare nutrient patterns across the 27 EPIC centers, the arithmetic mean intake for the *i*th nutrient, $m(i)$, was calculated by sex and center for each of the 25 nutrients. The overall sex-specific EPIC mean intake, $M(i)$, was also calculated for the same nutrients as the arithmetic mean of the center mean intakes. To express variation in center mean intakes from the overall EPIC mean, percentage nutrient intake relative to the EPIC mean was calculated for each nutrient, by sex and center, as: $100\% \times [m(i)/M(i)]$.

A multi-dimensional "radar" graphic presentation of the relative nutrient intakes was used to illustrate contrasts in nutrient patterns by sex and center; their corresponding values are provided in the **Supplemental Table 1**. Sex-specific EPIC means, used as the common denominator to calculate deviations, are indicated in each figure by a reference circle of radius 100%. If the relative intake of a nutrient is above 100%, it indicates that the given center is characterized by a relatively high intake of that nutrient compared with the reference EPIC mean and vice versa when the relative intake is below 100%. The same scale was used in the graphs for all countries and men and women (0–150%). The end peaks of means exceeding 150% are not reported in the graphs but are indicated in the Supplemental Table 1.

Before calculating $M(i)$, mean individual intakes were adjusted for age and weighted by season and day of the week of recall using generalized linear models to control for different sampling procedures of the 24-HDR interviews across seasons and days of the week. Total energy intake, height, and weight were also added to the model to correct for physiologic characteristic differences of the participants across the centers.

We also investigated the independent effect of adjustment for several potential confounders, including smoking status, educational level, and physical activity, on center ranking and on the R^2 of the fixed effects model as an estimation of the variability of mean nutrient intakes that can be explained by the potential confounder.

All analyses were conducted using the SAS statistical software (version 9.1, SAS Institute).

Results

Figures 1–3 show the adjusted mean daily intake of 25 nutrients for women relative to the overall sex-specific EPIC mean intake of the respective nutrient across 10 European countries. Corresponding graphical presentation for men is available in **Supplemental Figure 1**. Country results are stratified by sex and center (if applicable) and discussed according to a south-north gradient.

Greece. Relative to the EPIC means, participants in Greece reported particularly high intakes of vitamin E and monounsaturated fatty acids (MUFA) and in contrast, a low intake of cholesterol (Fig. 1*A* and Supplemental Fig. 1*A*). Intakes of phosphorus, calcium, iron, and total fat, reflecting the higher MUFA intake, were also relatively high. For example, phosphorus intake in men exceeded the EPIC mean by more than one-third (Supplemental Fig. 1*A*).

Spain. We observed diverse nutrient patterns within Spain, depicting a geographical gradient (Fig. 1*B* and Supplemental Fig. 1*B*). However, consistently below the EPIC mean was the intake of retinol (up to 53%). In all centers, alcohol intake was below the EPIC mean in women, but not in men. We observed a south-north gradient in both men and women regarding intake of MUFA and vitamin C, which exceeded the respective EPIC means markedly in the southern centers (Granada and Murcia), and Navarra for MUFA, but less so in the northern centers (Asturias and San Sebastian). We observed a reverse picture regarding intake of vitamin D, vitamin B-12, cholesterol, total protein, and iron, with intakes exceeding the corresponding EPIC means in northern centers and intakes approximately equal to EPIC means in the southern centers.

Italy. A relatively high intake of starch in all centers and both men and women, which exceeded the EPIC mean by up to 44% was characteristic for Italy (Fig. 1*C* and Supplemental Fig. 1*C*). In contrast, intakes of vitamin D and retinol were markedly below the respective EPIC means (except for retinol intake in women from Florence). For example, vitamin D intake of men living in Varese was 70% below the EPIC mean (Supplemental Fig. 1*C*). Alcohol intake differed considerably between centers for men and women and was ~50% below the EPIC mean in Ragusa and, in contrast, ~28% above the EPIC mean in Turin. Intake of MUFA exceeded the EPIC mean in women (up to 25% in Ragusa), but not in men.

France. Characteristic for France was the relatively high intake of β-carotene contrasted by a relatively low intake of vitamin D (Fig. 1*D*). Less pronounced, but consistently above the EPIC means, were intakes of riboflavin and SFA in all 4 regions of France. We observed similar high intakes relative to the EPIC means for vitamin B-12 and alcohol, except for the south of France. In the 2 centers in the north, we observed relatively high intakes of magnesium and cholesterol.

