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Indexes of overall diet quality

A review of the literature

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Abstract

Indexes of overall diet quality. A review of the literature
A 'holistic' approach to diet provides an appealing way to evaluate the diet of the Dutch population. In our critical review of the existing literature on diet quality scores and dietary patterns, we found current methods to have several drawbacks and limitations. This was a reason to propose constructing a diet quality index specific to the Netherlands, using a new approach.
Changes in food consumption habits have both positive and negative effects on the health of the Dutch population. However, the exact consequence to health cannot be assessed through the common approach of considering individual foods and nutrients. Rather, in assessing quality, the diet of the Dutch population should be considered as a whole. Two distinct methods are commonly used. These are diet quality scores (defined beforehand and based on current nutritional knowledge) and dietary patterns (derived afterwards from food consumption data with the use of statistical methods). Both methods are discussed extensively.

keywords: dietary patterns; diet quality score; diet quality; dietary assessment

Rapport in het kort

Voedingsindexen. Een overzicht van de literatuur
Een 'holistische' benadering, waarbij eetpatronen als uitgangspunt worden genomen, is een aantrekkelijke manier om de voeding van de Nederlandse bevolking te beoordelen. We hebben de huidige literatuur over voedingsindexen en afgeleide eetpatronen onderzocht en vonden meerdere tekortkomingen en beperkingen voor de gebruikte methoden. Daarom stellen we voor om middels een nieuwe aanpak een geïntegreerde voedingsindex te ontwikkelen, specifiek voor de Nederlandse situatie.
Veranderingen in het voedingspatroon hebben zowel positieve als negatieve gevolgen voor de voedingsstoffenvoorziening en de gezondheid van de Nederlandse bevolking. De precieze impact van deze veranderingen op de gezondheid kan niet worden bepaald door de voedingsstoffen en voedingsmiddelen afzonderlijk te bekijken, de meest gangbare benadering. Om de kwaliteit van de voeding van de Nederlandse bevolking te bepalen, dient deze in zijn geheel te worden beschouwd. Dit gebeurt op twee verschillende manieren. Door het opstellen van een voedingsindex (vooraf, op basis van bestaande kennis omtrent gezonde voeding) of door het afleiden van eetpatronen (achteraf, uit beschikbare voedselconsumptiegegevens met behulp van statistische methoden). Dit rapport bevat een kritische beschouwing van de huidige literatuur op dit gebied.

Trefwoorden: eetpatronen; voedingsindex; kwaliteit van de voeding; voedselconsumptiebeoordeling

Contents

Summary

In the last decades various socio-demographic shifts have resulted in significant changes in food choices and eating habits in the Netherlands. These changes have had both positive and negative effects on the nutrient supply and consequently health of the Dutch population. The question rises how exactly these aspects should be weighted.
When diet quality is evaluated generally the dietary components, nutrients and foods, are considered individually. A ‘holistic’ approach would be more realistic though, as people have diets: they do not consume nutrients but combinations of foods.
Two kinds of dietary pattern analysis can be distinguished: theoretically or *‘a priori’* defined dietary patterns and empirically, *‘a posteriori’,* derived dietary patterns. This report provides an overview of existing indexes of overall diet quality and methods used to derive dietary patterns and their potentials and limitations. For this purpose published literature has been searched and reviewed. Based on the findings a recommendation is made for the development of a diet quality index for use in the Netherlands.

Theoretically defined indexes of diet quality
Theoretically defined indexes of diet quality consist of nutritional variables, most often nutrients and foods or food groups that are assumed to be either healthful or detrimental. The index variables are quantified and summed to provide an overall measure of dietary quality. The definition of diet quality depends on attributes selected by the investigator. It is built upon current nutrition knowledge or theory or based on a diet that has proven healthful, like the Mediterranean diet.
As many choices have to be made in the composition of an index of overall diet quality, a large degree of subjectivity exists. Several different predefined diet quality scores have been proposed. Four of them have gained most attention: the Healthy Eating Index, the Diet Quality Index, the Healthy Diet Indicator, and the Mediterranean Diet Score.

