THE DUTCH HEALTHY DIET INDEX

Development, Evaluation, and Application

Linde van Lee

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Abstract

Background:

Dietary indices evaluate the conformity of an individual's diet with pre-defined standards. Generally, dietary guidelines are used for this purpose. As no index based on the current dietary guidelines was available in the Netherlands, the aim of the present thesis was to develop, evaluate, and apply a dietary index for use in the country.

Methods and results:

The Dutch Healthy Diet index (DHD-index) was developed on the basis of the 2006 Dutch dietary guidelines using data relating to 749 young adults who completed two 24-hour recalls in the Dutch national food consumption survey 2003. The index comprises ten components on physical activity, vegetables, fruit, dietary fibre, saturated fatty acids, trans fatty acids, consumption occasions with acidic drinks and foods, sodium, and alcohol. Scores for each component range between 0 (no adherence) and 10 (complete adherence) points. The DHD-index was inversely associated with energy intake and positively associated with most micronutrient intakes when adjusted for energy intake. We compared the DHD-index score based on two 24-hour recalls with the index based on the food frequency questionnaires (FFQ) of 121 adults from the European Food Consumption Validation study. We revealed an acceptable correlation (r=0.48) and absolute agreement between the indices based on the two methods. The prospective relationship with mortality outcomes was studied in 3593 of the Rotterdam Study participants who were followed for 20 years. The DHD-index per 10 points increment was associated with a 9% (95% CI 0.87-0.96) risk reduction for all-cause mortality, and non-significantly associated with risk reductions for cardiovascular disease, coronary heart disease, and stroke mortality. Among women, shared dinners were associated with lower DHD-index scores for that day than solo dinners in 1740 participants who contributed multiple 24-hour recalls in the Nutrition Questionnaires plus study. Among men and women, dinners shared with family members were associated with a higher DHD-index score on that day than dinners shared with others. Furthermore, in a subsample of 1235 participants in the Nutrition Questionnaires plus study, we evaluated the DHD-index based on the newly developed 34-item DHD-FFQ, a short questionnaire to assess diet quality in time-limited settings. The DHD-index based on the DHD-FFQ showed an acceptable correlation (r=0.56) with the index based on a 180-item FFQ, but showed a large variation in bias at individual level.

Conclusions:

The DHD-index based on an FFQ, on multiple 24-hour recalls, or on the DHD-FFQ was considered a valid tool to rank participants according to their diet quality. The DHD-index was therefore considered useful to monitor populations, study diet–disease associations, and identify subpopulations at risk of poor diet quality.

CONTENTS

1

GENERAL INTRODUCTION

Dietary intake has a substantial impact on the development of chronic diseases such as cardiovascular diseases, diabetes, and several cancers[1-3]. The effects of single nutrients and foods on the development of chronic diseases have been studied and translated into dietary guidelines. These guidelines represent the current state of scientific knowledge and are designed to prevent nutrient deficiencies and chronic diseases[4-7]. In 2006, the current Dutch dietary guidelines were defined. They include ten quantitative guidelines on physical activity level and the intakes of vegetables, fruit, dietary fibre, fish, saturated fatty acids, trans fatty acids, sodium, alcohol, and the number of consumption occasions with acidic drinks and foods. Unfortunately, adherence to these guidelines is low. The latest Dutch National Food Consumption Survey (DNFCS) 2007-2010 revealed that the Dutch population consumes too little fruit, dietary fibre, and fish, too few vegetables, too many saturated fatty acids, and too much salt compared to the Dutch recommendations[8, 9].

Adherence to the individual dietary guidelines is monitored using data from the DNFCS. However, it has been suggested[10-13] that the overall diet should be studied as well, because people are not consuming single nutrients or foods, but combinations of these in different behavioural patterns. These combinations of foods may be interactive or synergistic. Dietary pattern analysis takes account of these interactions and also avoids multiple testing of single nutrients and foods in relation to health. Furthermore, improving individuals' diet quality by introducing healthy foods should be examined in the context of their total diet to determine the actual health effects of these dietary changes[14], as introducing new foods into a diet could lead to substitution of, or compensatory effects on, other dietary compounds. For all these reasons, the focus on dietary patterns has been proposed as a promising direction within nutritional epidemiology and public health practice.

Dietary patterns can be studied using several methods, broadly classified as a posteriori and a priori methods.

A posteriori dietary pattern analyses

The a posteriori dietary pattern approaches detect dietary patterns from dietary data without prior assumptions on health or disease associations. The two best-known methods to assess dietary patterns are cluster analysis and principal component analysis (PCA). Cluster analysis aggregates persons into distinct non-overlapping groups (i.e. clusters) with similar characteristics (e.g. diets)[15]. PCA is a well-known method to define dietary patterns by data reduction, whereby a large number of variables (i.e. foods) are replaced by a smaller number of independent variables (i.e. dietary patterns) which still represent the whole[16]. Each individual receives a factor score for each derived pattern, representing the level of adherence to that dietary pattern. The obtained dietary patterns give insights into the current dietary habits or meal patterns in the population under study, which may not be the ideal diet from a health perspective. The dietary patterns can be addressed in public health interventions or used to study associations with health outcomes in nutritional epidemiology.

A priori dietary pattern analyses

The a priori dietary pattern analyses evaluate the conformity of an individual's diet with pre-defined standards. These standards are based on current knowledge of, for example, associations between dietary components and health. Generally, international or national dietary guidelines are used as standards, but disease-specific dietary guidelines[17] or evidence from epidemiological studies[18, 19] may also be used. To develop a dietary index, several arbitrary decisions need to be taken: 1) selecting components to be included, 2) assigning foods to food groups, 3) choosing the scoring system, 4) defining cut-off points, 5) adjusting for energy intake, and 6) applying weights to components[13, 20].

These dietary scores can be used to study the relation between diet quality and health, evaluate diet quality in (sub)populations, monitor diet over time, assess effectiveness of nutrition interventions, or evaluate other tools such as nutrient density indices[21], or they can serve as a confounder that represents the whole diet[16, 22].

A well-known example of a dietary index is the Healthy Eating Index (HEI), developed using the dietary guidelines for Americans in 1995 and updated in 2005 and 2010[22-24]. The HEI-2010 comprises[12] components including total fruit, whole fruit, total vegetables, greens and beans, whole grains, dairy, total protein, plant and seafood protein, fatty acids, refined grains, sodium, and empty calories. The maximum number of points allocated to each component serves as a weighting factor, and most component scores are weighting equally at 10 points. The component empty calories from added sugars, solid fats, and alcohol has a maximum of 20 points. Furthermore, the components fruit, vegetables, and protein foods have two constituents (total and subgroup) with a maximum of 5 points each. Each component is scored proportionally (range 0 to maximum), resulting in a summed total score ranging between 0 and 100 points, where higher scores represent higher adherence to these dietary guidelines.

For the Dutch situation, Löwik *et al.*[25] developed a food-based dietary guidelines index and a dietary quality index based on the 1986 guidelines for a healthy diet. This quality index included components on total fat, saturated fat, cholesterol, carbohydrates, and mono- and disaccharides. Each component was given a maximum of 1 point when achieved, resulting in a summed total score ranging between 0 and 5 points. Because the Dutch guidelines for a healthy diet were updated in 2006[5], a new or updated diet quality index was needed. Therefore, we developed the Dutch Healthy Diet index (DHD-index), representing the ten dietary guidelines as defined by the Dutch Health Council[5].

Evaluation of a diet index

Newly developed dietary indices such as the DHD-index should be evaluated regarding their validity[16]. Suggested evaluation strategies include examining the relationship of the index with nutrient intakes; assessing content validity, construct validity, and reliability[16, 26-28]; and studying the comparability of the index when it is derived from different dietary assessment methods dietary assessment methods[29, 30].

The relationship between nutrient intakes and a dietary index can be studied by comparing nutrient intakes of individuals with a low level of adherence to the recommendations with those of individuals with a high level of adherence. It is hypothesized that participants with higher DHD-index scores will have higher intakes of both vitamins and minerals and have a more nutrient-dense diet.

Content validity includes a qualitative check on the selection and food grouping of components comprising the index. Practically, in the Dutch context, this involves a visual check on whether the DHD-index captures the various key aspects of the Dutch dietary recommendations[27].

Construct validity includes a quantitative check on the extent to which the index measures what it is supposed to measure, i.e. adherence to the dietary guidelines. This can include evaluating whether the index can distinguish between subpopulations with known differences in their dietary intake – for example, examining whether there is a relationship with participants' characteristics such as educational level, because individuals with a low socio-economic status are known to have a lower diet quality[31]. Moreover, the relationship between the DHD-index and energy intake should be evaluated. If diet quality is dependent on energy intake, its relationship with absolute nutrient intakes will probably be affected, as nutrient intakes are positively associated with energy intake. Consequently, to account for the relationship between diet quality and energy intake, adjustment strategies should be evaluated. Furthermore, examining the correlations between components could give insight into the underlying structure of the index. Highly correlated components may result in unintentional weighting of components[13] or lower diagnostic capacity[32]. Additionally, the scoring system (i.e. dichotomous or proportional) can be evaluated by examining the variation in the index scores between individuals. The score should provide a large range to end up with a score that is able to discriminate between individuals. High discriminative power also makes it possible to monitor trends in dietary intake over time or dietary changes in trials. Lastly, the relationship of the index with chronic disease or mortality can be studied using data from prospective observational studies. However, due to the probable residual confounding in observational studies, the relationship between adherence to the dietary guidelines and chronic diseases should, ideally, be studied in a randomized trial[33], such as was done in the PREDIMED study[34].

Reliability is the consistency of a measurement, thus the extent to which the index measures similarly each time. Two methods are commonly measured: test/retest reliability and internal consistency. Test/retest reliability is determined by repeating the measure, but this is not very useful for the evaluation of the DHD-index because the index will be calculated in the exact same way when the calculations are repeated using the same dietary data. Internal consistency can be evaluated by examining the Cronbach's coefficient alpha. This coefficient represents the degree to which the multiple components within an index measure the same underlying, unidimensional, latent construct. Furthermore, the robustness of the total score can be studied by examining the relative contribution of the components to the total score. The relative contribution of components can be studied by excluding one single component at a time and examining the differences in results with an outcome measure.This will show whether one of the components has more influence than any of the others on the total score.

Lastly, the comparability of a dietary index based on different dietary assessment methods is important because measurement errors of the dietary assessment method will be reflected in the indices[29, 35]. Multiple dietary assessment methods are available. The two most commonly used are the food frequency questionnaire (FFQ) and the 24-hour recall (24hR) method. Typically, an FFQ consists of questions on the consumption frequency of food items, portion sizes, and preparation methods, the answers to which that can be used to estimate habitual intake. The 24hR is a method that asks participants to recall their dietary intake of the previous day. For an estimate of habitual intake, two or more non-consecutive recalls are required. Because of each individual's natural day-to-day variation, estimates from FFQs and 24hR, especially for episodically consumed foods, will therefore differ. These differences have already been extensively examined; however, the effect of these on the validity of dietary indices should also be studied[29, 30].

The HEI is an example of a well-evaluated dietary index. The original HEI, developed in 1995, was evaluated on the basis of its relation with nutrient intakes, its content validity, and its construct validity by visually comparing the components to the guidelines, exploration of the range of scores among the population, and study of the relationship with energy intake[24]. The updated HEI-2005 was again qualitatively evaluated regarding content, and quantitatively on the relationship with energy intake, whether the index correctly scored pre-defined menus that illustrated high diet quality, its ability to distinguish smokers from non-smokers on their diet quality, the underlying structure of the components, its internal consistency, the relative contribution of the components to the total score[27, 28] and the relationship with major chronic diseases[36-38]. On the basis of these results, the HEI-2005 was considered a valid measure of diet quality as based on the 2005 dietary guidelines for Americans[22].

Diet quality screeners

Both the FFQ and the 24hR are time-consuming methods that can be quite burdensome for participants and are time costly to administer and process for researchers. In time-limited settings, such as clinical practice in hospitals or general practices, there is need for a quick dietary assessment method (e.g. a screener) to determine unhealthy dietary intake, guide counselling, and monitor diet quality over time[26, 39]. Only a few screeners are available that provide information on diet quality[39-43]. These screeners were specifically designed to estimate adherence to an intervention diet to lower CVD risk[39], the Mediterranean Diet[40, 41], the Dietary Approaches to Stop Hypertension (DASH) diet[42], or the USA dietary recommendations[43]. The screeners were evaluated by comparing them to a more detailed dietary assessment method. This showed that the screeners were able to reasonably rank participants according to their intake of foods and nutrients[40-43]. Moderate agreement was observed for Mediterranean Diet Adherence Screener[40], the Short Dietary Quality Screener[41], and the Brief Mediterranean Diet Score Screener[41], whereas for the other screeners absolute agreement was not studied[39, 42, 43]. Furthermore, diet quality as assessed by the Start The Conversation Screener was sensitive to dietary intake changes due to an intervention[39], and the Short Dietary Quality Screener was able to predict changes in waist circumference and the development of an unfavourable cardio-metabolic profile, using data from an FFQ to simulate the screener score in a cohort study with nine years of follow-up[44]. Suggested applications for these screeners included their use in large epidemiological studies experiencing time limitations, identification of patients with poor dietary intake, and as an intervention tool to achieve dietary changes in individuals[39, 40, 42, 43]. As no screener or short questionnaire is available to assess diet quality in the Netherlands, we developed and evaluated the DHD-FFQ, a short questionnaire to assess the DHD-index score.

Aim and outline of this thesis

The overall aim of this thesis is to develop, evaluate, and apply the Dutch Healthy Diet index (DHD-index).

Chapter 2 describes the development of the DHD-index, representing the current Dutch dietary guidelines. Furthermore, the DHD-index is evaluated by exploring its association with nutrient intakes and individuals' characteristics. For this purpose, we used data from the 2003 DNFCS including 749 men and women aged between 19 and 30 years old. **Chapter 3** describes the comparison between the DHD-index derived from an FFQ and the DHD-index derived from two 24hRs in a Dutch subsample of the European Food Consumption Validation (EFCOVAL) study. Furthermore, associations of the DHD-index with biomarkers of dietary intake (i.e. urinary sodium, fish fatty acids from phospholipids, and serum carotenoids) and with a biomarker of cardio-metabolic health (i.e. serum total cholesterol concentration) are studied. **Chapter 4** describes the association of the DHD-index with mortality outcomes in the Rotterdam Study, the ultimate evaluation of the DHD-index. The Rotterdam Study is a cohort study with 20-year follow-up among 3593 Dutch adults of 55 years and older. **Chapter 5** describes the association between company at dinner and the DHD-index score on that specific day. This chapter gives an example of an application of the DHD-index and studies the extent to which certain behaviours can influence dietary intake. We used multiple 24hRs from 895 men and 845 women aged 20-70 years old from the Nutrition Questionnaires plus (NQplus) study. This study collected extensive information on the context of food intake. **Chapter 6** describes the development of the DHD-FFQ, a short food frequency questionnaire for use in clinical practice, and the evaluation of the DHD-index derived from the 34-item DHD-FFQ. For this purpose, we compare the DHD-index derived from a reference method with the DHD-index derived from the DHD-FFQ in a subsample (n=1235) of the NQplus study. **Chapter 7** describes an a posteriori dietary pattern analysis, using principal component analysis. The derived dietary patterns give insight into the current dietary patterns existing in a general Dutch population from the NQplus (n=1465) study. These patterns are studied in relation to the prevalence of metabolic syndrome and its separate components. **Chapter 8** discusses the main findings and implications from chapters 2-7.

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2

THE DUTCH HEALTHY DIET INDEX (DHD-INDEX): AN INSTRUMENT TO MEASURE ADHERENCE TO THE DUTCH GUIDELINES FOR A HEALTHY DIET

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Abstract

Background: The objective was to develop an index based on the Dutch Guidelines for a Healthy Diet of 2006 that reflects dietary quality and to apply it to the Dutch National Food Consumption Survey (DNFCS) to examine the associations with micronutrient intakes.

Methods: A total of 749 men and women, aged 19-30 years, contributed two 24-hour recalls and additional questionnaires in the DNFCS of 2003. The Dutch Healthy Diet index (DHD-index) includes ten components representing the ten Dutch Guidelines for a Healthy Diet. Per component the score ranges between zero and ten, resulting in a total score between zero (no adherence) and 100 (complete adherence).

Results: The mean ± SD of the DHD-index was 60.4±11.5 for women and 57.8±10.8 for men (P for difference =0.002). Each component score increased across the sex-specific quintiles of the DHD-index. An inverse association was observed between the sex-specific quintiles of the DHD-index and total energy intake. Calcium, riboflavin, and vitamin E intake decreased with increasing DHD-index, an inverse association which disappeared after energy adjustment. Vitamin C showed a positive association across quintiles, also when adjusted for energy. For folate, iron, magnesium, potassium, thiamin, and vitamin B6 a positive association emerged after adjustment for energy.

Conclusions: The DHD-index is capable of ranking participants according to their adherence to the Dutch Guidelines for a Healthy Diet by reflecting variation in nine out of ten components that constitute the index when based on two 24-hour recalls. Furthermore, the index showed to be a good measure of nutrient density of diets.

Introduction

Diets have a complex nature, as foods and nutrients are consumed in combinations which can induce interactions and synergies between dietary components. Dietary pattern analysis, therefore, is assumed a more appropriate approach for investigating diet-disease associations than focusing on a single food or nutrient[1-4].

One approach of assessing dietary patterns is to construct an a priori dietary index. These indices are mainly based on national or international dietary recommendations, which are designed to decrease the risk of chronic diseases and nutrient deficiencies[5, 6]. Indices can be used to measure dietary quality in populations and monitor it over time[7] or measure changes in diets in intervention studies[8]. Furthermore, in epidemiological studies an index can be used to investigate the diet-disease associations[9]. Additionally, confounding by diet can be controlled through the use of a dietary pattern variable or a diet index score[10]. A well-known example of an index is the American 'Healthy Eating Index-2005' (HEI-2005)[11, 12]. This index has been associated with health outcomes[13], and has been used as monitoring tool in American populations[7]. However, the HEI-2005 cannot be used for the Dutch situation, because the American dietary guidelines are different from those in the Netherlands. The 2005 Dietary Guidelines for Americans, on which the HEI-2005 is based, mention all the major food groups while the Dutch guidelines do not. Furthermore, the Dutch guidelines include a restriction on the number of consumption occasions with acidic drinks and foods (ADF)[5].

To date, two Dutch indices have been developed by Löwik *et al.*[14], both based on the Dutch Guidelines for a Healthy Diet of 1986. The first dietary quality index consisted of five criteria: less than 35% energy from total fat, less than 10% energy from saturated fatty acids (SFA), less than 33 mg/MJ cholesterol, more than 50% energy from carbohydrates and less than 25% energy from mono- and disaccharides. For each criterion, one point was assigned to individuals who adhered. The score, ranging from zero (low quality) to five (high quality), was inversely related to energy intake and positively associated with a higher prevalence of following a prescribed diet and a higher educational level[14]. The second index was a food-based dietary guideline index with seven components. The score, ranging from zero (low quality) to seven (high quality), was positively associated with energy intake and all evaluated nutrient densities (calcium, iron, vitamin A, thiamin, riboflavin, vitamin B_6 and vitamin C)[14].

In 2006, the Dutch Guidelines for a Healthy Diet were revised by the Health Council of the Netherlands by adding new guidelines on physical activity, number of consumption occasions with ADF and excluding the guidelines on cholesterol and mono- and disaccharides[5]. Furthermore, evidence-based quantitative recommendations for vegetable, fruit, fish, *trans* fatty acids (TFA), and alcohol consumption were formulated.

The guideline for ADF is added to the guidelines in view of the prevention of dental caries and risk reduction of dental erosion. Due to the revision of the Dutch guidelines, no Dutch index is yet available. Therefore, we developed a new index, the Dutch Healthy Diet index (DHD-index), based on the Dutch Guidelines for a Healthy Diet of 2006[5], the official background document[15] and the information provided by the Netherland Nutrition Centre (NNC)[16]. Furthermore, we applied the index to data of the Dutch National Food Consumption Survey of 2003 (DNFCS-2003) to examine the associations with micronutrient intakes. We hypothesized that participants with higher DHD-index scores will have both higher intakes of vitamins and minerals and have a more nutrient-dense diet.

Materials and Methods

Study design

The DNFCS-2003 is a population-wide food consumption survey in the Netherlands and has been described in detail elsewhere[17]. Briefly, data were collected in 2003 and respondents (n=750) were men and women aged between 19 and 30 years and randomly selected from a representative consumer panel of households. One participant was excluded from these analyses due to an incomplete short questionnaire to assess health enhancing physical activity (SQUASH), which led to a total of 749 participants. Their dietary intake was assessed by two non-consecutive 24-hour recalls (24hR) administered by telephone using EPIC-Soft. EPIC-Soft is a computerized 24hR program that follows standardized steps[18, 19]. Recall days were randomly selected from all days of the week. Characteristics of the recall days such as following a diet regime and special day were asked during the 24-hour recalls. In addition, a baseline questionnaire was administered on subjects' characteristics (weight, height, age, education, and income) and demographics (postal code), and the SQUASH. Furthermore, a food frequency questionnaire (FFQ) was included to assess consumption frequencies of episodically consumed foods (e.g. fish, eggs, chips). After data collection, macronutrient and micronutrient intakes were estimated by using the Dutch food composition database of 2001[20]. We selected the micronutrients calcium, folate, iron, magnesium, potassium, riboflavin, thiamin, vitamin A, vitamin B_6, vitamin B_{12}, vitamin C, and vitamin E by relevance and availability in the database[16, 21]. Furthermore, a quality check was done on inconsistencies between first and second interview on general data as birth date. Differences in energy ratio between interviewers and weeks of data collection were checked by using the estimated energy intake divided by estimated basal metabolic rate. Missing values, false answers (that were not in range of possible answers) and typing errors were changed in EPIC-soft using the original recall data. Underreporting, based on the estimated energy intake divided by estimated basal metabolic rate, was observed to be 11%.

Development of the DHD-index

The DHD-index is a continuous score with ten components that represent the ten Dutch Guidelines for a Healthy Diet of 2006 (**Table 2.1**). By choosing a continuous scoring system we assume that we can observe changes in diets of intervention studies better than with a dichotomous scoring system. For all components a maximum of ten points can be allotted, resulting in a range of zero to 100 points. The components physical activity, vegetable, fruit, fish, and fiber are adequacy components, and the components SFA, TFA, number of consumption occasions of ADF, sodium, and alcohol are moderation components. Cut-off values represent the required amount of consumption or physical activities undertaken (minimum for adequacy and maximum for moderation components), whereas the threshold values represents the level of intake that deserves zero points for the moderation components. For the component ADF the threshold value was lower than the recommended maximum of seven ADF consumption occasions. Consequently, this component was scored dichotomously. The components and their cut-off, and threshold values are shown in **table 2.1**.

The first component assesses physical activity; the Health Council of the Netherlands recommends being active for minimally 30 minutes of at least moderate intensity for at least five days per week[5]. The second component is based on the recommendation of 150-200 grams of vegetables per day. The higher of the two recommendations was chosen as the cut-off value of the component. The third component is based on the recommendation of 200 grams of fruits per day. The NNC communicates that a maximum of 100 grams can be replaced by fruit juices, which naturally contain folate, and vitamin C[22]. In the DNFCS-2003, six types of juice complied with the criterion (orange juice with and without pulp, pineapple juice, berry juice, grapefruit juice, and mixed fruit juice) and could be included in the fruit group for a maximum of 100 grams in total. The fourth component is based on the recommendation of 30-40 grams of dietary fiber per day. The criterion used was stated in the background document and was 14 grams dietary fiber per 4.2 MJ per day[15]. The fifth component, fish, is estimated based on the fish fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are likely to be the protective components of fish[15]. At least 450 mg/day of these fish fatty acids are recommended[15] and their intake can be achieved by fish consumption or by using fish oil capsules. Although, fish consumption is preferred by the Health Council of the Netherlands, fish oil capsules are permitted as substitute for fish for people who do not eat fish[23]. Fish oil capsules were assumed to contain 200 mg of fish fatty acids per capsule, based on labeling information of the fish oil capsules available in the Netherlands. The average daily intake of EPA and DHA from the capsules was added to the 2-day average intake of EPA and DHA from fish. The sixth and seventh components were based on the recommendations to consume less than ten energy percent of SFA and less than one energy percent of TFA respectively. The eighth component is based

Table 2.1 Components and Dutch dietary guidelines of the DHD-index and their cut-off (maximum score) and threshold values (minimum score)

Components		Dutch Guidelines for a Healthy Diet	Minimum score (=0)	Maximum score (=10)
1.	Physical activity (week)	At least 30 minutes of moderate intensity physical activity – brisk walking, cycling, gardening, etc – at least five days a week, but preferably every day.	0 activities*	≥ 5 activities
2.	Vegetable (day)	Eat 150 to 200 grams of vegetables.	0 g	≥200 g
3.	Fruit + fruit juices (day)*	Eat 200 grams of fruit a day.	0 g	≥ 200 g
4.	Fiber (day)	Eat 30 to 40 grams a day of dietary fiber, especially from sources such as fruit, vegetables and whole-grain cereal products.	0 g/4.2MJ	≥14 g/4.2MJ
5.	Fish (day)†	Eat two portions of fish a week, at least one of which should be oily fish.	0 mg EPA+DHA	≥ 450 mg EPA+DHA
6.	SFA (day)	Limit saturated fatty acid consumption to less than 10 percent of energy intake.	≥ 16.6 en%	< 10 en%
7.	TFA (day)	Limit mono *trans*-fatty acid consumption to less than 1 percent of energy intake.	≥ 1.6 en%	< 1 en%
8.	ADF (day)‡	Limit consumption of foods and beverages that contain easily fermentable sugars and drinks that are high in food acids, to seven occasions a day (including main meals).	> 7 occasions	≤ 7 occasions
9.	Sodium (day)	Limit consumption of table salt to 6 grams a day.	≥ 2.45 g	< 1.68 g
10.	Alcohol (day)	If alcohol is consumed at all, male intake should be limited to two Dutch units (20 gram ethanol) a day and female intake to one.	♂: ≥ 60 g ♀: ≥ 40 g	♂: ≤ 20 g ♀: ≤ 10 g

SFA: saturated fatty acids, TFA: *trans* fatty acids, ADF acidic drinks and foods
*Maximum of 100 gram of juice could be included
†EPA and DHA intake form foods and fish oil capsules
‡The number of consumption ocassions was defined as the number of hours where at least one food or drink with a pH<5.5 and total acidity>0.5 was consumed

on the maximum recommended number of ADF consumption occasions which is seven occasions per day including the three main meals. The operational definition of a ADF consumption occasion is every half an hour where a food item or drink with a pH level lower than 5.5 and a total acidity higher than 0.5% is consumed[24]. Consumption of less than 2.4 grams of sodium per day, as recommended in the corresponding guideline, is scored in ninth component. In the DNFCS and most other studies, no data is available on salt added during cooking and at the table. The contribution of sodium of these sources was assumed to be on average about 30% of total sodium intake, based on available literature[25-27]. Therefore, we lowered the cut-off and threshold value for this component by 30%. The last component, alcohol, is differentiated by sex. For men, the recommendation is to consume maximally two Dutch units of alcohol, and for women to consume maximally one Dutch unit per day. One Dutch unit of alcohol contains 10 grams of ethanol[5].

Scoring

All scores were based on the 2-day average intake. For the adequacy components, the minimum score of zero was allotted when there was no consumption, or no activity. The scores for the intakes or activities between zero and the cut-off value were calculated by dividing the reported intake or activity, by the cut-off value and subsequently multiplying this ratio by ten. The maximum score of ten points was allotted if the recommended amount of intake, or activities, was achieved.

For the moderation components, we determined threshold values above which to assign the score of zero, because no scientific evidence specifies the quantity of intake that deserves zero points. The threshold values were determined based on the 85th percentiles of the 2-day average intakes of the sample population. For alcohol intake, however, evidence on upper levels is available and we used the criteria for binge drinking as threshold value[28]. Zero points were allotted when reported intakes were above the threshold values. Ten points were allotted when intake were below the cut-off values. The scores for intake between threshold and cut-off value were calculated by dividing the difference between the intake and cut-off value by the difference between threshold and cut-off value, and subsequently multiplying this ratio by ten. Because the score has to decrease when intake increases, the outcome was subtracted from ten. The ADF component was scored dichotomously and only 3.5% of the population was assigned a score of zero, while all others received a score of ten.

To be able to apply the DHD-index to the data of the DNFCS-2003, two components were adapted due to limitations of the dataset. Firstly, the SQUASH reported activities per week and not per day. Ten points were allotted when five activities per week, meeting the recommendation, were reported. It was not known on how many days these activities were performed. Secondly, the component ADF was redefined as the number of hours during which foods or drinks fulfilling the criterion were consumed, because intake data was available per hour.

Data analysis

All food and nutrient intakes and number of ADF occasions were averaged over two days before being used to score individual dietary intakes. Sex-specific quintiles of the DHD-index scores were estimated. Means across the quintiles were tested using P for trend from linear regression analysis. Micronutrient intake was reported with and without total energy adjustment. Adjusted intakes are presented as mean nutrient intakes per 9.8 MJ, which was the average energy intake of the population. For the component fruit, a sensitivity analysis was done by excluding the fruit juices. SAS (version 9.2, SAS Institute, Cary, NC) was used for all calculations and a P value of <0.05 was considered statistically significant.

Results

Mean ±SD age of the population was 25.0 ±3.6 years and did not differ between women and men. BMI was significantly higher for women (24.5 ±4.6) compared to men (23.3 ±3.2), as was prevalence of supplement use (17.5% vs. 9.6% respectively) and following a diet regime (9.9% vs. 0.9% respectively). Furthermore, 26.5% of women were classified as lower educated compared to 18.5% of men. The distribution of recalls over week and weekend days did not differ between men and women.

The mean ±SD DHD-index score for the total population was 59.2 ±11.2 and it was significantly higher for women than for men (mean difference of 2.4 points; **Table 2.2**). Women scored significantly higher on the components physical activity, dietary fiber, sodium and alcohol, whereas men scored significantly higher on the components vegetable, SFA and TFA. No significant differences between men and women were observed for the components fruit, fish and ADF.

The DHD-index score was normally distributed and ranged from 28.1 to 88.0 in men and from 24.4 to 95.0 in women. All the DHD-index components showed a significant positive association across the sex-specific quintiles of the index (**Table 2.3**). Energy intake was inversely associated with the DHD-index (P<0.001; **Table 2.4**). Following a diet regime, prescribed or on own initiative, was positively associated with the DHD-index score (P=0.005). Age, BMI, education and prevalence of supplement use did not show a significant trend across quintiles of the index score.

Table 2.2 Mean (SD) scores of the DHD-index components in 749 Dutch men and women aged between 19 and 30 years

	Total (n=749)	Men (n=352)	Women (n=397)	P-value between sex*
DHD-index	59.2 (11.2)	57.8 (10.8)	60.4 (11.5)	0.002
1. Physical activity	9.4 (1.9)	9.1 (2.3)	9.7 (1.4)	0.001
2. Vegetable	4.8 (2.9)	5.2 (2.9)	4.4 (2.8)	<0.001
3. Fruit	4.6 (3.7)	4.4 (3.7)	4.8 (3.6)	0.130
4. Fiber	6.1 (2.3)	5.9 (2.3)	6.3 (2.3)	0.022
5. Fish	1.1 (2.4)	1.1 (2.4)	1.1 (2.3)	0.798
6. SFA	5.2 (3.5)	5.5 (3.4)	4.9 (3.5)	0.011
7. TFA	7.0 (3.9)	7.5 (3.6)	6.5 (4.0)	0.005
8. ADF	9.7 (1.8)	9.6 (2.0)	9.7 (1.6)	0.267
9. Sodium	2.4 (3.8)	1.1 (2.6)	3.6 (4.2)	<0.001
10. Alcohol	8.9 (2.8)	8.4 (3.3)	9.3 (2.1)	<0.001

SFA:saturated fat, TFA:*trans* fatty acids, ADF:acidic drinks and foods
*Independent t-test comparing men and women

For the micronutrients calcium, and vitamin E significant inverse associations across sex specific quintiles of the DHD-index scores were observed **(Table 2.5)**. However, when these intakes were adjusted for mean energy intake these associations disappeared. Riboflavin also showed an inverse association across quintiles of the DHD-index, however, after adjustment for energy intake the association changed to a positive association. For the micronutrients folate, iron, magnesium, potassium, thiamin, and vitamin B_6, significant positive associations with the DHD-index score were shown for the energy adjusted intakes, but not for the unadjusted intakes. Vitamin C was positively associated across the quintiles both in mg/day and in mg/9.8MJ.

When as part of a sensitivity analysis fruit intake was estimated excluding the intake of fruit juices, mean intake decreased by 83 grams, and the mean score changed from 4.6 to 3.7 points. In total 139 (18.6%) subjects adhered to the guideline when fruit juices were included as compared to 106 (14.2%) subjects based on whole fruit consumption only. The correlation between the scores with and without juices was very high (r=0.91, P<0.001).

