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ORIGINAL ARTICLE

Relative validity and reproducibility of a food frequency questionnaire to assess dietary fiber intake in Danish adults

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Abstract

Background: Differences in habitual dietary fiber intake may modify effects of dietary fiber interventions, thus measurement of habitual dietary fiber intake is relevant to apply in intervention studies on fiber-rich foods, and food frequency questionnaire (FFQ) is a commonly used method. Rye bread is the major contributor of dietary fiber in the Danish population, and a nation-specific FFQ is therefore needed.

Objective: The aim of this study was to assess the relative validity and reproducibility of a self-administered quantitative FFQ designed to assess total dietary fiber intake among Danish adults.

Design: In order to assess the relative validity of the FFQ, a total of 125 participants completed both a 7-day weighed dietary recording (DR) and an FFQ consisting of 60 questions. To evaluate the reproducibility of the FFQ, a sub-group of 12 participants subsequently completed an FFQ approximately 6 months later.

Results: Estimates of mean dietary fiber intake were 24.9 ± 9.8 and 28.1 ± 9.4 g/day when applying the FFQ and DR, respectively, where FFQ estimates were $\sim 12\%$ lower ($p < 0.001$). Pearson's correlation coefficient between the estimated dietary fiber intake of the two methods was $r = 0.63$ ($p < 0.001$), and 62% of the participants were grouped into the same tertile of intake according to the two methods. The estimates of mean dietary intake of first and second FFQ were very similar (22.2 ± 4.0 and 23.3 ± 4.1 g/day, respectively, $p = 0.42$) and showed a correlation of $r = 0.95$ (95% CI 0.83–0.99).

Conclusion: The developed FFQ showed moderate underestimation of dietary fiber intake (g/day), adequate ranking of subjects according to their dietary fiber intake, and good reproducibility. The FFQ is therefore believed to be a valuable tool for epidemiology and screening in human interventions, where intake of dietary fibers is of specific interest.

Keywords: *nutrient intake*; *dietary fiber*; *cereal fiber*; *fruit and vegetable fiber*; *food frequency questionnaire*; *validation*; *reproducibility*; *Danish population*

Many observational studies associate high intakes of dietary fiber and fiber-rich foods with a reduced risk for all coronary events (1) and type 2 diabetes (2), a reduction in cholesterol concentration (3), reduced blood pressure (4), and lower body weight gain (5). In the small intestine, dietary fibers exert their effects by binding water, slowing gastric emptying, and delaying nutrient absorption. Additionally, they have effects in the colon, where dietary fibers are partly or completely fermented by the gut microbiota. Short-term responses to high-fiber foods may change following regular consumption as a result of learning and physiological adaptation as indicated by others (6), which potentially could attenuate a true diet–disease relationship. Thus, it is relevant to know the habitual dietary fiber intake of individuals taking part in intervention studies

investigating the effect of dietary fiber. The measurement of habitual dietary intake can be applied as a screening tool and be used to investigate whether habitual dietary fiber intake modulates the effect of the intervention.

Data collection, processing costs, and respondent burden are lower for a food frequency questionnaire (FFQ) than for other intake assessment methods such as weighed food recording and 24-h recalls. These features make FFQ attractive to apply when dietary intake is not a primary outcome. However, as FFQ is a self-administered tool with high risk of recall bias it is of importance to verify the accuracy of the FFQ-derived estimates of intake. The most accurate and objective reference method for measuring absolute validity of dietary intake is by using validated biomarkers. When reliable biomarkers are not available food records are perceived to be the optimal

dietary method for evaluating relative validity as they are not associated with recall bias, thus validation of an FFQ against a food record is commonly applied (7).