Food groups included in the large majority of indexes are vegetables and fruits, cereals or grain, and meat and meat products. As for nutrients unanimity seems to exist on the incorporation of fat in the index: total fat, and/or saturated fat (SFA) or the ratio of mono-unsaturated fatty acids (MUFA) to SFA. Cholesterol and alcohol are also included in many indexes.
Several composite indexes contain a variable indicating dietary variety. This concept is generally made operational as the quantity of different foods or food groups consumed in a given period of time. Dietary variety has also been considered on itself in so-called Dietary Variety Scores.
Not only the choice of the index items but also the way in which they are quantified provides many options. An intake cut-off or range for each index variable needs to be chosen. Some

researchers have chosen (a) specific value(s), others the population median. Both choices have advantages and disadvantages. In some indexes energy intake is accounted for. Although very important, the relative contribution of the various index items to the total score has seldom been addressed. In most indexes all individual variables have the same weight, i.e. they contribute equally to the total score.

In several studies proposed indexes have been validated by relating the index score with nutrient adequacy and/or health outcome. For most of the indexes an association with disease or mortality was reported. These associations were generally moderate, casting doubts on the validity of the indexes.

We think that a diet quality index should be merely food-based. A few macronutrients could be included to assure the diet to be overall balanced, and a few nutrients that are regarded fairly deleterious may also be comprised. Furthermore energy intake should be considered and, although complicated, the relative weights of the individual index items should be seriously addressed.

Empirically derived dietary patterns

Another way of examining dietary patterns is an '*a posteriori'* approach, in which statistical methods like factor and cluster analysis are used to generate patterns from collected dietary data.

In factor analysis dietary patterns, the so-called factors, are discerned based on correlations between variables, generally foods or food groups. Correlated variables are grouped together, distinct from groups of variables with which they are not correlated. Individuals have a score on each factor. In contrast to factor analysis, cluster analysis does not aggregate intake variables but individuals into relatively homogenous subgroups (clusters) with similar diets. A summary score for each pattern can be derived and used in either correlation or regression analysis to examine relationships between various eating patterns and the outcome of interest, such as nutrient intake, cardiovascular risk factors, and other biochemical indicators of health.

Although factor and cluster analysis are 'data-driven' a degree of subjectivity exists, as choices have to be made in each of the consecutive steps in the analytical process. These steps are somewhat alike for factor and cluster analysis. First the foods or food groups for entry into the analysis need to be selected, foods need to be assigned to food groups, and input variables can (or cannot) be adjusted for example for energy intake. In the majority of studies in nutrition between 20 and 50 food groups were entered for factor analysis. The average number of food groups entered for cluster analysis was apparently smaller and ranged from 10 to 40 for most studies.

The analysis itself and the identification of the dietary patterns or clusters are not straightforward either and also involve choices. In the majority of factor analysis studies in

nutritional epidemiology principal components analysis has been applied, using orthogonal rotation and eigenvalues >1. In cluster analysis studies K-Means method was most often used, but Ward's Method was also regularly applied.
Both the parameters of the resulting factor and cluster solutions and the interpretability as decided on by the researcher determine which solution is finally reported. The number of derived factors reported generally ranged from 2 to 25 and for most studies the total of variance explained by all factors was limited, in general between 15 and 40 percent. The number of resulting clusters varied from 2 (only once) to 8.
The researcher also gives names to the factors or clusters. And although the factor or cluster loadings are generally reported in the published results, labeling does play a critical role in the interpretation.
At this moment there is not yet enough insight in to what extent outcomes are influenced by choices including treatment of the input variables and the factor or clustering method used.

Many studies in which dietary patterns have been derived by factor or cluster analysis have reported positive and/or negative associations between certain patterns and a measure of health outcome. These patterning methods therefore seem able to distinguish healthy and less healthy eating patterns. However, if a dietary pattern obtained by either factor or cluster analysis turns out to be a risk factor for a specific disease, an explanation is often difficult to find. In addition some studies could not find any association between any of the factors or clusters derived and health outcome. A reason is that explaining as much variation in food intake as possible does not mean that these patterns represent ideal diets.