Discussion

The DHD-index is capable of ranking participants according to their adherence to the Dutch Guidelines for a Healthy Diet by reflecting variation in the components that

Table 2.3 Distribution of components scores (means (SD)) across sex-specific quintiles of the DHD-index in 749 Dutch men and women*

	Sex-specific quintiles of DHD-index										
	Q1 (n=148)		Q2 (n=150)		Q3 (n=151)		Q4 (n=149)		Q5 (n=150)		P for trend
DHD-index	43.8	(5.2)	52.9	(2.2)	58.7	(2.1)	65.2	(2.6)	75.0	(4.9)	<0.001
Physical activity	8.7	(2.8)	9.5	(1.6)	9.5	(1.6)	9.5	(1.9)	9.8	(1.0)	<0.001
Vegetable	3.5	(2.6)	4.3	(2.5)	4.6	(2.8)	5.1	(2.9)	6.6	(2.8)	<0.001
Fruit	2.1	(2.5)	3.4	(3.1)	3.9	(3.5)	5.7	(3.5)	7.8	(2.9)	<0.001
Fiber	4.5	(1.8)	5.0	(1.7)	6.1	(2.0)	6.7	(2.2)	8.1	(1.9)	<0.001
Fish	0.6	(1.4)	0.8	(1.8)	0.8	(1.8)	1.3	(2.6)	2.0	(3.4)	<0.001
SFA	3.3	(3.6)	3.9	(3.3)	4.8	(3.1)	6.1	(3.0)	7.6	(2.6)	<0.001
TFA	3.8	(4.0)	5.8	(4.0)	7.7	(3.5)	8.3	(2.8)	9.3	(2.1)	<0.001
ADF	8.9	(3.1)	9.8	(1.4)	9.9	(1.1)	9.7	(1.6)	9.9	(0.8)	<0.001
Sodium	0.7	(2.1)	1.8	(3.3)	2.3	(4.2)	3.3	(4.2)	4.0	(4.3)	<0.001
Alcohol	7.7	(3.7)	8.5	(3.2)	9.0	(2.6)	9.4	(1.9)	9.8	(0.9)	<0.001

SFA:saturated fat, TFA:*trans* fatty acids, ADF:acidic drinks and foods
*Cut-off quintiles men: 47.7, 54.9, 60.6, 67.2; cut-off quintiles women: 50.4, 56.5, 62.8, 70.6

constitute the index, except for the component ADF. This component showed a low variation and is consequently not discriminative in ranking subjects according to their adherence to the guidelines. Furthermore, the index score is positively associated with 'following a diet regime' and inversely associated with energy intake, which were not included in the index. Additionally, the DHD-index showed to be a good measure of nutrient density of diets.

The components of the DHD-index were based on three different documents about the guidelines: the guidelines as communicated by the health council of the Netherlands[5], the background document describing the guidelines and the evidence in more detail[15] and the information provided by the NNC[16]. The NNC communicates the guidelines in a more understandable way and provides food-based examples of the dietary guidelines to the general Dutch population and subpopulations. These three documents were more or less comparable to each other and we decided to stay as close as possible to the guidelines, with three exceptions. For the component dietary fiber, the background document indicated an energy-dependent recommendation which was more specific than the range of 30-40 gram mentioned in the guidelines. For the fish component, the background document had a specified recommended amount of fish fatty acids instead of consuming two portions of fish. The third exception was the fruit component, which

Table 2.4 Distribution of characteristics (means (SD)) across sex-specific quintiles of the DHD-index in 749 Dutch men and women*

	Sex-specific quintiles of DHD-index					
	Q1 (n=148)	Q2 (n=150)	Q3 (n=151)	Q4 (n=149)	Q5 (n=150)	P for trend
Age (y)	24.8 (3.7)	25.1 (3.5)	24.8 (3.5)	24.7 (3.5)	25.4 (3.7)	0.346
BMI (kg/m^2)	23.9 (3.9)	24.1 (4.2)	23.6 (4.2)	24.1 (3.9)	24.0 (3.9)	0.799
Energy intake (MJ/day)	11.1 (3.5)	10.4 (3.2)	9.8 (3.0)	9.3 (3.0)	8.3 (2.7)	<0.001
Supplements (%)	28.2	20.8	32.5	24.7	29.3	0.750
Diet regime† (%)	2.0	5.4	10.6	4.6	12.0	0.005
Education‡ (%)						0.059
Low	25.7	28.0	23.8	20.8	15.2	
Moderate	44.6	46.7	44.4	55.0	50.1	
High	29.7	25.3	31.8	24.2	33.8	

*Cut-off quintiles men: 47.7, 54.9, 60.6, 67.2; cut-off quintiles women: 50.4, 56.5, 62.7, 70.6
†Diet regime: Salt restriction, fat/cholesterol restriction, diabetes, energy restricted, energy restricted (own initiative), light digestible, lactose restricted, vegetarian (no meat/fish), antroposophical, other
‡low education:primary school, vocational and lower general secondary education. Moderate:higher secondary education and intermediate vocational training. High:higher vocational education and university

was based on the recommendations of the NNC[22]. The NNC communicates that 100 grams of fruit can be replaced by all fruit juices complying to the criteria of naturally containing vitamin C and folate[22]. The sensitivity analysis showed that the total mean scores increased by an average of 0.86 after the inclusion of fruit juices.

For the threshold values of the moderation components, the 85th percentiles of the current population were used, as was done by others[11]. Although we used the 85th percentiles of the 2-day average, the HEI-2005 used the 1-day distribution[11]. Also other indices, such as the Heart Disease Prevention Eating Index[29] and the Mediterranean Diet Score[30], used the distribution of intake of the population under study for determining cut-off values. However, because of the use of the 85th percentiles of the distribution of the 2-day averages of 19 and 30-year-olds, the results of the DHD-index cannot be compared with other Dutch subpopulations, as the cut-off values will differ. An evidence-based threshold value for all moderation components, like the binge-drinking threshold values for the alcohol component, would be the most preferred. However, for the other moderation components these do not exist. Yet, a more appropriate solution would be to use 85th percentiles of usual or long-term intakes of a reference dataset representative of the total Dutch population for all future use.

All ten components of the DHD-index have similar weights, as mentioned in the guidelines[5]. However, some components were correlated, which indicates an overlap in dietary behaviors which causes indirectly more weight to that dietary behavior. The components vegetables and fruit were correlated to the component dietary fiber (r=0.36 and r=0.32, respectively), which can be explained by the fact that fiber represents consumption of vegetables and fruit in addition to wholegrain products. The correlation between the component SFA and TFA was 0.29, which is plausible as these fatty acids appear partly in the same products[15, 31]. These correlations should be studied in future research to explore the effect of the additional weight on diet-disease relations. If judged necessary, differential weighting of the components could be applied.

We hypothesized that participants who adhered to a higher degree to the Dutch Guidelines for a Healthy Diet have both higher absolute intakes of micronutrients and a more nutrient-dense diet. However, only vitamin C intake increased across quintiles of the DHD-index when energy was not taken into account. The intake of the micronutrients folate, iron, magnesium, potassium, thiamin, riboflavin and vitamin B_6 only showed a positive association across quintiles of the DHD-index after adjustment for energy intake. This latter result indicates that participants in the higher quintiles of the DHD-index have a more nutrient-dense composition of the diet. However, they have a lower absolute intake of these micronutrients, because of the inverse association of energy intake across quintiles of the DHD-index. The intake of calcium, riboflavin, and vitamin E showed a decline across the quintiles. Nevertheless, the mean average intake in all quintiles was still acceptable compared to the recommended average intakes[32], which made the lower intakes less worrisome for public health practices. The inverse association of these three micronutrients disappeared after energy adjustment.

In contrast to energy intake, BMI was not inversely associated with the DHD-index score. This result may be due in part to the self-reported nature of the dietary data, which could invoke underreporting[33]. It can also be caused by specific subject characteristics like restrained eating in the higher quintiles of the DHD-index score. This hypothesis can be confirmed by the increasing percentage of participants following a diet regime in the higher quintiles of the DHD-index score. Unfortunately, no data on other subject characteristics as eating behavior or true energy intake was available in the DNFCS-2003. In the HEI-2005, energy intake from solid fats, alcoholic beverages, and added sugars is included as component of the index[11]. For the Dutch situation, no operational guideline for energy intake is available. The health council states that the guidelines are meant for the apparently healthy population with a healthy and stable weight. Consequently, no component is constructed for energy intake in the DHD-index. Energy adjustment should be therefore applied when examining diet-disease associations.

The adherence to the physical activity criterion was quite high compared to previously described physical activity levels in the Netherlands[34]. This may be due to a possible over-reporting by using the SQUASH[35], although it is a validated questionnaire for estimating usual physical activity[36]. It was suggested by Ocké *et al.*[17] that the population under study was slightly different compared to the general Dutch population in the same age category, which may partly explain the high level of physical activity.

The average score of the component ADF ranged from 8.9 to 9.9 across quintiles, consequently, the variation of this component was low (SD=1.8). Therefore, this component is not that discriminative in ranking subjects according to their adherence to the guidelines. The component was included in the Dutch guidelines because it is important for the prevention of dental erosion, which is quite different from the aims for prevention of chronic diseases and nutrient deficiencies of the other recommendations[5]. We advise to adapt or delete the component ADF from the index in future research, if variation in the component appears to be low in other studies as well.

Data on sodium intake is expected to be underestimated through lacking information on sodium added at the dinner table and during cooking. We have tried to correct for this by lowering the guideline by 30%. However, the variation in intake of sodium within the population was ignored by this method, which could have biased the results. Preferably, sodium intake is measured in 24-hour urine samples, which is considered the standard for measuring sodium intake[37].

The estimation of the components of the DHD-index was based on the 2-day average of dietary intake. Although, two non-consecutive 24hR are acceptable for assessing dietary intake on group level[38], the 2-day average will not be a good estimate to assess usual intake distributions for some components, e.g. fish and alcohol, due to a low frequency of consumption. An FFQ designed to assess usual intake could give better estimates for intake of episodically consumed foods. An FFQ, however, is designed for ranking participants according to their intake and not for estimation of absolute intakes[39]. Moreover, an FFQ cannot be used to estimate the component ADF. Statistical models as the Multiple-Source-Method or the National Cancer Institute method can be used to estimate usual intake distributions or individual usual intakes[40-45]. However, these statistical models have their limitations as well. Altogether, dietary assessment methods are prone to errors which will be reflected by the estimates of the DHD-index. Therefore, care should be taken when comparing DHD-index scores based on different dietary assessment methods.

Conclusion

The DHD-index can be used to estimate the adherence to the Dutch Guidelines for a Healthy Diet and is a good measure of nutrient density of diets. In future research the DHD-index can be used as monitoring tool in public health research, or as tool for assessing a Dutch dietary pattern and studying diet-health associations.

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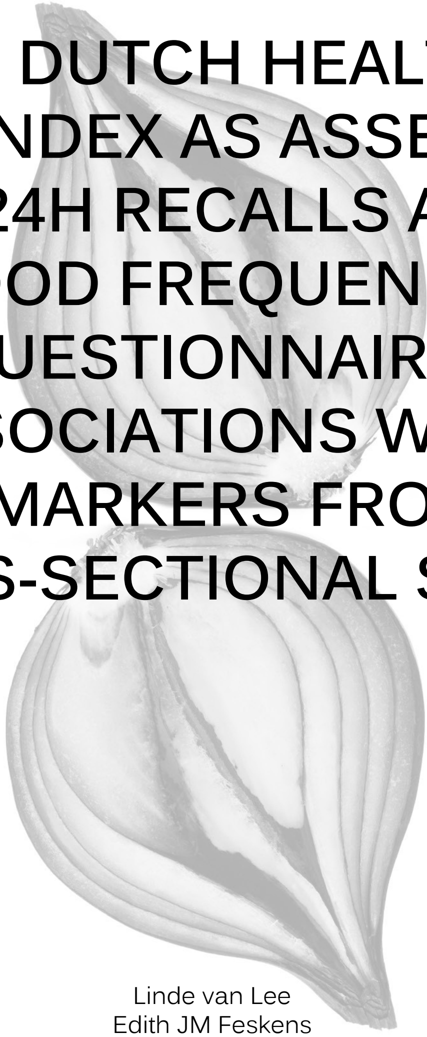
THE DUTCH HEALTHY DIET INDEX AS ASSESSED BY 24H RECALLS AND FOOD FREQUENCY QUESTIONNAIRE: ASSOCIATIONS WITH BIOMARKERS FROM A CROSS-SECTIONAL STUDY



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Abstract

The Dutch Healthy Diet index (DHD-index) was developed using data of two 24-hour recalls (24hR) and appeared useful to evaluate diet quality in Dutch adults. As many epidemiologic studies use food frequency questionnaires (FFQ), we now estimated the DHD-index score using FFQ data. We studied whether this score showed similar associations with participants' characteristics, micronutrient intakes, and biomarkers of intake and metabolism compared with the DHD-index using 24hR data. Data of 121 Dutch participants of the European Food Consumption Validation study were used. Dietary intake was assessed by two 24hR and a 180-item FFQ. Biomarkers measured were serum total cholesterol and carotenoids, EPA+DHA in plasma phospholipids and 24-hour urinary sodium. A correlation of 0.48 (95% CI 0.33, 0.61) was observed between the DHD-index score based on 24hR data and on FFQ data. Classification of participants into the same tertiles of the DHD-index was achieved for 57%. Women showed higher DHD-index scores. Energy intake was inversely associated with both DHD-index scores. Furthermore, age and intakes of folate, iron, magnesium, potassium, vitamin B_6, and vitamin C were positively associated with both DHD-index scores. DHD-index scores showed acceptable correlations with the four combined biomarkers taking energy intake into account (r_{24h}0.55, r_{FFQ}0.51). In conclusion, the DHD-index score based on FFQ data showed similar associations with participants' characteristics, energy intake, micronutrient intake, and biomarkers compared with the score based on 24hR data. Furthermore, ranking of participants was acceptable for both methods. FFQ data may therefore be used to assess diet quality using the DHD-index in Dutch populations.

Introduction

Nutrients and single foods have been used in many epidemiological studies as dietary exposures to examine associations with various disease outcomes. To better reflect the complexity of dietary intake, an alternative approach is to investigate overall diet quality. This can be assessed through diet indices, which may give insight in the association of foods, combinations of nutrients and other dietary components with health outcomes[1-5].

We recently developed the Dutch Healthy Diet index (DHD-index) that consists of ten components representing the Dutch Guidelines for a Healthy Diet of 2006[6]. In that study, we used data of the Dutch National Food Consumption Survey of 2003 (DNFCS-2003) to examine the association of the DHD-index with energy and micronutrient intakes. We found an inverse association with energy intake and positive associations with several micronutrients when adjusting for energy intake. We concluded that the DHD-index can be used to estimate adherence to the Dutch dietary guidelines and as a monitoring tool in public health research[6]. In the DNFCS-2003, two non-consecutive 24-hour recalls (24hR) were used to assess dietary intake. In many epidemiologic studies, however, a food frequency questionnaire (FFQ) is used instead[7]. To evaluate wider applicability of the DHD-index, it is important to compare the DHD-index based on FFQ data with the index based on 24hR data.

An FFQ is designed to assess usual intake whereas 24hR assess detailed information on dietary intake of one day or more. Due to natural day-to-day variation within an individual, comparing the DHD-index score based on FFQ data is expected to differ from the DHD-index score based on 24hR. For example, fish is considered episodically consumed in the Netherlands, estimations of fish intake from an FFQ are expected to be higher compared to data from two 24hR. This example of measurement error is a feature of the dietary assessment method as such and will influence the DHD-index scores. Therefore, it is important to not only compare the DHD-index based on FFQ data with the DHD-index based on 24hR data, but also examine associations with objective urinary and plasma biomarkers of dietary intake and metabolism. Serum total cholesterol, eicosapentanoic acid (EPA), docosahexanoic acid (DHA), and several carotenoids have shown significant associations with existing indices of diet quality[8-12]. These significant correlations between diet quality indices and single biomarkers ranged between 0.19–0.44[8, 11, 12].

Our objective was to assess whether the DHD-index score derived from FFQ data showed similar associations with participants' characteristics, micronutrient intakes, and biomarkers of dietary intake and metabolism compared with the DHD-index score based on 24hR data. Furthermore, we will compare the ranking of participants between the DHD-index scores based on the two dietary assessment methods. The biomarkers of dietary intake were selected based on literature[8-12] and on availability of data.

Methods

Subjects

Data of the Dutch participants of the European Food Consumption Validation (EFCOVAL) study, including 121 men and women aged 45-65 years, were used for the present study. All subjects were healthy individuals representing all educational levels. Subjects were excluded when they could not speak and write Dutch, were currently taking diuretics, were pregnant or lactating, were having diabetes mellitus or kidney disease, and had been donating blood or plasma less than four weeks before the study. All subjects signed an informed consent and the present study was conducted according to the guidelines laid down in the Declaration of Helsinki. All procedures involving human subjects were approved by the medical ethical committee in Wageningen.

Study design

The EFCOVAL study is an observational study in five European countries and has been described in more detail by Crispim *et al.*[13, 14]. The aim of the study was to validate the duplicate 24hR method using EPIC-Soft; a computerized 24hR program that follows standardized procedures[15, 16].

At enrolment, all subjects filled out the Short QUestionnaire ASsessing Health enhancing physical activity (SQUASH)[17] and a general questionnaire on lifestyle, food habits, and supplement use. Fish oil supplement users were identified when at least on one of the recalled days or during the past three months at least one supplement containing EPA or DHA was consumed. Furthermore, body weight and height were measured following standardized protocols at the study centre. After that, a 24hR and a 24-hour urine collection were obtained covering the same reference day. The second 24hR and urine collection were obtained at least one month after the first one. At the end of the study period, all subjects received an FFQ by mail and filled it out at home.

Dietary assessment methods

Two non-consecutive 24hR were collected per subject, one by phone and one face-to-face at the research centre. All days of the week and the two modes of administration of 24hR were randomized among subjects, whereas the intake on Saturdays was recalled two days later on Mondays. Interviewers were all trained in interviewing techniques and in using EPIC-Soft (version 9.16). Portion size estimation was done using household measures, weight/volume, standard units and portions, bread shapes, and photographs.

Nutrient intakes were calculated using the Dutch food composition table[18].

The 180-item semi-quantitative FFQ was developed to assess intake of energy, macronutrients, dietary fibre and selected vitamins[19]. All questionnaires were checked on unusual or missing values, and if necessary, subjects received a phone call to obtain additional information. Average daily nutrient intakes were calculated by multiplying frequency of consumption of food items by portion size and nutrient content per gram based on the Dutch food composition table[18].

Biomarkers

More detail on the 24-hour urine collections, venepuncture, analyses and storage have been described elsewhere[13, 14, 20]. Briefly, para-aminobenzoic acid (PABA) was used to verify completeness of 24-hour urine collections. Subjects were asked to fill out a short diary about time of taking PABA, completeness of the urine collection and medication use. Five urine samples with PABA recoveries below 50% were excluded from the data analyses. Recoveries between 50% and 85% were proportionally adjusted to 93% of PABA recovery, as suggested by Johansson *et al.*[21]. Recoveries above 85% were included without adjustments. Urinary sodium was measured by an ion-selective electrode on a Beckman Synchron LX20 analyser (Beckman Coulter) as biomarker for dietary sodium intake[22].

Non-fasting blood samples were taken by a trained laboratory technician. Percentage of EPA and DHA in relation to the total measured fatty acids (=35 fatty acids) was used as the concentration biomarker of fish intake[23]. The carotenoids, α-carotene, β-cryptoxanthin, β-carotene, lutein and zeaxanthin were analysed as described by Nguyen *et al.*[24] and their sum was used as the marker of fruit and vegetable intake[25]. Serum total cholesterol was measured spectrofotometrically on a Synchron LX20 clinical analyser (Beckman Coulter) and was used as biomarker of saturated fatty acids (SFA) and *trans* fatty acids (TFA)[23].

DHD-index

The DHD-index consists of ten components (physical activity, vegetables, fruit, fibre, fish, SFA, TFA, consumption occasions of acidic drinks and foods (ADF), sodium and alcohol) representing the ten Dutch Guidelines for a Healthy Diet of 2006 (**Table 3.1**). The maximum score of each component is 10 points, resulting in a total score ranging from zero (no adherence) to 100 (complete adherence). The criteria used to calculate the DHD-index have been described in detail elsewhere[6]. Briefly, the required amount of consumption or physical activities stated in the Dutch Guidelines for a Healthy Diet were used as cut-off values for the maximum number of points. For the components physical activity, fruit, vegetables, fish, and dietary fibre the minimum score of zero was assigned when no intake or activities were undertaken. For the components SFA, TFA, consumption occasions with ADF, and sodium the minimum score was based on the 85th percentile of the 2-day average intake of a Dutch reference population[26]. These threshold values are recommended for all future use of the DHD-index to make it possible to compare results between different study populations. The cut-off value for the component TFA was lower than the dietary recommendation, consequently the component TFA was scored dichotomously. The cut-off values for the component sodium were lowered by 30% to adjust for sodium added during cooking and at the table[27, 28], which is not taken into account by both dietary assessment methods. The minimum score for the component alcohol was based on the cut-off values of binge-drinking[29]. Between zero and 10 points the score was calculated proportionally.

For the 24hR data, component scores were based on reported 2-day average intake. For calculation with the FFQ data, scores were based on the reported usual intake. The component ADF could not be estimated with FFQ data, as the number of consumption occasions per day was not assessed. Therefore, component ADF occasions was omitted from the index in all further analyses. In addition, the component physical activity was omitted from further analyses because the SQUASH was assessed only once; consequently the component score was the same for both indices based on the two different dietary assessment methods.

Statistical analyses

Ranking of the participants between the DHD-index scores based on FFQ data and the DHD-index score based on 24hR data was studied by analyzing the correlations and cross-classification of tertiles. Partial correlation coefficients were calculated between the DHD-index score and its components based on FFQ data and the DHD-index score based on 24hR data, adjusting for energy intake assessed by FFQ and by 24hR. Additional adjustment for sex did not alter the results. Pearson correlations were used for normally distributed variables and Spearman correlations for skewed variables. The 95% confidence intervals (95% CI) of the correlation coefficients were calculated by Fisher's Z-transformation. Differences between medians were tested with the Wilcoxon signed rank test and chi-square test for the dichotomous TFA component. To study the association of the DHD-index with participants' characteristics and micronutrient intakes, the DHD-index was divided in sex-specific tertiles. Means (SD) and P for trend were calculated with general linear models.

The four biomarkers were used as independent variables in a linear regression to provide,

Table 3.1 Components of the DHD-index and their cut-off (maximum score) and threshold values (minimum score)

Components		Minimum score (=0)	Maximum score (=10)
1.	Physical activity (week)	0 activities	≥ 5 activities
2.	Vegetable (day)	0 g	≥200 g
3.	Fruit + fruit juices (day)*	0 g	≥ 200 g
4.	Fiber (day)	0 g/4.2MJ	≥14 g/4.2MJ
5.	Fish (day)†	0 mg EPA+DHA	≥ 450 mg EPA+DHA
6.	SFA (day)	≥ 16.6 en%	< 10 en%
7.	TFA (day)	≥ 1.6 en%	< 1 en%
8.	ADF (day)‡	> 7 occasions	≤ 7 occasions
9.	Sodium (day)	≥ 2.45 g	< 1.68 g
10.	Alcohol (day)	♂: ≥ 60 g ♀: ≥ 40 g	♂: ≤ 20 g ♀: ≤ 10 g

SFA: saturated fatty acids, TFA: trans fatty acids, ADF acidic drinks and foods
*Maximum of 100 gram of juice could be included
†EPA and DHA intake form foods and fish oil capsules
‡The number of consumption ocassions was defined as the number of hours where at least one food or drink with a pH<5.5 and total acidity>0.5 was consumed

hypothetically, the best objective 'marker' of diet quality based on available data. We expected correlations of 0.4 between the DHD-index and the four linear combinations of biomarkers based on published correlations between single biomarkers and diet indices[8, 11, 12]. The square-root of R^2 from linear regression models, including energy intake as an independent variable, was used to calculate the energy-adjusted correlation coefficient between the DHD-index score and the four biomarkers. The 95% confidence interval for this correlation was estimated with bootstrap analyses using 10,000 replications. Partial correlation coefficients for the separate biomarkers were calculated for the DHD-index scores based on the two dietary assessment methods and for the component scores of interest adjusting for energy intake. Additional adjustment for sex did not change the results. All statistical analyses were performed using SAS 9.2 (SAS Institute Inc.).

Results

The mean age of the study population was 56.2 (SD 5.1) years and mean BMI was 26.0 (SD 4.5) kg/m^2. Almost 50% of the study population completed a level of higher education and 10% of the study population followed a diet regimen.

The mean DHD-index score based on FFQ data was 6.0 points higher for women than

Table 3.2 Median (IQR) of the Dutch Healthy Diet index (DHD-index) and its component scores based on two 24hR and on an FFQ in 121 Dutch subjects of the European Food Consumption Validation study and partial correlations (95% CI) between the two scores.

	24hR		FFQ			
	Median	IQR	Median	IQR	Correlation*	95% CI
DHD-index†	51.7	(20.7)	57.30	(15.8)	0.48	0.33, 0.61
Vegetable	8.8	(3.3)	6.3	(5.2)	0.29	0.12, 0.45
Fruit	10.0	(3.9)	10.0	(4.4)	0.41	0.25, 0.55
Fibre	7.9	(3.1)	9.0	(2.3)	0.58	0.45, 0.69
Fish	0.7	(5.3)	3.3	(3.9)	0.33	0.16, 0.48
SFA	4.7	(8.6)	6.5	(5.8)	0.43	0.27, 0.57
TFA	10.0	(0.0)	10.0	(0.0)	0.16	-0.02, 0.33
Sodium	1.1	(7.9)	4.1	(9.9)	0.30	0.13, 0.46
Alcohol	10.0	(4.5)	10.0	(1.6)	0.65	0.54, 0.70

IQR: interquartile range, SFA: saturated fatty acids, TFA: trans fatty acids
*Adjusted for energy intakes assessed by FFQ and 24hR
†Excluding the components acidic drinks and foods consumption occasions and physical activity

for men (P=0.003), and 5.7 (P=0.018) points higher for women when the DHD-index was based on 24hR data. Mean DHD-index score for the sum of eight components was 49.9 (13.5) based on 24hR data and 56.0 (SD 11.0) based on FFQ data (P<0.001; **Table 3.2**). The median component score for vegetable based on 24hR data was higher than the median based on FFQ data (P<0.001). The four components fibre, fish, SFA, and sodium showed significant lower median scores when the scores were based on 24hR data compared with FFQ data. The components fruit, TFA and alcohol showed similar medians for both methods, whereas the alcohol component score distributions were different (P<0.001).

The results from cross-classification revealed that 57% of the participants was classified in the same tertile and 7% was classified in the opposite tertile when comparing DHD-index score based on FFQ and 24hR data, with Kendall's tau-b of 0.47 (95% CI 0.33, 0.60). The correlation between the DHD-index scores based on FFQ and 24hR data was 0.58 (95% CI 0.45, 0.69) and after energy adjustment this correlation decreased to 0.48 (95% CI 0.33, 0.61; **Table 3.2**). The correlations between the components scores based on 24hR and FFQ data ranged between 0.16 and 0.65. The lowest correlation was observed for the component TFA and was not significant. The two highest correlations were observed for the components alcohol and fibre. Moderate correlations between the components fruit and vegetable with fibre (r=0.42, r=0.46, respectively) and for SFA with TFA (r=0.39) were observed when the DHD-index was based on FFQ data.

The participants' age showed a positive trend across the sex-specific tertiles of the DHD-index score based on FFQ data (P for trend = 0.004; **Table 3.3**). Energy intake showed an inverse trend across the tertiles of the FFQ DHD-index score (P for trend <0.001), whereas BMI, supplement use, smoking and educational level did not show a significant trend across the tertiles. Intakes of the micronutrients folate, iron, magnesium, thiamin, vitamin B_6, and vitamin C expressed per 4.2 MJ were positively associated with the DHD-index score based on FFQ data. Intakes of the micronutrients calcium, riboflavin, vitamin A, vitamin B_{12}, and vitamin E showed no significant trend across tertiles of the FFQ DHD-index score. The DHD-index score based on 24hR data showed similar positive associations with participants' characteristics and micronutrient intakes. Additionally, vitamin E was positively associated (P<0.022) with the DHD-index score based on 24hR data (data not shown).

The correlation, estimated using linear regression models, between the four biomarkers carotenoids, EPA+DHA, total cholesterol and urinary sodium on the one hand, the DHD-index score based on 24hR data on the other hand, was 0.55 (95% CI 0.44, 0.68), and for the DHD-index score based on FFQ data 0.51 (95% CI 0.40, 0.67). The DHD-index scores based on FFQ data and 24hR data were positively correlated with serum EPA+DHA (both 0.19; **Table 3.4**). No significant correlations were observed between the biomarkers serum carotenoids, urinary sodium, or serum total cholesterol and the DHD-index scores based on the two dietary assessment methods.

The vegetable component scores based on FFQ data and 24hR data were both positively correlated with serum carotenoids (r_{24hR}=0.25 and r_{FFQ}=0.17), although the correlation was not significant for the FFQ data (**Table 3.4**). For the fruit component score based on FFQ data, a significant correlation was observed with serum carotenoids (r=0.25, 95% CI 0.08, 0.41), while it was 0.09 and non-significantly for the fruit component score based on 24hR data. Significant correlations were observed between serum carotenoids and the fibre component score based on FFQ data (r=0.20) and the fibre component based on 24hR data (r=0.21). Serum EPA+DHA was associated with the fish component scores, the correlation being higher for the one based on FFQ data compared to 24hR data (r=0.53 vs. r=0.30, respectively). Urinary sodium was inversely correlated with the sodium component although, not significantly for the sodium component based on 24hR data. These inverse correlations were expected, because higher scores on the component sodium were expected to associate with lower dietary sodium intake. No significant associations were observed between total cholesterol and the components SFA and TFA for both dietary assessment methods.

Table 3.3 Participants' characteristics, biomarkers and micronutrient intakes across sex-specific tertiles of the Dutch Healthy Diet index (DHD-index) based on FFQ data in 121 Dutch subjects of European Food Consumption Validation study

	Sex-specific tertiles DHD-index*†						
	T1(n=40)		T2 (n=41)		T3 (n=40)		P for trend
	Mean	SD	Mean	SD	Mean	SD	
Age (years)	55.0	(5.5)	55.5	(4.9)	58.3	(4.5)	0.004
BMI (kg/m²)	26.9	(5.1)	25.0	(2.9)	26.2	(5.0)	0.479
Energy intake (MJ/day)	8.9	(2.2)	7.8	(2.2)	6.6	(1.6)	<0.001
Supplements users (%)	45.0		65.9		50.0		0.653
Smokers (%)	15.0		2.5		5.0		0.088
Diet regime (%)	12.5		4.5		12.5		1.000
Education (%)							0.578
Low	22.5		19.5		25.0		
Mediate	30.0		26.8		35.0		
High	47.5		53.6		40.0		
Biomarkers‡							
Carotenoids (µg/100ml)	114.4	(89.1)	113.8	(84.7)	128.7	(90.2)	0.234
Fish fatty acids (% of total fat)	4.5	(2.2)	4.3	(2.2)	4.3	(2.2)	0.019
Total cholesterol (mmol/L)	5.6	(2.2)	5.5	(2.2)	5.6	(2.2	0.763
Urinary sodium (mmol/d)	388.9	(1164.9)	171.6	(1095.6)	293.1	(1168.2)	0.538
Micronutrients (per 4.2MJ)							
Calcium (mg)	545	(160)	544	(157)	540	(116)	0.874
Folate (µg)	90.1	(17.1)	106.3	(27.4)	121.1	(26.9)	<0.001
Iron (mg)	4.8	(0.9)	5.6	(0.9)	6.1	(1.0)	<0.001
Magnesium (mg)	157.7	(25.6)	171.1	(29.8)	186.8	(31.7)	<0.001
Potassium (mg)	1634	(248)	1830	(246)	2028	(344)	<0.001
Riboflavin (mg)	0.8	(0.3)	0.8	(0.2)	0.9	(0.2)	0.839
Thiamin (mg)	0.7	(0.1)	0.7	(0.1)	0.8	(0.1)	0.004
Vitamin A (RAE)	575	(269)	591	(267)	576	(274)	0.988
Vitamin B6 (mg)	0.9	(0.2)	0.9	(0.1)	1.0	(0.1)	<0.001
Vitamin B12 (µg)	2.2	(0.9)	2.1	(1.1)	2.3	(1.1)	0.829
Vitamin C (mg)	35.9	(17.6)	51.1	(30.1)	64.2	(22.3)	<0.001
Vitamin E (mg)	5.3	(1.4)	5.7	(1.4)	5.7	(1.2)	0.155

RAE, Retinol Activity Equivalents (µg)
*Excluding the components consumption occasions acidic drinks and foods and physical activity
†Cut-off values tertiles men: 42.1 and 53.1. Cut-off values tertiles women: 47.7 and 61.1
‡Adjusted for energy intake

Table 3.4 Partial correlations* (95% CI) Associations between biomarkers and the Dutch Healthy Diet index (DHD-index) and seven separate components of DHD-index based on FFQ and 24h recall (24hR) data in 121 Dutch subjects of European Food Consumption Validation study

	Serum Carotenoids†		EPA + DHA		Urinary sodium		Serum total cholesterol	
	Correlation	(95% CI)	Correlation	(95% CI)	Correlation	(95% CI)	Correlation	(95% CI)
DHD-index 24hR‡	0.06	(-0.12, 0.24)	0.19	(0.02, 0.36)	-0.04	(-0.22, 0.14)	-0.04	(-0.22, 0.14)
DHD-index FFQ‡	0.13	(-0.05, 0.30)	0.19	(0.01, 0.35)	0.02	(-0.16, 0.20)	-0.03	(-0.21, 0.15)
Vegetable 24hR	0.25	(0.07, 0.41)						
Vegetable FFQ	0.17	(-0.01, 0.34)						
Fruit 24hR	0.09	(-0.09, 0.27)						
Fruit FFQ	0.25	(0.08, 0.41)						
Fibre 24hR	0.21	(0.03, 0.37)						
Fibre FFQ	0.20	(0.02, 0.37)						
Fish 24hR			0.26	(0.08, 0.42)				
Fish FFQ			0.55	(0.41, 0.66)				
SFA 24hR							0.00	(-0.18, 0.17)
SFA FFQ							-0.00	(-0.18, 0.18)
TFA 24hR							-0.05	(-0.22, 0.13)
TFA FFQ							-0.03	(-0.16, 0.20)
Sodium 24hR					-0.16	(-0.33, 0.02)		
Sodium FFQ					-0.23	(-0.39, -0.05)		

SFA: saturated fatty acids, TFA: *trans* fatty acids
*Adjusted for energy intake
†α-Carotene, β-cryptoxanthin, β-carotene, lutein and zeaxanthin
‡Excluding the components acidic drinks and foods consumptions occasions and physical activity

Discussion

In the present study, we examined the performance of the DHD-index based on a 180-item FFQ by studying its association with participants' characteristics, micronutrient intakes and biomarkers of intake and compared its performance with the performance of the DHD-index based on 24hR data. The DHD-index score based on FFQ data showed similar associations with participants' characteristics and micronutrient intakes as the DHD-index score based on 24hR data. For both dietary assessment methods, correlations between DHD-index and the combined four biomarkers were higher than the expected magnitude of 0.4 based on the literature. These results confirm the previous conclusion that the DHD-index based on 24hR can be used to assess diet quality and suggests that the DHD-index based on FFQ data can also be used to rank participants according to their diet quality in Dutch populations.

