The Relative Validity of Vitamin Intakes Derived from a Food Frequency Questionnaire Compared to 24-Hour Recalls and Biological Measurements: Results from the EPIC Pilot Study in Germany

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Background. For the European Prospective Investigation into Cancer and Nutrition (EPIC) study Germany, a self-administered food frequency questionnaire (FFQ) was developed and tested for its relative validity and reproducibility in 1991/1992. Study participants were 92 potential cohort members. This paper reports results regarding retinol, carotenoids, tocopherols and ascorbic acid.

Methods. Study participants were invited to the study centre in Heidelberg once a month over one year. At each visit, a 24-hour recall was obtained. The FFQ was filled in twice with a 6-month interval (FFQ1, FFQ2). In addition, a questionnaire on general consumption frequencies of 14 broad food groups was completed. This information was combined with estimates derived from FFQ2 and frequency-corrected food and nutrient intakes were calculated (FFQcorr). Blood specimens were taken in winter and summer 1992.

Results. The intraclass correlation of the FFQ ranged from 0.65 to 0.67 for retinol, tocopherols, carotenoids, and ascorbic acid. Intake of carotenoids by FFQcorr showed de-attenuated Pearson correlation coefficients with blood values in the order of 0.37, and with recall data of 0.44. Respective correlations for retinol were 0.21 and 0.29, for tocopherols 0.18 and 0.52, and for ascorbic acid 0.36 and 0.69. Errors of FFQcorr and 24-hour diet recalls were not correlated.

Conclusions. In general, it was demonstrated that the FFQ was able to rank participants into biologically meaningful categories of intake or blood concentrations for carotenoids and ascorbic acid, but misclassification was higher for tocopherol and retinol.

Keywords: vitamin intakes, food frequency questionnaire, diet recalls, relative validity, EPIC
errors between the surrogate measure and the reference method if the measurement error is to be corrected. Correlation of errors might lead to biased estimates of relative risks through inadequate correction for measurement error by means of regression calibration.2

A widely used surrogate measure in large-scale cohort studies with tens of thousands of participants is a food frequency instrument.3 This instrument was also selected to estimate dietary intake in the previous year in the prospective cohort study in Germany as part of the EPIC project. In a pilot study the relative validity and reproducibility of the food frequency questionnaire (FFQ) was therefore examined.4,5 This paper reports the analyses on carotenoids, retinol, tocopherols, and ascorbic acid comparing estimates derived from the FFQ with biological samples. These substances may play a particular role in the aetiology of chronic diseases due to their antioxidant properties.6,7 The relative validity and reproducibility of the FFQ with respect to food groups and macronutrients are presented in the accompanying papers.4,5

SUBJECTS AND METHODS

Subjects

The design of the pilot study followed the general outline for testing dietary questionnaires proposed by the co-ordinating centre of EPIC at IARC in Lyon.8 In total, 528 members of the local health insurance (AOK—Allgemeine Ortskrankenkasse) in Heidelberg in the age range of 35–64 years were invited to participate in a validation study in September 1991. It was intended to recruit the EPIC cohort Germany from this population. Of those invited, 115 agreed to participate. In addition, eight volunteers joined the study population.4

The study started with 123 participants in October 1991. By the end of the study in October 1992, 104 of them had provided complete information. The final study group consisted of 92 subjects because 12 subjects’ data gave rise to the suspicion that they provided invalid reference data (24-hour recall).

Collection of Blood Specimens

Blood specimens were taken from each person in January or February 1992 and in June or July 1992. Twenty ml of blood was obtained on each occasion using two vacutainers (Beckton Dickinson). One vacutainer contained heparin as anticoagulant. Immediately after drawing the blood, the vacutainers were wrapped in aluminium foil in order to prevent exposure to light. Both tubes of heparinized and non-heparinized blood were centrifuged for 10 minutes. Serum and plasma were aliquotted and stored at −80°C. A solution of metaphosphoric acid was added to one aliquot to stabilize vitamin C. Concentrations of α-carotenes, β-carotenes, retinol, α-tocopherols, γ-tocopherols and ascorbic acid were measured by Hoffmann LaRoche in Basel using established procedures.9,10 Ascorbic acid could not be determined for two subjects because of insufficient blood.