The Nordic nutrition guidelines recommend a daily consumption of at least 25–35 g dietary fibers (8); yet, the average intake for the Danish adults [21 ± 7.5 g/day (mean ± SD)] is somewhat below the recommended levels (9). The dietary pattern in Denmark, and to some extent in other Scandinavian countries, differs from other European countries, especially due to the large consumption of rye bread. Rye bread, commonly consumed as whole-grain rye bread, is a staple food primarily at lunch. Rye bread is the single most important contributor to whole-grains consumed in Denmark among both children and adults (10), and rye bread is therefore also a major contributor of dietary fiber. When studying dietary fiber intake in a Danish population, it is therefore of importance to cover the intake of rye bread and other nation-specific fiber-rich foods. This highlights the relevance of locally developed FFQs.

The aim of this study was to assess relative validity and reproducibility of a self-administered quantitative FFQ designed to assess total dietary fiber intake among Danish adults. The FFQ was developed to be used in future studies where habitual dietary fiber intake may be of interest as a potential confounder or as a screening tool.

Experimental section

Participants
In total, 126 participants were recruited for the study by advertising in the area of Copenhagen and at www. forsøgsperson.dk. Both men and women with a body mass index (BMI) of 18–40 kg/m^2 and aged between 18 and 65 were included. All participants were apparently healthy adults with no known chronic illnesses. After having received verbal and written information, all participants gave written consent about the study in accordance with the Declaration of Helsinki. The study was carried out at the Department of Nutrition, Exercise and Sport, Faculty of Science, University of Copenhagen, Denmark, and was approved by the local ethics committee (H-B-2009-071).

Anthropometric measurements
At entry into the study, anthropometric measurements were performed in the morning after an overnight fast (>10 h) and abstention from alcohol and physical exercise for 24 h. Body weight was measured on an electronic scale while the participants were wearing light clothing and no shoes (Tanita BWB-600, Japan). At the first visit, height was measured to the nearest 0.5 cm by using a wall-mounted stadiometer (Seca, Hultafors, Sweden) without shoes.

Food frequency questionnaire
The quantitative FFQ was designed to measure the habitual intake of dietary fiber during the previous month. It included 60 questions in total concerning the intake of foods from eight main food groups which contain dietary fibers, that is, foods containing cereals, fruits, vegetables, legumes, lentils, and nuts. A list of food items included in the questionnaire is given in Table 1 together with the estimated dietary fiber content of each food group as well as sub-groups. The dietary fiber content of the foods was based on the national food composition database (foodcomp.dk, National Food Institute, Danish Technical University) for fruits and vegetables, legumes, lentils, dried fruits, and nuts. For breads and other cereals, a comprehensive list of brand-specific foods was made based on availability in super-markets. All foods were then sub-categorized based on dietary fiber content into the groups listed in Table 1. The questionnaire's options for frequency of consumption was given as times per day (either 1, 2, 3, or more than 3), times per week (either 1–2, 3–4, or 5–6), less than once per week, or never. When consumption was more than three per day, the subject was asked to write down the frequency. When consumption was given as an interval, for example, 1–2 times per week, a mean value of 1.5 was used for calculating the intake. When consumption was either less than once per week or never, contribution from this food item was disregarded. After each question of frequency, the responder was asked about the average portion size of each time of consumption. Portion size was presented in household units, for example, slices, pieces, spoonful, or the portion size was estimated using pictures of four different portion sizes. Mean daily intake of total fiber as well as dietary fibers from cereals, fruits and vegetables, and other sources was calculated. The FFQ, which is in Danish, may be obtained from the authors for use in other studies.

Six months after completing the first FFQ (FFQ1), a small proportion of the participants were asked to fill in a second FFQ (FFQ2). The questionnaires were the same and FFQ2 was only used for evaluating reproducibility.

Seven-day-weighed DR
Participants completed a weighed DR over a period of seven consecutive days. This record was carried out within a month after completing FFQ1. All recorded foods and beverages were entered into the Dankost 3000 dietary assessment software which is based on the same food composition database as used in the FFQ (foodcomp.dk, National Food Institute, Danish Technical University) (Dankost 3000, version 2.5, Danish Catering Center, Herlev, Denmark), and mean daily total intake of energy, fat, carbohydrates, protein, alcohol, and total dietary fiber was calculated for each 7-day registration period.