Other statistical methods to derive dietary patterns

Constructing a diet quality index and deriving dietary patterns by means of factor or cluster analysis are approaches that have frequently been applied in nutritional epidemiology. Other statistical methods however exist that may also have potential in dietary pattern analysis. Two methods are discussed.

Regression analysis, multiple, logistic or Cox proportional-hazards regression, is a very commonly performed statistical procedure in nutritional epidemiology. It is commonly used to predict a dependent variable (e.g. incidence of disease, or mortality) on the basis of a set of independent variables (e.g. dietary variables).
Some researchers have used a regression model to predict disease risk from specific risk factors, generally for use in a clinical setting. In a similar way regression analysis could be employed to derive dietary patterns that are associated with for example mortality.

Reduced Rank Regression (RRR) is a statistical method that determines linear functions of predictors (for example foods) by maximizing the explained variation in responses (for example disease-related nutrients, disease or mortality). This method has been applied in two studies only to identify dietary patterns with mixed results. Its potential should be further examined though as it may provide another way to analyze the overall diet.

Conclusions and recommendations

To monitor (changes in) food consumption and to be able to set policy priorities a tool is needed to evaluate the quality of the diet. Studying individual dietary components can reveal the role of individual nutrients in the development of disease, but goes beyond the actual fact that people have diets. When the quality of the overall diet is assessed existing correlations and interactions between dietary components need to be taken into account. For this reason a holistic approach is warranted.

However, although exploratory methods may be used to gain insight into correlations in intakes between foods and prevailing eating patterns, factor or cluster analysis cannot contribute significantly to the construction of an overall diet quality score.

A predefined index of overall diet quality on the other hand could serve to assess the diet of the Dutch population. Yet, development of an index demands many arbitrary choices to be made and existing indexes are only marginally able to predict disease or mortality.

We therefore propose a slightly different method, as the importance of a holistic approach to assess diet quality is evident. Based on the findings in this report a global framework for an index can be constructed. In a next step regression (survival) analysis can be conducted in an appropriate Dutch cohort to establish the final model. In this way a diet quality score can be constructed specific for the Dutch population based on both current insights into the relation of nutrition and health, and existing correlations and interactions between dietary components.

Samenvatting

Voedingsindexen. een overzicht van de literatuur

Sociaaldemografische ontwikkelingen in de afgelopen decennia hebben geleid tot aanzienlijke veranderingen in de voedselkeuze en het voedingspatroon van de Nederlandse bevolking. Deze veranderingen hebben zowel positieve als negatieve gevolgen voor de voedingsstoffenvoorziening en de gezondheid. De vraag is echter hoe deze aspecten onderling dienen te worden afgewogen.
Bij het beoordelen van de voedselconsumptie wordt in het algemeen gekeken naar afzonderlijke voedingsstoffen of voedingsmiddelen. Maar mensen eten geen nutriënten maar combinaties van voedingsmiddelen. Een meer 'holistische' benadering, waarbij eetpatronen als uitgangspunt worden genomen, is daarom realistischer.
Dit wordt op twee verschillende manieren in de praktijk gebracht: theoretische kan een 'a priori' voedingsindex worden opgesteld of eetpatronen kunnen empirisch, 'a posteriori', worden afgeleid uit beschikbare voedselconsumptiegegevens.
Voor dit rapport is de huidige literatuur doorzocht en beoordeeld om een overzicht te kunnen geven van tot nu toe gebruikte voedingsindexen en de statistische methoden om eetpatronen af te leiden. De mogelijkheden en beperkingen van beide methoden worden besproken. Op basis van de bevindingen wordt een aanbeveling gedaan voor het ontwikkelen van een index voor Nederlands gebruik.

Bestaande voedingsindexen

Een geïntegreerde voedingsindex is in het algemeen opgebouwd uit een aantal voedingsstoffen en voedingsmiddelen of –groepen die gezond of juist ongezond worden geacht. Deze elementen worden gekwantificeerd en bij elkaar opgeteld en vormen zo een maat voor de kwaliteit van het dieet of voedingspatroon. De definitie van kwaliteit hangt dus af van de voedingsfactoren die de onderzoeker selecteert en van de manier waarop hij of zij deze kwantificeert. Dit gebeurt op basis van huidige kennis en inzichten omtrent gezonde voeding. Een index kan echter ook gebaseerd zijn op een voedingspatroon waarvan wetenschappelijk is aangetoond dat het 'gezond' is, zoals het Mediterrane voedingspatroon. Aangezien er veel keuzes moeten worden gemaakt is het opstellen van een voedingsindex in grote mate subjectief. Er zijn al verschillende indexen opgesteld. De vier meest bekende zijn de 'Healthy Eating Index', de 'Diet Quality Index', de 'Healthy Diet Indicator', en de 'Mediterranean Diet Score'.