In the present study, the component ADF consumption occasions was omitted, because the number of consumption occasions could not be assessed by the FFQ. Previously, the component ADF consumption occasions showed not to be discriminating in ranking subjects according to the guideline[6]. Furthermore, no significant differences were seen in the associations with DHD-index based on 24hR and participants' characteristics, micronutrients, biomarkers when the component ADF consumption occasions was excluded (data not shown). This suggests that the component ADF consumption occasions may be omitted to arrive at a more simple form of the index. However, the DHD-index is not yet evaluated by studying diet-disease associations, which might alter this conclusion.

Ranking of the participants based on the two DHD-index scores was studied by examining the correlations and cross-classification. The correlation between the DHD-index based on FFQ data and based on 24hR data was comparable to the correlation (r=0.48) reported by Benítez-Arciniega *et al.*[30], who compared the Modified Mediterranean Diet Score based on FFQ data with the score based on twelve 24hR. However, our observed correlation was lower than the correlation (r=0.72) reported by Newby *et al.*[11]. The latter correlation, however, compared the Diet Quality Index Revised based on FFQ data with the index based on two 1-week diet records. The reference period covered by these two dietary assessment methods are probably more comparable to each other than the reference periods covered by our FFQ and two 24hR, which could explain the lower correlation in the present study.

Well over the half of the participants in the present study were classified into the same tertile, this result was similar to the results from cross-classifications between a FFQ and 24hR on food groups[30, 31]. Furthermore, the Kendall's tau-b coefficient showed a moderate agreement between the tertiles of the DHD-index based on FFQ and 24hR data. Based on the present results, we can conclude that ranking of participants was acceptable for both DHD-index scores.

The DHD-index component scores based on 24hR data and the DHD-index component scores based on FFQ data were all significantly correlated to each other, except for the component TFA. This might be due to the fact that the component TFA was scored dichotomously and thus showed little variation. The component alcohol showed the highest correlation between 24hR and FFQ, this can be due to the fact that FFQ and 24hR are both known for a satisfactory ranking between individuals according to alcohol intake[32]. The correlation between the vegetable components was rather low. In most validation studies the FFQ tends to overestimate vegetable intake compared to vegetable intake assessed by multiple 24hR[33], however the results of the present study showed the opposite. We could not explain this discrepancy. The correlation between sodium components was rather low probably because the FFQ was not specifically designed to assess sodium intake levels. Furthermore, fish components was also rather poorly correlated probably due to the fact that two recalls were unable to assess the usual intake of episodically consumed foods such as fish[34].

To improve comparability between the two DHD-index scores based on FFQ and 24hR data, usual intakes could be estimated for 24hR data by statistical models, like the National Cancer Institute method and the Multiple Source Method[34, 35]. These methods eliminate intra-individual variability from the data. Unfortunately, estimation of usual intakes requires a bigger sample size[36] and the statistical methods may have their limitations[37]. Age and energy intake showed significant trends across the sex-specific tertiles of both DHD-index scores. The inverse association of the DHD-index score with energy intake was also observed in the population of the DNFCS-20036. The positive association with age, however, was not seen in that population. This may be due to the smaller age range (19-30 years) in the DNFCS-2003 population compared to the age range (45-65 years) of the EFCOVAL study population.

The positive associations of micronutrient intakes with the DHD-index score based on FFQ data in the present study were similar to the associations with the DHD-index based on 24hR and to our earlier findings in DNFCS-2003 data[6]. Newby *et al.* found similar associations for the 'Diet Quality Index Revised' with the micronutrients vitamin A, vitamin B_6, vitamin C, folate, magnesium and iron[11]. In the present study, however, also vitamin E showed a positive association across tertiles of the DHD-index based on 24hR ($P<0.022$), which was comparable to others[8-10]. We assumed that the combination of the four biomarkers was the best available approach to evaluate diet quality as estimated by the DHD-index. The magnitude of the correlations was higher than the expected correlation of 0.4 based on published correlations of diet indices with single biomarkers[8, [11, 12]. Based on these results, we may conclude that for both dietary assessment methods the DHD-index can be used to assess diet quality on population level.

A limitation of both dietary assessment methods is the inaccurate assessment of dietary sodium intake. Dietary sodium intake assessed by the two methods is probably underestimated due to lacking data on salt added during cooking or at the table[38]. Furthermore, the FFQ used was not specifically designed for estimation of sodium, and did not include questions on all sodium rich food products such as soy sauce. By lowering the cut-off values by 30%, we tried to adjust for these measurement errors. In the present study however, we also measured urinary sodium, the preferred method of estimating dietary sodium intake[22]. The mean sodium component score was 2.4 (SD 3.5) when based on urinary sodium, 3.5 (SD 4.1) when based on 24hR data, and 4.8 (SD 4.3) when based on FFQ data. These differences are quite substantial, consequently, conclusions regarding the DHD-index component score based on sodium intake assessed by FFQ or 24hR data must be drawn with caution. Preferably, data of urinary sodium is used for estimation of the component sodium to overcome measurement errors. If urinary sodium is used, the original cut-off values without additional adjustment should be used; maximum points will be assigned when sodium intake is lower or equals 2400 mg and zero points will be assigned when sodium intake is above 3600 mg.

In the present study, the biomarkers used were initially selected to validate two non-consecutive 24hR using EPIC-Soft within the EFCOVAL study. Unfortunately, the biomarkers carotenoids and total cholesterol have some limitations for the present study. First, plasma carotenoids is already known for its modest correlation with fruit and vegetable intake[39], also observed in the present study. This can be explained by the influence of many other factors as absorption and metabolism on plasma carotenoid concentrations[40]. Additional adjustment for serum total cholesterol and smoking did not improve the results between plasma carotenoids and the components fruit, vegetable, and fibre. Unfortunately, a more accurate biomarker for fruit and vegetable intake is not available.

Second, serum total cholesterol was used as biomarker for SFA and TFA intake. In the present study, no significant correlations were observed between the DHD-index and serum total cholesterol, which was comparable with the results of others[9, 12, 41]. In some other studies, however, significant associations were observed[8, 11, 42]. Suggested explanations for these discrepancies were the differences between intake levels of populations, the differences between dietary assessment methods, and the differences between indices used[8-11]. Preferably, serum LDL cholesterol concentrations should be used to study associations with types of fat intake[43, 44], but these were not available in the present study.

In conclusion, the DHD-index based on a 180-item FFQ showed similar associations with participants' characteristics, micronutrient intake and biomarkers of dietary intake and metabolism compared to the DHD-index based on two non-consecutive 24hR. Furthermore, the ranking of participants was acceptable for both DHD-index scores. Therefore, both dietary assessment methods can be used to assess diet quality by using the DHD-index in Dutch populations. Future research should focus on the evaluation of the DHD-index by studying associations with disease outcomes.

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4

ADHERENCE TO THE DUTCH DIETARY GUIDELINES IS INVERSELY ASSOCIATED WITH 20-YEAR MORTALITY IN A LARGE PROSPECTIVE COHORT STUDY

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Abstract

Background: The Dutch guidelines for a healthy diet aim to reduce major chronic diseases. However, supporting evidence on their overall association with all-cause and cause-specific mortality is limited. Recently, the Dutch Healthy Diet-index (DHD-index) has been developed to assess adherence to these guidelines.

Objective: To examine the association between the DHD-index and all-cause mortality and deaths from cardiovascular disease (CVD), coronary heart disease (CHD), stroke and cancer.

Design: We followed 3,593 men and women aged 55 years and older enrolled in the Rotterdam Study, a population-based prospective cohort study, from baseline in 1990-1993 to 2011. A validated 170-item food frequency questionnaire was used to calculate the DHD-index score (maximum 90 points). Cox proportional hazard models were used to estimate hazard ratios (HR) adjusting for age, sex, total energy intake, smoking and educational level.

Results: Mean DHD-index score was 60.6 (SD 10.6). The score was inversely associated with all-cause mortality (highest vs. lowest quartile HR 0.77; 95% CI 0.67, 0.89). Inverse but non-significant associations were observed for mortality due to CVD (HR 0.74; 95% CI 0.55, 1.01), CHD (HR 0.60; 95% CI 0.34, 1.06) and stroke (HR 0.67; 95% CI 0.36, 1.22), while no association was observed with cancer mortality (HR 0.99; 95% CI 0.90, 1.11).

Conclusions: A higher level of adherence to the Dutch dietary guidelines, as assessed with the DHD-index, was associated with a lower risk of all-cause mortality, probably due to an inverse association with cardiovascular causes of death.

Introduction

Traditionally, nutritional epidemiology focused on investigating associations between single foods or nutrients and diseases. However, several biological and statistical arguments have been put forward to investigate associations of nutrients and foods combined in dietary patterns[1-4]. These arguments include the fact that individuals consume combinations of foods consisting of several nutrients, which can interact. Dietary pattern analysis accounts for these interactions and also avoids multiple testing of single foods and nutrients[2-4].

One method of deriving dietary patterns is using dietary indices that are based on a-priori knowledge obtained from studies on single foods and nutrients. Typically, dietary indices are developed based on international or national dietary guidelines and are evaluated with regard to their association with nutritional adequacy[5]. The ultimate evaluation for dietary quality indices is to observe an association with chronic disease outcomes[2, 6], as dietary guidelines are not only developed for prevention of nutrient deficiencies, but also for prevention of chronic diseases. To date, diet quality scores assessing adherence to (inter-) national dietary guidelines (e.g. Healthy Eating Index, Healthy Diet Indicator) were consistently associated with lower risk of all-cause mortality[7-14] and cardiovascular disease (CVD) mortality[8, 9, 11, 13, 15-18]. However, results regarding cancer mortality were inconsistent[8, 9, 11, 13, 15-25].

Recently, we developed the Dutch Healthy Diet-index (DHD-index) to assess adherence to the current Dutch dietary guidelines which include recommendations regarding physical activity, vegetable, fruit, dietary fiber, fish, saturated fatty acids (SFA), *trans* fatty acids (TFA), consumption occasions with acidic drinks and foods, sodium and alcohol[26, 27]. The DHD-index differs from indices based on the USA dietary guidelines by including a component on physical activity and not having a component on empty calorie intake or protein intake. The DHD-index was shown to be associated with micronutrient intakes and objective biomarkers of dietary intake and metabolism[26, 28], but not with cancer incidence[25]. However, its prospective relation with all-cause and cause-specific mortality has not yet been evaluated. We aimed to investigate the association between adherence to the Dutch dietary guidelines, as assessed by the DHD-index score, and mortality and causes of death in a Dutch population-based cohort study.

Participants and Methods

The Rotterdam Study is a population-based prospective cohort study in the district of Ommoord, Rotterdam, the Netherlands. The study design and population have been described in detail elsewhere[29]. The study protocol was approved by the medical ethics committee of Erasmus Medical Centre and all participants gave written informed consent. Briefly, the first cohort included 7,983 men and women aged 55 years and older. Baseline data, collected in 1990 to 1993, consisted of a home-interview and multiple physical examinations at the study center focusing on risk indicators for chronic diseases. Physical activity was measured in the third research cycle between 1997 and 1999.

In total, 6,521 independently living participants attended the study center and were eligible for a dietary interview. Dietary intake was not assessed in 271 participants who participated in the pilot phase of the Rotterdam Study (**Figure 4.1)**. An additional 603 participants were not interviewed, due to suspicion of dementia (n=122), due to logistics reasons (n=481), or because participants were institutionalized (n=1462). Furthermore, we excluded participants with unreliable dietary data (n=212) and participants with missing values on dietary components needed (n=446). Additionally, we excluded participants with incomplete data on physical activity (n=1,376) Furthermore, 606 participants with missing cause of death (n=100) or with baseline CVD, hypertension, or diabetes mellitus were excluded, when investigating the relationship with cause-specific mortality. Participants diagnosed with cancer at baseline could not be excluded, because this information was not collected at baseline. This resulted in a cohort of 3,593 participants for the analyses of all-cause mortality and a cohort of 2,987 participants for the analyses of cause-specific mortality. Follow-up data were collected until 1st January 2011.

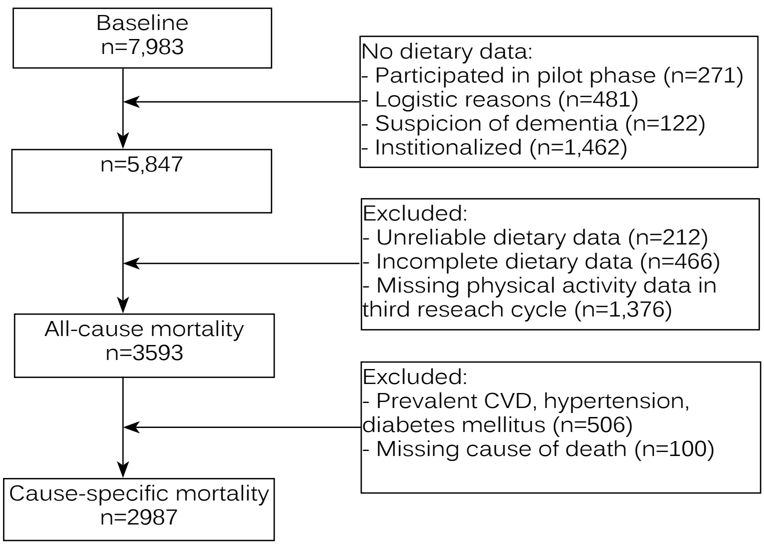

Figure 4.1 Flow chart on exclusion on participants of the Rotterdam Study

Case ascertainment

Information on vital status of participants was obtained through linkage with municipal population registries on regular intervals. Information on fatal events was obtained through linkage with computer-based information systems of general practitioners within the research area and pharmacies' databases. Events were independently coded according to the International Classification of Diseases 10th version (ICD-10)[30] by two research physicians[31].

All-cause mortality was defined as participants who died within the follow-up period. CVD mortality was defined as ICD-10 codes I00-I99, CHD mortality cases were defined as ICD-10 codes I21, I24, I25, I46, I49, I50, stroke mortality cases were defined as ICD-10 codes I60-I69, cancer mortality cases were defined as ICD-10 codes C00-C97, D00-D09 and D37-D48[30].

Dutch Healthy Diet-index

Habitual dietary intake was estimated during an interview with a trained dietician who used a validated 170-item semi-quantitative food frequency questionnaire. The food frequency questionnaire was validated for macro- and micronutrient intakes and for use in an elderly population[32, 33]. Total energy intake and nutrients were estimated using the Dutch food composition table of 1993[34]. Physical activity was assessed using a questionnaire from the Zutphen Elderly study with questions on household activities added[35].

The DHD-index comprises ten components: physical activity, vegetable, fruit, dietary fiber, fish, SFA, TFA, consumption occasions with acidic drinks and foods sodium and alcohol[26, 28], which represent the 2006 Dutch dietary guidelines[27]. For the present study, we omitted the component 'consumption occasions with acidic drinks and foods' because the food frequency questionnaire did not assess the number of consumption occasions per day. Furthermore, we adapted the cut-off value of the component physical activity (originally 5 days per week with activities of 30 minutes or more) to 'being active for at least 150 minutes per week', as information on activity per day was not available.

The scores for each of the nine DHD-index components ranged between 0 and 10 points, resulting in a total summed score ranging between 0 – 90 points. Higher scores correspond to a higher level of adherence to the Dutch dietary guidelines.

Covariates

Smoking was categorized as never, former, and current smoking. Educational level was categorized as high (university or college), intermediate (secondary or higher vocational education), and low (primary or lower education). Following a diet was categorized as yes or no. BMI was calculated from weight divided by squared height and categorized as normal (<25 kg/m^2) or overweight and obese (≥25 kg/m^2). Abdominal obesity was categorized as a waist circumference ≥102 cm for men and ≥88 cm for women. Hypertension was defined as a systolic blood pressure ≥160 mmHg or diastolic blood pressure ≥ 100 mmHg or use of anti-hypertensive medication[36]. Dyslipidemia was defined as total/HDL cholesterol ratio ≥ 5[37].

Statistical analyses

Baseline characteristics were presented according to sex-specific quartiles of the DHD-index score. Survival time was calculated as the number of years from study entry until the time of the until death, or until 1st January 2011. Cox-proportional hazard models adjusted for age and sex were used to obtain hazard ratios (HR) for all-cause and cause-specific mortality comparing quartiles of the DHD-index. In model 2, additional adjustments were made for education, energy intake, and smoking status and in model 3 we additionally adjusted for BMI, as a potential confounder or intermediate. Interactions were examined for age, sex, BMI, smoking, and cholesterol ratio by adding interaction terms of these variables with diet quality to the final model. We explored the relative contribution of the DHD-index components to the associations for those mortality outcomes that were associated with the DHD-index (P<0.10). For this, we excluded each single component of the DHD-index one at the time and adjusted for that component in the model. Additionally, stratified analyses for age, sex, BMI categories, smoking categories and dyslipidemia were performed for the mortality outcomes with more than 300 cases. The proportional hazards assumption was met for all variables in the models. Statistical analyses were performed using SAS 9.3 software (SAS institute, INC., Cary, NC).

Results

The mean (SD) of the DHD-index score was 60.6 (10.6) for the total population, 58.2 (10.4) for men and 62.3 (10.4) for women, indicating that women had a higher adherence to the Dutch dietary guidelines (**Table 4.1**). Women had significantly higher mean scores than men for the components physical activity, fruit, dietary fiber, sodium, and alcohol, whereas men had a higher mean score for the component fish.

The mean DHD-index score was 47.3 (SD 5.0) points in the lowest sex-specific quartile and 74.2 (SD 4.5) points in the highest quartile, and the score ranged between 28.2 – 88.8 out of the possible 90 points (**Table 4.2**). Participants with a high DHD-index score were younger, had a lower energy intake, slightly higher BMI, higher completed education, were more likely to have hypertension, and were less often a never-smoker and more often a former smoker. During the 20-year follow-up, 1831 (51%) deaths were identified. For the cause-specific population (n=2987), we identified 400 (13.4%) deaths from CVD, 112 (3.7%) from CHD, 102 (3.4%) from stroke, 362 (12.1%) from cancer and 380 (12.7%) from other causes.

A higher DHD-index score was significantly associated with lower risk of all-cause mortality (highest vs. lowest quartile HR 0.74; 95% CI 0.65, 0.85; P for trend<0.001) when adjusting for age and sex (**Table 4.3**). This association remained after additional adjustment for energy intake, smoking and educational level (HR 0.77; 95% CI 0.67, 0.89; P for trend=0.001) and after additional adjustment for BMI (HR 0.76; 95% CI 0.66, 0.88; P for trend=0.001). The HR per 10 points increment of the DHD-index showed an inverse association with all-cause mortality (model 2 HR 0.91; 95% CI 0.87, 0.96). Exclusion of baseline CVD, hypertension, or diabetes mellitus resulted only in minor changes in the HR between the DHD-index score and all-cause mortality. Non-linearity of the association between all-cause mortality and the DHD-index was tested with restricted cubic splines and was not significant (P=0.53; data not shown), so linearity could be assumed.

For CVD mortality, a higher DHD-index score was significantly associated with a lower risk when adjusting for age and sex (HR 0.69; 95% CI 0.52, 0.92), but after additional adjustment for energy intake, smoking and educational level this association attenuated

Table 4.1 Baseline DHD-index score and its components in participants of the Rotterdam Study

	Men (n = 1,454)	Women (n = 2,139)	
	Mean ± SD	Mean ± SD	P-value
DHD-index*	58.2 ± 10.4	62.3 ± 10.4	<0.001
Physical activity	9.9 ± 0.9	9.9 ± 0.7	0.040
Vegetable	8.8 ± 1.9	8.7 ± 1.9	0.184
Fruit	7.9 ± 2.9	8.7 ± 2.3	<0.001
Dietary fiber	8.6 ± 1.5	9.2 ± 1.2	<0.001
Fish	2.4 ± 2.2	2.2 ± 2.2	0.028
SFA	3.2 ± 3.4	3.1 ± 3.5	0.626
TFA	5.6 ± 5.0	5.5 ± 5.0	0.424
Sodium	3.1 ± 3.7	5.8 ± 3.8	<0.001
Alcohol	8.7 ± 2.5	9.2 ± 2.1	<0.001

DHD-index, Dutch Healthy Diet-index; SFA, saturated fatty acids; TFA, *trans* fatty acids
*Excluding acidic drinks and foods consumption occasions[26]

Table 4.2 Baseline characteristics of 3,593 participants according to sex-specific Dutch Healthy Diet index quartiles in the Rotterdam Study

	Sex-specific quartiles of the DHD-index score*				
	Q1 (n = 898)	Q2 (n = 899)	Q3 (n = 898)	Q4 (n = 898)	P for trend
DHD-index	47.3 ± 5.0	56.9 ± 3.1	64.6 ± 3.3	74.2 ± 4.5	
Age (y)	65.8 ± 7.0	65.9 ± 6.8	65.2 ± 6.8	64.8 ± 6.4	0.001
Energy intake (kcal)	2182 ± 540	1988 ± 484	1950 ± 473	1777 ± 425	<0.001
BMI (kg/m²)	26.0 ± 3.5	26.4 ± 3.7	26.3 ± 3.5	26.4 ± 3.5	0.029
Abdominal obesity [n (%)]	412 (45.9)	412 (45.8)	408 (45.4)	398 (44.3)	0.752
Hypertensive [n (%)]	210 (23.4)	249 (27.7)	259 (28.8)	284 (31.6)	0.002
Dyslipidemia [n (%)]	441 (49.1)	446 (49.7)	458 (50.9)	461 (51.4)	0.752
Smoking [n (%)]					<0.001
Never	220 (29.5)	177 (23.7)	137 (18.3)	117 (15.7)	
Former	293 (22.7)	291 (22.6)	331 (44.3)	374 (50.1)	
Current	233 (31.2)	279 (37.4)	280 (37.4)	255 (34.2)	
Education [n (%)]					0.007
Low	256 (34.3)	233 (31.2)	214 (28.6)	201 (26.9)	
Intermediate	430 (57.6)	439 (58.8)	459 (61.4)	452 (60.6)	
High	60 (8.0)	75 (10.0)	75 (10.0)	93 (12.5)	

*Cut-off values quartiles men: 50.3, 58.0, 66.4; women 54.2, 62.2, 70.3

(HR 0.74; 95% CI 0.55, 1.07; p for trend=0.084). After additional adjustment for BMI, the association remained similar (HR 0.74; 95% CI 0.55, 1.01; P for trend=0.084). Non-significant inverse associations between the DHD-index score and CHD and stroke mortality were observed for all three models (model 2 HR 0.60; 95% CI 0.34, 1.06 for CHD; HR 0.67; 95% CI 0.36, 1.22 for stroke). Per 10 points increment in DHD-index score, the HR (model 2) for mortality due to CVD, CHD and stroke were 0.92 (95% CI 0.83, 1.02), 0.91 (95% CI 0.76, 1.11) and 0.90 (95% CI 0.74, 1.10), respectively. The DHD-index score was not associated with cancer mortality (highest vs. lowest quartile HR 0.97; 95% CI 0.71, 1.34; per 10-units HR 0.99; 95% CI 0.90, 1.11).

In general, excluding the DHD-index components one at a time only marginally changed our results for all-cause and CVD mortality (**Table 4.4**). The HR of the 8-component score per 10 points increment with all-cause mortality ranged between 0.89 (95% CI 0.84, 0.95) when excluding the component TFA and 0.94 (95% CI 0.90, 0.98) when excluding the component physical activity or the component fruit 0.94 (95% CI 0.90, 0.99). For CVD mortality, the range of HRs was comparable to those for all-cause mortality.

Table 4.3 Hazard ratios (HR) and 95% confidence intervals of mortality outcomes and the Dutch Healthy Diet index in participants of the Rotterdam Study.

	Sex-specific quartiles of the Dutch Healthy Diet index*					
	Q1	Q2	Q3	Q4		
	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	P for trend	HR per 10 points (95% CI)
All causes (n = 3,597)						
Cases	517	476	449	389		
Model 1	1.0 (reference)	0.92 (0.81, 1.04)	0.89 (0.78, 1.00)	0.74 (0.65, 0.85)	<0.001	0.90 (0.86, 0.94)
Model 2	1.0 (reference)	0.93 (0.82, 1.06)	0.93 (0.81, 1.05)	0.77 (0.67, 0.89)	0.001	0.91 (0.87, 0.96)
Model 3	1.0 (reference)	0.92 (0.80, 1.05)	0.91 (0.79, 1.04)	0.76 (0.66, 0.88)	0.001	0.91 (0.87, 0.96)
CVD (n = 2,987)						
Cases	120	103	99	78		
Model 1	1.0 (reference)	0.90 (0.69, 1.17)	0.87 (0.66, 1.13)	0.69 (0.52, 0.92)	0.013	0.89 (0.81, 0.98)
Model 2	1.0 (reference)	0.92 (0.71, 1.21)	0.95 (0.72, 1.25)	0.74 (0.55, 1.07)	0.084	0.92 (0.83, 1.02)
Model 3	1.0 (reference)	0.92 (0.70, 1.20)	0.95 (0.72, 1.25)	0.74 (0.55, 1.01)	0.084	0.92 (0.83, 1.02)
CHD (n = 2,987)						
Cases	37	26	28	21		
Model 1	1.0 (reference)	0.73 (0.44, 1.20)	0.79 (0.48, 1.28)	0.59 (0.35, 1.01)	0.073	0.89 (0.75, 1.07)
Model 2	1.0 (reference)	0.71 (0.43, 1.19)	0.85 (0.51, 1.41)	0.60 (0.34, 1.06)	0.134	0.91 (0.76, 1.11)
Model 3	1.0 (reference)	0.69 (0.41, 1.16)	0.84 (0.50, 1.39)	0.60 (0.34, 1.06)	0.134	0.92 (0.76, 1.11)

table 4.3 continues on page 62

	Sex-specific quartiles of the Dutch Healthy Diet index*					
	Q1	Q2	Q3	Q4		
	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	P for trend	HR per 10 points (95% CI)
Stroke (n = 2,987)						
Cases	34	22	28	18		
Model 1	1.0 (reference)	0.68 (0.40, 1.17)	0.87 (0.53, 1.43)	0.58 (0.33, 1.02)	0.116	0.85 (0.70, 1.02)
Model 2	1.0 (reference)	0.72 (0.42, 1.25)	0.99 (0.59, 1.66)	0.67 (0.36, 1.22)	0.356	0.90 (0.74, 1.10)
Model 3	1.0 (reference)	0.73 (0.42, 1.26)	0.99 (0.59, 1.68)	0.67 (0.37, 1.23)	0.360	0.90 (0.74, 1.10)
Cancer (n = 2,987)						
Cases	92	92	94	84		
Model 1	1.0 (reference)	1.03 (0.77, 1.37)	1.02 (0.77, 1.36)	0.90 (0.67, 1.20)	0.480	0.96 (0.87, 1.06)
Model 2	1.0 (reference)	1.06 (0.79, 1.42)	1.09 (0.81, 1.47)	0.97 (0.71, 1.34)	0.926	0.99 (0.90, 1.11)
Model 3	1.0 (reference)	1.06 (0.79, 1.42)	1.09 (0.82, 1.47)	0.99 (0.71, 1.34)	0.927	1.00 (0.90, 1.11)

Model 1: adjusted for age (y) and sex
Model 2: adjusted for model 1 and energy intake (kcal/d), smoking (never, former, current) and educational level (low, intermediate, high)
Model 3: adjusted for model 2 and BMI (kg/m^2)
*cut-off values quartiles men: 50.3, 58.0, 66.4; women 54.2, 62.2, 70.3

The interaction terms between the DHD-index and age, sex, BMI, smoking and dyslipidemia were not statistically significant (model 2, p<0.10). Stratified analyses for age, sex, BMI, smoking and dyslipidemia showed minor differences in the HRs of the DHD-index per 10 points increment with all-cause, CVD, and cancer mortality outcomes (**Supplement 4.1**).

Discussion

In this Dutch prospective cohort study, those in the highest quartile of adherence to the Dutch dietary guidelines as assessed by the DHD-index had a 23% lower risk of all-cause mortality than those in the lowest quartile. This was probably due to cardiovascular causes of death, and not due to cancer. Excluding single DHD-index components did not significantly affect the association of the DHD-index with mortality, suggesting that overall diet rather than single components contribute to mortality risk. Based on these results we conclude that an overall higher adherence to the Dutch dietary guidelines, as assessed with the DHD-index, is associated with a lower risk for mortality.

These results confirm the existing evidence regarding indices based on adherence to dietary guidelines and all-cause mortality[7-11, 13, 14, 38]. The associations between diet quality and CVD, CHD and stroke mortality in our study were not statistically significant. However, the estimates per 10 points increment were similar to those for total mortality, and even

Table 4.4 Hazard Ratio for all-cause and CVD mortality with the DHD-index per ten points increment and alternate exclusion of each of the separate components*

	All-cause mortality (n=3593) HR (95% CI)	CVD mortality (n=2987) HR (95% CI)
Total	0.91 (0.87, 0.96)	0.92 (0.83, 1.02)
Excl. physical activity	0.94 (0.90, 0.98)	0.95 (0.87, 1.04)
Excl. vegetable	0.91 (0.87, 0.96)	0.94 (0.85, 1.03)
Excl. fruit	0.94 (0.90, 0.99)	0.94 (0.85, 1.04)
Excl. fiber	0.93 (0.89, 0.98)	0.93 (0.84, 1.03)
Excl. fish	0.92 (0.88, 0.96)	0.93 (0.85, 1.02)
Excl. SFA	0.91 (0.86, 0.96)	0.90 (0.80, 1.01)
Excl. TFA	0.89 (0.84, 0.95)	0.89 (0.78, 1.00)
Excl. sodium	0.93 (0.89, 0.97)	0.92 (0.84, 1.01)
Excl. alcohol	0.93 (0.89, 0.97)	0.93 (0.85, 1.02)

SFA, saturated fatty acids; TFA, *trans* fatty acids
*Adjusted for age (y), sex, energy intake (kcal/day), smoking (never, former, current) and educational level (low, intermediate, high) and excluded component

stronger when comparing the highest vs. lowest quartile estimates. Lower power due to smaller numbers of cases in the cause-specific analyses may have played a role. In a large prospective cohort study of 112,524 participants, the 'Healthy Eating index-2005' based on the USA dietary guidelines showed significant inverse associations with CVD, CHD and stroke mortality of similar strength as in the present study[15]. Furthermore, the 'Recommended Food Score' also based on the USA dietary guidelines was significantly associated with lower CHD and stroke mortality in 42,254 women[9, 11]. Lastly, a smaller study with 2,897 participants showed a non-significant inverse association for CVD mortality with higher adherence to Australian dietary guidelines[13].

We observed no association between diet quality and cancer mortality, which agrees with earlier studies on dietary indices based on dietary guidelines (e.g. Healthy Eating Index, Programme National Nutrition Santé Guideline Score, Healthy Diet Indicator, Total Diet Score)[13, 16-20, 24]. Moreover, in the European Prospective Investigation into Cancer and Nutrition-Netherlands cohort, the DHD-index was not associated with overall cancer incidence or smoking-related cancer incidence[25]. An explanation could be that cancer is a heterogeneous disease and that associations with diet quality differ between types of cancer[39]. In the present study, 66% of the cancer deaths were due to cancers known for their association with diet (cancers of digestive tract, digestive organs, breast and prostate). However, also no association between the DHD-index and these cancer cases was observed (HR 1.03, 95% CI 0.70, 1.50). Another explanation could be that the Dutch dietary guidelines were not specifically designed to prevent cancer. For example, they do not address red or processed meat intake or prohibit alcohol intake, which are known risk factors for cancer[39]. Adherence to more specific cancer guidelines as the World Cancer Research Fund/American Institute for Cancer Research guidelines, including components on BMI, red meat intake, breastfeeding and intakes of sugary and energy-dense foods, did show a 9% (95% CI 0.89, 0.93) lower risk for cancer mortality in 378,864 participants of the EPIC study[40].

The covariate BMI could have biased the association between diet quality and mortality outcomes as a confounder as BMI is associated with misreporting of diet[41]. However, when additionally adjusting for BMI in the final model, the associations only marginally changed. Furthermore, the interaction terms for BMI categories with diet quality were not significant ($P<0.22$). These results suggest that in the present study probably no effect modification or confounding by BMI was present.

The DHD-index is based on the Dutch dietary guidelines and differs from indices based on dietary guidelines such as the 'Healthy Eating Index-2005'and the 'Healthy Diet Indicator' by including a component on physical activity, while the components fruit, vegetable, and saturated fats are similar. All national dietary guidelines are based on nutritional knowledge, but cultural habits (e.g. high consumption of dairy in the Netherlands) and feasibility are taken into account when formulating the guidelines, resulting in differences between countries[27]. Therefore, dietary indices based on (inter-) national dietary guidelines will differ and one single optimal diet score that applies to all populations is thus not very realistic[2, 42].

For the present study we made some adjustments to the DHD-index score. Firstly, the original DHD-index comprised ten components instead of the nine we used[26]. The component on the number of consumptions occasions with acidic drinks and foods was excluded because no information was available. This component was defined specifically for dental health, which is associated with mortality[43]. Nevertheless, we do not think that omitting this component has had major impact on the results, because this component showed not to be discriminating in ranking subjects according to the DHD-index score in a Dutch representative population[26]. Secondly, we adapted the cut-off value for the component score of physical activity to 150 minutes per week instead of 5 days per week for at least 30 minutes. It is possible that this cut-off value resulted in a higher percentage of adherences to this guideline, as the original scoring for physical activity was based on activities that lasted at least 30 minutes a day and therefore did not include short lasting activities.