Table 1. Food questionnaire

Food group	Food type	Portion size	Dietary fiber content (g/100 g)
Breakfast cereals	Coarse breakfast cereals	Four portion sizes assessed using pictures	8
	Fine, light breakfast cereals		3
	Fine, high-fiber breakfast cereals		15
Breads	Rye bread	Half slices	8
	White wheat bread	Slices/buns	3
	Coarse wheat bread	Slices/buns	8
	Coarse crisp bread	Pieces	15
	Fine crisp bread	Pieces	7
	Coarse biscuits	Pieces	6
	Fine biscuits	Pieces	3
Other cereal foods	White rice	Four portion sizes assessed using pictures	1
	Brown rice		1
	Pasta		3
	Whole-grain pasta		7
	Bulgur		3
	Couscous		3
	Noodles		3
Potatoes		Pieces	1.5
Legumes, lentils		dL, uncooked	5
Vegetables	Fine	Four portion sizes assessed using pictures	1.5
	Coarse		3
	Cabbage		3
Fruits	Fresh	Pieces	2
	Dried	dL	6
	Smoothies	Glass (2 dL)	2
Nuts, seeds		Half dL	8

Specific food items and their dietary fiber content used in the calculation of daily dietary fiber intake. Frequency of consumption was given as times per day, 1–2, 3–4, 5–6 times per week, daily, less than once per week or never, depending on the food item.

Statistical analyses

All statistical analyses and calculations were performed using the Statistical Analysis System software package, version 9.3 (SAS Institute Inc., Cary, NC, USA). Normal distribution was checked by visual inspection of normal probability plots and histograms.

Data from the FFQ and DR were compared using several different methods. Dietary fiber intake as assessed by DR and FFQ was compared using an ANCOVA model, where sex and method were modeled as fixed variables, subject as a random variable, and age and BMI were included as covariates. Pearson correlation coefficients were computed to measure the strength of the relationship between the two measurement methods. A Bland–Altman plot was performed with difference between FFQ and DR plotted against mean dietary intake of the two methods. The plot was used to assess homogeneity of the individual data and to evaluate if under-/overreporting was relative to average dietary fiber intake. Also, participants were classified into tertiles of dietary fiber intake according to both methods (FFQ and DR) to assess the ability of the method to correctly group individual participants.

Difference between the first and second FFQ estimates (FFQ1 and FFQ2) of dietary fiber intake was investigated using an ANCOVA model, where FFQ (1 or 2) were modeled as a fixed variable and subject as a random variable. Additionally, Pearson's correlation coefficient was measured as a measure of the relationship.

Results

A total of 125 participants completed both the FFQ and the dietary record. Normal weight, overweight, and obese individuals were included with a mean BMI of 25.7 ± 5.4 kg/m^2. Also, all age groups were represented ranging from 18 to 60 years with a mean age of 32.3 ± 11.0 years.

Relative validity

The mean intakes of dietary fiber estimated by the DR and FFQ1 were 28.1 ± 9.4 and 24.8 ± 9.9 g/day, respectively (Table 2), thus the estimated dietary fiber intake was ~12% lower when using the FFQ compared to the DR ($p < 0.001$) after adjusting for sex, age, and BMI. Excluding sex, age, and BMI from the model did not change the result. Among the covariates, only BMI was

Table 2. Characteristics of participants ($n = 125$)

	Mean (SD)
Female/male (n)	85/40
Age (y)	32.3 ± 11.0
BMI (kg/m^2)	25.8 ± 5.4
Total energy intake (kJ/day)	$10{,}185 \pm 2{,}338$
Dietary fiber intake (g/day), DR	28.1 ± 9.4
Dietary fiber intake (g/day), FFQ1	24.9 ± 9.8
From cereals (g/day), FFQ1	15.1 ± 7.3
From fruits and vegetables (g/day), FFQ1	7.5 ± 4.6
From other sources (g/day), FFQ1	2.3 ± 1.9

BMI, body mass index; DR, dietary record; FFQ, food frequency questionnaire.

associated with dietary fiber intake so that increased BMI was associated with decreased dietary fiber intake ($p = 0.01$). As expected, cereals were the main contributor of dietary fiber followed by fruit and vegetables. The estimated dietary fiber intake ranged from 7 to 50 g/day, thus providing sufficient range in fiber intake to assess the relative validity.