24-hour Recalls

The 24-hour diet recalls were taken monthly for one year maintaining a balance between different days of the week. Fridays and Saturdays were not covered. The 24-hour diet recalls were carried out face-to-face by trained interviewers and lasted 20 minutes on average. The enquiry followed the meal sequence. Coloured photographs and household measures were used to quantify portion sizes. A checklist was used to ask particularly for foods that are often forgotten like sauces or fats.4

The 24-hour diet recalls were coded according to a Federal Coding System with about 12 000 food items, provided by the previous Institute of Social Medicine and Epidemiology of the Federal Health Office, Berlin.11 The Federal Coding System included a nutrient database that gives detailed information on nutrient and energy concentrations for every food item. In this study we used the vitamin concentrations of version 2.1 under the headings carotenoids, retinol, tocopherols, and ascorbic acid.

The 24-hour diet recalls were checked for under-reporting by comparing the reported energy intake with the calculated energy requirements defined as multiples of the basal metabolic rate.12 From the 104 participants, 12 were identified having a ratio of energy intake to basal metabolic rate <1.07. A value of 1.07 was found to be the lower limit of the 95% confidence interval for that ratio if energy was correctly estimated in a steady-state situation.13 Because the 24-hour diet recalls of 12 participants may be invalid and systematically biased they were excluded from the analysis.

Food Frequency Questionnaire (FFQ)

The FFQ was applied twice, in January 1991 (FFQ1) and September 1992 (FFQ2). The FFQ was developed using data from a national nutrition survey (Nationale Verzehrstudie) with 7-day food records conducted in 1985–1988 in Germany.14 In a stepwise procedure, 158 food items were identified which were significantly related to the intake of the corresponding food group and explained most of the inter-individual variation of food group intake. This FFQ was designed to be filled in by study participants and to be read by an optical scanner. Previous versions of the questionnaire were tested in specific populations for handling and clarity.
Food intake data were derived by two different approaches. In one approach data were used as obtained in FFQ1 and FFQ2. The frequency information was combined with the given portion sizes to calculate the average amount of intake. Another approach included the information that had been given in the questionnaire on general consumption pattern. This questionnaire was distributed in January 1993 and asked for the overall frequencies of consumption of 14 broad food groups such as bread, cereals, fruits, vegetables, legumes, potatoes, cheese, soft drinks, fats, sauces, meat, desserts, and soups during the last year. These frequencies were compared with frequencies of consumption of the same food groups obtained by summing the frequencies of the respective food items given in FFQ2. The FFQ2 frequencies were corrected by the ratio of frequencies of general consumption pattern to the FFQ-derived frequencies. After correction of food intake estimates were derived as described above. The latter estimates were labelled FFQcorr. This procedure of correcting frequencies appeared to be necessary for those study participants who tended to overestimate the total frequency because many single food items were asked about. The FFQcorr approach was shown to provide more valid estimates of food intake compared to 24-hour dietary recalls than using the data straight from the FFQ.\(^4\)

The nutrient concentrations for each food item of the FFQ were derived by taking values provided of the Federal Coding System.\(^11\) Nutrient values for each FFQ item were calculated as average of respective food items of the Federal Coding System weighted by intake observed in the 24-hour diet recalls data.\(^5\)

**Statistical Analysis**

The distribution of dietary intake values was checked for normality. All dietary variables generated by the 24-hour diet recalls or FFQ required log transformation to approximate normal distribution. Blood values except ascorbic acid were also log transformed. Alpha- and β-carotenoid concentrations in blood were combined to carotenoids and α- and γ-tocopherols to tocopherols on a molar basis. Tocopherol concentration in blood was related to cholesterol concentration for lipid adjustment.

For blood concentrations and intake measurements by 24-hour diet recalls and FFQ, intraclass correlation coefficients were calculated as the percentage of between-person variance over total variance. For this analysis data were taken from FFQ1 and FFQ2. For comparison of the FFQ with the reference measures data from the FFQcorr procedure were used. Surrogate measurements and reference measures were compared by computing Pearson correlation coefficients, adjusted for sex and smoking status (smokers, ex-smokers, non-smokers). The Pearson correlation coefficients were also corrected for attenuation due to intra-individual variation in the reference methods as described by Liu *et al.*\(^15\) The variance ratio was calculated as the ratio of within-person variance to between-person variance.