A limitation of the present study was the timing of the physical activity assessment. This assessment was done in the third examination cycle from 1997 to 1999, seven years after the baseline measurements. The participants who deceased (n=505) or were lost to follow-up (n=1163) between baseline and the third examination cycle consequently had missing data on physical activity and were for that excluded from analyses. This resulted in loss of power due to lower number of cases. Furthermore, selection bias could have been introduced because the mean DHD-index score without physical activity component of these excluded participants was somewhat lower (49.0, SD 10.5) compared to the population under study (50.7, SD 10.6). Furthermore, the excluded participants probably had a higher mortality rate. However, to affect our conclusion, the association between the DHD-index and mortality should have been extremely positive in the excluded participants, and that is not very likely.

Another limitation was the assessment of sodium intake using a food frequency questionnaire, which was probably underestimated because discretionary sodium was not taken into account. To take this in account we lowered the sodium component cut-off and threshold values by 30%[26]. Note that this may have eliminated some between-person variation, and hence increased misclassification of exposure to some extent. Moreover, diet was measured at baseline and changes in diet in response to subclinical diseases or symptoms (e.g. hypertension, diabetes mellitus) cannot be ruled out. However, to limit this possibility, we excluded the participants with prevalent hypertension, diabetes mellitus or CVD at baseline.

The strength of the present study was the long follow-up time of 20 years, resulting in many person-years. Furthermore, we used a 170-item food frequency questionnaire to estimate dietary intake, which was validated for the use in an elderly population and for intake of macro- and micronutrients[32, 33].

In conclusion, higher adherence to the Dutch dietary guidelines, as reflected by higher DHD-index scores, was associated with a lower all-cause mortality risk, which is probably due to cardiovascular causes of death. These results provide the first evidence that adherence to the Dutch dietary guidelines as assessed by the DHD-index score is associated with a lower risk of mortality in the Netherlands.

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The authors declare that they have no competing interest. The contributions of the authors were as follows: LL, AG, NJ, NV, and EF designed research; LL, AG, EF conducted the research; JK, JW, AH, and OF provided the cohort database; LL performed statistical analyses; LL, AG, and EF wrote manuscript; EF had primary responsibility for final content. All authors read and approved the final manuscript.

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Supplement 4.1 Stratified hazard ratios and 95% confidence intervals per 10 points increment of the DHD-index for all-cause, CVD and cancer mortality outcomes in the Rotterdam Study*

	All-cause mortality		CVD mortality		Cancer mortality	
	Cases	HR (95% CI)	Cases	HR (95% CI)	Cases	HR (95% CI)
Age						
- < median (65 y)	521	0.90 (0.83, 0.98)	128	0.95 (0.79, 1.13)	189	0.95 (0.82, 1.09)
- ≥ median (65 y)	1310	0.87 (0.82, 0.92)	272	0.83 (0.74, 0.94)	173	1.02 (0.87, 1.19)
P for interaction		*0.13*		*0.65*		*0.54*
Sex						
- Men	847	0.91 (0.85, 0.98)	182	0.94 (0.81, 1.09)	173	0.93 (0.80, 1.09)
- Women	984	0.91 (0.86, 0.97)	218	0.89 (0.78, 1.02)	189	1.05 (0.91, 1.22)
P for interaction		*0.64*		*0.34*		*0.57*
BMI						
- Normal (<25 kg/m^2)	681	0.92 (0.86, 0.99)	144	0.92 (0.78, 1.08)	139	0.90 (0.76, 1.06)
- Overweight and obese (≥25 kg/m^2)	1150	0.89 (0.84, 0.95)	256	0.91 (0.80, 1.03)	169	1.05 (0.91, 1.21)
P for interaction		*0.82*		*0.94*		*0.22*
Smoking						
- Never	460	0.93 (0.85, 1.02)	112	0.84 (0.70, 1.01)	103	1.03 (0.85, 1.24)
- Former	802	0.91 (0.84, 0.98)	170	0.92 (0.79, 1.07)	153	0.96 (0.81, 1.13)
- Current	569	0.92 (0.84, 1.01)	118	1.03 (0.85, 1.26)	106	1.06 (0.86, 1.30)
P for interaction		*0.62*		*0.17*		*0.60*
Dyslipidemia						
- No (total/HDL cholesterol < 5)	843	0.92 (0.86, 0.99)	174	0.96 (0.82, 1.12)	184	1.04 (0.90, 1.21)
- Yes (total/HDL cholesterol ≥ 5)	988	0.91 (0.85, 0.97)	226	0.88 (0.77, 1.01)	178	0.95 (0.82, 1.11)
P for interaction		*0.36*		*0.98*		*0.38*

*Adjusted for age (y), sex, energy intake (kcal/d), smoking (never, former, current) and educational level (low, intermediate, high)

5

ASSOCIATIONS BETWEEN COMPANY AT DINNER AND DAILY DIET QUALITY IN DUTCH MEN AND WOMEN FROM THE NQPLUS STUDY

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In preparation

Abstract

Objective: To examine the association between company at dinner and daily diet quality.

Design: Dietary intake data was assessed by multiple 24-hour recalls (6013 recalls) to estimate the Dutch Healthy Diet index (0-80 points) representing daily diet quality.

Setting: Dutch population-based study.

Participants: Men (n=895) and women (n=845) aged between 20 and 70 years

Analysis: Sex-specific linear mixed models adjusting for age, energy intake, educational level, place of residence, employment, household composition, day of the week, and dinner location. Dinner location (out-of-home dinners) and company at dinner were strongly associated (r=0.66), hence in additional analyses away-from-dinners were excluded.

Results: Among men, days with shared dinners were of similar daily diet quality than days with solo dinners, but among days with family dinners had higher daily diet quality (46.0, SE 0.3) compared to days with dinners shared with others (42.3, SE 0.7; P=0.001). Adjustment for dinner location in the full model attenuated this difference. However, the differences were also observed when excluding out-of-home dinners. Among women, shared dinners were associated with lower daily diet quality (49.3, SE 0.4) than solo dinners (45.7, SE 0.6; P=0.001). Dinners shared with family were associated with higher daily diet quality (49.3, SE 0.4) than dinners shared with others (45.7, SE 0.6; P=0.001). These differences persisted when excluding out-of-home dinners.

Conclusion and implications: Company at dinner was associated with daily diet quality; among men lowest daily diet quality was observed for dinners shared with other, among women the highest daily diet quality was seen for solo dinners.

Introduction

Sharing meals, defined as consuming a meal in company of others, is an important cultural practice that enables many social functions. For example, it can serve as a time and place for social engagement, and strengthen social connections by having a shared experience[1]. Traditionally, shared meals take place within the family context and mostly during the evening due to norms for proper meals and family dinners[2, 3]. Family meals have been associated with provision of family solidarity, unity, and identity. Furthermore, family meals can provide daily communication and monitoring of behaviours[4].

Next to societal benefits of shared meals there are also potential nutritional and health benefits of sharing meals with others. Fulkerson and colleagues concluded in a recent review that a higher frequency of family meals was associated with a higher consumption of fruit, vegetables, grains, and calcium-rich foods, and inversely associated with ready-made meals, soft-drinks, fried foods and candy in children, adolescents, and parents[5]. Possible mechanisms for these associations include social facilitation, social support and social control[2, 5].

Only a few studies examined the association between shared meals and overall diet quality[6-9]. Overall diet quality can be assessed using dietary indices that are commonly based on national dietary guidelines. Higher scores for these dietary indices have been associated with lower risk of mortality and cardiovascular diseases[6, 7]. Woodruff and colleagues observed a positive association between frequency of family dinners and the Healthy Eating Index-C scores, based on the Canadian dietary guidelines, in Canadian students[8]. Furthermore, diet quality as assessed with the Diet Quality Index International was positively associated with frequency of family supper in students from Nova Scotia[9].

So far, the association between family meals and overall diet quality has not been studied in adults. We examined the association between sharing meals and diet quality in Dutch adults. Because not all shared dinners are consumed with family, we compared sharing versus alone, and thereafter, we compared sharing with family members with sharing dinner with others.

Methods

Study design and population

The Nutrition Questionnaires plus (NQplus) study is an ongoing observational study in the Netherlands. The NQplus study was designed to study associations between diet and intermediate health outcomes. Between May 2011 and December 2013, 2048 men and women were included in the NQplus study. Inclusion criteria were ability of speaking and writing Dutch and aged between 20 and 70 years old. Participants were recruited by sending invitations to randomly selected inhabitants of the neighbouring cities Wageningen, Ede, Renkum, and Arnhem. In Veenendaal, one person per household was invited to participate in the NQplus study. The NQplus study was approved by the Medical Ethics Committee of Wageningen University and all participants signed written informed consent.Baseline measurements consisted of physical examination (e.g. blood pressure and body weight measurement), a fasting venipuncture, 24-hour urine collection and questionnaires on lifestyle (e.g. physical activity, and smoking), history of disease and demographics. Dietary intake was assessed using multiple 24-hour recalls (24hR).

Dietary assessment

For the present study, we used dietary intake data as assessed by 24hR. The recalls were self-administered using a web-based program. Unannounced invitations were sent via e-mail on the day that the recall was scheduled. Invitations for the recalls were randomly scheduled with at least 40 days in between each other. When invitations were refused, reminders were sent at random within three to ten days.

The web-based program guided participants to accurately report all foods and drinks consumed the previous day. The program was developed based on the five-step multiple pass method, which is a validated technique to increase the accuracy of recalls[10]. The program made it possible to select foods and standard recipes commonly used in the Dutch dietary pattern. Furthermore, it was possible to adapt the standard recipes or describe personal recipes. Participants could make notes to clarify consumed products when these were not found in the program. Portion sizes were reported in commonly used household measures, standard portions, and weight in grams or volume in litres. Nutrient and energy intakes were calculated by multiplying intake by the nutrient composition using the Dutch food composition table of 2011[11]. Furthermore, supplement intake and following a diet regime, prescribed or at own initiative, were registered. Trained dieticians processed all notes made by the participants and checked the 24hR for extreme portion sizes.

From 31st January 2012 until 1st March 2014, a total of 6217 recalls were collected from 1751 participants. Recalls with zero energy intake due to illness (79 recalls) and recalls with missing information on company at dinner (125 recalls) were omitted, resulting in a total of 6013 recalls from 895 men (median 3 recalls, range 1-10 recalls) and 845 women (median 4 recalls, range 1-9 recalls) were included in the present study. Recalls were evenly distributed across the seasons of the year (range 23.2-28.9%) and the days of the week (range 11.8-15.6%).

Diet quality

The Dutch Healthy Diet index (DHD-index) was used as measure of diet quality and was calculated for each recalled day. This index was developed on the basis of the current Dutch dietary guidelines[12] and comprises ten components on physical activity, vegetable, fruit, dietary fibre, fish, saturated fatty acids (SFA), *trans* fatty acids (TFA), consumption occasions with acidic drinks and foods (ADF), sodium and alcohol[13, 14]. The physical activity component was omitted because it was estimated only once per person. For the components vegetable, fruit, dietary fibre, and fish, no intake resulted in zero points, whereas meeting the guideline resulted in the maximum of 10 points. For the components SFA, TFA, consumption occasions with ADF, sodium and alcohol, zero points were allotted when intakes were above the threshold values, which were based on the 85th percentiles of a Dutch reference population and for alcohol cut-off values for binge-drinking were used. The maximum number of points were allotted when intake was equal to or below the guidelines. Between minimum and maximum number of points, scores were calculated proportionally, except for TFA and consumption occasions with ADF that were scored dichotomously. Component scores were summed, resulting in a total DHD-index score ranging from 0 to 90 points.

Food environment

Information on the context of dinner was collected at the same moment as the dietary intake. Participants were asked to indicate time, place and with whom they consumed their dinner. The answer categories for place were 'home', 'at work', 'at friends place' and 'other' and were categorized into home or out-of-home. The answer categories for with whom they consumed the meal were 'alone', 'with your partner', 'with your children (and partner)', 'with others as friends, colleagues, etc.', and were categorized as dinner eaten alone, with family members or with others. If participants had dinner with both family and others, it was categorized as meal eaten with family members (71 recalls).

Covariates

Age (y), sex, household composition (alone, with partner, with partner and children), highest achieved education level [high (university or college), intermediate (secondary or higher vocational education), and low (primary or lower education)], smoking (never, former, current), and currently employed (yes/no) were assessed in the general questionnaire. Physical activity was assessed by the short questionnaire to assess health enhancing physical activity (SQUASH)[15] and was categorized as adherent or non-adherent to the Dutch recommendation of being active for minimally 5 days per week for at least 30 minutes. Height and weight were measured and used to calculate BMI (kg/m^2).

Statistical analysis

All statistical analyses were performed using SAS software (version 9.3). The association between company at dinner and diet quality for that day was studied using linear mixed models using the GLIMMIX procedure with subject as random factor. The component consumption occasions with ADF did not converge due to a too low number of non-adherent persons; therefore, this component was excluded in all analyses, resulting in a maximum DHD-index score of 80 points. A significant interaction was observed between sex and shared meals in the association of company at dinner and diet quality (P=0.047), therefore all analyses were done separately for men and women. Selection of confounders was done using directed acyclic graphs[16] and associations were adjusted for age, education level, place of residence, employment, household composition, dinner location and day of the week. Furthermore, energy intake was included in the models, because the DHD-index showed inverse associations with energy intake and consequently with absolute nutrient intakes. It was, therefore, recommended to include energy intake in all analyses[13, 14]. Statistical model 1 included age and energy, model 2 additionally included education level, place of residence, employment, household composition, and day of the week, and model 3 additionally included dinner location. Missing values for education level (n=35), and household composition (n=85) were imputed five times. Statistical analyses were performed on five imputed datasets and results were pooled using the MIANALYZE procedure.

The robustness of the results was checked by repeating the analysis and excluding persons with less than three 24hR. Furthermore, the dinners consumed with family members were separated in shared dinners with and without children joining.

Results

In the present study population, men were somewhat older, had a slightly higher BMI, were more likely to live in Veenendaal, to be current smokers and to adhere to the physical activity guideline than women (**Table 5.1**). Women were more likely to live alone or with children than men.

Men consumed 75% of their dinners with family members, 13% alone and 12% with others (e.g. colleagues, friends, etc.; **Table 5.2**). Women consumed 69% of the dinners with family members, 17% alone and 14% with others. Dinners shared with others were associated with the lowest daily diet quality (men 40.6 points, women 44.9 points) and the highest daily total energy intake (men 9.8 MJ, women 8.0 MJ), they were also more often out-of-home dinners (men 68%, women 70%), and weekend days (men 41%, women 41%). Among men, family dinners were associated with the highest daily supplement intake (28%); among women with highest daily supplement intake was observed with solo dinners (41%).

Among men, shared dinners were borderline significant associated with lower daily diet quality (45.4, SE 0.3) compared to solo dinners (model 1: 46.7, SE 0.7; P=0.08; **Table 5.3**). This difference attenuated when adjusting for the covariates in model 2 (P=0.58) and model 3 (P=0.97). When dinners were shared with family members, daily diet quality was higher than when dinners were shared with others (model 1: 46.0, SE 0.3 vs. 41.8, SE 0.7; P<0.001). In model 2, the difference in daily diet quality attenuated but remained significant (46.0, SE 0.3 vs. 42.3, SE 0.7; P=0.001). When additionally adjusting for dinner location, this difference attenuated (45.7, SE 0.3 vs. 44.2, SE 0.8) and became borderline significant (P=0.08).

Table 5.1 Participants' characteristics of 895 men and 845 women of the NQplus study

	Men		Women	
Age, y (mean, SE)	54.7	0.37	49.1	0.42
BMI, kg/m² (mean, SE)	26.4	0.12	25.3	0.15
Employed* (n,%)	604	71.2	564	73.7
1-person household (n,%)	76	8.8	135	16.7
Household with children† (n,%)	267	31.3	291	36.4
Place of residence (n,%)				
Wageningen	93	10.4	149	17.6
Ede	176	19.7	286	33.8
Renkum	27	3.0	79	9.3
Arnhem	65	7.3	133	15.7
Veenendaal	534	59.7	198	23.4
Education level‡ (n,%)				
Low	125	14.2	134	16.1
Intermediate	253	28.8	248	29.8
High	500	57.0	449	54.0
Smoking** (n,%)				
Never	305	42.7	387	57.7
Former	329	46.1	233	34.7
Current	80	11.2	51	7.6
Physical active†† (n,%)	403	49.9	305	43.7

BMI: Body Mass Index
*127 missing values, †85 missing values, ‡35 missing values, **355 missing values
††Adherent to the Dutch guideline for physical activity, 235 missing values

Table 5.2 Characteristics of 6013 recalled days for categories of company at dinner among 895 men and 845 women of the NQplus study

	Men (n recalls 2938)						Women (n recalls 3075)					
	Alone		Family		Others		alone		family		others	
Recalls (n, %)	383	13.0	2209	75.2	346	11.8	531	17.3	2116	68.8	428	13.9
DHD-index (mean, SE)	46.2	0.72	46.3	0.35	40.6	0.7	51.3	0.64	49.6	0.37	44.9	0.63
Energy intake, MJ (mean, SE)	9.2	0.17	8.8	0.09	9.8	0.16	7.4	0.11	7.4	0.07	8.0	0.11
Supplement use (n, %)	79	20.6	618	28.0	77	22.3	215	40.5	774	36.6	150	35.1
Diet regime* (n, %)	16	4.3	145	6.7	20	5.9	63	12.2	225	10.9	48	11.5
Time dinner, hh:mm (mean, SE)	18:40	00:03	18:13	00:01	18:19	00:03	18:26	00:03	18:18	00:02	18:19	00:03
Dinner out-of-home (n, %)	28	7.3	120	5.4	234	67.6	30	5.7	92	4.4	301	70.3
Weekend day† (n, %)	91	23.8	632	28.6	143	41.3	141	26.6	561	26.5	174	40.7

DHD-index; Dutch Healthy Diet index
*136 missing values
†Weekend day included Saturdays and Sundays

Among women, shared dinners were associated with lower daily diet quality compared to solo dinners (model 1: 51.4, SE 0.6 vs. 48.8, SE 0.3; P<0.001). In model 2, this difference attenuated (51.1, SE 0.6 vs. 48.9, SE 0.3; P<0.001) and became borderline significant when additionally adjusting for dinner location (P=0.07). When dinners were shared with family members, daily diet quality was higher than when dinner was shared with others (model 1: 49.4, SE 0.4 vs. 45.6, SE 0.6, P<0.001). This difference remained similar when adjusting for the covariates in model 2 (49.3, SE 0.4 vs. 45.7, SE 0.6; P=0.001), but attenuated when additionally adjusting for out-of-home dinners (P=0.14).

In model 3, the association between company at dinner and daily diet quality attenuated when additionally adjusting for dinner location. Dinner location and dinner company were highly correlated (r=0.66). Hence in further analyses we excluded all days of which dinner was consumed out-of-home (382 recalls from men, 423 recalls from women) as a method to avoid confounding. In these analyses, family meals among men remained associated with higher daily diet quality compared to dinners shared with others (46.4, SE 0.3 vs. 43.7, SE 0.7; P=0.021; **Table 5.3**). Also among women, the results of model 2 were sustained; shared dinners were associated with lower daily diet quality than solo dinners (49.7, SE 0.4 vs. 51.5, SE 0.7; P=0.021), and family meals among women were associated with higher daily diet quality than when meals were shared with others (49.6, SE 0.4 vs. 47.5 SE 1.1; P=0.049).

Using model 2 and regarding the DHD-index in men, shared dinners as compared to solo dinners had a lower daily component score for vegetables and a higher daily component score for TFA (**Table 5.4**). When dinners were shared with family, daily component scores were higher for vegetable, fruit, dietary fibre, fish, TFA, and alcohol than when dinners were shared with others. Among women, shared dinners as compared to solo dinners were significantly associated with lower dietary component scores for dietary fibre, SFA and alcohol. When dinners were shared with family, daily dietary intake was significantly higher for vegetable, fruit, dietary fibre, TFA and alcohol than when dinners were shared with others.

Excluding persons who contributed less than three 24hR (944 recalls from 633 persons) did not alter the results notably. The DHD-index scores did not differ between family meals with and without children (data not shown).

Discussion

In the present analysis, we studied associations between company at dinner and daily diet quality in Dutch men and women. Among men, family dinners were associated with higher daily diet quality compared to dinners shared with others. Among women,

Table 5.3 Dutch Healthy Diet index score for categories of company at dinner among 895 men and 845 women of the NQplus study

	Alone		Shared			Family		Others		
	Mean*	SE	mean*	SE	P-value	Mean*	SE	Mean*	SE	P-value
Men										
N recalls	383		2555			2209		346		
Model 1	46.7	0.7	45.4	0.3	0.08	46.0	0.3	41.8	0.7	<0.001
Model 2	46.0	0.7	45.6	0.3	0.58	46.0	0.3	42.3	0.7	0.001
Model 3	45.6	0.7	45.6	0.3	0.97	45.7	0.3	44.2	0.8	0.08
Women										
N recalls	531		2544			2116		428		
Model 1	51.4	0.6	48.8	0.3	<0.001	49.4	0.4	45.6	0.6	<0.001
Model 2	51.1	0.6	48.9	0.3	<0.001	49.3	0.4	45.7	0.6	0.001
Model 3	50.3	0.6	49.0	0.3	0.07	48.9	0.4	47.7	0.8	0.14
Excluding dinners consumed out-of-home										
Men										
N recalls	355		2201			2089		112		
Model 2	46.1	0.8	46.3	0.3	0.77	46.4	0.3	43.7	0.7	0.021
Women										
N recalls	501		2151			2024		127		
Model 2	51.5	0.7	49.7	0.4	0.021	49.6	0.4	47.5	1.1	0.049

Model 1: Adjusted for age and energy intake
Model 2: model 1 and additionally adjusted for education level, place of residence, employment, household composition, and weekend day (sat-sun)
Model 3: model 2 and additionally adjusted for dinner out-of-home
*Adjusted mean and SE

shared dinners were associated with lower daily diet quality than solo dinners. When dinner was shared with family, diet quality was higher than when dinner was shared with others. When excluding dinners out-of-home these differences were similar, but attenuated when additionally adjusting for dinner location. These results suggest that there is a sex-specific association between company at dinner and daily diet quality.

Among women, solo dinners were associated with higher daily diet quality and a higher mean component score for TFA among men. The findings of De Castro and colleagues corroborate ours by showing that men and women who shared their meals consumed

Table 5.4 Dutch Healthy Diet index component scores for categories of company at dinner among 895 men and 845 women of the NQplus study

	Alone		Shared			Family		Others		
	Mean*	SE	Mean*	SE	P-value	Mean*	SE	Mean*	SE	P-value
Men										
N recalls	383		2555			2209		346		
Vegetables	4.4	0.2	5.1	0.1	0.003	5.2	0.1	4.1	0.2	0.001
Fruit	5.3	0.2	4.9	0.1	0.11	5.0	0.1	4.3	0.2	0.005
Dietary fibre	7.5	0.1	7.5	0.1	0.82	7.5	0.1	6.8	0.1	0.001
Fish	2.3	0.2	2.3	0.1	0.59	2.2	0.1	2.6	0.2	0.07
SFA	5.5	0.2	5.1	0.1	0.08	5.1	0.1	4.9	0.2	0.44
TFA	9.0	0.2	8.5	0.1	0.014	8.6	0.1	8.0	0.2	0.005
Sodium	3.8	0.2	3.7	0.1	0.86	3.8	0.1	3.8	0.2	0.95
Alcohol	8.5	0.2	8.5	0.1	0.86	8.6	0.1	7.8	0.1	0.001
Women										
N recalls	531		2544			2116		428		
Vegetables	6.1	0.2	5.7	0.1	0.08	5.8	0.1	5.2	0.2	0.005
Fruit	6.2	0.2	6.1	0.1	0.68	6.1	0.1	5.6	0.2	0.021
Dietary fibre	8.2	0.1	7.9	0.1	0.022	8.0	0.1	7.4	0.1	0.001
Fish	2.4	0.2	2.1	0.1	0.17	2.1	0.1	2.3	0.2	0.24
SFA	5.5	0.2	4.9	0.1	0.006	4.9	0.1	4.6	0.2	0.17
TFA	8.6	0.2	8.2	0.1	0.08	8.3	0.1	7.7	0.2	0.002
Sodium	5.2	0.2	5.3	0.1	0.62	5.3	0.1	5.0	0.2	0.13
Alcohol	9.1	0.1	8.5	0.1	0.001	8.7	0.1	8.0	0.1	0.001

SFA: saturated fatty acids; TFA: trans fatty acids
*Adjusted for age, energy intake, education level, place of residence, employment, household composition, and weekend day (sat-sun)

44% more energy by higher consumption of fat and carbohydrates compared to participants who consumed their meal alone[17]. On the one hand this increased energy intake may result from increased meal duration, resulting in longer exposure time and thereby larger intakes[18, 19]. On the other hand, individuals who consumed their meal alone may be less distracted from their meals and thus pay more attention, resulting in lower intakes[17, 18]. Nevertheless, De Castro *et al.* reported the total amount of the meal and did not focus on the overall diet quality of that day. More research is, therefore, needed to examine the possible mechanism of the association between shared meals and diet quality.

When comparing family dinners with dinners shared with others (i.e. friends, colleagues), family meals were associated with higher daily diet quality in men and women. De Castro[18] observed differences between family members, friends, and others, showing the largest and of longest duration for meals that were consumed with friends. They suggested that family members and friends, compared to others, let participants feel more comfortable and relaxed, resulting in larger intake[18]. Another study showed no association between types of company (i.e. alone, family or friends) with diet quality in Canadian adolescents[8]. Due to these discrepancies, more research is needed to confirm the possible unfavourable association of the presence of non-family members on diet quality.

In the present study, we observed that the association between company at dinner and daily diet quality differed between men and women. Among women, shared dinners were associated with lower daily quality compared with solo dinners, whereas among men it was not. These sex differences may be explained by the observation that men may be less sensitive to environmental influences as company at dinner than women[20]. Larson and colleagues also observed differences between gender, showing associations between frequency of shared meals and more favourable intakes of fruit, sugar-sweetened beverages, fibre, iron, calcium potassium and folate for fathers, but not for mothers[21]. Using qualitative research methods, it was suggested that food choices of men were more influenced by taste whereas the food choices of women were more influenced by quality, health and family preferences[22]. Furthermore, it was suggested that women are more likely to serve food preferred by their partner and children than their own often more health- conscious food choices[22-24].

The present study examined the association between company at dinner and diet quality for that specific day. It could be speculated that this association would be stronger when examining the quality of the dinner as such. However, there are no dietary recommendations regarding specific meals. Furthermore, food intake is a dynamic process and individuals can adjust their dietary intake throughout the day according to special occasions[25]. Therefore, we feel that it is more important to study the impact of sharing dinners on diet quality for the entire day.

The associations between company at dinner and daily diet quality disappeared when additionally adjusting for dinner location. Dinners consumed out-of-home have been associated with lower diet quality[26] and therefore this variable was included as a confounder in the model. Nevertheless, when excluding all dinners consumed away from home, we observed significant associations between company at dinner and daily diet quality. The mean differences were comparable, although somewhat weaker, than the ones without adjustment for dinner location. Place and company at dinner were highly correlated (r=0.66), hence including dinner location in the model may have introduced over-adjustment. In conclusion, company of meals was associated with daily diet quality independently from dinner location.

A limitation of the present study may have been the new web-based administration mode of the 24hR, which was not yet validated. Suggested limitations of web-based 24hR are the requirement of computer literacy and skills and the possibility of increased reporting and memory bias[27]. Toevier and colleagues[28] observed energy-adjusted correlations ranging between 0.58 to 0.93, when comparing nutrient intakes from the web-based NutriNet Santé dietary records with recalls conducted by a dietician on the same day. The Automated Self-Administered (ASA) 24h dietary recall developed by the National Cancer Institute showed moderate correlations ranging between 0.38 to 0.61 when comparing estimated nutrient intake to those assessed by four food records and was considered valid[29]. In the NQplus study, a subsample of the population (n=344) also completed three telephone-based 24hR. The correlation between the DHD-index based on three telephone-based 24hR and based on three web-based 24hR was considered moderate (r=0.48), but in similar range as for ASA-24. The web-based administration showed somewhat lower diet quality scores, but based on these results we do not expect that the administration method affected our results notably.

Another limitation is that we cannot rule out the possibility of residual confounding due to measurement errors or unmeasured covariates. For example, we did not have information on who prepared dinner (e.g. participant, partner, ready-made), or the presence of distraction from eating other than company (e.g. watching television), which could have confounded the observed associations.

Strength of the present study was the large number of recalls from a general Dutch population. Moreover, dietary data and information on the presence of others during meals was collected for the same day, making it possible to study the direct impact for that specific day instead of studying frequency of shared meals as was done previously[5, 8, 21]. Furthermore, most participants (82%) contributed multiple recalls through which both within-person and between-person variation could be accounted for. Lastly, to the best of our knowledge we are the first to study the association between sharing dinners and overall diet quality in a European population.

In conclusion, we showed that company at dinner was associated with daily diet quality, differently for men and women; among men the lowest daily diet quality was observed for dinners shared with other, and among women the highest daily diet quality was seen for solo dinners. Excluding out-of-home dinners showed similar results but most results attenuated when additionally adjusting for dinner location, suggesting that place and company of dinner have a joined impact on daily diet quality. Future research should confirm the present results in other populations.

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EVALUATION OF A SHORT FOOD FREQUENCY QUESTIONNAIRE TO ASSESS DIET QUALITY IN THE NETHERLANDS

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Abstract

Generally, there is a need for short questionnaires to estimate diet quality in the Netherlands. We developed a 34-item food frequency questionnaire (FFQ), the DHD-FFQ, to estimate adherence to the current Dutch dietary guidelines using the Dutch Healthy Diet index (DHD-index). The objective was to evaluate the DHD-index derived from the DHD-FFQ by comparing it to the index based on a reference method and to examine associations with participants' characteristics, nutrient intakes and levels of cardio-metabolic risk factors. Data of 1235 Dutch men and women, aged between 20 and 70 years, participating in the NQplus study were used. The DHD-index was calculated from the DHD-FFQ and from a reference method consisting of a 180-item FFQ and a 24-hour urinary sodium. Ranking was studied using Spearman correlations coefficients and absolute agreement was studied with a Bland-Altman plot. Nutrient intakes derived from the 180-item FFQ were studied according to quintiles of the DHD-index using DHD-FFQ data. The correlation between the DHD-index derived from the DHD-FFQ and derived from the reference method was 0.56 (95% CI 0.52-0.60). The Bland-Altman plot showed a small mean overestimation of the DHD-index derived from the DHD-FFQ compared to the reference method. Associations in expected direction between the DHD-index score and most macro- and micronutrient intakes were observed when adjusting for energy intake. Weak inverse associations of the DHD-index score with fasting triglycerides and Hba1C were observed. In conclusion, the DHD-index derived from the DHD-FFQ is able to rank and monitor individuals according to their diet quality and to identify subpopulations at high risk.

Introduction

Nutrition is an important risk factor in the development of chronic diseases such as cardiovascular diseases, diabetes, and several cancers[1]. To decrease the risk of chronic diseases, dietary guidelines were developed on the basis of scientific evidence[2]. When developing public health interventions or health education programs, it is important to monitor the adherence to dietary guidelines. Moreover, monitoring adherence to dietary guidelines can also be useful for identification of individuals with a low diet quality in clinical settings such as the general practitioners practice.

Recently, the Dutch Healthy Diet index (DHD-index) was developed that comprises ten components representing the current Dutch dietary guidelines on physical activity, vegetable, fruit, dietary fibre, fish, consumption occasions with acidic drinks and foods, saturated fatty acids (SFA), *trans* fatty acids (TFA), sodium, and alcohol[2, 3]. Since the DHD-index score was in favourably direction associated with several micronutrient intakes, and biomarkers of dietary intake[3, 4], it was considered a useful tool to assess diet quality in the Dutch population. Calculation of the DHD-index requires data on dietary intake for instance assessed by multiple 24-hour recalls, food diaries or a food frequency questionnaire (FFQ). Unfortunately, these dietary assessment methods are time-consuming and therefore less likely to be used in everyday clinical and public health practice. In these situations, there is need for a method that quickly assesses diet quality of individuals[5]. To date, short food questionnaires have been developed for the Mediterranean diet[6, 7] and for the American diet[8, 9]. However, no fast method to assess diet quality according to the Dutch dietary guidelines was available. Therefore, we developed a short FFQ, entitled the DHD-FFQ, to estimate the DHD-index score for ranking individuals based on their diet quality.

The objective of the present study was to evaluate the DHD-index derived from the DHD-FFQ. For this, we examined correlations and the absolute agreement between the DHD-index and its components based on the DHD-FFQ to those based on a reference method. The reference method consisted of a full length FFQ combined with a 24-hour urinary sodium value. Correlation coefficients of 0.4 or higher were previously considered acceptable[6, 8, 10]. Secondly, we examined associations of the DHD-index based on the DHD-FFQ with participants' characteristics, and energy and nutrient intakes derived from the full length FFQ. Thirdly, we compared the associations between cardio-metabolic risk factors and the DHD-index score derived from the DHD-FFQ with the score derived from the reference method.

Methods

Study population and design

The Nutrition Questionnaires plus (NQplus) study is a 3-year observational study in the general Dutch population. It was designed for multiple aims: to validate a newly developed FFQ, to start a reference database for nutrition research and to study associations between diet and intermediate health outcomes. Between May 2011 and December 2013, recruitment was done by sending letters and e-mails to randomly selected inhabitants of Wageningen, Renkum, Ede, and Arnhem and to one person per household in Veenendaal. Inclusion criteria were aged between 20-70 years and able to speak and write Dutch. Participants were randomly assigned to the so-called 'FFQ-group' who were invited to fill out the newly-developed FFQ or to the so-called 'recall-group' who were invited to fill out several 24-hour dietary recalls. The NQplus study was approved by the Medical Ethics Committee of Wageningen University and was conducted according to the guidelines laid down in the declaration of Helsinki. All participants gave written informed consent before the study started.

Baseline measurements consisted of dietary assessment, physical measurements (e.g. height, weight, blood pressure), venipuncture, a 24-hour urine collection, general questionnaires (e.g. demographics, history of disease), and lifestyle questionnaires including physical activity (Short QUestionnaire to ASses Health enhancing physical activity)[11]. Physical activity level was classified as adherent or non-adherent to the Dutch physical activity guideline of being moderate physical active for at least 5 days per week for 30 minutes[2]. Medication use was determined and classified according to the Anatomical Therapeutic Chemical (ATC) classification system.