Germany. In the 2 German cohorts, intakes of retinol, β-carotene, vitamin E, PUFA, and SFA were consistently above the respective EPIC means (Fig. 2*A* and Supplemental Fig. 1*D*). For example, retinol intake in men living in Potsdam exceeded the EPIC mean by 44% (Supplemental Fig. 1*D*). In contrast, intakes of starch, total protein, and MUFA were consistently below the respective EPIC means. All other deviations from EPIC means were of lesser magnitude, except for alcohol intake in women from Heidelberg, which exceeded the EPIC mean by 44% (Fig. 2*A*).

The Netherlands. In the Netherlands, intakes of retinol, sugar, and vitamin D were relatively high and in contrast, intakes of β-carotene, vitamin B-12, cholesterol, and MUFA were below the respective EPIC means (Fig. 2*B* and Supplemental Fig. 1*E*). In women, alcohol intake exceeded the EPIC mean in both centers, but this was more pronounced in Utrecht. In Bilthoven, but not in Utrecht, participants reported a relatively high intake of PUFA, particularly men (Supplemental Fig. 1*E*).

United Kingdom. Reported nutrient intakes in the UK general population deviated less extremely from the overall EPIC means (Fig. 2*C* and Supplemental Fig. 1*F*). However, mean intakes of thiamin, riboflavin, vitamin B-6, and sugar exceeded the respective EPIC means by up to 37%. In addition, the alcohol intake of women exceeded the EPIC mean by ~50%. In contrast, intake of MUFA was ~20% below the EPIC mean in men and women.

The UK cohort also includes a heterogeneous group of ovo-lacto vegetarians, pure vegans, and fish (but not meat) eaters.