The magnitudes of correlation of error between 24-hour diet recalls and FFQcorr were estimated using the following error model:\(^16\)

\[
X_{ij} = x_i + e_{Xij}, \quad i = 1, \ldots, n_v, \quad j = 1, \ldots, r_i
\]

\[
Z_i = a + bx_i + e_{Zi}; \quad i = 1, \ldots, n_v
\]

\[
W_i = c + dx_i + e_{Wi}; \quad i = 1, \ldots, n_v
\]

with \(X_{ij}, r_i\) being multiple measures of the reference method of the \(i\)’s subject. \(Z_i\) is the FFQ measurement, and \(W_i\) is the biomarker measurement of the \(i\)’s subject. Independence of \(e_W\) from \(e_X\) and \(e_Z\) and also independence of all errors from the true exposure level \(x\) were further assumed. The correlation of \(e_X\) and \(e_Z\) was calculated by

\[
\text{Côrr (}e_X, e_Z\text{)} = \frac{\text{Côv (}X_{ij}, Z_i\text{)} - [\text{Côv (}Z_i, W_i\text{)}]/\text{Côv (}X_{ij}, W_i\text{)}]}{\text{Vâr (}x\text{)}}
\]

The variance of Côrr (\(e_X, e_Z\)) was estimated conservatively by Fisher’s Z transformation. To unlink \(e_W\) from \(e_X\) and \(e_Z\) measurements of \(W\) are adjusted for Quetelet index (weight/height\(^2\)) and age.

The ability of the measures to differentiate groups of subjects with different intake or blood values was evaluated by calculating the means in quintile categories. For example, the allocation to quintiles was based on ranks derived from the surrogate measure (FFQcorr) and the means were obtained from the reference measures.

All analyses were performed with the Statistical Analysis System SAS.\(^17\)

**RESULTS**

The study group consisted of 43 men and 49 women aged 35–64 years. Mean age was 48 years for men and 49 years for women. The number of current smokers was 23, ex-smokers 32, and non-smokers 38. Smoking status was unknown for two people. Vitamin supplements were mentioned by 14 of the 43 men (33%) and 31 of the 49 females (63%) on at least one of the 12 dietary recall days.

Table 1 shows intraclass correlations and the ratios between intra- to inter-individual variance components for each instrument and investigated compound. Intraclass correlation of blood values was high for carotenoids, retinol, and tocopherols (corresponding to variance component ratios <1), but were low for ascorbic acid.
The intraclass correlations of the FFQ were lower compared to blood values. Recall data exhibited the lowest intraclass correlations corresponding to variance component ratios well above 1. Intake of carotenoids from 24-hour diet recalls showed the highest intra-individual variation.

Correlation coefficients between FFQ corr and 24-hour diet recalls were higher than between FFQ corr and blood values on average (Table 2). Correction for intra-individual variation in the reference measures improved the correlation coefficients. The correlation of intake of carotenoids between FFQ corr and concentration of carotenoids in blood increased from 0.35 to 0.37, for retinol from 0.19 to 0.22, for tocopherols from 0.16 to 0.18, and for ascorbic acid from 0.24 to 0.36. The correlation coefficients between FFQ corr and 24-hour diet recalls data after correction were 0.69 (ascorbic acid), 0.52 (tocopherols), 0.44 (carotenoids) and 0.29 (retinol). Among non-supplement users the attenuated correlation coefficients improved from 0.24 to 0.36 between FFQ corr and vitamin C concentrations in blood. Among this group notable changes in correlations were not seen for carotenoids or tocopherols. No detailed information was recorded in this study about the amount of vitamin C consumed as supplements. Further investigation of the correlations of levels of ascorbic acid in blood with dietary intake by FFQ and 24-hour diet recalls revealed that the values in the summer were atypically low compared to those in the winter collection (data not shown). The mean values during summer had been 11.6 mg/ml and during winter 13.6 mg/ml. Therefore we assume there may have been

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**Table 1** Intraclass correlations and variance ratios of carotenoids, retinol, tocopherols, and ascorbic acid intake or status in the Heidelberg validation study (n = 92)