The full length FFQ was administered one month after the start of the study for the participants assigned to the 'recall group' or in July - August 2013 for the participants assigned to the 'FFQ group'. The DHD-FFQ was administered in both groups between June and October 2013. Both FFQs were administered online using the open-source survey tool Limesurvey™ (LimeSurvey Project Team / Carsten Schmitz. Hamburg, Germany, 2012). The FFQs were administered with at least one month in between (median range: 3.4 months, interquartile range 11.9 months). Order of administration was dependent on progress within the NQplus study; 27% of the participants filled out the DHD-FFQ before the 180-item FFQ.

Dietary assessment

DHD-FFQ

The DHD-FFQ was developed using the Dutch FFQ-TOOL™[12] using data of the Dutch

National Food Consumption Survey (DNFCS) 2007-2010[13] as a reference. This tool was developed to generate and process FFQs using reproducible and valid procedures[12]. The DHD-index components physical activity and consumption occasions with acidic drinks and foods cannot be assessed with most FFQs, therefore, we did not take these components into account during development of the DHD-FFQ. The food items that contributed most to the level of the following nutrient intakes were selected: dietary fibre, SFA, TFA, and sodium. This procedure of selecting food items based on their percentage contribution to the absolute nutrient intake in a reference population was suggested by Willett[14] and refers to the first MOMent (MOM1) of the intake of a nutrient[15]. Additionally, the food items representing the food groups vegetable, fruit, fish and alcohol were included. Furthermore, sodium intake was separated in two parts: sodium intake from foods and discretionary salt; two questions on discretionary sodium were included to estimate salt or sodium-rich products (i.e. soy sauce and soup flavouring) added during cooking and at the table. This resulted in a list of 34 food items, which together accounted for 73% of total dietary fibre intake, 70% of total SFA intake, 81% of total TFA intake, and 73% of total sodium from foods intake within the adult population of the DNFCS 2007-2010 (**Table 6.1**). The percentage between-person variability explained by the selected 34 food items, the so-called second MOMent (MOM2) of the nutrient intake distribution[15], was 73% for dietary fibre, 71% for SFA, 88% for TFA and 76% for sodium. In total, the DHD-FFQ comprises 25 questions, representing the 34 items, on intakes of bread, fruit, vegetable, potatoes, milk, cheese, meat, meat products, fish, cookies, pastries, crisps, soup, fats and oils, Asian foods, pizza, alcoholic beverages and discretionary sodium. The answer categories for the frequency questions ranged from ‘never’ to ‘every day’. Portion sizes were assessed in natural portions or commonly used household measures as glasses or bowls. Nutrient intakes were estimated by multiplying the portion sizes with the frequency of intake and nutrient content per gram using the Dutch food composition table of 2011[16]. All food items were used to calculate the intakes of dietary fibre, SFA, TFA and sodium.

Face validity of questions and answer categories was evaluated in a research panel of 688 Dutch persons. Based on these results, questions were optimized. Mean estimated time to administer the DHD-FFQ was 7.8 (SD 5.6) minutes in these 688 persons and was considered acceptable.

Full length FFQ

The 180-item semi-quantitative FFQ was used to assess habitual dietary intake and was validated for energy intake, macronutrients, dietary fibre and selected vitamins[17-19]. Answer categories for frequency questions ranged between ‘never per month’ to ‘six to seven days per week’ and portion sizes were estimated using natural portions and

Table 6.1. Selection of food items for development of the DHD-FFQ

	DHD-index components							
	Vegetable	Fruit	Dietary fibre	Fish	SFA	TFA	Sodium	Alcohol
Bread*			X				X	
Fruit		X	X					
Cooked vegetables	X		X					
Raw vegetables	X		X					
Potatoes			X					
Milk†					X			
Cheese at dinner†					X		X	
Cheese other†					X		X	
Meat					X			
Meat products					X		X	
Fish at dinner†				X				
Fish other				X				
Cookies						X		
Cake and pastries						X		
Crisps						X		
Soup							X	
Fats and oils‡					X	X		
Asian foods							X	
Pizza							X	
Fruit juice		X						
Alcohol								X
Discretionary sodium**							X	
MOM1†† (%)	100	100	73	100	70	81	73	100
MOM2†† (%)	100	100	73	100	71	88	76	100

SFA: saturated fatty acids, TFA: trans fatty acids, MOM1: percentage of absolute intake estimated by the DHD-FFQ, MOM2: percentage of between-person variability estimated by the DHD-FFQ
X = selected for estimation of nutrient or food group
*Included items on wholegrain and white bread
†Included items on low-fat and high fat food items
‡Included items on butter (2x), margarine, semi-fat margarine, cooking fat, low-fat cooking fat and oils
**Added sodium during cooking or at table
††Data of the Dutch national food consumption survey 2007-2010 was used as reference

commonly used household measures. Average daily nutrient intakes were calculated by multiplying frequency of consumption by portion size and nutrient content per gram using the Dutch food composition table of 2011[16].

24-hour urinary sodium

Sodium intake was assessed using a 24-hour urine collection, the gold standard method[20]. Para-aminobenzoic acid (PABA) was used as check for completeness of the urinary collections and measured using HPLC method[21] (laboratory Division of Human Nutrition, Wageningen University, the Netherlands). PABA is assumed to be excreted almost quantitatively within 24 hours and a urine with a recovery of at least 78% (187 mg) of the 3*80mg ingested PABA was considered a complete urine collection[21]. Nine urine samples with PABA recoveries below 50% were excluded from the data analyses. Recoveries between 50% and 78% (n=121) were proportionally adjusted to the mean PABA recovery of 88% using linear regression equations as was suggested by others[22, 23].

Urinary sodium was measured by an ion-selective electrode from a Roche/Hitachi 917 analyser[20] at SHO in Velp, the Netherlands. Total 24-hour sodium excretion was calculated by multiplying total weight of collected urine by sodium concentration. Additionally, this was divided by 0.86, assuming that 86% of sodium intake is excreted in the urine[24].

DHD-index

The scoring for the DHD-index has been described in detail elsewhere[3, 4] and has been summarized in **table 6.2**. Briefly, for the components vegetable, fruit, dietary fibre and fish, no intake resulted in a component score of zero points. Intakes equal to or above the cut-off values representing the dietary guidelines received the maximum of ten points. For the components SFA, TFA, sodium and alcohol, intakes below the cut-off values received the maximum of ten points. A score of zero points was assigned when intake was higher than the binge drinking threshold values for the alcohol component[25] or higher than the threshold values representing the 85th percentiles of the intakes of a Dutch reference population[13] for the components SFA, TFA and sodium. Scores between zero and 10 points were calculated proportionally, except for TFA that was scored dichotomously. The summed total score could range between 0 (no adherence) to 80 (complete adherence).

Since the DHD-FFQ was not designed to estimate total energy intake, the DHD-index scoring had to be slightly adapted, when it was applied to the DHD-FFQ data. The cut-off and threshold values for the energy dependent components dietary fibre, SFA, and TFA were calculated using sex-specific average energy requirements (10.5 MJ for men and 8.4 MJ for women)[26]. These sex-specific average energy requirements and sodium cut-off values were proportionally lowered matching the percentage coverage of total energy intake as assessed by the DHD-FFQ (6.7 MJ for men and 5.4 MJ for women) to arrive at cut-off and threshold values that were appropriate for the estimated dietary intake assessed by the DHD-FFQ (**Table 6.2**). Furthermore, score for sodium intake was separated in two parts. The answers on discretionary sodium contributed three points based on the assumption that about 30% of total sodium intake is from added salt[27, 28]. Sodium intake from foods contributed the remaining seven points. Lastly, the fish component score was based on the frequency of lean or oily fish intake instead of fish fatty acid intake.

Cardio-metabolic risk factor assessment

Physical examination

All physical measurements were performed by trained research assistants following a standardized protocol. Height and waist circumference were measured to the nearest 0.5 centimetre using a stadiometer (SECA, Germany) and a non-flexible tape,

Table 6.2. Cut-off and threshold values for calculation of the DHD-index component scores for the reference method and the DHD-FFQ

	Reference method*		DHD-FFQ	
	Min points (=0)	Max. points (=10)	Min points (=0)	Max. points (=10)
Vegetable	0 g	≥ 200 g	0 g	≥ 200 g
Fruit	0 g	≥ 200 g	0 g	≥ 200 g
Fibre	0 g / 4.2 MJ	≥ 14 g / 4.2 MJ	0 g	♂: ≥ 22.40 g‡ ♀: ≥ 17.92 g‡
Fish	0 mg EPA+DHA	≥ 450 mg EPA+DHA	0 times fish / week	2 times fish/week
SFA	≥ 15 en%	< 10 en%	♂: ≥ 26.67 g ♀: ≥ 21.33 g	♂: < 17.78 g‡ ♀: < 14.22 g‡
TFA	≥ 1 en%	< 1 en%	♂: ≥ 1.78 g ♀: ≥ 1.42 g	♂: < 1.78 g‡ ♀: <1.42 g‡
Sodium	≥ 3600 mg	< 2400 mg	≥ 2304 mg†	< 1536 mg†
Alcohol	♂: ≥ 60 g ♀: ≥ 40 g	♂: ≤ 20 g F: ≤ 10 g	♂: ≥ 6 drinks ♀: ≥ 4 drinks	♂: ≤ 2 drinks ♀: ≤ 1 drink

*Full length FFQ combined with a 24-hour urinary sodium value
†Sodium from foods accounted for a maximum of 7 points, and discretionary sodium for a maximum of 3 points
‡Cut-off values were calculated with sex-specific average energy requirements times coverage of energy intake assessed by the DHD-FFQ (M:6.7 MJ, F:5.4 MJ)

respectively. Participant's weight was measured to the nearest 0.1 kg on a digital scale while wearing light clothing without shoes (SECA, Germany or Tanita Corporation, the Netherlands). After 10 minutes of rest, blood pressure (IntelliSense HEM-907, Omron Health Care, USA) was measured six times on the left arm with two minutes rest in between the measurements. The first blood pressure measurement was discarded for validity reasons, the five remaining blood pressure measurements were averaged.

Blood sampling and analyses

Participants underwent a venipuncture in fasting state at the hospital in Ede or Velp, the Netherlands. Blood sample analyses were done in the accompanying hospital laboratories. Both laboratories joined an external quality control program and used the same methodology and protocols for risk factor assessments. Total cholesterol, high-density lipoprotein cholesterol (HDL), and fasting triglycerides were determined with enzymatic methods[29] using a Siemens Dimension Vista 1500 automated analyser in Ede and a Hitachi Modular P800 Chemistry Analyser in Velp. Haemoglobin A1C (HbA1C) was determined with HPLC measurement technology using an ADAMS A1c 8160 analyser (Siemens, Germany) at both locations.

Data analyses

Complete data from the 180-item FFQ and the DHD-FFQ were available for 1247 participants. We excluded 12 participants who were pregnant or had a non-fasting blood sample, resulting in a total sample of 1235 participants.

Mean (SD) scores of the DHD-index and its components calculated from the DHD-FFQ and the reference method were presented. Spearman correlations coefficients were calculated between scores derived from the reference method and from the DHD-FFQ to examine agreement in ranking of participants. Confidence intervals for these correlations were obtained using Fisher Z-transformation. Agreement of the DHD-index score between the two methods was examined by a Bland-Altman plot[30].

Participants' characteristics, and energy, macro- and micronutrient intakes estimated from the full length FFQ were examined according to quintiles of the DHD-index score derived from the DHD-FFQ. We adjusted macro- and micronutrient intakes for energy intake estimated from the full length FFQ as well as for energy intake estimated from the DHD-FFQ. Linear trends across the quintiles were examined using general linear models.

Furthermore, partial Spearman correlations between the DHD-index and the cardio-metabolic risk factors total cholesterol, HDL-cholesterol, triglycerides, HbA1C, and systolic and diastolic blood pressure were examined adjusting for age, sex, smoking (never, former, current) and adherence to physical activity guideline (y/n). We additionally adjusted for BMI as a potential intermediate. Missing values for the covariates education level (n=11), smoking (n=86) and physical activity (n=90) were imputated for five times and results were pooled using the MIANALYZE procedure in SAS. Participants using medication for diabetes mellitus, hypertension, or dyslipidemia (ATC codes: A10, C1-C9, C10) were excluded from the analyses when examining the association between diet quality and cardio-metabolic risk factors (n=29, n=180, n=110, respectively). All analyses were done with SAS statistical software version 9.3 (SAS Institute Inc.) and statistical significance was set at P<0.05.

Results

The mean DHD-index score based on DHD-FFQ data was 57.6 (SD 9.6) out of a possible total score of 80 points, and was similar to the score using the reference method consisting of a full length FFQ combined with a urinary sodium value (mean 54.0, SD 10.1; **Table 6.3**). The Spearman correlation between the two scores was 0.57 (95% CI 0.53, 0.60). When comparing the mean DHD-index component scores between the reference method and the DHD-FFQ, the smallest absolute difference was seen for the fibre component (8.2 vs. 7.8 points) and the largest absolute difference was seen for the sodium component (2.4 vs. 6.3 points). The lowest correlation was observed for the component TFA (r=0.09, 95% CI 0.03, 0.14). For the components fibre, SFA, and sodium, correlations ranged between 0.2 and 0.4 whereas for the components vegetable fruit, fish, and alcohol the correlations were 0.5 and higher.

Absolute agreement was studied using a Bland-Altman plot and accompanying limits of agreement (**Figure 6.1**). The mean difference, the DHD-index score based on the reference method minus the DHD-index score based on the DHD-FFQ, was -3.6 points, and limits of agreement were -21.7 and 14.5 points. The DHD-index based on the DHD-FFQ showed an overestimation in the lower scores and an underestimation in the higher scores when compared to the DHD-index based on the reference method.

Positive associations were observed between the DHD-index score derived from DHD-FFQ data and age (P for trend <0.001), following a diet regime (P for trend=0.001), supplement use (P for trend<0.01), and antihypertensive medication use (P for trend=0.035; **Table 6.4**). Furthermore, participants in the higher quintiles were less likely to be men than those in the lower quintiles. For the participants' characteristics BMI, smoking, education level, adherence to the physical activity guideline, use of lipid modifying drugs and diabetic drugs, no association with the DHD-index was observed.

Table 6.3. Mean, SD and Spearman correlations (95% CI) of the DHD-index and its component scores using reference data and DHD-FFQ data in 1235 participants of the NQplus study

	Reference method*		DHD-FFQ				
	Mean	SD	Mean	SD	R	95% CI	
DHDI†	54.0	10.1	57.6	9.6	0.57	0.53	0.60
Vegetable	7.0	2.7	6.7	2.6	0.54	0.50	0.58
Fruit	7.2	3.4	8.0	2.7	0.66	0.63	0.69
Fibre	8.2	1.4	7.8	1.9	0.31	0.26	0.36
Fish	4.1	2.9	5.5	3.2	0.61	0.57	0.64
SFA	6.1	3.4	5.5	4.0	0.38	0.33	0.43
TFA	9.9	1.0	9.2	2.7	0.09	0.03	0.14
Sodium	2.4	3.7	6.3	2.8	0.24	0.19	0.29
Alcohol	9.2	1.9	8.6	2.7	0.58	0.54	0.61

SFA: saturated fatty acids, TFA: *trans* fatty acids
*Full length FFQ combined with a urinary sodium value
†Excluding the components physical activity and consumption occasions with acidic drinks and foods

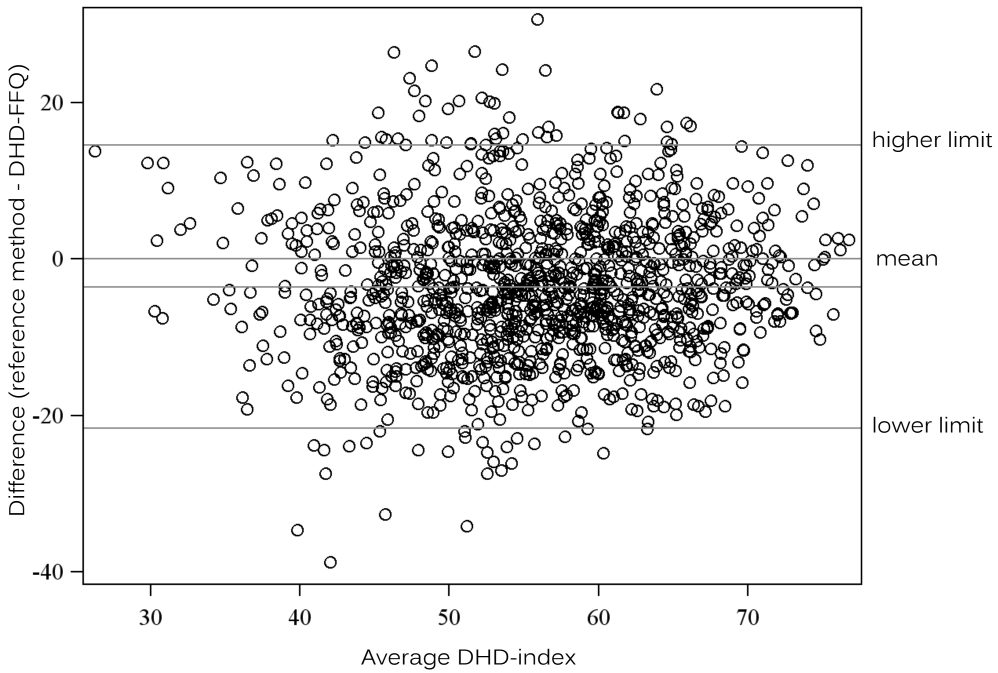

Figure 6.1. Bland-Altman plot of the DHD-index based on the DHD-FFQ and the DHD-index based on the reference method consisting of a full length FFQ combined with a urinary sodium value in 1235 participants of the NQplus study.

Intakes of energy, carbohydrates, protein, total fat, and alcohol derived from the full-length FFQ were inversely associated with the DHD-index score based on DHD-FFQ, whereas dietary fibre intake was positively associated (**Table 6.5**). When additionally adjusting for energy intake estimated from the full length FFQ, the intake of total fat and alcohol remained inversely associated with the DHD-index, whereas the intake of carbohydrates, and fibre became positively associated. Similar trends were observed when adjusting for energy intake estimated from the DHD-FFQ, except for carbohydrates where the positive association disappeared.

Regarding the intakes of micronutrients, calcium, vitamin A, vitamin B_1, vitamin B_2, and vitamin B_{12} were inversely associated with the DHD-index score whereas the micronutrients folate and vitamin C were positively associated and vitamin E was not associated (**Table 6.6**). When additional adjusting for energy intake estimated from

Table 6.4. Selected characteristics across quintiles of the DHD-index based on the DHD-FFQ in 1235 participants of the NQplus study

	Quintiles DHD-index derived from the DHD-FFQ						
	Q1 (n=247)		Q3 (n=247)		Q5 (n=247)		P for trend
Men (n, %)	139	56.3	121	49.0	105	42.5	0.001
Age, y (mean, SD)	50.5	11.9	54.1	11.3	55.8	10.0	<0.001
BMI, kg/m² (mean, SD)	25.8	4.1	25.7	3.6	25.2	3.8	0.218
Diet regime (n,%)	5	2.0	8	3.2	21	8.5	0.001
Supplement use (n,%)	89	36.0	91	36.8	125	50.6	<0.001
Smoking* (n, %)							0.062
Never	126	51.0	122	49.4	121	49.0	
Former	90	36.4	109	44.1	112	45.3	
Current	31	7.9	16	6.5	14	5.7	
Education* (n,%)							0.634
Low	36	14.6	43	17.4	36	14.6	
Intermediate	70	28.3	70	28.3	73	29.6	
High	140	56.7	134	54.3	138	55.9	
Physical activity* (n, %)	119	48.2	107	43.3	106	42.9	0.675
Medication use (n, %)							
Lipid modifying drugs	20	8.1	23	9.3	25	10.1	0.778
Diabetic drugs	5	2.0	8	3.2	5	2.0	0.895
Anti-hypertensive drugs	24	9.7	33	13.4	42	17.0	0.035

Cut-off values for quintiles: 49.5, 55.8, 60.6, 65.8
*Frequencies and percentages are estimated based on five imputations

the full length FFQ, the association with intakes of calcium and vitamin A disappeared, whereas all other micronutrients became positively associated across quintiles of the DHD-index score. Similar positive trends were observed for most micronutrients, when adjusting for energy intake estimated from the DHD-FFQ.

The DHD-index score derived from the reference method was inversely associated with fasting triglycerides (P<0.01; **Table 6.7**) and HbA1C (P<0.05) when adjusting for age, sex, smoking, physical activity level and energy intake. After additionally adjustment for BMI, the associations disappeared. The DHD-index derived from the DHD-FFQ was borderline inversely associated with fasting triglycerides and HbA1C when adjusting for age, sex, smoking, physical activity (P<10). After additional adjustment for BMI, the association with fasting triglycerides disappeared and the association with HbA1C remained similar (P=0.10).

Table 6.5. Macronutrient intakes estimated from the full length FFQ across quintiles of the DHD-index based on the DHD-FFQ in 1235 participants of the NQplus study

	Quintiles DHD-index derived from the DHD-FFQ						
	Q1 (n=247)		Q3 (n=247)		Q5 (n=247)		
	Mean	SEM	Mean	SEM	Mean	SEM	P for trend
Energy (MJ)	9.2	0.2	8.4	0.1	7.6	0.1	<0.001
Carbohydrates (g)	229.6	5.0	217.9	4.3	199.6	3.8	<0.001
Model 1	210.5	1.8	219.1	1.8	220.1	1.8	<0.001
Model 2	211.8	3.7	218.1	3.6	219.6	6.7	0.163
Protein (g)	77.8	1.4	72.5	1.3	67.9	1.2	<0.001
Model 1	72.5	0.6	72.9	0.6	76.6	0.6	0.228
Model 2	72.4	1.1	72.6	1.0	73.9	1.1	0.534
Total Fat (g)	89.5	2.2	78.5	1.6	69.6	1.7	<0.001
Model 1	81.6	0.7	79.0	0.7	78.0	0.8	0.001
Model 2	83.5	1.6	78.5	1.6	76.2	1.6	0.001
Fibre (g)	22.9	0.5	23.4	0.5	24.8	0.5	0.001
Model 1	21.2	0.3	23.5	0.3	26.6	0.3	<0.001
Model 2	21.2	0.4	23.4	0.4	26.7	0.4	<0.001
Alcohol (g)	14.2	1.0	10.1	0.6	8.2	0.7	<0.001
Model 1	13.1	0.8	10.1	0.8	9.3	0.8	<0.001
Model 2	14.2	0.8	10.1	0.8	8.2	0.8	<0.001

Model 1: Adjusted for energy intake estimated by full length FFQ
Model 2: Adjusted for energy intake estimated by DHD-FFQ

Table 6.6 Micronutrient intakes estimated from the full length FFQ across quintiles of the DHD-index based on the DHD-FFQ in 1235 participants of the NQplus study

	Quintiles DHD-index derived from the DHD-FFQ						
	Q1 (n=247)		Q3 (n=247)		Q5 (n=247)		
	Mean	SEM	Mean	SEM	Mean	SEM	P for trend
Calcium (mg)*	979.0	25.1	933.9	20.5	885.2	19.0	0.001
Model 1	917.0	17.2	937.9	17.0	951.7	17.2	0.085
Model 2	916.0	19.8	934.4	19.4	956.1	19.9	0.151
Vitamin A (RAE)*	1038.2	44.9	930.6	32.4	900.3	30.3	0.001
Model 1	964.0	34.5	935.4	34.2	980.0	34.5	0.886
Model 2	949.4	36.1	931.4	35.3	1000.3	36.3	0.692
Folate (µg)*	254.2	5.8	265.5	6.1	291.2	6.0	<0.001
Model 1	237.6	4.7	266.6	4.6	309.1	4.7	<0.001
Model 2	237.2	5.4	265.7	5.3	310.4	5.4	<0.001
Vitamin B_1 (mg)*	1.03	0.02	1.00	0.02	0.93	0.02	<0.001
Model 1	0.96	0.01	1.00	0.01	1.01	0.01	0.001
Model 2	0.96	0.02	1.00	0.02	1.01	0.02	0.055
Vitamin B_2 (mg)*	1.48	0.03	1.44	0.03	1.37	0.03	0.001
Model 1	1.38	0.02	1.45	0.02	1.48	0.02	0.007
Model 2	1.38	0.03	1.44	0.03	1.49	0.03	0.028
Vitamin B_6 (mg)*	1.60	0.03	1.55	0.03	1.55	0.03	0.247
Model 1	1.48	0.02	1.56	0.02	1.68	0.02	<0.001
Model 2	1.49	0.03	1.55	0.03	1.67	0.03	<0.001
Vitamin B_{12} (µg)*	4.2	0.1	4.0	0.1	4.0	0.1	0.096
Model 1	4.0	0.1	4.0	0.1	4.3	0.1	0.046
Model 2	4.0	0.1	4.0	0.1	4.4	0.1	0.062
Vitamin C (mg)*	57.5	2.1	87.5	2.4	98.5	2.5	<0.001
Model 1	64.1	2.1	87.7	2.1	103.2	2.1	<0.001
Model 2	64.3	2.3	87.5	2.2	103.3	2.3	<0.001
Vitamin E (mg)*	13.0	0.3	12.7	0.3	12.5	0.3	0.210
Model 1	11.9	0.2	12.8	0.2	13.8	0.2	<0.001
Model 2	12.0	0.3	12.7	0.3	13.7	0.3	<0.001

RAE; Retinol Active Equivalents (µg)
Model 1: Adjusted for energy intake estimated by full length FFQ
Model 2: Adjusted for energy intake estimated by DHD-FFQ
*Crude assocations

Discussion

In the present study, we evaluated the DHD-index derived from the DHD-FFQ and compared it to the DHD-index derived from a full length FFQ combined with a 24-hour urinary sodium value. The DHD-FFQ was designed to estimate diet quality in time-limited situations such as clinical or public health practice where full length FFQs are impractical to use. We showed that the DHD-index derived from the DHD-FFQ was acceptably correlated with the DHD-index derived from the reference method. Absolute agreement, as studied by the Bland-Altman plot, showed a small mean overestimation of the DHD-index score derived from the DHD-FFQ as compared to the reference method.

Table 6.7. Spearman correlation coefficients between cardio-metabolic risk factors and the DHD-index derived from the DHD-FFQ and from the reference method in participants of the NQplus study.

	Total cholesterol†	HDL cholesterol†	Triglycerides†	Hba1C‡	SBP††	DBP††
Reference method‡‡						
Model 1	-0.03	0.03	-0.08**	-0.05*	-0.04	-0.06
Model 2	-0.03	-0.03	-0.04	-0.03	-0.01	-0.01
DHD-FFQ						
Model 1	-0.01	0.02	-0.04	-0.06	-0.03	-0.05
Model 2	-0.02	0.01	-0.03	-0.05	-0.02	-0.04

SBP: systolic blood pressure, DBP: diastolic blood pressure
Model 1: adjusted for age, sex, smoking, physical activity and energy intake estimated by accompanying FFQ
Model 2: model 1 and additionally adjusted for BMI
*P<0.05, **P<0.01
†Excluding 110 lipid modifying agent users, mmol/L
‡Excluding 29 diabetic drugs users, mmol/mol
††Excluding 180 anti-hypertensive drugs users, mmHg
‡‡Full length FFQ combined with a urinary sodium value

Furthermore, the DHD-index score derived from the DHD-FFQ was positively associated with age, frequency of antihypertensive drugs use, most micronutrient intakes, and inversely associated with energy intake, while fasting triglycerides and HbA1C were non-significantly weakly associated.

We observed a Spearman correlation of 0.57 (95% CI 0.53, 0.60) between the DHD-index score based on the DHD-FFQ data and the reference method, which was considered acceptable when assuming a maximum achievable correlation ranging between 0.66-0.72. This maximum achievable strength of the correlation was based on the reproducibility of the DHD-index derived from a full length FFQ after 1 year (r=0.69, 95% CI 0.64, 0.74), the reproducibility of the Starting The Conversation screener (r=0.66)[5] and the reproducibility of the Diet Quality Index Revised (r=0.72)[31]. The observed correlation in the present study was comparable to that of Schröder *et al.*[6] who observed a Pearson correlation coefficient of 0.52 comparing compliance to the PREDIMED dietary intervention derived from the 14-item Mediterranean Diet Adherence Screener and a 137-item FFQ. In another study by Schröder *et al.*[10], a Pearson correlation coefficient of 0.61 was observed comparing the Diet Quality Index derived from the Short Diet Quality Screener and derived from ten 24-hour recalls. Furthermore, a correlation of 0.40 was observed for the 'Modified Mediterranean Diet Score' derived from the 'Brief Mediterranean Diet Score Screener' compared to the score derived from ten 24-hour recalls[10].

Absolute agreement using the Bland-Altman plot showed a small mean overestimation of the DHD-index score derived from the DHD-FFQ compared to the DHD-index score derived from the reference method. Diet quality estimated by the DHD-FFQ was therefore considered acceptable on a group level. The Bland-Altman plot showed furthermore relatively wide limits of agreement. More extensive dietary assessment methods may therefore be needed when using individual scores for follow-up activities as dietary advice. Taking together the results from ranking and absolute agreement, the results suggests that the DHD-index score based on DHD-FFQ data can be used for ranking of participants and identification of high risk subpopulations according to their diet quality.

For the components dietary fibre, SFA, and TFA, the correlations between the DHD-index score based on the DHD-FFQ data and the reference method were lower than the expected value of 0.4. These low correlations could be explained by the lower percentages of MOM2 (71-88%) covered by the DHD-FFQ for these components compared to MOM2 (100%) for fruit, vegetable, fish and alcohol. The full-length FFQ showed considerable higher MOM2 percentages for the nutrients dietary fibre, SFA and TFA (>97%). Meaning that the DHD-FFQ estimates around 25% less variation of nutrient intakes as compared to the full length FFQ. Therefore, estimates for the component scores dietary fibre, SFA, and TFA derived by the DHD-FFQ should be used carefully.

The component sodium derived from the DHD-FFQ was compared to the score based on a 24-hour urinary sodium, which could explain the low correlation of 0.24, since it is known that estimating sodium intake using an FFQ is challenging. When comparing the sodium component based on the full length FFQ data to the sodium component based on 24-hour urinary excretion data, the correlation was as low as for the DHD-FFQ data (0.20 vs. 0.24). Furthermore, when comparing the sodium component derived from the full length FFQ to the sodium component derived from the DHD-FFQ, the correlation was acceptable (r=0.64 (95% CI 0.61-0.68)). These results suggest that the DHD-FFQ assesses sodium intake similarly as the full length FFQ and both showed only a moderate association with the urinary sodium component. Conclusions on the sodium component score, estimated either by DHD-FFQ or full length FFQ, should therefore be drawn with caution.

The DHD-index derived from the DHD-FFQ was associated with sex, age, following a diet regime, supplement use, smoking and antihypertensive medication use. The DHD-index scores based on a full length FFQ and on two 24-hour recalls showed similar associations with sex[3, 4, 32], age[4, 32], smoking[32], and following a diet regime[3] in other Dutch populations. However, in these other populations the DHD-index was also associated with higher education[32], which was not seen in the present study. This discrepancy may be explained by the high percentage of highly educated participants (53.9%) in the present study.

Intakes of most macro- and micronutrients showed associations with the DHD-index derived from the DHD-FFQ in the expected direction when we adjusted for energy intake estimated by either the full length FFQ or the DHD-FFQ. Although, the DHD-FFQ was not designed to estimate energy intake and the estimated energy intake coverage was low (64%), the estimated energy intake was highly correlated with energy intake estimated by the full length FFQ (r=0.60 (95% CI 0.57-0.64)). This correlation shows a good ranking capacity and therefore, the energy intake estimate may be used as a covariate, making the DHD-FFQ useful for epidemiologic research. The favourable associations of the DHD-index with nutrient intakes were also observed in the DNFCS-2003 using two 24-hour recalls to calculate the DHD-index score[3] and in the European Food Consumption Validation study using a 180-item FFQ[4]. We showed that also the DHD-index derived from the DHD-FFQ was able to reflect associations with nutrient intakes in favourable direction.

The DHD-index derived from both the DHD-FFQ and the reference method showed weak inverse associations with fasting triglycerides and HbA1C. The weak and absent associations between diet quality and cardio-metabolic risk factors could be caused by the relatively healthy participants in the present study. In participants with high risk for coronary heart disease, Schröder and colleagues[6] observed significant associations of HDL cholesterol, triglycerides, and fasting glucose with adherence to the Mediterranean diet using a 14-item questionnaire.

We aimed to keep the calculation of the DHD-index components based on the DHD-FFQ as similar to the original calculation as possible, however, we had to make some adjustments. Firstly, instead of lowering the cut-off values for the sodium component with 30%, as was done previously[3, 4], we aimed to estimate discretionary sodium by adding two questions on salt use during cooking and the use of salt or sodium-rich products at the table that accounted for three points out of the maximum of 10 points. When excluding these questions from the sodium component calculation, the correlation with the urinary sodium component was similar (0.24 vs. 0.25). These findings were supported in literature showing that questions on salt preference and discretionary salt poorly estimated sodium intake[33, 34]. The reason why the additional questions on discretionary sodium did not improve the correlation with the urinary sodium component is unclear and needs further investigation. Secondly, the energy-dependent cut-off values for the components fibre, SFA, and TFA were based on average energy requirements used in the Netherlands, because the DHD-FFQ was not designed to estimate energy intake. Furthermore, the cut-off values for the components fibre, SFA, and TFA were lowered in accordance with the estimated percentage of coverage for the energy intake (64%) assessed by the DHD-FFQ. Lowering the cut-off values was chosen because otherwise participants could not receive the maximum or minimum number of points, because the DHD-FFQ did not assess complete dietary intake. However, due to the likely individual deviations from the average energy intake requirements, misclassifications could have been introduced to the DHD-index scores.