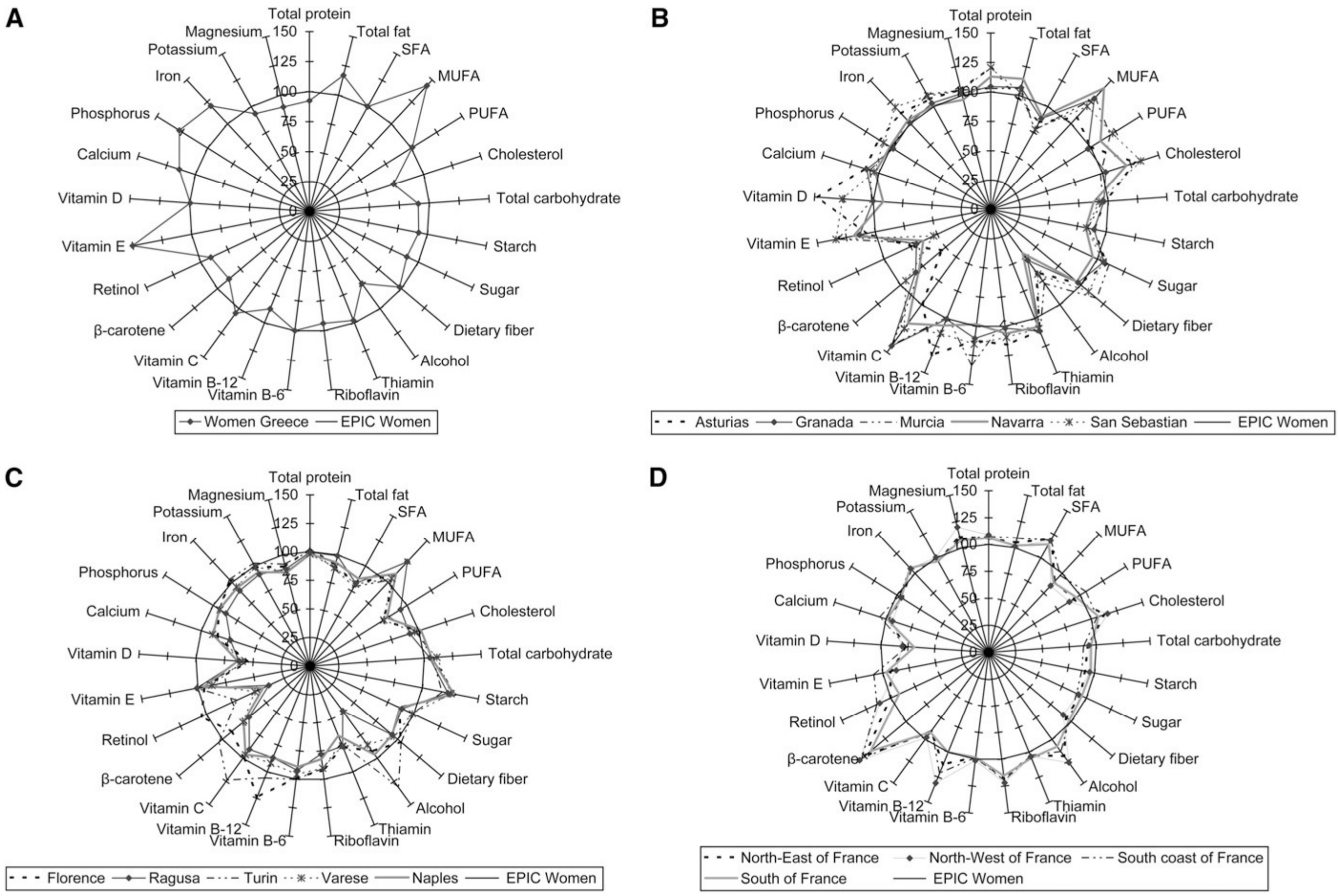

FIGURE 1 Deviation (%) of center-adjusted (by age, weight, height, and total energy intake and weighted for day of the week of recall and season) mean nutrient intakes from the sex-specific EPIC-means among women from Greece (*A*), Spain (*B*), Italy (*C*), and France (*D*). The reference circle of the radius (100%) corresponds to the EPIC means and the spikes indicate the deviation of specific mean nutrient intakes from the reference EPIC means. **Supplemental Figure 1** shows the corresponding analysis for men. All corresponding values are provided in **Supplemental Table 1**. Total carbohydrate = glycemic carbohydrates including starch and sugar; sugar = sum of mono- and disaccharides; dietary fiber = total dietary fiber defined by the AOAC.

Characteristic for that group was the high intake of thiamin, which exceeded the EPIC mean by ~50% and in contrast, the low intake of vitamin B-12 and cholesterol (~50% below the EPIC means).

Denmark. Participants in Denmark reported relatively high intakes of retinol and alcohol, and in contrast, relatively low intakes of vitamin E, vitamin C, and MUFA (Fig. 2*D* and Supplemental Fig. 1*G*). Particularly in women, alcohol intake exceeded the EPIC mean by >2-fold in Copenhagen and by 70% in Aarhus. In women, particularly in Aarhus, β-carotene intake exceeded the EPIC mean, but not in men (Supplemental Fig. 1*G*). Intake of SFA markedly exceeded the EPIC mean in men (~25%) but less so in women (~9%).

Sweden. Participants in Sweden reported a particularly high intake of retinol, which exceeded the EPIC mean by 2-fold, a high intake of vitamin D (~80% above the EPIC mean) as well as a high intake of SFA (~34% and ~20% above the EPIC mean in men and women, respectively) (Fig. 3*A* and Supplemental Fig. 1*H*). In contrast, intake of several nutrients was relatively low, at least 10% below the corresponding EPIC means. This was particularly the case for β-carotene, vitamin E, alcohol (particularly in Umea), vitamin C, dietary fiber, and iron.

Norway. Norwegian women reported relatively high intakes of retinol, vitamin D, and to a lesser extent, PUFA and SFA, and in contrast, relatively low intakes of vitamin E, vitamin B-6, MUFA, alcohol, vitamin C, and iron (Fig. 3*B*). In the south-east of Norway, β-carotene intake was also below the EPIC mean, by ~20%.

Discussion

In this work, we depicted the diversity of nutrient patterns across 10 European countries participating in the EPIC study by expressing the intake of 25 nutrients relative to the overall EPIC means. Thus, we aimed to highlight nutrients that exhibit a large variability in intake among these countries. This analysis complements the comparison of absolute intakes across the EPIC study populations, which is discussed in detail elsewhere (14).

We identified 3 main region-specific patterns. In Mediterranean regions, including Greece, Italy, and the southern centers of Spain, the nutrient patterns were dominated by relatively high intakes of vitamin E and MUFA, whereas intakes of retinol and vitamin D were relatively low. In contrast, in Nordic countries, including Norway, Sweden, and Denmark, reported intake of these same nutrients resulted in almost opposite patterns. Germany, The Netherlands, and UK general population shared a fatty acid pattern of relatively high intakes of PUFA and SFA, and relatively low intakes of MUFA, in combination with a relatively high intake of sugar.