<table>
<thead>
<tr>
<th></th>
<th>Intraclass correlation</th>
<th>Variance ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>blood</td>
<td>24HDR</td>
</tr>
<tr>
<td>Carotenoids</td>
<td>0.81</td>
<td>0.10</td>
</tr>
<tr>
<td>Retinol</td>
<td>0.70</td>
<td>0.11</td>
</tr>
<tr>
<td>Tocopherols</td>
<td>0.57</td>
<td>0.20</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>0.29</td>
<td>0.22</td>
</tr>
</tbody>
</table>

\* Blood values adjusted for total cholesterol.
\* n = 89.
\* 24-hour diet recall.
\* Food frequency questionnaire.

**Table 2** Pearson correlation coefficients of dietary intake of carotenoids, retinol, tocopherols, and ascorbic acid by food frequency questionnaire (FFQ) and intake or status measures by the reference methods—adjusted to sex and smoking status and corrected for measurement error (n = 92)

<table>
<thead>
<tr>
<th></th>
<th>FFQ corr</th>
<th>raw correlations with</th>
<th>FFQ corr</th>
<th>corrected for attenuation with</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>blood</td>
<td>24HDR</td>
<td>FFQ</td>
<td>blood</td>
</tr>
<tr>
<td>Carotenoids</td>
<td>0.35</td>
<td>0.33</td>
<td>0.37</td>
<td>0.44</td>
</tr>
<tr>
<td>Retinol</td>
<td>0.19</td>
<td>0.22</td>
<td>0.21</td>
<td>0.29</td>
</tr>
<tr>
<td>Tocopherols</td>
<td>0.16</td>
<td>0.45</td>
<td>0.18</td>
<td>0.52</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>0.24</td>
<td>0.61</td>
<td>0.36</td>
<td>0.69</td>
</tr>
</tbody>
</table>

\* Blood values adjusted for total cholesterol.
\* n = 89, winter blood collection.
\* 24-hour diet recall.
95% confidence intervals for Pearson’s correlation coefficients with n = 92: 0.90 (0.85–0.93); 0.80 (0.71–0.86); 0.70 (0.58–0.79); 0.60 (0.45–0.72); 0.50 (0.33–0.64); 0.40 (0.21–0.55); 0.30 (0.10–0.48); 0.20 (0.01–0.39); 0.10 (0.11–0.30).
Formula: \(\text{tanh} ((0.5*\ln((1 + r)/(1 – r)) – 1.96*(1/\sqrt{92 – 3}))\).
problems with preservation of ascorbic acid at the summer collection that also may have affected the intra-individual variation.

The study participants were ranked into quintiles according to FFQ corr estimates and the mean blood concentrations and intake by 24-hour diet recalls of each quintile was calculated (Table 3). Only a small variation in blood concentrations across quintiles was seen for retinol and tocopherols. Mean blood concentrations of carotenoids increased steadily by quintiles. The values of the highest quintile compared to the lowest reflected a 1.6-fold difference. The mean values of ascorbic acid in each quintile, calculated from the winter blood collection only, ranged from 12.4 mg/ml to 14.2 mg/ml. Gradients in mean intake by 24-hour diet recall across quintiles could be observed for each intake measurement of vitamins. Ranking on the basis of the FFQ corr yielded factors of 1.5 for carotenoids, 1.3 for retinol, 1.6 for tocopherols, and 2.1 for ascorbic acid between lowest and highest quintile (Table 3).

A similar analysis was performed based on the 24-hour diet recalls estimates (Table 4). The right-hand section of Table 4 reflects the full difference in mean intake between quintiles based on the reference measurement. The intake of lowest compared to highest quintile was found to increase by a factor of 3.6 for carotenoids, 5.3 for retinol, 2.4 for tocopherols, and 3.6 for ascorbic acid. The reduced ability to rank subjects from the FFQ

### Table 3

Mean blood concentrations and mean dietary intake by 24-hour dietary recall (24HDR) across quintiles of dietary intake defined by food frequency questionnaire corrected for frequency (FFQ corr) in the Heidelberg validation study (n = 92; mean [STD])