A limitation of the present study may be the large number of highly educated persons, through which generalizability of the usability of the DHD-FFQ to populations with lower educational level is difficult. Furthermore, the web-based administration of the full length FFQ and the DHD-FFQ was not validated and disadvantages as lower reliability and validity of data obtained have been suggested[35]. However, Beasly and colleagues showed that web-based administration of FFQs produce similar results as paper-based administration[36]. Furthermore, advantages as restriction for the range of answer possibilities and obligatory questions were also mentioned[35]. The possible dis- and advantages might have affected both FFQs similarly, thus it is unlikely that it affected our results.

Strength of the present study was the large study population used to evaluate the DHD-index derived from the DHD-FFQ. Furthermore, the reference method consisted of a 180-item FFQ, validated for energy, macro- and micronutrients[17-19], combined with a urinary sodium excretion, the gold standard for sodium assessment[20].

In conclusion, the DHD-index score based on the DHD-FFQ was acceptable in ranking of participants according to their diet quality and was associated with several participants' characteristics, macro- and micronutrient intakes in the present study. Therefore, the DHD-FFQ can be used for calculation of the DHD-index and thereby rank and monitor individuals according to their diet quality and identify high risk subpopulations in the Netherlands.

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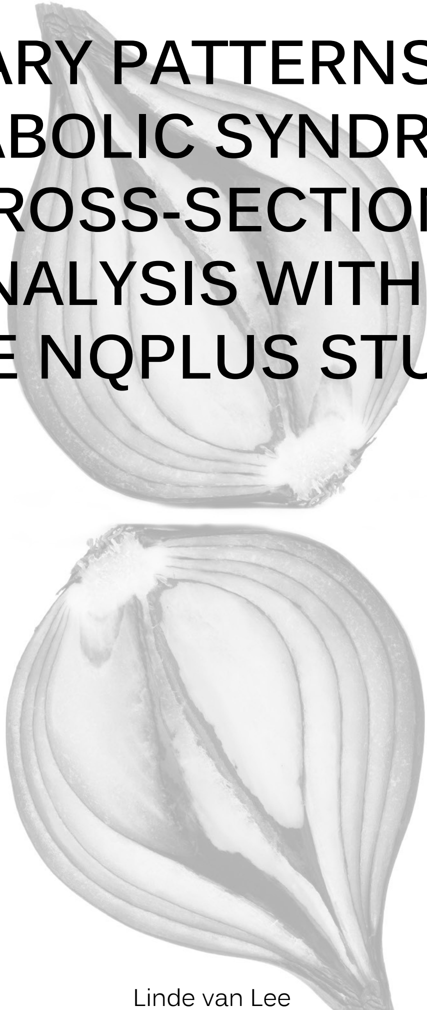
DIETARY PATTERNS AND METABOLIC SYNDROME: A CROSS-SECTIONAL ANALYSIS WITHIN THE NQPLUS STUDY



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Abstract

Background: Diet is a major risk factor for development of metabolic syndrome (MetS), a cluster of five risk factors for cardiovascular disease. The aim was to describe dietary patterns in a general Dutch population and to examine the cross-sectional association between these dietary patterns and the prevalence of MetS.

Methods: Data of 1465 Dutch men and women aged 20-70 years were included. BMI, waist circumference, blood pressure, triglycerides, HDL cholesterol and fasting glucose were measured. A 180-item food frequency questionnaire was administered to estimate dietary intake. The items were grouped in 43 food groups and energy adjusted prior to the principal component analysis. Prevalence ratios between the derived dietary patterns and MetS were calculated adjusting for age, sex, education level, smoking, physical activity, supplement use and energy intake.

Results: Three dietary patterns were derived. The 'meat' pattern showed high factor loadings for liquid cooking fat, beef, poultry, pork and processed meat and a negative loading for soy- and vegetarian products. The 'healthy' pattern showed high factor loadings for vegetables, and oils and dressings. The 'snack' pattern showed high factor loadings for sauces, and snacks and fries. The 'meat' pattern was positively associated with prevalence of MetS (highest vs. lowest tertile; PR 1.72, 95% CI 1.17-2.54), while the 'healthy' pattern (PR 1.08, 95% CI 0.76-1.54) and the 'snack' pattern (PR 1.08, 95% CI 0.75-1.54) were not associated.

Conclusions: A dietary pattern characterised by meat intake was significantly associated with a higher prevalence of MetS in a Dutch population.

Introduction

The metabolic syndrome (MetS) is a cluster of risk factors for cardiovascular disease and diabetes mellitus[1]. MetS is defined as the presence of at least three out of the five following risk factors: abdominal obesity, elevated blood pressure, elevated triglycerides, lowered high-density lipoprotein (HDL) cholesterol, and elevated fasting glucose[1]. Diet is considered an important risk factor for MetS. High intakes of saturated and trans fatty acids, or low intakes of dietary fibre, fruit, vegetables and several micronutrients were shown to be risk factors for development of MetS[2, 3.] Next to single foods and food groups, MetS was also studied in relation to dietary patterns. Especially the Mediterranean-style diets and dietary patterns that were considered 'healthy' were associated with a reduced risk of MetS, whereas 'Western-style' dietary patterns were associated with an increased risk of MetS[2, 4, 5.]

The focus on studying dietary patterns instead of single nutrients, foods or food groups is rising. The reasoning for this shift is to include possible synergies between foods and food groups that are consumed together[6]. One approach of deriving dietary patterns is by statistically modelling using data reduction methods as principal component analysis (PCA)[7]. The derived dietary patterns will give insight into the present dietary patterns in the population that can then be used for intervention planning. Moreover, results can be more helpful in disseminating diet-related messages to consumers since dietary patterns appear easier to understand than the single nutrients or foods recommendations[8].

To date, in Dutch populations 'traditional' dietary patterns consisted of high intakes of potatoes, animal products, and processed and refined food products[9-11]. Van Dam et al.[10] showed that this 'traditional' pattern was positively associated with several components of MetS, namely HDL cholesterol, systolic blood pressure and non-fasting glucose. However, prevalence of MetS was not studied. Therefore, the present study aims to describe dietary patterns in a Dutch adult cohort and to examine the associations between these patterns and MetS.

Methods

Study population and design

The Nutrition Questionnaires plus (NQplus) study is a Dutch cohort designed for multiple aims: 1) to develop a national dietary assessment reference database, 2) to validate a newly developed food frequency questionnaire (FFQ), 3) to study the association between nutrition and intermediate health outcomes. Baseline data from 1479 participants, collected in 2011-2013, were used for the present study. Men and women aged between 20 and 70 years old who could speak and write Dutch were included in the NQplus study. Recruitment was done via invitations to randomly selected inhabitants of Wageningen, Ede, Renkum, and Arnhem and to all households in Veenendaal. Baseline measurements consisted of questionnaires on history of disease, dietary intake, physical activity, lifestyle behaviours, and demographics. Furthermore, medication use was determined and classified according to the Anatomical Therapeutic Chemical (ATC) classification system. Moreover, anthropometric measurements, and a blood drawing were done. The NQplus study was approved by the medical ethical committee of Wageningen University and all participants signed written informed consent prior to start of the study.

Dietary assessment

Habitual dietary intake including alcoholic beverages was assessed using a 180-item FFQ, which was validated for assessment of intakes of energy, fatty acids, cholesterol and B vitamins[12-14]. Frequency of consumption for each food item ranged from 'never per month' to 'six to seven days per week' on a seven point scale. Portion sizes were assessed by commonly used household measures (e.g. spoons, glasses). Energy was calculated by multiplying frequency by portion size with the nutrient content of the food derived from the 2011 Dutch food composition table[15]. The FFQ was administered online using the open-source survey tool Limesurvey™ (LimeSurvey Project Team / Carsten Schmitz. Hamburg, Germany, 2012). All questions were obligatory to answer and, based on conditional responses, irrelevant questions could be skipped following a skip pattern.

Components of MetS

The anthropometric measurements were done following a standard protocol by trained research assistants. Waist circumference was measured twice with a non-flexible tape and the average of the two was used. After 20 minutes of rest, blood pressure was measured for six times using an Omron HEM-907 device (Omron Health care, Illinois, USA). The first blood pressure measurement was discarded for validity reasons, whereas the remaining five measurements were averaged.

Blood sampling was done in fasting state by a trained nurse in hospital Gelderse Vallei in Ede or hospital Rijnstate in Velp. Blood analyses were done on the day of collection in the hospital laboratories following a standardized protocol. Fasting glucose, HDL cholesterol and triglyceride levels were determined with enzymatic methods[16] using a Siemens Dimension Vista 1500 automated analyser in Ede and a Roche Modular P800 Chemistry Analyser in Velp. We excluded 14 participants who had a non-fasting blood sample, resulting in a total sample of 1465 participants.

Table 7.1. Definition and prevalence of the metabolic syndrome[1]

Components	Cut-off values	Prevalence
Waist circumference	♂ ≥ 104 cm ♀ ≥ 88 cm	32.6%
Elevated triglycerides	≥ 1.7 mmol/L Or drug treatment for elevated triglyceride levels (ATC: C10)	23.2%
Reduced HDL cholesterol	♂: < 1.0 mmol/L ♀: < 1.3 mmol/LOr drug treatment for reduced HDL cholesterol levels (ATC: C10)	21.0%
Elevated blood pressure	Systolic ≥130 mm Hg orDiastolic ≥ 85 mm HgOr drug treatment for elevated blood pressure (ATC: C1-C9)	47.4%
Elevated fasting glucose	≥ 5.6 mmol/LOr drug treatment for elevated glucose levels (ATC: A10)	38.7%
Metabolic syndrome	Having three out of five risk factors	25.3%

ATC: Anatomical Therapeutic Chemical Classification System

The definition for MetS presented by the international Diabetes Federation Task force on Epidemiology and Prevention was used in the present study (**Table 7.1**)[1].

Covariates

Age (y), sex, highest achieved education level [high (university or college), intermediate (secondary or higher vocational education), and low (primary or lower education)], and smoking (never, former, current) were assessed in a general questionnaire. Physical activity was assessed by the short questionnaire to assess health enhancing physical activity (SQUASH)[17] and categorized as adherent or non-adherent to the Dutch recommendation of being active for minimally 5 days per week for at least 30 minutes. Height and weight were measured and used to calculate BMI (kg/m^2).

Statistical analyses

First, the 180 food items of the FFQ were grouped based on nutrient profile and culinary use using the 23 food groups from the Dutch food composition table 2011[15] as basis. Foods different in fat or fibre content or representing suspected dietary habits (e.g. alcohol use) were grouped separately, resulting in a total of 43 food groups. Individual intakes of these food groups were log-transformed, non-consumers were set at 1 prior to log-transformation, and adjusted for energy intake using the residual method as described by Willett *et al.*[18]. Food group intakes were energy adjusted because we were interested in diet quality independent of total energy intake. PCA was applied to these 43 food groups to derive dietary patterns. Varimax rotation was used to obtain orthogonal factors. The number of patterns to retain was determined based on the Scree plot, Velicer's minimum average partial19 and interpretability of the factors. The effect of food grouping on the dietary patterns was checked by rerunning the PCA with all 180 food items included in the FFQ. Similar dietary patterns emerged (Pearson correlation coefficients ranged between 0.85-0.91).

For each dietary pattern, scores were divided in tertiles based on the population distribution. Prevalence ratios (PR) were calculated to examine the association between dietary patterns and MetS using Cox proportional hazard regression analysis with the covsandwich option to obtain robust estimates[20]. PR were used because odds ratios could overestimate the strength of the association in non-case-control studies when the disease is not rare[20, 21]. The variables age, sex, education level, physical activity, smoking, supplement use, and total energy intake were included as covariates in the second model. Missing values for physical activity (n=150), smoking (n=202) and education (n=18) were imputed for five times. Statistical analysis was done on five datasets and results were pooled using the MIANALYZE procedure for SAS software. BMI was additionally included in the third model, as it could be a potential confounder based on weight-related misreporting of intake as well as a potential intermediate in the causal pathway of diet to MetS. Linear trends were investigated using the tertile variables continuously in the model. Effect modification was tested for the covariates age, sex, education level, and BMI by adding interaction terms to the final model. Statistical analyses were performed using SAS version 9.3 (SAS Institute Inc. Cary).

Results

In total, 25.3% of participants were classified as having MetS, whereas 32.6% were classified with abdominal obesity, 23.2% with elevated triglycerides, 21.0% with reduced HDL cholesterol, 47.4% with elevated blood pressure and 38.7% with elevated fasting glucose (**Table 7.1**). The PCA identified three dietary patterns that explained 8.4% of the dietary intake variance (**Table 7.2**). The 'meat' pattern showed high factor loadings (≥ |0.4|) for liquid fat, beef, poultry, pork, and processed meat, and a negative loading for soy- and vegetarian products. The 'healthy' pattern was characterised by high factor loadings for cruciferous, leafy, and other vegetables, and oils and dressings. Lastly, the 'snack' pattern was characterised by high factor loadings for snacks and fries, low fat, and high fat sauces. Participants with higher scores on the 'meat' dietary pattern were more likely to be men, were older, had higher BMI, were using medication (lipid modifying, anti-hypertensive and diabetes drugs) and having Mets (**Table 7.3**). Furthermore, participants with higher scores were less likely highly educated, adhere to physical activity guideline and to use dietary supplements compared to those with lower scores for the 'meat' pattern.

Participants with higher scores on the 'healthy' dietary pattern were more likely to be women, were older, followed a diet regime (prescribed or at own imitative), used dietary supplements, had a higher education level and were former or current smoker compared to those with lower scores on the 'healthy' pattern. Participants with higher scores on the 'snack' pattern were more likely to be younger, to adhere to the recommendation for physical activity, and were less likely to take lipid modifying or anti-hypertensive drugs.

The 'meat' pattern was associated with a 91% (95% CI 1.51-2.41) higher prevalence of MetS comparing the highest to the lowest tertile after adjustment for age and sex (**Table 7.4**). This association attenuated after additional adjustment for education level, smoking, adherence to physical activity norm, supplement use and energy intake (PR 1.72, 95% CI 1.17-2.54; P for trend = 0.021). When additionally adjusting for BMI, a possible intermediate, the association attenuated and became non-significant (PR 1.39, 95% CI 0.94-2.04). Regarding the individual MetS components, the 'meat' pattern

Table 7.2 Median and IQR intake of 43 food groups and rotated factor loadings of the three identified dietary patterns in 1465 participants of the NQplus study

Food group (g)	Median intake	IQR	Factor 1 'Meat'	Factor 2 'Healthy'	Factor 3 'Snack'
Potatoes	37.4	52.3	0.28	.	.
Pasta and rice plain	26.5	41.8	.	.	0.25
Pasta and rice wholegrain	12.3	27.6	-0.32	.	.
Coffee and tea	687.5	410.7	.	.	.
Non-alcoholic beverages	21	96.4	.	.	0.38
Fruit juices	21.4	91.1	.	.	0.20
Alcoholic beverages	12.2	85.7	0.22	.	.
Wine	25.3	86.8	.	0.39	.
White bread	9.8	26.4	0.20	.	0.25
Brown and wholegrain bread	105.1	72	.	-0.28	-0.36
Cereals and breakfast products	0.4	17.1	.	.	.
Diverse*	5	12.5	.	.	0.36
Pizza	6.4	16.1	.	.	0.37
Soups	22.3	35.7	.	.	.
Eggs	8.9	10.7	.	0.37	.
Fruit	204.2	156.4	.	0.24	-0.31
Pastry, cakes and cookies	24.4	28.6	.	-0.27	.
Cruciferous vegetables	17.5	16.4	.	0.60	.

table continues on page 122

Food group (g)	Median intake	IQR	Factor 1 'Meat'	Factor 2 'Healthy'	Factor 3 'Snack'
Leafy vegetables	17.4	17	.	0.62	.
Other vegetables	103.5	86.7	.	0.61	.
Low fat cheese	5.5	12.4	.	.	.
Fat cheese	12.9	23	.	.	.
Full fat dairy	22.9	56.2	.	.	0.30
Semi skimmed dairy	97.4	188	.	.	.
Skimmed dairy	69.1	158.8	.	.	-0.28
Nuts and seeds	11.9	19.2	-0.34	0.20	.
Snacks and fries	22.9	34.1	0.21	.	0.60
Legumes	7.7	19.2	-0.23	0.20	.
Soy and vegetarian	0	7.2	-0.57	.	.
Sugar, sweets	20.7	28.1	.	-0.26	.
Oils and dressings	3.5	4.3	-0.28	0.53	.
Solid cooking fat	1.3	4.6	.	.	0.22
Liquid cooking fat	2.1	4.7	0.40	.	.
Margarine	0.3	5.5	.	.	.
Low fat margarine	7.9	22.3	0.25	.	-0.25
High fat sauces	5.3	7.4	.	.	0.67
Low fat sauces	4.7	6.4	.	.	0.52
Fish	18.1	18	.	0.39	.
Organ meat	0	1.1	0.26	0.24	.
Beef	12.6	12.6	0.66	.	.
Poultry	9.5	10.9	0.61	.	.
Pork	25	25.1	0.79	.	.
Processed meat	11.3	22.5	0.64	.	.
Variance explained			3.3	2.7	2.4

IQR: interquartile range
Factor loadings < |0.20| were omitted for simplicity
Factor loadings ≥ |0.40| were made bold
*Including marmite, pancakes, water ice, and salad

showed positive non-significant associations with abdominal obesity (PR 1.81, 95% CI 1.31-2.50), elevated triglycerides (PR 1.44, 95% CI 0.97-2.14), reduced HDL cholesterol (PR 1.36, 95% CI 0.89, 2.08), elevated blood pressure (PR 1.21, 95% CI 0.97-1.51) and a significant association with elevated fasting glucose (PR 1.47, 95% CI 1.12-1.95) when adjusting for age, sex, education level, smoking, adherence to physical activity norm,

Table 7.3 Participants' characteristics (mean and SD or N and %) according to tertiles of the three dietary patterns in 1465 participants of the NQplus study

	'Meat' pattern						'Healthy' pattern						'Snack' pattern					
	T1 (n=489)		T2 (n=488)		T3 (n=488)		T1(n=489)		T2(n=4888)		T3(n=488)		T1(n=489)		T2(n=487)		T3(n=489)	
Men (%)	191	39.1	266	54.5	303	62.1*	276	56.4	265	54.3	219	44.9*	241	49.3	257	52.8	262	53.6
Age (y)	52.1	11.3	53.4	11.5	54.4	11.6*	51.8	12.5	53.9	11.3	54.2	10.5*	58.0	9.1	53.7	11.1	48.3	11.9*
Energy intake (MJ)	8.5	2.6	8.9	2.7	8.4	2.2	8.5	2.5	8.8	2.5	8.5	2.4	8.4	2.4	8.8	2.5	8.5	2.5
BMI (kg/m^2)	24.7	3.5	26.2	4.2	27.0	4.1*	25.6	4.0	26.1	4.1	26.1	4.1	25.6	4.0	26.1	4.1	26.0	4.1
Diet regime (%)	53	10.8	39	8.0	38	7.8	32	6.5	35	7.2	63	12.9*	44	9.0	38	7.8	48	9.8
Supplement use (%)	320	65.4	278	57.0	243	49.8*	271	55.4	267	54.7	303	62.1*	289	59.1	287	58.9	265	54.2
Education level (%)						*						*						
Low	66	13.4	74	15.2	98	20.0	87	17.9	88	18.0	62	12.7	93	18.9	77	15.9	68	13.8
Intermediate	133	27.2	143	29.3	158	32.3	165	33.7	138	28.3	131	26.8	135	27.6	131	26.8	168	34.4
High	290	59.4	271	55.5	233	47.7	237	48.4	262	53.7	295	60.5	261	53.4	279	57.3	253	51.8
Smoking† (%)						*						*						
Never	259	53.0	256	52.3	224	45.8	272	55.7	241	49.3	225	46.1	237	48.5	237	48.6	264	54.1
Former	194	39.8	195	40.0	208	42.6	174	35.6	207	42.5	216	44.3	218	44.6	213	43.8	167	34.1
Current	36	7.3	37	7.6	56	11.5	43	8.7	40	8.1	47	9.6	34	7.0	37	7.6	58	11.8
Physically active†‡ (%)	236	48.3	209	42.8	188	38.5*	222	45.3	207	42.5	204	41.8	191	39.0	215	44.2	227	46.4*
Medication (%)																		
Lipid modifying drugs	34	7.0	38	7.8	72	14.8*	49	10.0	45	9.2	50	10.3	67	13.7	43	8.8	34	7.0*
Anti-hypertensive drugs	62	12.7	63	12.9	112	23.0*	70	14.3	81	16.6	86	17.6	100	20.5	77	15.8	60	12.3*
Diabetes drugs	7	1.4	14	2.9	20	4.1*	17	3.5	15	3.1	9	1.8	14	2.9	15	3.1	12	2.5
Metabolic syndrome (%)	79	16.2	115	23.6	177	36.3*	120	24.5	126	34.0	125	25.6	140	28.6	116	23.8	115	23.5

*Significant linear trend ($P<0.05$)
†Frequencies and percentages are estimated based on five imputations
‡Adherence to the Dutch recommendation for physical activity

supplement use and energy intake. These associations attenuated to non-significant positive associations when additionally adjusting for BMI, except for elevated fasting glucose that remained significantly associated with the 'meat' pattern (PR 1.35, 95% CI 1.01-1.79).

The 'healthy' pattern showed no association with MetS when comparing the highest tertile to the lowest (PR 1.01, 95% CI 0.82-1.25; Table 7.5), but did show an association with abdominal obesity (PR 1.21, 95% CI 1.01-1.45; P for trend 0.040). After additional adjustments, no association was observed between the 'healthy' dietary pattern and MetS or its components.

The 'snack' pattern showed a borderline significant 20% higher prevalence of Mets (95% CI 0.97-1.48; P for trend 0.151) comparing highest tertile to the lowest (Table 7.6). This association disappeared when adjusting for education level, physical activity, smoking, supplement use and energy intake (PR 1.08, 95% CI 0.75-1.54; P for trend 0.605). The 'snack' pattern was positively associated with abdominal obesity (model 2: PR 1.42, 95% CI 1.04-1.94) but not with the other components of MetS. After additional adjustment for BMI, the positive association with abdominal obesity attenuated (PR 1.32, 95% CI 0.99-1.77).

The interactions between the three dietary patterns and sex, age, BMI and energy intake were not statistically significant (P<0.20). Repeating the analysis when excluding the missing values, did not alter the results.

Discussion

The objective of the present study was to describe Dutch dietary patterns using PCA and examine their relationship with the prevalence of MetS. Three dietary patterns were derived, namely, the 'meat' pattern, the 'healthy' pattern and the 'snack' pattern. Higher scores for the 'meat' pattern were associated with a 72% higher prevalence of MetS; the 'snack' and 'healthy' pattern were not associated with MetS. The 'meat' pattern was positively associated with MetS, abdominal obesity and elevated fasting glucose. The 'snack' pattern was positively associated with abdominal obesity, the 'healthy' pattern was not associated with any of the separate components of MetS.

The three derived dietary patterns together explained only 8.4% of the total variance in the consumption of the 43 food groups in the present study population. Other studies in Dutch populations using PCA observed substantially higher explained variances; three patterns explaining 25% of the total variance from intakes of 22 food groups[9], two patterns explaining 21% from intakes of 22 food groups[11], and three patterns explaining 18.4% of

Table 7.4 Prevalence ratio (PR) and 95% confidence intervals for metabolic syndrome and its components according to tertiles of the 'Meat' dietary pattern in 1465 participants of the NQplus study.

	Tertiles of 'Meat' pattern						
	T1		T2		T3		
	PR	95% CI	PR	95% CI	PR	95% CI	P for trend
Metabolic syndrome							
Cases	79		115		177		
Model 1	1.0	Reference	1.32	(1.03, 1.70)	1.91	(1.51, 2.41)	<0.001
Model 2	1.0	Reference	1.31	(0.87, 1.98)	1.72	(1.17, 2.54)	0.021
Model 3	1.0	Reference	1.08	(0.71, 1.62)	1.39	(0.94, 2.04)	0.069
Abdominal obesity							
Cases	111		161		206		
Model 1	1.0	Reference	1.51	(1.23, 1.85)	1.96	(1.62, 2.37)	<0.001
Model 2	1.0	Reference	1.48	(1.06, 2.07)	1.81	(1.31, 2.50)	0.010
Model 3	1.0	Reference	1.14	(0.77, 1.61)	1.41	(0.99, 2.00)	0.050
Elevated triglycerides							
Cases	82		105		153		
Model 1	1.0	Reference	1.14	(0.88, 1.47)	1.55	(1.22, 1.96)	0.001
Model 2	1.0	Reference	1.14	(0.74, 1.74)	1.44	(0.97, 2.14)	0.062
Model 3	1.0	Reference	0.99	(0.65, 1.51)	1.20	(0.81, 1.77)	0.218
Reduced HDL cholesterol							
Cases	81		93		133		
Model 1	1.0	Reference	1.08	(0.82, 1.42)	1.50	(1.17, 1.92)	0.002
Model 2	1.0	Reference	1.06	(0.67, 1.66)	1.36	(0.89, 2.08)	0.109
Model 3	1.0	Reference	0.94	(0.59, 1.47)	1.17	(0.77, 1.80)	0.317
Elevated blood pressure							
Cases	190		231		274		
Model 1	1.0	Reference	1.10	(0.96, 1.26)	1.23	(1.08, 1.40)	0.003
Model 2	1.0	Reference	1.11	(0.88, 1.39)	1.21	(0.97, 1.51)	0.070
Model 3	1.0	Reference	1.02	(0.82, 1.29)	1.09	(0.87, 1.36)	0.309
Elevated fasting glucose							
Cases	140		183		244		
Model 1	1.0	Reference	1.20	(1.01, 1.44)	1.53	(1.30, 1.80)	<0.001
Model 2	1.0	Reference	1.20	(0.90, 1.61)	1.47	(1.12, 1.95)	0.022
Model 3	1.0	Reference	1.12	(0.84, 1.51)	1.35	(1.01, 1.79)	0.044

Model 1: adjusted for age and sex; Model 2: adjusted for model 1 and education level, smoking, physical activity, supplement use and energy intake; Model 3: adjusted for model 2 and BMI

Table 7.5 Prevalence ratio (PR) and 95% confidence intervals for metabolic syndrome and its components according to tertiles of the 'Healthy' dietary pattern in 1465 participants of the NQplus study.

	Tertiles of 'Healthy' pattern						
	T1		T2		T3		
	PR	95% CI	PR	95% CI	PR	95% CI	P for trend
Metabolic syndrome							
Cases	120		126		125		
Model 1	1.0	reference	0.99	(0.80, 1.22)	1.01	(0.82, 1.25)	0.901
Model 2	1.0	reference	1.03	(0.73, 1.46)	1.08	(0.76, 1.54)	0.538
Model 3	1.0	reference	0.90	(0.63, 1.29)	0.97	(0.69, 1.36)	0.793
Abdominal obesity							
Cases	134		165		179		
Model 1	1.0	Reference	1.16	(0.96, 1.39)	1.21	(1.01, 1.45)	0.040
Model 2	1.0	Reference	1.80	(0.87, 1.60)	1.26	(0.93, 1.71)	0.093
Model 3	1.0	Reference	1.07	(0.75, 1.54)	1.20	(0.88, 1.62)	0.143
Elevated Triglycerides							
Cases	114		117		109		
Model 1	1.0	Reference	0.99	(0.79, 1.23)	0.97	(0.77, 1.21)	0.763
Model 2	1.0	Reference	1.01	(0.70, 1.46)	0.99	(0.68, 1.45)	0.950
Model 3	1.0	Reference	0.92	(0.64, 1.33)	0.91	(0.63, 1.31)	0.451
Reduced HDL cholesterol							
Cases	110		102		95		
Model 1	1.0	Reference	0.92	(0.73, 1.17)	0.89	(0.70, 1.13)	0.339
Model 2	1.0	Reference	0.94	(0.63, 1.40)	0.92	(0.61, 1.40)	0.566
Model 3	1.0	Reference	0.88	(0.59, 1.31)	0.86	(0.57, 1.28)	0.295
Elevated Blood Pressure							
Cases	233		225		237		
Model 1	1.0	Reference	0.92	(0.82, 1.05)	1.01	(0.89, 1.14)	0.910
Model 2	1.0	Reference	0.94	(0.77, 1.16)	1.03	(0.84, 1.27)	0.663
Model 3	1.0	Reference	0.91	(0.74, 1.11)	0.99	(0.81, 1.21)	0.854
Elevated fasting glucose							
Cases	175		202		190		
Model 1	1.0	Reference	1.11	(0.95, 1.29)	1.08	(0.92, 1.26)	0.357
Model 2	1.0	Reference	1.14	(0.88, 1.47)	1.11	(0.85, 1.45)	0.293
Model 3	1.0	Reference	1.09	(0.85, 1.41)	1.07	(0.82, 1.39)	0.475

Model 1: adjusted for age and sex; Model 2: adjusted for model 1 and education level, smoking, physical activity, supplement use, and energy intake; Model 3: adjusted for model 2 and BMI

Table 7.6 Prevalence ratio (PR) and 95% confidence intervals for metabolic syndrome and its components according to tertiles of the 'Snack' dietary pattern in 1465 participants of the NQplus study.

	Tertiles of 'Snack' pattern						
	T1		T2		T3		
	PR	95% CI	PR	95% CI	PR	95% CI	P for trend
Metabolic syndrome							
Cases	140		116		115		
Model 1	1.0	reference	0.97	(0.79, 1.19)	1.20	(0.97, 1.48)	0.151
Model 2	1.0	reference	0.97	(0.69, 1.36)	1.08	(0.75, 1.54)	0.605
Model 3	1.0	reference	0.86	(0.61, 1.22)	1.00	(0.71, 1.39)	0.832
Abdominal obesity							
Cases	153		165		160		
Model 1	1.0	Reference	1.26	(1.06, 1.51)	1.49	(1.24, 1.80)	<0.001
Model 2	1.0	Reference	1.27	(0.95, 1.71)	1.42	(1.04, 1.94)	0.035
Model 3	1.0	Reference	1.09	(0.80, 1.49)	1.32	(0.99, 1.77)	0.061
Elevated triglycerides							
Cases	127		115		98		
Model 1	1.0	Reference	0.99	(0.80, 1.24)	0.98	(0.77, 1.24)	0.857
Model 2	1.0	Reference	1.00	(0.69, 1.43)	0.90	(0.61, 1.33)	0.462
Model 3	1.0	Reference	0.92	(0.65, 1.32)	0.84	(0.58, 1.22)	0.229
Reduced HDL cholesterol							
Cases	109		92		106		
Model 1	1.0	Reference	0.86	(0.68, 1.10)	1.03	(0.81, 1.32)	0.905
Model 2	1.0	Reference	0.86	(0.57, 1.30)	0.96	(0.63, 1.44)	0.687
Model 3	1.0	Reference	0.82	(0.54, 1.22)	0.90	(0.60, 1.35)	0.437
Elevated Blood Pressure							
Cases	248		241		206		
Model 1	1.0	Reference	1.09	(0.96, 1.22)	1.09	(0.96, 1.24)	0.167
Model 2	1.0	Reference	1.08	(0.89, 1.32)	1.06	(0.85, 1.32)	0.404
Model 3	1.0	Reference	1.03	(0.85, 1.26)	1.00	(0.81, 1.24)	0.906
Elevated fasting glucose							
Cases	202		191		174		
Model 1	1.0	Reference	1.05	(0.90, 1.22)	1.10	(0.94, 1.30)	0.247
Model 2	1.0	Reference	1.05	(0.82, 1.35)	1.06	(0.81, 1.40)	0.497
Model 3	1.0	Reference	1.00	(0.78, 1.29)	1.01	(0.77, 1.33)	0.886

Model 1: adjusted for age and sex; Model 2: adjusted for model 1 and education level, smoking, physical activity, supplement intake and energy intake; Model 3: adjusted for model 2 and BMI

46 food groups[10]. Our low variance may be explained by the number of food groups that were used in the PCA. However, using less food groups in the PCA may lead to dietary patterns that show weaker associations with disease outcomes[22]. Furthermore, it might be more important to focus on interpretability of the derived dietary patterns, rather than on variance explained, given that individuals are unlikely to limit their food choices to one pattern exclusively[22].

The 'meat' dietary pattern was positively associated with MetS and with two of its components, which was also observed by others[23, 24]. In a Lebanese population, participants in the highest quintile of the 'high protein' pattern had a higher risk for hypertension compared to subjects in the lowest quintile (OR 2.98, 95% CI 1.26, 7.02)[23]. Furthermore, in a review, it was concluded that dietary patterns heavily loading on meat were associated with increased risk of hyperglycaemia, and abdominal obesity[24].

The 'healthy' dietary pattern showed no associations with MetS or its components. Generally, dietary patterns with high loadings on vegetables, fish, wine and oils, which also loaded positively on our 'healthy' pattern, are associated with lower prevalence of MetS and its components[5, 24, 25]. The absence of an association between the 'healthy' pattern and MetS in the present study might be caused by the relatively high loading for organ meat and a negative loading for brown and wholegrain bread in our 'healthy' pattern.

The 'snack' dietary pattern showed positive associations with the risk factor abdominal obesity. This dietary pattern loaded heavily on sauces, fried snacks and French fries, which are energy-dense foods and thus likely to be causally related to abdominal obesity[26]. Williams *et al.* observed a snack-like dietary pattern consisting of eggs, fried food, processed meat, cheese and fried fish in a UK-population cohort[27]. This pattern was associated with higher BMI and waist-to-hip ratio, however it was not associated with other components of MetS or type II diabetes. In the Dutch EPIC population, a dietary pattern showing high loadings for French fries, snacks and soft drinks was observed[28]. Subjects with higher scores for this dietary pattern were more likely to have a higher waist circumference and 70% (95% CI 1.31, 2.20) higher odds for type II diabetes. These results corroborate our findings that 'snack' dietary patterns were positively associated with obesity.

All associations between dietary patterns and MetS attenuated when BMI was additionally added to the model. This was expected, as waist circumference, which was highly correlated with BMI (r=0.84), was part of the MetS definition and BMI is a risk factor for high blood pressure, high glucose and triglycerides levels and low HDL cholesterol levels[29]. Confounding by BMI could be possible, because overweight and obese individuals tend to underestimate their dietary intake[30]. Nevertheless, after additional adjustment for BMI, the association between fasting glucose and the 'meat' pattern remained statistically significant, meaning that independent of weight status, a dietary pattern high in meat intake was inversely associated with glucose metabolism.