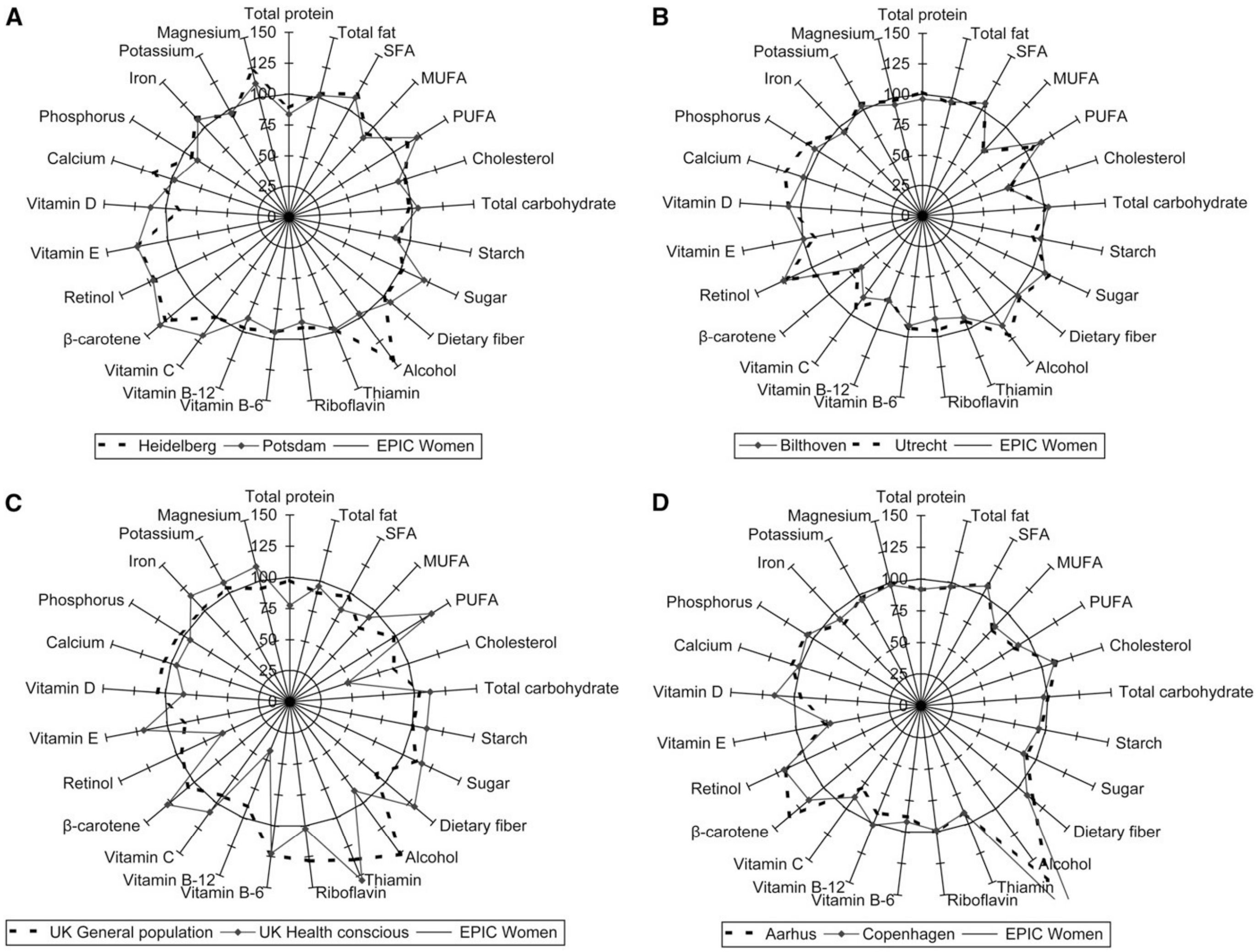

FIGURE 2 Deviation (%) of center-adjusted (by age, weight, height, and total energy intake and weighted for day of the week of recall and season) mean nutrient intakes from the sex-specific EPIC-means among women from Germany (*A*), The Netherlands (*B*), United Kingdom (*C*), and Denmark (*D*). The reference circle of the radius (100%) corresponds to the EPIC means and the spikes indicate the deviation of specific mean nutrient intakes from the reference EPIC means. Supplemental Figure 1 shows the corresponding analysis for men. All corresponding values are provided in Supplemental Table 1. Total carbohydrate = glycemic carbohydrates including starch and sugar; sugar = sum of mono- and disaccharides; dietary fiber = total dietary fiber defined by the AOAC.