<table>
<thead>
<tr>
<th>Quintiles</th>
<th>Carotenoids (µg/ml mg/ml)</th>
<th>Retinol (µg/ml)</th>
<th>Tocopherols (mg/ml)</th>
<th>Ascorbic acid (mg/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(229)</td>
<td>(118)</td>
<td>(1.1)</td>
<td>(4.0)</td>
</tr>
<tr>
<td>2</td>
<td>(239)</td>
<td>(125)</td>
<td>(1.3)</td>
<td>(3.3)</td>
</tr>
<tr>
<td>3</td>
<td>(362)</td>
<td>(147)</td>
<td>(1.3)</td>
<td>(3.7)</td>
</tr>
<tr>
<td>4</td>
<td>(500)</td>
<td>(165)</td>
<td>(1.7)</td>
<td>(2.7)</td>
</tr>
<tr>
<td>5</td>
<td>(349)</td>
<td>(113)</td>
<td>(1.3)</td>
<td>(2.6)</td>
</tr>
</tbody>
</table>

### Table 4

Mean blood concentrations and mean dietary intake by 24-hour dietary recall (24HDR) across quintiles of dietary intake defined by 24HDR in the Heidelberg validation study (n = 92; mean [STD])

<table>
<thead>
<tr>
<th>Quintiles</th>
<th>Carotenoids (µg/ml mg/ml)</th>
<th>Retinol (µg/ml)</th>
<th>Tocopherols (mg/ml)</th>
<th>Ascorbic acid (mg/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(146)</td>
<td>(143)</td>
<td>(1.3)</td>
<td>(3.9)</td>
</tr>
<tr>
<td>2</td>
<td>(386)</td>
<td>(137)</td>
<td>(1.4)</td>
<td>(4.3)</td>
</tr>
<tr>
<td>3</td>
<td>(363)</td>
<td>(94)</td>
<td>(1.2)</td>
<td>(2.6)</td>
</tr>
<tr>
<td>4</td>
<td>(610)</td>
<td>(123)</td>
<td>(1.3)</td>
<td>(2.7)</td>
</tr>
<tr>
<td>5</td>
<td>(753)</td>
<td>(179)</td>
<td>(1.3)</td>
<td>(1.9)</td>
</tr>
</tbody>
</table>

### Notes

* Blood values adjusted for total cholesterol.
* n = 89, winter blood collection.
* Carotenoids and retinol are measured as µg/ml, tocopherol and ascorbic acid as mg/ml.
compared to the 24-hour diet recalls was particularly evident for dietary retinol; confirming the low correlations for this vitamin between FFQcorr and 24-hour diet recalls. Blood concentrations of retinol and tocopherols did not increase with increasing dietary intake as measured by 24-hour diet recalls. The mean values of ascorbic acid in blood across quintiles were similar to the previous analysis on the basis of FFQcorr and ranged from 12.7 mg/ml for the lowest quintile to 14.9 mg/ml for the highest quintile. Blood values of carotenoids increased markedly across quintiles of intake by 24-hour diet recalls.

The mean values in quintiles of ascorbic acid concentrations in blood were also calculated. For ascorbic acid mean values were found to be 9.5, 10.9, 12.5, 12.9, 16.0 mg/ml from the first to fifth quintile. These values corresponded to mean dietary intakes from 24-hour diet recalls of 73.8, 83.6, 116.0, 116.3, and 118.2 mg/day, respectively. The percentage of subjects with vitamin supplements mentioned in the 24-hour diet recall increased with increasing categories of ascorbic acid from foodstuffs.

The correlations of error between surrogate and reference measure are shown in Table 5. There appeared to be no correlation of errors between the 24-hour diet recalls and the FFQcorr for the vitamins examined.

### DISCUSSION
This paper describes the reproducibility and relative validity of an FFQ with respect to dietary intake of the vitamins—retinol, carotenoids, tocopherols, and ascorbic acid. The reference methods were 12 repeated 24-hour diet recalls and blood concentrations. Relative validity and error structure were calculated for FFQcorr. The FFQcorr-approach was found to show the best relative validity in respect of food and macronutrients and is applied in the EPIC cohort study.