A limitation of the present study might be the high education level of the participants. Therefore, extrapolation of these results to the general Dutch population should be done with care. Furthermore, PCA requires some arbitrary decisions on the classification of food items into food groups, the number of food groups used, the number of factors to retain, the rotation and the labelling of the factors. We aimed to take these decisions as objectively as possible by examining several sensitivity analyses to check the robustness of the results. First, the food classification was examined by analysing all 180-food items of the FFQ in the PCA, which resulted in similar dietary patterns. Second, we used three methods to decide on the number of factors to retain: Velicer's minimum average partial[19], the scree plot and interpretability of the retained patterns, all resulting in three factors to retain. Finally, the loadings for the obtained factors are presented, to make interpretation and labelling transparent.

A strength of the present study was the large study population of the NQplus study. Furthermore, the components of MetS were measured using standard protocols by trained personnel. Lastly, the validated FFQ[12-14] was administered online. This has the advantage that none of the questions could be missed, restrictions in answers were applied, skipping pattern was included, no data-entry was necessary, and sending reminders was done automatically, which altogether was hypothesized to have resulted in a more complete dietary dataset.

In conclusion, the Dutch 'meat' dietary pattern was associated with higher prevalence of MetS as well as its separate components. The 'snack' pattern was associated with abdominal obesity. These results can be used for intervention planning to improve cardio-metabolic health in the Netherlands.

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8

GENERAL DISCUSSION

The overall aim of this thesis was to develop, evaluate, and apply the Dutch Healthy Diet index (DHD-index) in the Netherlands. This chapter first describes the main findings of this thesis, followed by a discussion of these main findings, methodological considerations, implications for public health, and recommendations for future research.

Main findings

The DHD-index is based on the current Dutch guidelines for a healthy diet and includes ten components on physical activity, intakes of vegetables, fruit, dietary fibre, fish, saturated fatty acids, *trans* fatty acids, sodium, alcohol, and number of consumption occasions with acidic drinks and foods (chapter 2). The score was evaluated on the basis of associations with nutrient intakes and showed associations in the expected direction with intakes of selected macro- and micronutrients when energy intake was taken into account (chapters 2, 3, and 6; **Table 8.1**). Associations were also observed between the index and biomarkers of dietary intake (chapter 3). Content validity was visually evaluated, and the DHD-index components reflected the dietary guidelines (chapter 2, table 2.1). Construct validity was satisfactory, as shown by significant associations with age (chapters 3, 5, 6), supplement use (chapter 2), educational level (chapter 4), and smoking (chapter 6), and weakly inversely associated with serum total cholesterol (chapter 3), fasting serum triglycerides, and HbA1c (chapter 6; **Table 8.1**). Moreover, we observed inverse associations between the DHD-index and all-cause mortality (highest vs. lowest quartile HR 0.77; 95% CI 0.67, 0.89), and non-significant inverse associations with mortality due to CVD (HR 0.74; 95% CI 0.55, 1.01), CHD (HR 0.60; 95% CI 0.34, 1.06), and stroke (HR 0.67; 95% CI 0.36, 1.22; chapter 4). The score was considered robust as none of the components seemed to contribute relatively more to the total score in the association with all-cause mortality (chapter 4). Lastly, for comparability between the DHD-index based on a food frequency questionnaire (FFQ) and the DHD-index based on two 24-hour recalls (24hR), we found acceptable ranking (r=0.48) and absolute agreement (Kendall's tau-b=0.47; chapter 3).

The DHD-index was used to study the association between company at dinner and diet quality on that day using multiple 24hRs from 845 men and 895 women from the Nutrition Questionnaires plus (NQplus) study (chapter 5). Among women, daily intake was less in conformity with the dietary guidelines when dinner was shared (48.9, SE 0.3) than when dinner was consumed alone (46.0, SE 0.7; P<0.001). Among men, daily diet intake was more in conformity with dietary guidelines when dinner was consumed with family members (46.0, SE 0.3) than when dinner was consumed with others (42.3, SE 0.8; P=0.001). Excluding out-of-home dinners showed similar results, but the results attenuated when this was additionally adjusting for.

Selection of components

The DHD-index includes ten components: five adequacy components on physical activity level, vegetables, fruit, dietary fibre, and fish; and five moderation components on saturated fatty acids (SFA), *trans* fatty acids (TFA), consumption occasion with acidic drinks and foods (ADF), sodium, and alcohol, representing the 2006 Dutch dietary guidelines[4] (chapter 2). Some DHD-index components need further discussion. The component consumption occasions with ADF is based on a guideline specifically aimed at prevention of dental erosion and risk of caries. This aim differs from the other aims of the dietary guidelines to prevent nutrient deficiency and chronic diseases[4]. To be able to operationalize this component, dietary intake data per 30 minutes are needed. As most FFQs do not include information on actual daily food intake, this component could not be calculated when FFQ data were used (chapters 3 and 5). Furthermore, in the studies reported in chapters 2, 3, and 5, and in the Dutch National Food Consumption Survey (DNFCS) 2007-2010[5], the prevalence of adherence to this component was very high (range 92-97%), resulting in low variation and discrimination between participants. Also, the correlation between the DHD-index based on 24hR and on an FFQ was similar when the component ADF consumption occasions was excluded (r=0.58 vs. r=0.60; results not shown). However, to correctly classify individuals, this component may be important. Furthermore, the number of consumption occasions with ADF is probably higher in children, partially due to higher frequency of soft drinks consumption[6]. In summary, in adults, this component can be omitted to arrive at a simpler index if the aim is to assess diet quality at population level.

TFA intake showed a decreasing trend from 1987 onwards in the DNFCS7. This decline can be attributed to the decline of industrial TFA in foods[7]. This positive development has resulted in a high prevalence of adherence (range 85-92%) to the TFA guideline, and consequently the TFA component showed low variation between persons. However, at individual level, this component may make an important contribution to the total score. When mean DHD-index scores at group level are being estimated, this component may, therefore, be omitted from the DHD-index, or the cut-off value can be lowered, as the Health Council have argued that TFA intake must by as low as possible[8].

Although all current quantitative dietary guidelines as defined by the Health Council of the Netherlands were included in the DHD-index[4], some important dietary components may be lacking. In chapter 4 and in the Dutch participants of the EPIC study[9], the DHD-index showed no association with cancer incidence or mortality. Over 25 years, the incidence of cancer cases has doubled[10], thus the focus on the association between the dietary guidelines and cancer is important. The World Cancer Research Fund/ American Institute for Cancer Research (WCRF/AICR) guidelines were specifically aimed at cancer prevention and included dietary recommendations on body fatness,

Table 8.1 Overview of the main findings of the DHD-index*

	Chapter 2	Chapter 3a	Chapter 3b	Chapter4	Chapter 6a	Chapter 6b
Study	DNFCS-2003[1]	EFCOVAL-NL[2]	EFCOVAL-NL[2]	Rotterdam Study[3]	NQplus	NQplus
N	749	121	121	3593	1279	1279
Dietary assessment	2 24hr recalls	2 24hr recalls	FFQ	FFQ	FFQ	DHD-FFQ
Age mean (range)	25.0 (19-30)	56.2 (45-65)	56.2 (45-65)	66.1 (55-90)	53.8 (20-70)	53.8 (20-70)
Max DHD-index score	0-100	0-80†	0-80†	0-90‡	0-80†**	0-80†
Mean (SD)	59.2 (11.2)	49.9 (13.5)	56.0 (11.0)	60.6 (10.6)	56.7 (10.1)	57.7 (9.7)
Mean (SD) max 80*	40.9 (10.6)	49.9 (13.5)	56.0 (11.0)	50.7 (10.6)	56.7 (10.1)	57.7 (9.7)
High vs. low DHD-index scores						
Men (%)	↓	↓	↓	↓	↓	↓
Energy intake	↓	↓	↓	↓	↓	↓
Age	-	↑	↑	↓	↑	↑
BMI	-	-	-	↑	-	-
Education level	-	-	-	↑	-	-
Current smoking	NA	-	-	↑	↓	↓
Micronutrients††	↑	↑	↑	NA	↑	↑
Biomarkers of intake	NA	EPA+DHA: ↑ Sodium: ↓ Carotenoids: -	EPA+DHA: ↑ Sodium:- Carotenoids: ↓	NA	NA	NA
Risk factors of disease	NA	Total cholesterol:-	Total cholesterol:-	NA	Triglycerides:↓ Hba1C:↓ BP:- HDL cholesterol:-	Triglycerides:- Hba1C:- BP: - HDL cholesterol:-

Mortality	NA	NA	NA	NA	all cause: ↓ CVD: ~↓ CHD: ~↓ Stroke: ~↓ Cancer: -	NA	NA

NA: Not applicable; ↓: inversely associated; ↑: positively associated; -: no association; ~: borderline
*Excluding chapter 5. Mean DHD-index based on multiple self-administered 24h recalls in men and women of the NQplus study was 47.7 (10.4)
†Excluding the components physical activity and consumption occasions with acidic drinks and foods
‡Excluding the component physical activity
**Sodium intake was assessed by 24h urine collection
††Adjusted for energy intake

We developed a short questionnaire consisting of 34 items, the DHD-FFQ, to estimate the DHD-index score in time-limited settings using data from 1235 NQplus study participants. The DHD-index based on the DHD-FFQ was associated in the expected direction with intakes of macro- and micronutrients estimated from a 180-item FFQ when adjusted for energy intake (**Table 8.1**). The ranking (r=0.56) between the DHD-index based on the DHD-FFQ and the reference method consisting of a 180-item FFQ and a 24h urinary sodium value was considered acceptable. There was a small mean overestimation of the DHD-index based on the DHD-FFQ compared to the index based on the reference method.

In addition to an a priori dietary pattern analysis, we used principal component analysis, an a posteriori dietary pattern analysis method, which revealed three main dietary patterns within the 1465 NQplus study participants; a ‘meat’ pattern, a ‘healthy’ pattern, and a ‘snack’ pattern (chapter 7). High adherence to the ‘meat’ pattern was positively associated with prevalence of metabolic syndrome (highest vs. lowest tertile; PR 1.72, 95% CI 1.17-2.54) and its components. The ‘snack’ pattern was positively associated with abdominal obesity (PR 1.42, 95% CI 1.04-1.94), but not with other metabolic syndrome components, whereas the ‘healthy’ pattern showed no association with prevalence of metabolic syndrome.

Dutch Healthy Diet index – Development

In chapter 1, the rationale for studying dietary patterns and the development of the DHD-index were described. During the development of the DHD-index, several arbitrary decisions were made that could have influenced the DHD-index score and its performance; these are now discussed.

physical activity, foods and drinks that promote weight gain, plant foods, animal foods, alcoholic drinks, and salt intake[11]. The guidelines on body fatness, animal foods, and foods and drinks that promote weight gain are not part of the DHD-index. Including a component on maintaining a healthy weight as expressed by BMI could potentially enhance the predictive power of the DHD-index for specific cancer risks[11], as was seen for indices that included BMI[12, 13]. Nevertheless, Struijk *et al.*[9] showed that including BMI as a component in the DHD-index did not lead to a significant association with cancer incidence in the Dutch EPIC population. Another WCRF/AIRC guideline that was not part of the DHD-index was to limit red and processed meat intake to less than 500 g/week[11]. Meat intake was included in the WCRF/AICR score[13] and the Non-Recommended Food Score[14], and both scores showed significant associations in a favourable direction with cancer mortality. Furthermore, because certain foods and drinks promote weight gain, it is suggested that there should be a limit on the intake of high energy-dense foods (energy density<125 kcal/100 g) and on the intake of sugar-sweetened beverages (<250 ml/day)[13]. Further investigation in Dutch populations is needed to study whether inclusion of these components can improve the diagnostic capacity of the DHD-index.

The Dutch dietary guidelines also include a qualitative guideline recommending a varied diet[4], which is not further quantified. It is assumed that a varied diet improves nutrient adequacy[15]. The report on the dietary guidelines only mentions variety specifically for vegetable and fruit intakes, as it is as yet unclear whether specific vegetables or fruits are more important than others for the association with health[4]. Several variety measures or index components that measure dietary variety have been proposed, but there is no consensus on the operationalization or reference period of dietary variety. Within dietary indices, variety is defined as the number of distinct pre-defined foods[16, 17], as the sum of the major food groups[18-20], or as the sum within the major food groups[21]. In developing countries, dietary variety is often used to estimate nutritional status or food security[22]. However, in developed countries, the risk of overconsumption is of more importance, as a large variety has been positively associated with energy intake[23]. In the Netherlands, variety between and within food groups and the total number of unique food items consumed were not associated with nutrient adequacy[24]. However, variety within the food groups vegetables and fruit was associated with higher micronutrient intakes[25]. As the DHD-index has already shown positive associations with micronutrient intake, it may not be necessary to integrate a variety component within the DHD-index.

The Health Council of the Netherlands has also defined nutrient-specific recommendations for the population[26]. These recommendations should ideally be achieved by a healthy and varied diet. However, some subpopulations more than others are at higher risk of specific nutrient deficiencies or have higher nutrient requirements and consequently are recommended to take dietary supplements or consume nutrientenriched foods. For example, women older than 50 years and men older than 70 years are recommended to take vitamin D supplements. The guidelines for a healthy diet, and consequently the DHD-index, were designed for the generally healthy population. Thus, people suffering from a disease such as osteoporosis have additional nutritional needs and should adhere to these additional recommendations. It may therefore not be necessary to include a component in the DHD-index on dietary supplement use. However, if the aim is to study diet quality in specific subpopulations, this additional component may be needed.

Assigning foods to food groups

Three components of the DHD-index represent specific food groups, namely, vegetables, fruit, and fish. We used the food group classification of the Dutch food composition table – available online – to assign foods to food groups[27]. For some foods, this food group classification differs from international grouping decisions. In countries such as the USA[28] and Denmark[15], potatoes are considered vegetables, whereas in the Netherlands they are not and are classified in a separate food group[15, 27]. Another example is legumes, which are considered vegetables in the USA[28], or considered part of the meat and fish group in Ireland, Portugal, and some Eastern European countries[29], but they are a separate food group in the Netherlands[24]. For this reason, it is challenging to compare indices between countries or to develop an international dietary index. Therefore, during the development of dietary indices, foods should be classified into food groups in a transparent way and according to the same assumptions as applied during the development of the dietary guidelines[4, 15].

Scoring system

The choice to adopt a proportional scoring system was based on the assumption that proportional scores show higher variation and sensitivity compared to dichotomous component scores[30]. In a simulation study, this hypothesis was confirmed[31]. Component scores with many partitions showed higher sensitivity, specificity, and area under the curve than components with fewer partitions, whereas continuous scoring achieved maximum diagnostic accuracy[31]. Nevertheless, some indices with dichotomous scoring systems were able to detect significant associations with health outcomes[32, 33]. Moreover, dichotomous scoring can provide an easier method to apply in clinical practice, for example calculating the score without calculators or statistical software, using simple screeners to assess dietary quality[34]. However, the use of smartphones and tablets may solve this issue nowadays. For the DHD-index, the assumed higher predictive capacity was judged more important than the possible practical advantages, and thus the proportional scoring system was applied.

Defining cut-off values

The cut-off values represent the required amount to reach the maximum number of points, for both the adequacy and the moderation components (**Figure 8.1**). The threshold values, only needed for the moderation components, represent the levels of intake that merit zero points.

The cut-off points were determined on the basis of the dietary guidelines, whereas in chapter 2 the threshold values were determined on the basis of the 85th percentiles of the study population. Percentiles were used because no biological references were available for the moderation components, except for alcohol intake where the binge-drinking cut-off points were used[35]. The choice of the 85th percentiles was arbitrary but in line with the threshold values for the HEI-2005[36]. In chapter 3, fixed threshold values were introduced for the DHD-index based on 85th percentiles from an adult reference population of the DNFCS 2007-2010[37]. Fixed cut-off points have the advantage that the score is comparable between study populations. Nevertheless, using cut-off points derived from the population under study, like the medians used in the Mediterranean Diet Score[33], has the advantage that the components always show large variation. When the aim is to develop an index for monitoring purposes, fixed cut-off values are necessary to be able to detect meaningful changes over time.

Role of energy intake

The DHD-index comprises three components based on intakes relative to energy intake, as described in the dietary guidelines[4]. The cut-off values for the components SFA and TFA were expressed in energy percentages and dietary fibre in energy density. Chapter

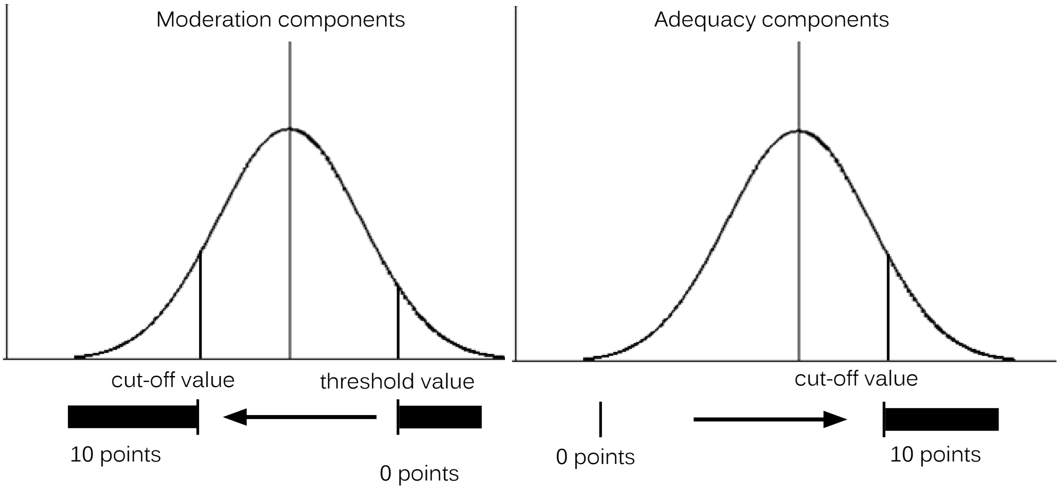

Figure 8.1 Cut-off values and scoring system of the DHD-index

5 describes the development of the DHD-FFQ, the short questionnaire to assess the DHD-index score. The DHD-FFQ was not designed to assess total energy intake, thus standard energy requirements were used to come up with sex-specific absolute cut-off values for the components dietary fibre, SFA, and TFA. The DHD-index score was inversely associated with energy intake in the populations studied in this thesis (**Table 8.1**). In the case of a relationship between energy intake and the outcome, when it is not an intermediate, one can argue that energy intake is a confounder. This was shown for the associations between the DHD-index and nutrient intakes, which were only positive when energy intake was adjusted for (chapters 2, 3, and 6). Thus only when adjusted for energy intake can the DHD-index be considered as a measure of diet quality. For all future research using the DHD-index, it is therefore recommended to take energy intake into account.

Adjusting for energy intake in statistical models is one of the solutions to take energy intake into account. Another option could be to express all components as relative measures, as was done in the HEI-2005 and HEI-2010[28, 32]. However, the absolute guidelines should then be translated into relative ones, although the rationale for relative guidelines for these components is not included in the Health Council recommendations[8].

It could also be argued that total energy intake as such should be included in the DHD-index. The dietary guidelines specifically mention that persons with undesirable weight gain or who are overweight should increase their physical activity level and lower their energy intake. Energy intake, together with energy expenditure, are the two sides of the energy balance equation. An imbalance of these two elevates the risk of obesity, a disease that consequently elevates the risk of many chronic diseases[38, 39]. Energy expenditure was already partly included in the index by means of physical activity level, but total energy intake was not. Unfortunately, assessment of total habitual energy intake is difficult[40]. Another possibility is to include a component on the outcome of the energy imbalance: a BMI above 25 kg/m^2. The possible impact of including an energy-related component in the DHD-index needs further research.

Application of weighting factors

Weighting factors were not applied to the components as none of the dietary guidelines was considered more important than the others[4]. However, components that were correlated with each other weighted inevitably more heavily in the total score[31, 41]. In chapter 3, moderate correlations were observed between the components fruit, vegetables, and dietary fibre, and between SFA and TFA. Consequently, these components weighted more heavily in the total score. In other words, if vegetable intake is improved, the component scores for vegetables and dietary fibre will increase. This collinearity can be removed by scoring dietary fibre from grains. Whether the correlations between the components should be eliminated for truly equally weighted components to improve diagnostic capacity is unclear and needs further research.

Some authors have argued that weighting factors should be applied in order to increase diagnostic capacity[30, 42, 43]. Suggested weighting factors include relative risks or odds ratios between a component and a certain health outcome. However, this approach would likely result in different weighting factors for the wide variety of health outcomes[41] and would thereby reduce comparability of the index between studies.

The choices made during the development of the DHD-index were driven by the aim of the DHD-index: assessment of adherence to the guidelines for a healthy diet in the general healthy population. If the aim is to target specific subpopulations, or risk prediction for specific diseases, the DHD-index might need alterations.

Dutch Healthy Diet index - Evaluation

Possible evaluation strategies for dietary indices were described in chapter 1 and results were reported in chapters 2, 3, and 4. We evaluated the DHD-index on the basis of the association with nutrient intakes, content validity, construct validity, reliability, and comparability across dietary assessment methods.

The internal consistency of the DHD-index was not reported in chapters 2, 3, and 4 and can be determined with Cronbach's alpha. This coefficient assesses the extent to which the score measures an underlying factor or construct; an alpha of 0.7 is considered satisfactory. Dietary indices may measure multiple constructs using partly independent components, thus the internal consistency was expected to be low. The Cronbach's alpha of the ten components was 0.39 when two 24hRs were used (DNFCS 2007-20107). The highest correlation with the total score was observed for dietary fibre (ɑ=0.49). The correlations between the total score and the other components ranged from 0.03 to 0.27. These results are comparable to the Cronbach's alpha for the HEI-2005 components44. The alpha of the 12 HEI-2005 components was 0.43, and the highest correlation to the total score was observed for calories from solid fat, alcohol, and added sugars (ɑ=0.57). These results suggest that the internal consistency of the DHD-index components is low and may measure multiple constructs.

In addition to its use in the studies reported in chapters 2, 3, and 4, the DHD-index has been used by others, and those results can contribute to the general evaluation of the index. The ability of the DHD-index to distinguish between subpopulations was shown in an investigation of preference for alcoholic beverages[5]. Diet quality was higher for individuals who preferred wine, had no preference, or drank no alcohol as compared to individuals who preferred beer in a cross-sectional study in adults from the DNFCS 2007-2010[7].

The ability to detect meaningful changes over time in an intervention setting has been shown by Hooft van Huysduynen *et al.*[45]. They carried out a 20-week intervention study, the OKE study, where dieticians gave tailored dietary advice five times to improve the level of adherence to the Dutch dietary guidelines. The study population comprised parents with children aged 4 to 12 years, to simultaneously improve the children's diet. The parents in the intervention group improved their DHD-index score by on average 7.8 points ($P<0.001$). This finding was confirmed by a significant increase in plasma phospholipid EPA and DHA ($P=0.016$) and a significant decrease in waist circumference ($P=0.027$). These results show that the DHD-index is useful for studying intervention effectiveness and monitoring diet quality changes over time.

In conclusion, the DHD-index is considered a valid tool to assess adherence to the dietary guidelines, monitor diet quality, assess the effectiveness of dietary interventions, and study diet and health associations.

Dutch Healthy Diet index - in perspective

The DHD-index vs. existing indices

Many dietary indices are currently available[46-48], raising the question of whether new indices are necessary and truly complement the existing ones.

All national dietary guidelines are based on nutritional knowledge, but cultural habits (e.g. high consumption of dairy in the Netherlands) and feasibility are taken into account in guideline formulation, resulting in differences between countries[4]. Therefore, dietary indices based on national dietary guidelines will differ, as well as dietary guidelines for subpopulations (e.g. Europeans)[49], the world population[50], or for specific chronic diseases (e.g. cancer, hypertension)[11, 51]. To monitor adherence to dietary guidelines, it is thus important to have a tool available that is able to assess those specific recommendations.

For etiologic nutrition research studying diet–health associations, it may not be necessary to develop national diet quality indices; it would, however, be desirable to develop one overall diet quality index covering all known important dietary components instead. For example, the Alternate Healthy Eating Index (AHEI) was developed using evidence from epidemiological research[52]. The AHEI differs from the HEI in that it includes components on whole grains, trans fatty acids, alcohol, and multivitamins, and excludes components on cholesterol and dairy. Furthermore, the components meat and fat are replaced by the fish and poultry to red meat ratio and the polyunsaturated to the saturated fat ratio, respectively. The AHEI showed associations that were approximately double those previously observed using the original HEI in the same population[52]. The HEI was updated according to the 2005 dietary guidelines for Americans and to include various types of vegetables, whole grains, and specific types of fat[36], which were also included in the AHEI[52].

Whether the DHD-index showed similar or weaker associations compared with other existing diet quality scores was studied by Struijk *et al.*[53]. They studied the association of the DHD-index, the Healthy Diet Indicator (HDI) based on the WHO guidelines, and the Dietary Approach to Stop Hypertension (DASH) score with cardiovascular disease risk in the EPIC-NL cohort. Neither the HDI nor the DHD-index was associated with incident CVD, whereas higher adherence to the DASH diet showed lower risk of developing incident CVD, CHD, and stroke.

Furthermore, we compared the DHD-index with the Nutrient Rich Food (NRF) index[54, 55], using data from the Rotterdam Study. The NRF9.3 index comprises nine nutrients to encourage and three nutrients to limit and evaluates the nutrient density of individual foods by scoring them on the basis of their nutrient composition. The NRF9.3 index was previously found to be inversely associated with all-cause mortality in the Rotterdam Study[56]. We observed a correlation of 0.62 (95% CI 0.59-0.63) between the DHD-index and the NRF9.3 in the Rotterdam Study. Furthermore, when the NRF9.3 index was additionally adjusted for, the HR between the DHD-index per ten units and all-cause mortality remained similar (HR 0.92, 95% CI 0.85-1.00), whereas the association between the NRF9.3 index and all-cause mortality disappeared (HR 0.99, 95% CI 0.99-1.00) when the DHD-index was additionally adjusted for. These results suggest that the DHD-index differs from the NRF9.3 index and from the DASH score. As the concepts of these indices are different – adherence to the Dutch dietary guidelines vs. nutrient density vs. lower hypertension risk, respectively – the appropriate diet index can be selected depending on the study aim.

DHD-index vs. principal component analysis

Both the DHD-index and principal component analysis (PCA) have their drawbacks due to arbitrary decisions during the process of defining dietary patterns. For PCA, arbitrary decisions include the number of food groups to incorporate, the number of factors to retain, naming of factors, and choice of rotation method (chapter 7). Both methods are extensively used in nutritional research[46].

When comparing the dietary patterns derived from PCA (chapter 7) with the DHD-index, we observed correlations in the expected direction. The DHD-index was inversely correlated with the 'meat' (r=-0.30) and 'snack' (r=0.33) pattern, and positively correlated with the 'health' pattern (r=0.38). The 'meat' dietary pattern was positively associated with prevalence of metabolic syndrome (highest vs. lowest tertile PR 1.72, 95% CI 1.17-2.54), whereas the DHD-index showed an inverse association with metabolic syndrome in the fully adjusted model (PR per 10 points increment: 0.87, 95% CI 0.79-0.96).

These methods may complement each other for their different applications in nutrition research[57]. Dietary patterns derived from PCA can be used in intervention programming targeting the specific dietary patterns observed in the population. Furthermore, emerged dietary patterns can provide new insights on dietary behaviours and their relationship with health.

In comparison, the DHD-index was more strongly related to all-cause mortality than the NRF9.3 index when both indices were modelled simultaneously in the Rotterdam Study. However, the DHD-index was not associated with incident CVD in the EPIC-NL cohort, whereas adherence to the DASH diet was. Furthermore, the DHD-index showed interpretable associations with the PCA-derived dietary patterns, and both methods showed associations with the prevalence of metabolic syndrome. The choice of one of the methods or of one of the dietary indices depends on study aim and application.

Dutch Healthy Diet index - Applications

Shared meals

The DHD-index was used as a measure of daily diet quality to study the association with company at dinner. Research on the determinants of dietary intake is important as it can explain variation in diet quality between persons and thereby provide opportunities for public health practitioners to guide individuals to healthier diets. For example, studies have shown that out-of-home foods are higher in fat and energy content than foods consumed at home[58]. Therefore, home meal preparation and less eating out has been encouraged by nutrition experts in the USA[59].

It is widely believed that shared meals are becoming less important and are occurring less often. This change can be explained by the individualization of society, resulting in increasing interest in individual choices and personal control of food and eating[60, 61]. A decreasing trend in frequency of shared meals may negatively affect diet quality and thereby health[62, 63]. Understanding national trends in relation to shared meals may therefore be important for policy and programme considerations[64]. Furthermore, the association between company at dinner and overall diet quality in adults has not yet been studied.

Chapter 5 described the association between company at dinner and daily diet quality in men and women in the NQplus study. When dinners out-of-home are excluded, family dinners were associated with higher daily diet quality scores than meals consumed with others among men (mean difference=2.7 points on an 80-point DHD-index score) and among women (mean difference=2.1 points). If the observed results are compared with those of the participants in the OKE intervention, there is an improvement in their DHD-index score of on average 7.8 points on a 100-point scale; the difference of 2.7 and 2.1 points out of 80 (i.e. 3.4 and 2.6 points on a 100-point scale) is relatively large. Furthermore, each point increase in the DHD-score is associated with a 1% risk reduction of all-cause mortality (chapter 4). Our results should be tested in other studies but may be used in intervention programmes to create awareness about making healthier food choices, including when one is having friends over for dinner.

DHD-FFQ

In time-limited settings, such as clinical practice in hospitals or general practices, there is need for a quick dietary assessment method (e.g. a screener) to determine unhealthy dietary intake. The DHD-index served as the starting point for the development of the 34-item DHD-FFQ. In chapter 6, we showed that the DHD-index based on the DHD-FFQ was able to rank persons according to their diet quality. However, the limits of agreement as assessed using a Bland-Altman plot were relatively wide, meaning a large variation in bias between the DHD-index based on the DHD-FFQ and the reference method at individual level. More detailed dietary assessment methods were recommended for follow-up activities such as dietary advice by a dietician. Improving the estimates from the DHD-FFQ by including more questions on additional food items will lead to a longer questionnaire, which is undesirable. Another option is not to focus only on quantities of foods consumed, but more on the quality. For example, ascertaining the type of bread, pasta, and fish consumed, or whether certain foods such as chips are consumed, could eliminate questions on quantity, thereby allowing the inclusion of more food items. In Germany, a list of 24 food items was composed that could be administered in five minutes and was compared to 7-day weighted records. The food frequency list could be used for analysis at group level, but at individual level caution was warranted[65]. More research is needed to examine whether, without making the DHD-FFQ longer, small changes can be made to improve the individual estimates.

The DHD-FFQ can be used in time-limited settings to quickly determine whether individuals have an unhealthy dietary intake that may need further action, such as professional dietary advice. To be able to refer individuals to dieticians, there is need for a cut-off value representing the number of points at which diet quality is considered too low. This cut-off value should represent the number of points needed to prevent nutrient deficiencies or, ideally, associated with the largest reduction in risk of chronic diseases. This raises the question of which health outcomes should be studied, because the cut-off value will probably differ between those. Furthermore, complete adherence to all guidelines should ideally be the aim. However, it is as yet unknown whether complete adherence will consequently result in most health benefits, because the results in this thesis were limited to the range of scores observed in the study populations (on average <1% with complete adherence). Setting a cut-off value for assessment of poor diet quality is challenging, but is of great importance in clinical settings. For this reason, this cut-off value is recommended to be used only for referral purposes and not to distinguish between persons in a research setting.

To find an appropriate cut-off value for assessment of poor diet quality, we further examined the association between the DHD-index per 10 points increment and all-cause mortality in the Rotterdam Study. With the use of cubic splines regression, we could examine possible plateaus or steep risk reductions at a certain number of points that could serve as a cut-off value. However, the association was linear (P nonlinearity=0.52). Next, the number of points needed to achieve an arbitrary 10% risk reduction for all-cause mortality was considered. This risk reduction was achieved at 60 points out of the total 90 points. Since the DHD-index based on the DHD-FFQ consists of a maximum of 80 points, the number of points was multiplied by 80/90 and was set at 53 points.

With this arbitrarily chosen cut-off value, we could study the accuracy of the DHD-FFQ to classify persons with poor diet quality. For this, we calculated the Receiver Operating Characteristics (ROC) curve and the Area Under the Curve (AUC). An AUC of 0.5 represents a predictive value equal to chance and an AUC of 1.0 represents perfect prediction. Dietary data in relation to 405 persons from the NQplus study based on three telephone-based 24hRs were considered the best available reference data. The accuracy of the DHD-index based on the DHD-FFQ was considered moderate (AUC=0.692; figure 8.2). As no other diet quality screeners were examined using the ROC, we could not compare our result to others. However, other diagnostic risk scores for prediction of CVD and type II diabetes had similar AUCs[66, 67].

The diagnostic capacity of a screener depends on both the discriminatory value and the prevalence of having poor diet quality. To study this, the prevalence of poor diet quality was studied in 2106 adults from the DNFCS 2007-2010. The frequency of a DHD-index score (ranging 0-80 points) below 53 points was 74.6%. Together with sensitivity (37%) and specificity (83%), using the cut-off of 53 points of the DHD-index based on the DHD-FFQ against the three dietary recalls, the positive predictive value was 91% and the negative predictive value was 21%. This means that, of all individuals who score less than 53 points on the DHD-index based on the DHD-FFQ, 9% will be wrongly referred to the dietician. However, of all individuals who score more than 53 points on the DHD-index based on the DHD-FFQ, 79% should be referred to the dietician. As a large part of the population should therefore be referred to the dietician, but will not when the DHD-FFQ is used, further research is needed to examine other cut-off values that show a better negative predictive value.

The DHD-index served as a starting point for the development of the DHD-FFQ and proved to be a useful tool when applied to study determinants of dietary intake.

Methodological considerations

When research results are being interpreted, it is important to consider the extent to which the observed results may have been affected by errors. These errors can arise from the population under study, the dietary assessment method, or confounding variables.