The differences described above can be explained by a diet high in plant foods and olive oil in Greece, Italy, and to some extent also in Spain (24,25). In contrast, the diet in Nordic countries, the Netherlands, Germany, and the UK general population is characterized by a higher consumption of animal, processed, and sweetened foods, including nonalcoholic beverages and soft drinks and, more specifically, added fats and dairy products, which are frequently fortified with retinol and vitamin D in individual Nordic countries (24–27). The food sources of PUFA in Germany and The Netherlands are mainly margarine and processed meat (28). In Germany, the food sources of vitamin E are margarine and sauces (26). Recently, a general north-south gradient for the contribution of highly industrially processed foods to overall food consumption in Europe has been shown (29).

Although the nutrient patterns were quite similar between centers within the individual Nordic countries, we observed more heterogeneous patterns within Spain and to a lesser extent also within France, where the recruited cohorts represented most of the country. In these latter 2 countries, we observed characteristics of both a Mediterranean nutrient pattern and a Western-like pattern (e.g. relatively high intakes of cholesterol, SFA, animal protein, and vitamin B-12), explained by a heterogeneous dietary pattern with high consumption of both plant foods and animal products (24).

The nutrient pattern of the UK "health conscious" cohort exhibits similar characteristics as the pattern of the UK general population, as nonanimal food sources are similar (24). However, as expected, intakes of cholesterol, vitamin B-12, and retinol, which are typical components of animal food sources, were far below respective intakes of the UK general population and EPIC means.

Within countries, the overall nutrient intakes were very similar between men and women, with the exception of alcohol. As described previously (24), men had a higher alcohol intake relative to the sex-specific EPIC mean compared with women in Spanish centers, Greece, and Italy (except in Florence and Turin). The pattern was opposite in all other population groups. Sex differences in drinking patterns are usually explained by biological differences and social or cultural factors (30). Another explanation of the differences observed might be a possible country- and sex-specific underreporting of alcohol intake.

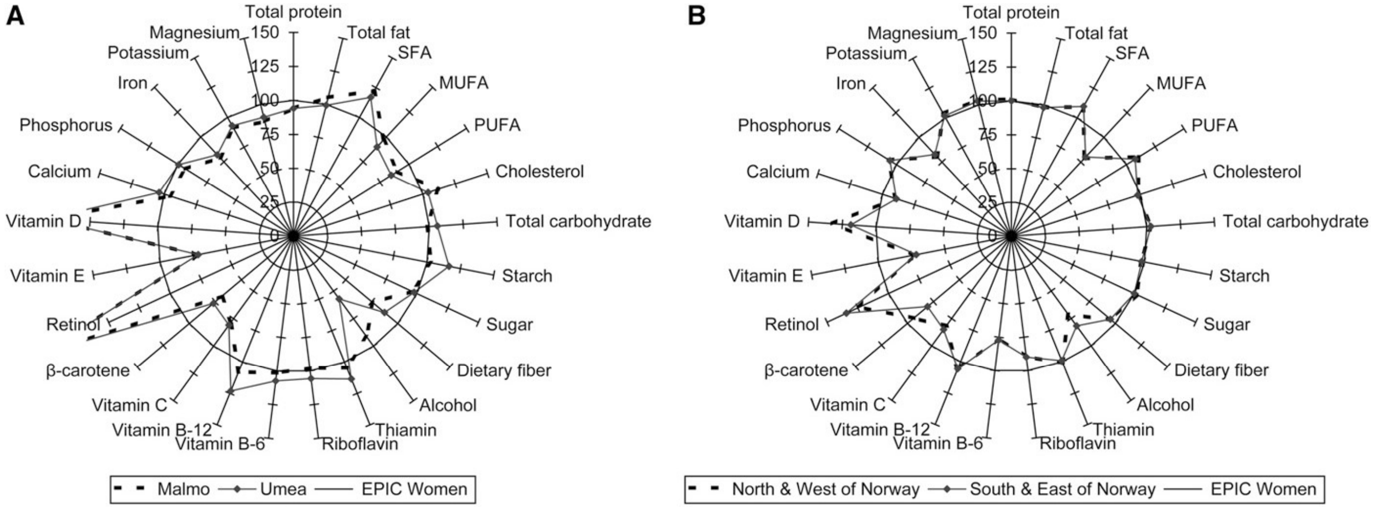

FIGURE 3 Deviation (%) of center-adjusted (by age, weight, height, and total energy intake and weighted for day of the week of recall and season) mean nutrient intakes from the sex-specific EPIC-means among women from Sweden (*A*) and Norway (*B*). The reference circle of the radius (100%) corresponds to the EPIC means and the spikes indicate the deviation of specific mean nutrient intakes from the reference EPIC means. Supplemental Figure 1 shows the corresponding analysis for men. All corresponding values are provided in Supplemental Table 1. Total carbohydrate = glycemic carbohydrates including starch and sugar; sugar = sum of mono- and disaccharides; dietary fiber = total dietary fiber defined by the AOAC.