Pearson's correlation coefficient between the estimated dietary fiber intake between the two methods was 0.63, $p < 0.001$ ($Y = 0.5975 \, X + 13.243$), where dietary fiber intake estimated by FFQ (Y) is a function of dietary fiber intake estimated by DR (X), (see Fig. 1). A relationship between the two methods is established and the strength hereof is considered moderate.

The Bland–Altman plot showed that the mean difference between the two methods (FFQ from DR) was 3.2 ± 8.3 g/day, and that for any new subject a difference inside the range of $-13.4 - 19.8$ g/day can be expected with 95% certainty (Fig. 2). A regression line of the plot resulted in a negative slope ($\beta = -0.05$), but as the
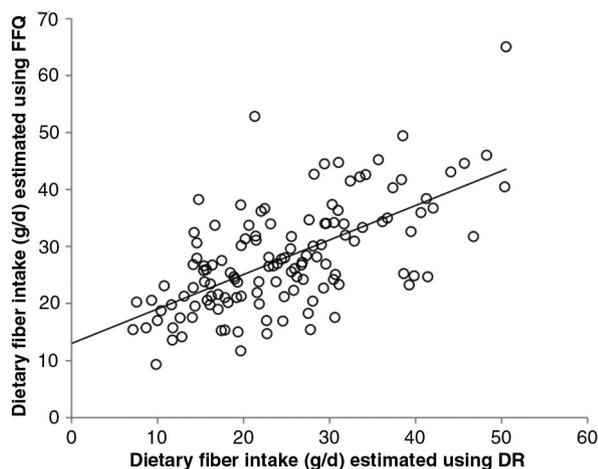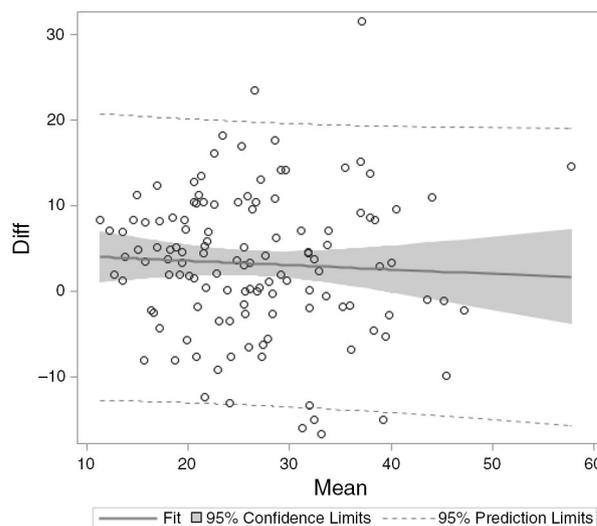

Fig. 2. Bland–Altman plot showing the relationship between the difference (Diff) in estimated dietary fiber intake of the two methods and the mean estimated dietary fiber intake (mean) ($n = 125$) with 95% confidence limits of the estimate as well as 95% prediction limits (2 SD).

estimate was not significant ($p = 0.56$), it can be assumed that the underestimation related to the FFQ is independent of the average dietary fiber intake.

The individuals were classified into tertiles of dietary fiber intake according to either DR or FFQ method. A total of 62% (78 subjects) was classified into the same tertiles of intake according to both methods (data not shown). However, only 5% (6 subjects) was misclassified into the opposite extreme of the tertiles.