Study populations

The participants in this thesis were 18 years of age and older. It seemed that the young adults had lower DHD-index scores than the adults older than 30 years; this was also shown by the positive associations of the index with age in most chapters (**Table 8.1**). As shown in chapter 4, elderly persons in the Rotterdam Study showed an inverse association between age and the DHD-index; this can possibly be explained by increased risk of lower dietary intake probably due to poor appetite and changes in elderly persons' social environment[68]. The index's positive association with BMI in this study further underpins this explanation as persons with lower dietary intake also had a lower weight.

All populations studied in this thesis consisted of both men and women, and women showed consistently higher DHD-index scores than men (**Table 8.1**). In general, women

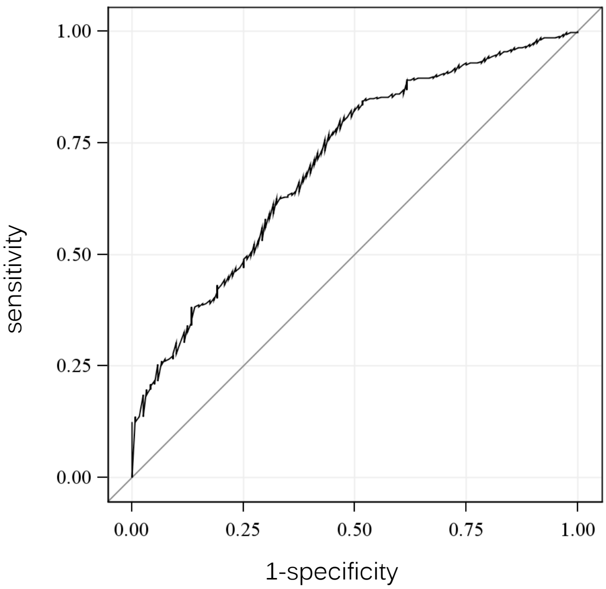

Figure 8.2 ROC to assess diagnostic accuracy of the DHD-FFQ in detecting poor diet quality

tend to consume more healthy diets than men; this can be explained by the assumption that women are in general more health conscious and consequently adapt their food choice on this basis[69, 70].

A large part of the population from the EFCOVAL-NL study and the NQplus study were classified as highly educated. This could be explained by the fact that more highly educated persons seem to be more willing than less educated persons to participate in studies[71]. The large number of highly educated persons might diminish the variation or range of exposure and therefore decrease the possibility of detecting associations. This is illustrated by the lack of an association between education level and the DHD-index in these two studies (**Table 8.1**). In the Rotterdam study and the DNFCS-2003, positive associations between education and DHD-index were observed (**Table 8.1**).

Dietary assessment method

Dietary intake cannot be measured without errors, and these errors will be reflected in the DHD-index. Comparison of the mean DHD-index scores across chapters reveals that the scores are generally higher when FFQs are used rather than 24hRs (**Table 8.1**); this was also shown in a direct comparison in chapter 3. The higher diet quality scores as assessed using FFQ data could be explained by higher scores for fish, as fish is an episodically consumed food and less well reported in 24hR. Also, higher scores for sodium are expected, as the FFQs used in chapters 2 and 6 were not specifically designed to assess salt intake.

In general, self-report dietary assessment methods may be influenced by socially desirable answers, and the participants' ability to recall dietary intake from the past and to correctly estimate portion sizes[72]. Systematic over- or underreporting of dietary intakes could result in over- or underestimation of the mean DHD-index score, but is unlikely to influence the ranking of individuals. However, person-specific bias and intake-related bias may influence the ranking[73]. An example is that obese persons with high intakes tend to report less than individuals with a normal weight and lower intakes[74]. Since the DHD-index was inversely associated with energy intake, this person-specific underestimation could have resulted in overestimation of the DHD-index scores and thereby misclassification. Furthermore, BMI is likely to be positively associated with the risk of health outcomes as studied in chapters 4 and 6, and thus the underreporting of overweight persons probably biased the results. This probable bias was taken into account by additionally including BMI as a covariate in the statistical models.

Sodium intake is difficult to assess using self-report dietary assessment methods, because salt use during cooking or at the table is hard to estimate. Moreover, the sodium content of manufactured foods varies, making it difficult to estimate these sources accurately[75]. In the DHD-FFQ, we included two questions on discretionary salt intake during cooking and added at the table; however, these did not improve the estimates (chapter 6). Additional questions on discretionary sodium in the Short Sodium Questionnaire[76] also showed poor correlations with 24h urinary sodium excretion. Moreover, one question about sodium preference was not effective in identifying high sodium consumers[77]. The sodium component based on the DHD-FFQ showed similar low correlations with urinary sodium excretion as the sodium component based on a 180-item FFQ (chapter 6). The 180-item FFQ was not designed to estimate salt intake and consequently did not include questions on all sodium-rich food products or discretionary sodium. Both the DHD-FFQ and the 180-item FFQ should preferably not be used to estimate salt, and results from these data must be interpreted with caution. Preferably the gold standard, 24h urinary sodium excretion, should be used to overcome measurement errors[78], although it is burdensome for participants and therefore not always feasible to use.

Web-based technologies are becoming more widely acknowledged in research. In the NQplus study (chapters 5, 6, and 7), the FFQ, the DHD-FFQ, and the (web-based) 24hR were administered online using the open-source tool Limesurvey (FFQs) or the newly developed programme Compl-eat (24hR). Advantages of online administration include lower costs, no data entry for researchers, ability to apply skipping patterns, restricting answers, and obligatory questions. However, suggested limitations include the requirement of computer literacy and skills, altered response behaviour, and possible increased reporting and memory bias[79, 80]. Validation studies suggest that online administration produces results comparable to those of the more traditional administration on paper or via the telephone[81-84]; however, it is important to study the potential biases that may arise from these technologies[79, 80]. In the NQplus study, the correlation between the DHD-index based on web-based 24hR and telephone-based 24hR was promising (r=0.48). Complementary innovations such as wearable cameras[85] and pictures of meals taken with smart phones[86] should be further investigated to contribute to increasing the validity of dietary assessment methods.

Confounding variables

Confounding variables are associated with outcome and exposure but are not an intermediate in the association between the two. The association of confounders with outcome can therefore be confused with the actual studied association. An advantage of dietary pattern analysis is that no other dietary components are likely to affect the association since these are included in the pattern. Nevertheless, certain other variables such as gender, age, and smoking could confound the association between dietary patterns and health outcomes. In all chapters, various confounders were included in the statistical models for adjustments. As always in observational studies, the possibility that the observed results might be partly explained by residual confounding – because of measurement errors or unmeasured confounders – cannot be excluded. However, main confounders were included in our data analyses.

The top three methods for selection of potential confounders are prior knowledge, effect estimate change, and stepwise regression[87], although the latter two are not recommended[88]. To make the selection of confounders more visible and repeatable, Directed Acyclic Graphs (DAGs) were suggested[89]. These graphs represent the causal structure of variables and covariates of the study and force thereby greater clarity about assumptions made[89]. DAGs can be drawn following a few basic rules using a priori knowledge on the associations of the covariates with exposure and outcome in the population under study[90]. In chapter 5, we made use of DAG methodology to select the possible confounders for the association between company at dinner and daily diet quality (**Figure 8.3**). The covariates minimally needed for full adjustment (i.e. the minimal solution) were included in the statistical model. We additionally included energy intake in the model because of previously found inverse associations with energy intake. However, the DAG classified energy intake as an intermediate. Including an intermediate in the model may have attenuated the association, as part of the association goes via energy intake. Nevertheless, the crude associations were similar to the mean DHD-index scores when adjusted for age and energy intake. Furthermore, dinner location

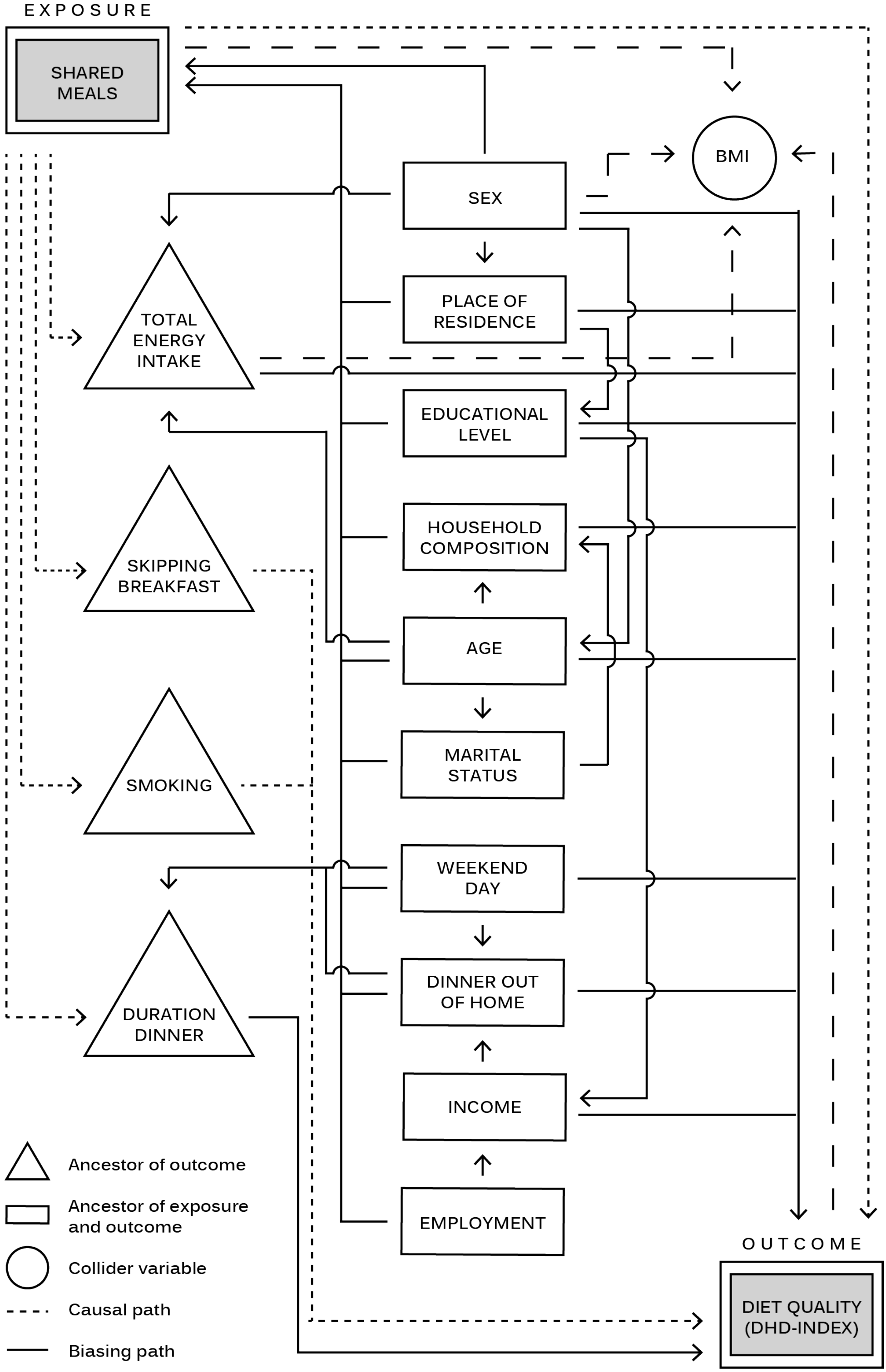

Figure 8.3 DIrected Acyclic Graph for the assocation between company at dinner and daily diet quality

was classified as a confounder in the association between company at dinner and daily diet quality. Location and company at dinner were highly correlated (r=0.66); thus we also excluded all dinners consumed out-of-home to avoid multicollinearity. We feel that selecting confounders with the use of DAG is a very useful method to understand, visualize, and select confounders in epidemiological studies.

Public health implications and Future research

DHD-index

The DHD-index can be used to study the relation between diet quality and health, evaluate diet quality in (sub)populations, monitor diet over time, identify high-risk subpopulations, assess effectiveness of nutrition interventions, evaluate other tools such as nutrient density indices[54], or serve as a confounder that represents the whole diet[91, 92].

It is recommended to use the DHD-index while taking energy intake into account to adjust for the relation between energy intake and the DHD-index. The components consumption occasions with ADF and TFA may be excluded from the total score when the DHD-index is being studied at population level. At individual level, these two components may be important for explaining variation in DHD-index scores between persons.

Future research should further adapt and evaluate the index for use with children, as the dietary guidelines were also meant for children between 2 and 18 years of age[4]. For this, the quantities should be translated to the dietary needs of children. The DNFCS 2007-2010 showed that children were more likely to eat dairy, cake, and sugar and confectionary, and less likely to consume vegetables, fish, and alcoholic beverages[7], meaning that the total score will show a different underlying construct. Therefore, the validity of an adapted DHD-index should be further examined for use with children and adolescents. Furthermore, further research is needed to study whether adding BMI to the index would be helpful to counterbalance the fact that the dietary guidelines were meant for the Dutch population with a healthy weight.

DHD-index version 2.0

Knowledge on diet and health associations is continuously updated with new insights from nutritional research[93]. It is therefore necessary to adapt scores according to these new insights. In 2015, the Dutch Health Council aims to present updated dietary guidelines for the Netherlands based on new scientific insights and the current national dietary habits. The results of this thesis could be taken into account for the development of these guidelines. As discussed before, dietary components for the prevention of cancer incidence and mortality could be included. Examples include guidelines to limit red and processed meat intake to 500 g/week and to maintain a healthy weight (BMI between 18.5-25 kg/m^2) to represent the imbalance in energy intake. When the 2015 guidelines become available, the DHD-index might need to be updated and subsequently evaluated.

Future research into diet quality and health outcomes such as mental health – including depression, cognitive functioning, and dementia[94, 95] – can provide evidence for potential important dietary components to include in the future Dutch dietary guidelines.

DHD-FFQ

The DHD-FFQ could be used in several research settings. The component scores estimated from the DHD-FFQ can indicate the most prominent opportunities for improvement. Furthermore, Dutch local monitoring surveys have only a limited number of questions available to determine the diet quality of a subpopulation, and the DHD-FFQ could provide the solution.

Future research should examine the feasibility and validity of a cut-off value for determination of poor diet quality. Furthermore, the development of online automatic dietary advice based on the DHD-FFQ component scores would give laypeople a useful tool to monitor – and hopefully improve – their diet quality. This notwithstanding, the effectiveness of online dietary advice should be further studied. Suggested drawbacks include high drop-out rates and no intention to use the internet for health behaviour change[96]. Furthermore, in online health programmes aimed at high risk subpopulations, it has been found that older and less educated persons are less likely to participate than younger or more educated persons[97].

Healthy diet

Adherence to the current Dutch dietary guidelines was positively associated with nutrient intake when adjusted for energy intake, and inversely associated with the prevalence of metabolic syndrome and risk of mortality from all causes, CVD, CHD, and stroke. Furthermore, an unhealthy diet with high intakes of meat and snacks was associated with unfavourable cardio-metabolic risk factors. Thus, it is suggested that promoting a healthy diet decreases the population burden of chronic disease and unfavourable developments in cardio-metabolic risk factors. The association between adherence to the dietary guidelines as assessed using the DHD-index and health outcomes such as type II diabetes, bone health, dementia, and more subjective health outcomes such as quality of life should be further studied.

Conclusions

Overall, this thesis shows that the DHD-index is a valid tool to assess adherence to the Dutch guidelines for a healthy diet. It can be used to assess associations with nutrient intakes, monitor diet quality in populations, distinguish between persons, and rank persons based on their diet quality, and thus it can be applied to multiple research settings to assess diet–disease associations but also to study behavioural determinants of dietary intake.

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SAMENVATTING
-
(SUMMARY IN DUTCH)

In traditioneel voedingsonderzoek wordt vaak één bepaalde voedingsstof of één voedingsmiddel in relatie tot gezondheid bestudeerd. Mensen eten echter geen afzonderlijke voeddingstoffen of voedingsmiddelen, maar maaltijden die bestaan uit combinaties van voedingsmiddelen die een combinatie van voedingsstoffen bevatten. Deze verschillende combinaties van voedingsstoffen kunnen uiteenlopende effecten hebben op de gezondheid. Daarom worden tegenwoordig ook voedingspatronen bestudeerd. Voedingspatronen kunnen op meerdere manieren gedefinieerd worden en één methoden is gebaseerd op voedingsrichtlijnen. Deze voedingsrichtlijnen representeren de optimale voeding voor preventie van chronische ziekten, zoals de Nederlandse Richtlijnen Goede Voeding. In Nederland was er nog geen score beschikbaar om de naleving van de huidige Richtlijnen Goede Voeding vast te stellen. Daarom is de Dutch Healthy Diet index (DHD-index) ontwikkeld. Zoals bij elk nieuw ontwikkeld meetinstrument, moet deze geëvalueerd worden op zijn beoogde werking. Dit proefschrift beschrijft de ontwikkeling, de evaluatie en twee mogelijke toepassingen van de DHD-index in Nederland.

Hoofdstuk 2 beschrijft de ontwikkeling van de DHD-index op basis van de Nederlandse Richtlijnen Goede Voeding die tien kwantitatieve aanbevelingen bevat. Deze tien richtlijnen gaan over: 1) lichamelijke activiteit, 2) het aantal eetmomenten met dranken en voedingsmiddelen met gemakkelijk vergistbare suikers en een hoog gehalte aan voedingszuren, de inname van 3) groenten, 4) fruit, 5) voedingsvezel, 6) vis, 7) verzadigde vetzuren, 8) transvetzuren, 9) natrium en 10) alcohol. De DHD-index bestaat uit 10 componenten, waarbij elke component een richtlijn vertegenwoordigt. De componenten kunnen een score tussen 0 en 10 punten krijgen op basis van de voedingsinname. Dit resulteert in een totaalscore tussen 0 en 100 punten, waarbij de maximale score toegekend wordt wanneer het dieet geheel voldoet aan de richtlijnen. Om de DHD-index te berekenen en te evalueren, hebben we gegevens gebruikt van 749 Nederlandse jongvolwassenen waar de voeding is nagevraagd. In deze studie zagen we dat de DHD-index in staat is om deelnemers te rangschikken naar de mate waarin men voldoet aan de Nederlandse voedingsrichtlijnen. Daarnaast consumeerde personen, die in hoge mate voldeden aan de voedingsrichtlijnen, minder energie maar ook minder vitaminen en mineralen. Zodra we corrigeerden voor de energie-inneming was de inname van vitaminen en mineralen hoger bij personen die in hoge mate voldeden aan de voedingsrichtlijnen dan bij personen die minder voldeden. Dit suggereert dat de DHD-index een goede maat is voor het bekijken van de naleving van de richtlijnen en de voedingsstoffendichtheid van een voeding.

Voor het beoordelen van de validiteit van de DHD-index is het belangrijk vast te stellen of deze vergelijkbaar is met twee veelgebruikte methoden om voeding na te vragen. In **hoofdstuk 3** is de DHD-index berekend op basis van 24-uurs voedingsnavragen vergeleken met de DHD-index berekend op basis van een voedselfrequentievragenlijst (FFQ). Een 24-uurs voedingsnavraag stelt gedetailleerde informatie over de voedingsinname van 1 of meer dagen vast. Een FFQ daarentegen stelt de gebruikelijke inname vast van de afgelopen 4 weken. Voor deze studie hebben we gegevens gebruikt van 121 Nederlandse mannen en vrouwen die zowel twee 24-uurs voedingsnavragen als een FFQ hadden ingevuld. De DHD-index score berekend met FFQ gegevens vertoonde vergelijkbare verbanden met kenmerken van de deelnemers, de inname van energie, vitamines en mineralen en bloedmarkers als de DHD-index op basis van de 24-uurs voedingsnavragen. De rangschikking van de deelnemers en de absolute overeenkomst tussen de twee methoden was aanvaardbaar.

De Richtlijnen Goede Voeding zijn gericht op de preventie van chronische ziekten zoals hart- en vaatziekten en kanker. Als de DHD-index een goede maat is om de naleving van de voedingsrichtlijnen te meten, zou er ook een verband met gezondheid gevonden moeten worden. Dit is onderzocht bij 3593 mannen en vrouwen die 20 jaar zijn gevolgd en waarbij de voeding is nagevraagd tussen 1990-1993 (**hoofdstuk 4**). De deelnemers met de hoogste DHD-index scores hadden een 23% lager risico op sterfte in vergelijking met de deelnemers met de laagste scores. Voor specifieke doodsoorzaken zoals hart- en vaatziekten werden minder sterke verbanden gevonden. Er werd geen verband gevonden met sterfte aan kanker.

Één van mogelijke toepassingen waarbij de DHD-index gebruikt kan worden is om de kwaliteit van de voeding te beoordelen. **Hoofdstuk 5** beschrijft het onderzoek naar het gezelschap tijdens de hoofdmaaltijd en de kwaliteit van de dagvoeding. De mannen en vrouwen van de NQplus studie hebben meerdere 24-uurs voedingsnavragen ingevuld met informatie over met wie en waar ze hun hoofdmaaltijden consumeerden. Bij mannen was er geen verschil in de kwaliteit van de voeding op dagen dat de hoofdmaaltijd al dan niet in gezelschap was genuttigd. Bij vrouwen was de kwaliteit van de dagvoeding gemiddeld lager op dagen dat de hoofdmaaltijd in gezelschap werd gegeten dan wanneer de hoofdmaaltijd alleen werd geconsumeerd. Als de maaltijd was genuttigd in gezelschap, dan was, bij zowel mannen als vrouwen, de dagvoeding gemiddeld van een hogere kwaliteit wanneer de hoofdmaaltijd werd genuttigd in gezelschap van familie dan wanneer dat gebeurde in gezelschap van anderen zoals vrienden, collega's, etc.

Het navragen van de voedingsinname kan vaak veeleisend zijn voor deelnemers doordat het veel tijd in beslag neemt. In veel situaties, zoals in de huisartsenpraktijk, is deze tijd niet beschikbaar en is er vraag naar een instrument dat snel de kwaliteit van de voeding kan beoordelen. Voor deze situaties is de Eetscore (Engels: DHD-FFQ) ontwikkeld (**hoofdstuk 6**). De Eetscore is een korte vragenlijst waarmee in 5 tot 10 minuten de DHD-index score kan meten. Voor de evaluatie van de Eetscore, hebben we deze vergeleken met de DHD-index berekend op basis van een gebruikelijke lange FFQ. Uit de resultaten bleek dat de Eetscore een goed meetinstrument is om deelnemers te rangschikken op basis van hun naleving van de Nederlandse voedingsrichtlijnen en om groepen personen te identificeren met een slechte kwaliteit van hun voeding.

In **hoofdstuk 7** is een andere methode gebruikt om voedingspatronen te bestuderen. Deze voedingspatronen zijn gebruikt om de relatie tussen voeding en het metabool syndroom en de afzonderlijke componenten te bestuderen. De diagnose metabool syndroom wordt gesteld als minstens drie van de vijf volgende elementen aanwezig zijn: grote middelomtrek, hoge bloeddruk, en in bloedwaarden een hoge concentratie van nuchter bloedsuiker en triglyceriden en een lage concentratie HDL cholesterol. Er zijn drie verschillende voedingspatronen gevonden, namelijk een 'Vlees', een 'Gezond' en een 'Snack' voedingspatroon. Deelnemers die in hoge mate voldeden aan het 'Vlees' patroon hadden 72% vaker het metabool syndroom vergeleken met deelnemers die minder voldeden aan het 'Vlees' patroon. Verder hadden de deelnemers die in hoge mate voldeden aan het 'Vlees' patroon ook 81% vaker een grote middelomtrek, en 47% vaker een verhoogde nuchtere bloedsuikerspiegel. Het 'Snack' patroon werd niet in verband gebracht met het metabool syndroom, maar mensen die in hoge mate voldeden aan het 'Snack' patroon hadden wel 42% vaker een te grote middelomtrek. We zagen geen verband tussen een 'Gezond' voedingspatroon en het metabool syndroom. Deze bevindingen bevestigen eerder onderzoek dat een voedingspatroon gekenmerkt door hoge inname van vlees een hoger risico geeft op het metabool syndroom en de afzonderlijke componenten.

De conclusie van het onderzoek beschreven in dit proefschrift is dat de DHD-index, berekend op basis van 24-uurs voedingsnavragen, FFQs of de Eetscore, een waardevol instrument is om de naleving van de voedingsrichtlijnen te beoordelen (**hoofdstuk 8**). Daarnaast kan de DHD-index gebruikt worden voor het monitoren van de voedingskwaliteit, het beoordelen van de effectiviteit van voedingsinterventies en het bestuderen van verbanden tussen voeding en gezondheid.

DANKWOORD - (ACKNOWLEDGEMENTS)

Yes! Mijn proefschrift is af! Na 4 jaar hard werken mag ik dan eindelijk mijn dankwoord schrijven. Een plekje om iedereen te bedanken en tegelijkertijd een definitieve afronding van mijn proefschrift. Na 8 hoofdstukken over de DHD-index, zal ook dit hoofdstuk nog over de DHD-index gaan, maar nu over mijn persoonlijke interpretatie hiervan ;-)

De DHD-index kan voor het dankwoord vrij vertaald worden naar 'De Hartelijke Dank index'. Ook deze DHD-index bestaat uit 10 compenten: de groepen personen die elk een bijdrage hebben geleverd aan dit proefschrift! De bijdragen verschillen van inhoudelijke hulp met schrijven, van verzamelen van data tot aan gezellige kletsen over het weekend. Elke bijdrage was van onschatbare waarde en heeft mede tot dit boekje geleidt! Om deze reden krijgt iedereen van mij het maximale aantal van 10 punten

Ik wil iedereen ontzettend bedanken voor zijn/haar inzet, tijd, en interesse in mij en mijn onderzoek! Door jullie kan ik terugkijken op een leerzame, maar ook gezellige periode!

Bedankt!

Linde

DE HARTELIJKE DANK INDEX

	Componenten	Personen	Punten
1	Promotoren	Edith Feskens Anouk Geelen	10
2	Projectleden	Pieter van 't Veer Jeanne de Vries Eveline Hooft van Huysduynen	10
3	Co-auteurs	Jessica Kiefte – de Jong Albert Hofman Oscar Franco Diewertje Sluik Saskia Meijboom Nicole Jankovic Thora Baks Noortje Vonk	10
4	Deelnemers van:	Voedselconsumptiepeiling 2003 European Food Consumption Validation study Rotterdam Study Nutrition Questionaires plus study	10
5	Paranimfen	Anne van de Wiel Martinette Streppel	10
6	Hulp bij data verzameling	Els Siebelink Corine Perenboom Dames van het 'call-center' Onderzoeksassistenten Laboratorium Vrijwilligers	10
7	Extra hulp	Janet van den Boer Marjolein Damman Anneke Flipse Soomaree Sriwong Hanne Straver	10
8	Collega's	Mede-PhD'ers Secretariaat Collega's Agro en Bio	10
9	Vrienden	Miepjes Ex-homies Wageningen - vriendjes Thuisthuis - vriendjes	10
10	Familie	Rick Mama Papa & José Myrte Fleur Schoonfamilie	10

ABOUT THE AUTHOR

Curriculum Vitae

Linde van Lee was born on 3rd March 1985 in Berghem, the Netherlands. After completing secondary school (Voortgezet Wetenschappelijk Onderwijs) at the Mondriaan College in Oss (2004), she continued her education at Wageningen University with her BSc and MSc Nutrition and Health. In 2009, Linde completed her final thesis entitled: 'The association between medication use and plasma homocysteïne concentration in a Dutch elderly population'. After that, she did an internship on the association between micronutrient intake and colorectal cancer at the Western Australian Institute for Medical Research in Perth, Australia. Linde received her MSc degree in 2009 with a major in Nutrition in Health and Disease and a minor in Communication Science. Shortly after graduation, she started working as a PhD candidate at the Division of Human Nutrition of Wageningen University. During her PhD, she attended several conferences and courses within the education program of the VLAG graduate school. Furthermore, she was appointed as researcher to study added sugars intake in the Netherlands sponsored by the Kenniscentrum Suiker Nederland.

List of publications

Publications in peer-reviewed journals

- Eveline Hooft van Huysduynen, Paul Hulshof, **Linde van Lee**, Anouk Geelen, Edith Feskens, Pieter van 't Veer, Cees van Woerkum, Jeanne de Vries (2014). Evaluation of using spot urine to replace 24-h urine sodium and potassium excretions. Public Health Nutr 17(11), 2505-2511..

- Diewertje Sluik, **Linde van Lee**, Edith Feskens (2014). Alcoholic beverage preference and diet in a representative Dutch population: the Dutch national food consumption survey 2007–2010. Eur J Clin Nutr 1-8.

- **Linde van Lee**, Edith Feskens, Eveline Hooft van Huysduynen, Jeanne de Vries, Pieter van 't Veer, Anouk Geelen (2014). The Dutch Healthy Diet index as assessed by 24h recalls and food frequency questionnaire: Associations with biomarkers from cross-sectional study. Journal of Nutritional Science 2.

- **Linde van Lee**, Anouk Geelen, Eveline Hooft van Huysduynen, Jeanne de Vries, Pieter van 't Veer, Edith Feskens (2012). The Dutch Healthy Diet index (DHD-index): an instrument to measure adherence to the Dutch guidelines for a healthy diet. Nutr J 11 (49).

- **Linde van Lee**, Jane Heyworth, Sarah McNaughton, Barry Iacopetta, Cassandra Clayforth and Lin Fritschi (2011). Selected dietary micronutrients and the risk of right- and left-sided colorectal cancers: a case-control study in Western Australia. Ann Epidemiol 21(3):170-7.

Submitted publicatons

- **Linde van Lee**, Edith JM Feskens, Saskia Meijboom, Eveline JC Hooft van Huysduynen, Pieter van 't Veer, Jeanne HM de Vries, Anouk Geelen. Evaluation of a short food frequency questionnaire to assess diet quality in the Netherlands. Submitted.

- **Linde van Lee**, Anouk Geelen, Thora L Baks, Eveline JC Hooft van Huysduynen, Jeanne HM de Vries, Pieter van 't Veer, Edith JM Feskens. Dietary patterns and metabolic syndrome: a cross-sectional analysis within the NQplus study. Submitted.

- **Linde van Lee**, Anouk Geelen, Jessica C Kiefte - de Jong, Jacqueline CM Witteman, Albert Hofman, Noortje Vonk, Nicole Jankovic, Eveline JC Hooft van Huysduynen, Jeanne HM de Vries, Pieter van 't Veer, Oscar H Franco, Edith JM Feskens. Adherence to the Dutch dietary guidelines is inversely associated with 20-year mortality in a large prospective cohort study. Submitted.

- Eveline JC Hooft van Huysduynen, **Linde van Lee**, Anouk Geelen, Pieter van 't Veer, Edith JM Feskens, Cees JM van Woerkum, Jeanne HM de Vries. Associations of breakfast skipping, dinner away-from-home, soft drink consumption, and snacking with healthy diets in a Dutch population. Submitted.

- Eveline JC Hooft van Huysduynen, Emely de Vet, **Linde van Lee**, Anouk Geelen, Edith JM Feskens, Pieter van 't Veer, Cees JM van Woerkum, and Jeanne HM de Vries Mediators of behavior change in a nutrition counselling intervention. Submitted.

- Eveline Hooft van Huysduynen, Cees JM van Woerkum, Corine WM Perenboom, Elisabeth CAM Verbruggen, **Linde van Lee,** Anouk Geelen, Edith JM Feskens, Pieter van 't Veer, Jeanne HM de Vries. Effects of a counselling intervention to improve diet quality: a randomized controlled trial in parents of 4 to 12 year old children. Submitted.

- Diewertje Sluik, Martinette T. Streppel, Linde van Lee, Anouk Geelen, Edith JM Feskens. Evaluation of a nutrient-rich food index score in the Netherlands. Submitted.

Published abstracts

- **Linde van Lee**, Noortje Vonk, Nicole Jankovic, Jessica Kiefte - de Jong, Albert. Hofman, Jacqueline Witteman, Eveline Hooft van Huysduynen, Jeanne de Vries, Anouk Geelen, Pieter van ‘t Veer, Oscar Franco, Edith Feskens (2013) Adherence to the Dutch dietary guidelines and 20-year mortality: The Rotterdam study. Ann Nutr Metab 63(suppl1) 1–1960

- Eveline Hooft Van Huysduynen, **L.inde van Lee**, Anouk Geelen, Edith Feskens, Pieter van ‘t Veer, Cees van Woerkum, Jeanne de Vries (2013). The effect of an individually tailored nutrition intervention for Dutch parents on dietary intake and physical activity of their children. Ann Nutr Metab 63(suppl1) 1–1960

Report

- Diewertje Sluik, Linde van Lee, Edith Feskens (2014) Consumptie van toegevoegde suikers in Nederland. Resultaten uit de Nederlandse Voedselconsumptiepeiling 2007-2010. Wageningen University, Wageningen.

Overview of completed training activities

Courses and workshops

Exposure assessment	2010
Masterclass Linear/logistic Regression	2010
Masterclass Multilevel Analysis	2011
Good Clinical Practice (GCP)	2011
Masterclass R	2012
Masterclass Longitudinal Data Analysis	2013
Masterclass Confounding	2014

Conferences and Meetings

Annual meeting NWO nutrition, Deurne	2010-2013
2nd luxembourgisch Nutrition Conference. Luxemburg, Luxemburg	2011
Annual meeting of the Netherlands Epidemiology Society	2011-2013
Werkgroep Voedingsgewoonten	2012
International Congress of Nutrition (ICN). Granada, Spain	2013
Food for Thought. Ede, Netherlands	2013

General activities

PhD-week	2010
PhD competence assessment	2010
Techniques for writing and presenting a scientific paper	2011
Teaching and supervising students	2011
Presenting skills - Louise Mennen	2012
Scientific writing	2013
Data management	2013

Optional courses and activities

Quantitative data analyses: multivariate techniques (YRM-60306)	2010
PhD-tour Mexico-USA	2011
Literature and discussion groups: ‘Epi-research’, ‘Methodology club’, ‘Dietary patterns club‘, ‘Old mobiles’, and ‘Paperclip’	2010-2014
Concepts and Methods in Epidemiology (HNE-38802)	2010-2011
PhD-tour Australia	2013

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Colophon

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