Alcohol intake may also be seen as more of a lifestyle indicator than a dietary pattern.

There was no large or consistent effect of other covariates examined, i.e. smoking status, education, and physical activity, on the shape of the nutrient patterns within countries or ranking of centers. Regression analysis often resulted in significant associations with nutrient intakes, particularly for educational level and smoking habits, but there was no substantial effect on overall nutrient patterns identified among the 10 countries. Culturally acquired food habits in the different countries and/or regions may thus have stronger effects on dietary patterns than do other factors, such as socioeconomic status or lifestyle (e.g. smoking).

The results presented are adjusted for total energy intake to reduce variation caused by correlations of nutrients with total energy intake. For the majority of the nutrients and in most centers, analyses unadjusted for energy were ~5% different relative to the EPIC means. In women from Aarhus, energy adjustment reduced relative nutrient intakes by ~10%. Alcohol intake was generally an exception, where energy adjustment caused a drop in relative intake of up to 30% in women from Aarhus and ~10% in some other centers. However, energy adjustment did not change the overall shape of patterns within countries or ranking of centers.

The overall food pattern, as described in Slimani et al. (24), is much more diverse than the overall nutrient pattern observed in the present study. This is expected, because various food sources exist for many nutrients and several nutrients are ubiquitous in many foods.

Similar to the heterogeneity in nutrient patterns between countries and north-south regions are the findings regarding the proportion of dietary supplement users in the same study populations (22), where a ~10-fold difference in supplement use has been described in women and an almost 100-fold difference in men with a clear north-south gradient. However, the most frequently used supplement ingredients are less different between countries. For example, vitamin C is among the most frequently used ingredients in virtually all of the 10 European countries either in men or in women or both, except for the UK general population. Vitamins E, D, and A (retinol and β-carotene together) are among the most frequently used ingredients in Nordic countries and in the UK, but not in southern European countries, with the exception of Greece.

This study has a number of strengths. It is the largest study to date describing nutrient patterns across several European countries with a large geographical span, which allows comparisons between European regions. The same standardized computerized dietary software (EPIC-Soft) was used to collect a (single) 24-HDR by interview from almost 37,000 participants, randomly selected from 27 regions in 10 European countries (11,12). Furthermore, a standardized nutrient database, the ENDB (13), was used to calculate energy and nutrient intakes from the 24-HDR, making it possible to derive reliable nutrient patterns across these countries.

A limitation of the study is that compositional data of some nutrients of public health interest were missing in the ENDB [e.g. folate, trans fatty acids, distinction between (n-6) and (n-3) PUFA], which is because of a lack of information and standardization of these nutrients across national food composition databases and were thus not included in the analysis. In addition, extrapolation to the general population of each region or to other study populations should be made with caution, because not all EPIC cohorts are population based.

These standardized comparisons of nutrient patterns across several European countries will be used in subsequent analyses, where nutrient patterns will be defined using multivariate data reduction techniques and related to chronic diseases in the international EPIC study. In this regard, the present work will be helpful to provide an interpretation of the empirically derived patterns. Furthermore, it may also help to evaluate the compatibility of these patterns between countries. It is conceived to use calibration against the standardized 24-HDR to evaluate robustness of results obtained from country-specific questionnaire data of the entire EPIC cohort (17).

In conclusion, we confirmed a large variability in nutrient intakes across the EPIC study populations and identified 3 main region-specific patterns with a geographical gradient within and between European countries. The presentation of mean nutrient intakes relative to the overall EPIC means captured both the contrasts between nutrient intakes that may be approximately independent and its variation across countries. Thus, our study may not only aid in the interpretation of results of future nutrient pattern analyses and their associations with chronic diseases in multi-center studies but may also lead to improved hypothesis generation in the field of nutritional epidemiology addressing possible interactions between nutrients in diet-disease associations.