Als we kijken naar de samenstelling van bestaande voedingsindexen dan blijken de voedselgroepen groente en fruit, granen, en vlees en vleesproducten in de meeste indexen wel terug te vinden. Ook de macrovoedingsstof 'vet' is opgenomen in vrijwel alle indexen: totaal

vet en daarnaast verzadigd vet of de verhouding tussen enkelvoudig onverzadigd en verzadigd vet. Cholesterol en alcohol zijn eveneens opgenomen in veel indexen. Verschillende indexen bevatten een component die de mate van gevarieerdheid van de voeding ('dietary variety') moet weergeven. Dit wordt meestal geoperationaliseerd als de hoeveelheid verschillende voedingsmiddelen of voedselgroepen die in een bepaalde tijdsperiode zijn gegeten. De gevarieerdheid van het dieet wordt ook wel op zichzelf beschouwd in de zogenaamde 'Dietary Variety Scores'.
Niet alleen moet besloten worden welke componenten worden opgenomen maar ook hoe deze worden gekwantificeerd. Er dient een waarde ('cut-off') te worden gekozen waaraan de inneming wordt getoetst. In sommige gevallen is gekozen voor (een) vastgestelde waarde(n), in andere gevallen voor de mediane inneming in de populatie. Aan beide keuzen zitten voor- en nadelen. In sommige indexen wordt rekening gehouden met energie-inneming. Er wordt echter zelden iets gezegd over de relatieve bijdrage van de afzonderlijke componenten aan de totale score, hoewel dat een zeer belangrijk punt is. In vrijwel alle indexen dragen alle componenten in gelijke mate bij aan de totaalscore.

Bestaande voedingsindexen zijn gevalideerd door te kijken naar associaties met voedingstoffenvoorziening en/of ziekte of sterfte. Hoewel de meeste indexscores wel een verband lieten zien met ziekte of sterfte, was dit over het algemeen niet heel sterk. De validiteit van de bestaande indexen staat dan ook enigszins ter discussie.

Volgens ons moet een voedingsindex vooral voedingsmiddelen of voedselgroepen bevatten. Een aantal macrovoedingsstoffen zou kunnen worden opgenomen om de gebalanceerdheid van het dieet te toetsen als ook enkele voedingsstoffen met sterk nadelige gezondheidseffecten. Verder is het van belang dat rekening gehouden wordt met energie-inneming en er dient, al is dit ingewikkeld, met nadruk aandacht te worden besteed aan de relatieve bijdrage van de afzonderlijke componenten aan de totaalscore.

Eetpatronen uit factor- en clusteranalyse

Factor- en clusteranalyse zijn statistische methoden om eetpatronen af te leiden uit beschikbare voedselconsumptiegegevens. Bij factoranalyse worden eetpatronen, de factoren, onderscheiden op basis van correlaties tussen variabelen (voedingsmiddelen of voedselgroepen). Variabelen die met elkaar samenhangen worden gegroepeerd, en zo gescheiden van variabelen waarmee ze geen correlatie vertonen. Elk individu heeft een score op iedere factor. Bij clusteranalyse worden de individuen, en dus niet de voedingsfactoren, met een vergelijkbaar dieet gegroepeerd in clusters.
Voor elk eetpatroon (dus elke factor of cluster) kan een totaalscore worden opgemaakt die gebruikt kan worden in correlatie- of regressieanalyse om zo verbanden tussen verschillende eetpatronen en een uitkomstmaat, zoals voedingsstoffenvoorziening, ziekte of sterfte te onderzoeken.