Reproducibility

In total, 12 participants (7 women and 5 men) completed a second FFQ approximately 6 months after completing the first one. The dietary fiber intake in this sub-group ranged from 8 to 48 g/day. The total dietary fiber intake from FFQ1 and FFQ2 was highly correlated ($r = 0.95$, 95% CI 0.83; 0.99, $p < 0.001$) and was very similar for the first and second FFQ (22.2 ± 4.0 and 23.3 ± 4.1 g/day, respectively) ($p = 0.42$). Also, the contribution of dietary fibers from different sources did not vary between the two FFQs (data not shown). The difference from FFQ1 in total dietary fiber intake was less than 25% for 9 out of 12 of the participants.

Discussion

Relative validity

Based on Pearson's correlation coefficient and the Bland–Altman plot, a relationship is established between dietary fiber intake measured by FFQ and DR, and the relative validity of the FFQ is considered moderate. In the present study, Pearson's correlation coefficient was 0.63 and classification into tertiles showed 62% of the subjects to be

Fig. 1. Scatterplot of estimated dietary fiber intake (g/day) for FFQ versus DR ($n = 125$). DR, dietary record; FFQ, food frequency questionnaire.

in the same category in both methods. Previous studies evaluating FFQs specific for assessing dietary fiber intake (11, 12) found lower percentages of the participants to be classified into the same category when comparing FFQ and DR. However, this might be explained by their division into more groups as they classified subjects into quartiles and quintiles. Only Sasaki et al. (11) reported the correlation coefficient (Spearmen's) which compared to the present study was quite low; 0.50 for men and 0.44 for women (11). A validation methodology, similar to the one used in the present study, was applied in a validation study by Ross et al. (13), where a whole-grain FFQ was evaluated by comparison to a 3-day weighed food record. They reported a Pearson's correlation coefficient of 0.75, and when classifying into tertiles, 72% of the subjects were in the same category in both methods (13). Compared to few other studies that had validated FFQ specific for assessing dietary fibers, the relative validity of the present FFQ developed for assessing dietary fiber intake in Danish adults appears comparable. When further comparing our results with a validation of a previous FFQ that was also developed for Danish adults but was assessing the general diet (14), we believe that the present FFQ provides more accurate information about dietary fiber intake. In the study by Tjønneland et al. (14), the FFQ was validated against two times 7 days of weighed diet records. For dietary fiber intake, the study reported a Pearson's correlation coefficient of 0.39 for men and 0.53 for women when adjusted for total energy intake (14), which are estimates lower than the correlation coefficient of 0.63 obtained in this study.

Intake of dietary fiber-rich foods is usually associated with a healthy life style. Therefore, an FFQ build to assess dietary fiber intake is prone to overestimation, as participants are more likely to over-report consumption of healthy food. However, in the current study, the estimated dietary fiber intake was lower using the FFQ compared to the DR and the underreporting for FFQ was found to be independent of the average dietary fiber intake. Two recent validation studies of self-administered quantitative FFQ showed significant overestimation of dietary fiber intake; 32% when compared to 7 days DR (15) and 57% for women and 22% for men when compared to 24-h recall (16). However, these studies evaluated several micro- and macronutrients along with dietary fibers. Among other FFQs developed specifically for determining dietary fiber intake in adults, one study found no difference in mean intake when compared to DR (11), while another found that crude and energy-adjusted dietary fiber intake was significantly underestimated in the FFQ compared to a 4-day DR (12). Together with previous studies, the present study indicates that overestimation of dietary fiber intake in general diet FFQs can be overcome by using FFQs developed specifically to assess dietary fiber intake.