There are many sources of variation that attenuate correlation coefficients which are not necessarily attributed to the instrument under study itself. For example, the 24-hour diet recall was found to be systematically biased towards low energy intake in some subjects probably because the 24-hour diet recall was integrated into the scheme of visiting the study centre and therefore predictable after the first visit. When it was checked for this type of bias, 12 subjects were identified with lower energy intake compared to cut-point values obtained from a multiple of calculated basal metabolic rates. These subjects were excluded from the analyses because doubts existed with regard to correct reference data. Systematic bias in blood measurements due to analytical or biological variation and trend over time may have also existed. In addition, the validity of nutrient values provided by the Federal Health Office is also unclear. During the last 2 years a complete revision of the nutrient database has been carried out, however, new values could not be integrated into the present analysis. All random variations over time in the reference measurements coming from the different sources were taken into account by calculating the intra-individual variation and subsequently the de-attenuated correlation coefficients.

Table 6 lists the results from other recent validation studies for the dietary compounds under study. Retinol levels in blood seem to be unrelated to dietary retinol intake. This lack of association was also found in the present study. However, at the level of dietary intake we observed no meaningful correlation between retinol intake estimated by FFQcorr and by 24-hour diet recalls. The reason for this lack of correlation needs further evaluation since the major dietary sources of retinol are food items of animal origin. In the accompanying paper the consumption of meat and meat products estimated by this FFQ correlated with 24-hour diet recalls in the order of 0.51 and 0.61, respectively.

For tocopherols our correlation coefficient between intake measurements was found to be at the lower end compared to other studies (Table 6). We also did not observe a meaningful correlation between dietary data of FFQcorr and blood values. This result was also reflected in the analysis based on quintiles (Tables 3 and 4). Quintiles of tocopherol intake by FFQcorr or 24-hour diet recalls did not correspond with the gradient of vitamin E concentrations in blood.

Intake of carotenoids estimated by FFQcorr correlated with estimates from 24-hour diet recalls in the order of

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Corr (eX, eZ)</th>
<th>95% confidence interval</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retinol</td>
<td>–0.03</td>
<td>(–0.24, 0.18)</td>
<td>92</td>
</tr>
<tr>
<td>Tocopherols</td>
<td>–0.03</td>
<td>(–0.23, 0.18)</td>
<td>92</td>
</tr>
<tr>
<td>Carotenoids</td>
<td>0.03</td>
<td>(–0.18, 0.24)</td>
<td>92</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>0.12</td>
<td>(–0.09, 0.32)</td>
<td>92</td>
</tr>
</tbody>
</table>

*95% confidence interval using Fisher’s Z transformation.*
A similar correlation was found for blood values of carotenoids. In the quintiles based on the FFQcorr ranking considerable gradients across quintiles were seen for intakes measured by 24-hour diet recalls and blood concentrations (Table 3).

The concentration of ascorbic acid in blood (13.6 mg/ml) in winter as median was found to be in the upper ranges compared to other reports in the literature. In these ranges the impact of dietary vitamin C intake on blood values seems to be limited. Thus, our attempt to relate intake values may have failed in some instances. In addition, it was observed that the highest three quintiles of blood values did not vary according to their mean dietary intake measured by 24-hour diet recalls. Measurements of ascorbic acid by FFQcorr and 24-hour diet recalls were found to correlate well (Table 2).

Validation data in nutritional epidemiology are usually used for calibration and therefore for correcting biased relative risk estimates in multivariate logistic or Cox regression models. A common method used for correcting effect estimates and their confidence intervals is the linear approximation method for logistic regression. This is a form of the regression calibration method.
approach. Wacholder et al.\textsuperscript{2} could show that relative risk estimates corrected by the linear approximation method are biased where the reference method is also prone to measurement error and the errors in the reference method and the surrogate measure are correlated. Table 5 shows no correlation of errors in the measurements of uptake of carotenoids, retinol, tocopherols, and ascorbic acid. This implies that correcting relative risk estimates and their confidence intervals by means of linear approximation is a valid method provided some further assumptions are met.\textsuperscript{23} It needs further investigation to determine to what extent the results obtained regarding correlation of errors can be expanded to food groups or macronutrients that contain these vitamins without having biomarkers measured.

In conclusion, it was demonstrated that the FFQ was able to rank participants into biologically meaningful categories of intake or blood concentrations for carotenoids and ascorbic acid, but misclassification was higher for tocopherol and retinol.

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