Hoewel bij factor- en clusteranalyse eetpatronen empirisch worden afgeleid uit bestaande data is er toch sprake van een bepaalde mate van subjectiviteit. In de analyse moeten namelijk verschillende keuzen worden gemaakt. Deze zijn voor factor- en clusteranalyse vergelijkbaar. Allereerst dienen de voedingsmiddelen of voedselgroepen die meedoen in de analyse te worden geselecteerd. Dan moeten voedingsmiddelen worden toegewezen aan deze voedselgroepen. En kunnen deze vervolgens al dan niet gecorrigeerd worden.
De meeste factoranalysestudies die zijn gevonden zijn uitgegaan van tussen de 20 en 50 voedselgroepen, terwijl dat er voor de clusteranalysestudies minder waren, tussen de 10 en de 40 voor de meeste studies.
Ook de analyse zelf en de identificatie van de uiteindelijke factoren of clusters vraagt om keuzes. In het merendeel van de factoranalysestudies is gekozen voor ‘principal components analysis’ (PCA) met orthogonale rotatie en een eigenwaarde >1. De meeste clusteranalysestudies gebruikten de ‘K-means’ methode, maar ook ‘Ward’s’ methode werd regelmatig toegepast.
Zowel de parameters van de factor- en clusteroplossingen als de mate waarin de onderzoeker vindt dat deze interpreteerbaar zijn, bepalen welke oplossing uiteindelijk wordt gepubliceerd. Het aantal gerapporteerde factoren varieerde grofweg van 2 tot 25. Voor de meeste studies was het percentage totaal verklaarde variatie gering, in het algemeen tussen de 15 en 40 procent. Het aantal gerapporteerde clusters varieerde van 2 (slechts eenmaal) tot 8.
De onderzoeker voorziet de factoren en clusters van een label. Hoewel de lading van de diverse input variabelen op de verschillende factoren of clusters meestal weergegeven wordt in de gepubliceerde resultaten, speelt de naamgeving een belangrijke rol in de interpretatie. Het is nog niet duidelijk in welke mate uitkomsten worden beïnvloed door keuzes zoals hoe de variabelen worden behandeld en de gebruikte factor- of clustermethode.

In veel factor- en clusterstudies binnen de voedingswetenschappen zijn positieve en/of negatieve associaties gerapporteerd tussen bepaalde eetpatronen (factoren of clusters) en ziekte of sterfte. Het lijkt daarom mogelijk met behulp van deze methoden gezonde en minder gezonde eetpatronen te onderscheiden. Een precieze reden waarom een bepaald eetpatroon een risicofactor is voor een bepaalde ziekte is echter vaak moeilijk te geven. In veel studies kon ook geen verband worden gevonden tussen één van de gerapporteerde factoren of clusters en een gezondheidsuitkomst. Een reden hiervoor is dat het verklaren van zoveel mogelijk van de variatie in voedselconsumptie niet betekent dat de zo gevonden eetpatronen ook optimaal zijn.

Andere statistische methoden om eetpatronen af te leiden

Er zijn in de voedingswetenschappen verscheidene pogingen geweest om een geïntegreerde voedingsindex op te stellen of om eetpatronen af te leiden met behulp van factor- of clusteranalyse. Er zijn echter ook andere statistische methoden denkbaar om inzicht te krijgen in (gezonde) eetpatronen.

Regressie-analyse, meervoudig (‘multiple’), logistische of Cox proportional-hazards regressie, wordt veel toegepast binnen de voedingswetenschappen en de epidemiologie. Deze methode wordt gebruikt om een afhankelijke variabele (bijvoorbeeld ziekte of sterfte) te voorspellen uit een reeks van onafhankelijke variabelen (bijvoorbeeld roken, lichamelijke activiteit en eetgewoonten).
In sommige studies wordt regressie-analyse toegepast om een risicomodel op te stellen voor klinisch gebruik. Op vergelijkbare wijze zou regressie-analyse kunnen worden aangewend voor het afleiden van voedingsfactoren die bijvoorbeeld zijn geassocieerd met sterfte.