A possible reason for the observed underestimation of dietary fiber intake in the FFQ might be that the questionnaire does not cover the full diversity of the dietary fiber containing products consumed by the participants. This is, however, not considered to be the case of the present FFQ, as it includes eight different food groups covering the main sources, recognized by surveys of Danish adults normally contributing to the dietary fiber intake (9). But the grouping of foods and the use of standard portion sizes in the FFQ might cause a lower average estimate of dietary fiber intake to be used for the calculations. Also, it is considered that especially vegetables used in mixed dishes are neglected in the reporting, when intake is measured by recall; thus contributing to the underestimation. Additionally, the type of reference method used when evaluating the relative validity might explain parts of the differences in measurements. The FFQ was designed to reflect the food pattern of the last month, whereas the 7-day food recording resembles only this particular week, thus a deviation from the habitual pattern during these 7 days may influence differences between the two methods on an individual level. However, as the DR method covers both week days and the weekend, the method takes into consideration one of the major sources of between-days variations, and the influence on the estimates on a group level is considered to be minimal.

Reproducibility

The results on reproducibility indicate that overall the two FFQs give similar results. This is based on a good correlation between total dietary fiber intake measured by the two FFQs, a narrow 95% CI of the correlation coefficient and that no difference between FFQ1 and FFQ2 was present. It can thereby be presumed that the within-subject variation is low compared to the between-subject variation captured by this FFQ. The reproducibility has not been evaluated for previous dietary fiber FFQs (11, 12), but an FFQ designed for measuring whole-grain intake evaluated the reproducibility to be good based on a correlation coefficient of $r = 0.75$ (13). Generally, correlations noted in literature between subsequent measurements of FFQ in adults range from $r = 0.5–0.8$ (17), and compared to this, the reproducibility correlation of the present study ($r = 0.95$) must be considered very good. The higher correlation estimate in the present study might be explained by the nutrient of interest in the FFQ. Since dietary fibers are found in many foods consumed frequently, the within-subject variability will be lower than for nutrients found in only few foods that are consumed occasionally. Additionally, the time interval between FFQ1 and FFQ2 in this study was about 6 months. As several months separate FFQ1 and FFQ2, there might be a minor seasonal variation in the responses but on the other hand this time frame prevented introduction of sequence or training effects. It can be argued that fruit and vegetable intake

varies with season; however, the enrolment into the study was not limited to a short period of time, thus reflecting more than one season. Also, whole-grain rye bread, which was the single food contributing most to total fiber intake (data not shown), is consumed throughout the year although with different spreads; thus, effect of different seasons is limited.

Strengths and limitations

A major strength of the study was the large group of participants, who represented the general population with a wide range in age and BMI as well as varied dietary fiber intake. This increases the external validity of the results, although a wide range in dietary fiber intake likely has improved the correlation. Furthermore, the present FFQ also provides a tool with possibility to associate specific fiber sources with outcomes. A limitation of the study is however the small number of participants with data available for assessment of reproducibility of the FFQ ($n = 12$); thus, our ability to assess this accurately may be limited. The FFQ, evaluated in the present study, is applicable for the Danish adult population but might also be relevant for adult populations in other countries with similar food patterns, especially in populations where rye is a major source of dietary fiber intake.

When evaluating relative validity, the use of DR as reference method does not optimally determine the actual habitual intake, as previous studies have shown both undereating and underreporting when using dietary records for measuring energy intake (18, 19). Both FFQ and DR are self-reporting methods and are affected by some of the same errors caused by observation and reporting effects. Therefore, a good agreement between the two methods does not certainly reflect good validity, but may to some degree also indicate similar errors in the two methods. However, as the DR method excludes recall bias and do not rely on conceptualization of portion size, which are major errors present in FFQs, it is a suitable reference method when evaluating the relative validity of the FFQ (7). However, improvement in the research of biomarkers could in the future reveal validated quantitative biomarkers of dietary fiber intake, whereby the dependence of self-reported reference methods for validation could be minimized.

Conclusions

To sum up, we have shown that the used FFQ was able to rank Danish adults adequately according to their intake of dietary fiber, however with moderate underestimation of dietary fiber intake when evaluating the relative validity. The reproducibility of the developed FFQ was good. Thus, we believe that the developed FFQ is a valuable method to be used in epidemiology as well as a screening tool when performing human intervention studies on dietary fiber.

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