Acknowledgments

We thank Carine Biessy for the statistical analyses. H.F. wrote the paper and prepared the figures, taking into account comments from all coauthors. N.S. had primary responsibility for the final content. M.T.F., A.M., M.C.O., P.F., M.J., T.N., and N.S. were members of the writing group and gave input on the statistical analyses, drafting of the manuscript, and interpretation of results. E.R. is the overall coordinator of the EPIC study and all other coauthors were local EPIC collaborators involved in the collection of dietary and other data. All of them gave input on drafting of the manuscript and interpretation of results. All authors read and approved the final manuscript.

Literature Cited

1. Newby PK, Tucker KL. Empirically derived eating patterns using factor or cluster analysis: a review. Nutr Rev. 2004;62:177–203.
2. Kant AK. Dietary patterns and health outcomes. J Am Diet Assoc. 2004;104:615–35.
3. Waijers PM, Feskens EJ, Ocké MC. A critical review of predefined diet quality scores. Br J Nutr. 2007;97:219–31.
4. Román-Viñas B, Ribas Barba L, Ngo J, Martínez-González MA, Wijnhoven TM, Serra-Majem L. Validity of dietary patterns to assess nutrient intake adequacy. Br J Nutr. 2009;101 Suppl 2:S12–20.
5. Ganganna P, Johnson AA. A new nutrient index for measuring nutritional well-being of Indian states. Int J Vitam Nutr Res. 1985;55: 315–22.
6. Ishimoto H, Nakamura H, Miyoshi T. Epidemiological study on relationship between breast cancer mortality and dietary factors. Tokushima J Exp Med. 1994;41:103–14.
7. Palli D, Russo A, Decarli A. Dietary patterns, nutrient intake and gastric cancer in a high-risk area of Italy. Cancer Causes Control. 2001;12: 163–72.
8. De Stefani E, Boffeta P, Fagundes RB, Deneo-Pellegrini H, Ronco AL, Acosta G, Mendilaharsu M. Nutrient patterns and risk of squamous cell carcinoma of the esophagus: a factor analysis in Uruguay. Anticancer Res. 2008;28: 4C:2499–506.
9. De Stefani E, Boffeta P, Ronco AL, Deneo-Pellegrini H, Acosta G, Gutiérrez LP, Mendilaharsu M. Nutrient patterns and risk of lung cancer: a factor analysis in Uruguayan men. Lung Cancer. 2008;61: 283–91.
10. Edefonti V, Decarli A, La Vecchia C, Bosetti C, Randi G, Franceschi S, Dal Maso L, Ferraroni M. Nutrient dietary patterns and the risk of breast and ovarian cancers. Int J Cancer. 2008;122:609–13.
11. Slimani N, Ferrari P, Ocké M, Welch A, Boeing H, Liere M, Pala V, Amiano P, Lagiou A, et al. Standardization of the 24-hour diet recall calibration method used in the European Prospective Investigation into Cancer and Nutrition (EPIC): general concepts and preliminary results. Eur J Clin Nutr. 2000;54:900–17.
12. Slimani N, Kaaks R, Ferrari P, Casagrande C, Clavel-Chapelon F, Lotze G, Kroke A, Trichopoulos D, Trichopoulou A, et al. European Prospective Investigation into Cancer and Nutrition (EPIC) calibration study: rationale, design and population characteristics. Public Health Nutr. 2002;5:1125–45.
13. Slimani N, Deharveng G, Unwin I, Southgate DA, Vignat J, Skeie G, Salvini S, Parpinel M, Møller A, et al. The EPIC nutrient database project (ENDB): a first attempt to standardize nutrient databases across the 10 European countries participating in the EPIC study. Eur J Clin Nutr. 2007;61:1037–56.
14. Margetts BM. Nutrient intake and patterns in the European Prospective Investigation into Cancer and Nutrition cohorts from 10 European countries. Eur J Clin Nutr. 2009;63 Suppl 4:S1–2.
15. Riboli E. Nutrition and cancer: background and rationale of the European Investigation into Cancer and Nutrition (EPIC). Ann Oncol. 1992;3:783–91.
16. Riboli E, Hunt KJ, Slimani N, Ferrari P, Norat T, Fahey M, Charrondière UR, Hémon B, Casagrande C, et al. European Prospective Investigation into Cancer and Nutrition (EPIC): study populations and data collection. Public Health Nutr. 2002;5:1113–24.
17. Ferrari P, Kaaks R, Fahey MT, Slimani N, Day NE, Pera G, Boshuizen HC, Roddam A, Boeing H, et al. Within- and between-cohort variation in measured macronutrient intakes, taking account of measurement errors, in the European Prospective Investigation into Cancer and Nutrition study. Am J Epidemiol. 2004;160:814–22.
18. Kaaks R, Plummer M, Riboli E, Esteve J, van Staveren WA. Adjustment for bias due to errors in exposure assessments in multicenter cohort studies on diet and cancer: a calibration approach. Am J Clin Nutr. 1994; **59** Suppl 1: S245–50.
19. Kaaks R, Riboli E, van Staveren WA. Calibration of dietary intake measurements in prospective cohort studies. Am J Epidemiol. 1995; 142:548–56.
20. Ferrari P, Day NE, Boshuizen HC, Roddam A, Hoffmann K, Thiébaut A, Pera G, Overvad K, Lund E, et al. The evaluation of the diet/disease relation in the EPIC study: considerations for the calibration and the disease models. Int J Epidemiol. 2008;37:368–78.
21. Brustad M, Skeie G, Braaten T, Slimani N, Lund E. Comparison of telephone vs face-to-face interviews in the assessment of dietary intake by the 24 h recall EPIC SOFT program–the Norwegian calibration study. Eur J Clin Nutr. 2003;57:107–13.
22. Skeie G, Braaten T, Hjartåker A, Lentjes M, Amiano P, Jakszyn P, Pala V, Palanca A, Niekerk EM, et al. Use of dietary supplements in the European Prospective Investigation into Cancer and Nutrition calibration study. Eur J Clin Nutr. 2009;63 Suppl 4:S226–38.
23. Haftenberger M, Schuit AJ, Tormo MJ, Boeing H, Wareham N, Bueno-de-Mesquita HB, Kumle M, Hjartåker A, Chirlaque MD, et al. Physical activity of subjects aged 50–64 years involved in the European Prospective Investigation into Cancer and Nutrition (EPIC). Public Health Nutr. 2002;5:1163–76.
24. Slimani N, Fahey M, Welch AA, Wirfält E, Stripp C, Bergström E, Linseisen J, Schulze MB, Bamia C, et al. Diversity of dietary patterns observed in the European Prospective Investigation into Cancer and Nutrition (EPIC) project. Public Health Nutr. 2002;5:1311–28.
25. Naska A, Fouskakis D, Oikonomou E, Almeida MD, Berg MA, Gedrich K, Moreiras O, Nelson M, Trygg K, et al. Dietary patterns and their socio-demographic determinants in 10 European countries: data from the DAFNE databank. Eur J Clin Nutr. 2006;60:181–90.
26. Jenab M, Salvini S, van Gils CH, Brustad M, Shakya-Shrestha S, Buijsse B, Verhagen H, Touvier M, Biessy C, et al. Dietary intakes of retinol, β-carotene, vitamin D and vitamin E in the European Prospective Investigation of Cancer and Nutrition (EPIC) Cohort. Eur J Clin Nutr. 2009;63 Suppl 4:S150–78.
27. Cust AE, Skilton MR, van Bakel MM, Halkjaer J, Olsen A, Agnoli C, Psaltopoulou T, Buurma E, Sonestedt E, et al. Total dietary carbohydrate, sugar, starch and fibre intakes in the European Prospective Investigation into Cancer and Nutrition. Eur J Clin Nutr. 2009;63 Suppl 4:S37–60.
28. Linseisen J, Welch AA, Ocké M, Amiano P, Agnoli C, Ferrari P, Sonestedt E, Chajès V, Bueno-de-Mesquita HB, et al. Dietary fat intake in the European Prospective Investigation into Cancer and Nutrition: results from the 24-hour dietary recalls. Eur J Clin Nutr. 2009;63 Suppl 4:S61–80.
29. Slimani N, Deharveng G, Southgate DA, Biessy C, Chajès V, van Bakel MM, Boutron-Ruault MC, McTaggart A, Grioni S, et al. Contribution of highly industrially processed foods to the nutrient intakes and patterns of middle-aged populations in the European Prospective Investigation into Cancer and Nutrition study. Eur J Clin Nutr. 2009; 63 Suppl 4:S206–25.
30. Wilsnack RW, Vogeltanz ND, Wilsnack SC, Harris R. Sex differences in alcohol consumption and adverse drinking consequences: cross-cultural patterns. Addiction. 2000;95:251–65.