Met behulp van een andere methode, Reduced Rank Regression (RRR), kan een lineaire functie van voorspellende variabelen (bijvoorbeeld voedingsmiddelen) worden opgesteld door de verklaarde variatie in responses (bijvoorbeeld ziekte of sterfte) te maximaliseren. Vooralsnog is deze methode in slechts twee studies toegepast met als doel eetpatronen te identificeren die voorspellend zijn voor een gezondheidsuitkomst. Dit was met wisselend resultaat.

Conclusies en aanbevelingen

Om (veranderingen in) de voedselconsumptie te monitoren en om tot beleidsprioritering te kunnen komen is een instrument nodig om de kwaliteit van de voeding te evalueren. Bij het bestuderen van individuele voedingsfactoren kan de rol van individuele nutriënten in de ontwikkeling van een ziekte worden blootgelegd, maar wordt voorbij gegaan aan het feit dat mensen eetpatronen hebben en geen individuele voedingsstoffen consumeren. Deze aanpak houdt geen rekening met de vaak hoge correlaties in de inneming van voedingsmiddelen en voedingsstoffen en hun mogelijke interacties. Daarom is een holistische benadering nodig.
Hoewel met behulp van exploratieve methoden inzicht kan worden verworven in correlaties in de consumptie van voedingsmiddelen en in bestaande eetpatronen, kunnen deze methoden niet werkelijk bijdragen aan het opstellen van een index om de kwaliteit van de totale voeding te beoordelen.
Daarentegen zou met behulp van een geïntegreerde voedingsindex de voeding van de Nederlandse bevolking kunnen worden beoordeeld. Echter, bij het ontwikkelen van een dergelijke index moeten meerdere arbitraire keuzen worden gemaakt en reeds bestaande indexen zijn slechts matig in staat om ziekte en sterfte te voorspellen. Daarom wordt een iets andere methode voorgesteld.
Op basis van de bevindingen in dit rapport zou een raamwerk kunnen worden opgesteld voor een nieuwe voedingsindex. In een volgende stap kan door middel van regressie- of overlevingsduuranalyse in een geschikt Nederlands cohort het uiteindelijke model worden vastgesteld. Op deze manier lijkt het mogelijk om een voedingsindex te ontwikkelen specifiek voor de Nederlandse bevolking, die gebaseerd is op zowel huidige kennis omtrent voeding en gezondheid en bestaande correlaties en interacties tussen factoren in de voeding.

1. Introduction

1.1 Background and rationale

In the last decades various socio-demographic shifts have resulted in significant changes in food choices and eating habits in the Netherlands. In September 2002 the National Health Council has published a report with the title: ‘Significant trends in food consumption in the Netherlands’ (24). This report describes the major dietary trends in the period 1987/88 to 1997/98 based on the three Dutch National Food Consumption Surveys[1].
Major developments reported were an ongoing decrease in the consumption of staple foods such as potatoes, vegetables, fruit and meat, accompanied by a rise in that of grains/cereals, fish, nuts/snacks, pre-prepared meals, and beverages. Consumption of margarine and full-cream milk products were reported to have lost some ground to the lighter ‘halvarine’ and semi-skimmed and skimmed milk products. These developments in food consumption have both positive and negative effects on the nutrient supply to the Dutch population.
A more recent report from the National Institute for Public Health and the Environment (RIVM) (51) deals with the health consequences of these (changes in) nutritional behavior. Two aspects concerning our eating habits are stressed. In the first place that energy intake is too high in relation to energy expenditure, resulting in a rising prevalence of overweight and obesity, and consequently, health loss. And secondly that for a large part of the population in several aspects the composition of the diet differs seriously from the recommendations. Although the trend is reported to be favorable for saturated fatty acids and trans fatty acids (intakes are declining), their intakes are still too high. Consumption of fruit and vegetables on the other hand is further decreasing, while consumption levels are only half of the recommended quantities.

The question rises how exactly these positive and negative aspects should be weighted. When diet quality is evaluated generally the dietary components, nutrients and foods, are considered individually as mentioned above, whereas it may be more realistic to consider the diet as a whole. Dietary pattern analysis, in which a ‘holistic’ approach is applied, has gained considerable attention in recent years and many studies considering dietary patterns have been published.

In this report an attempt is made to give an overview of existing indexes of overall diet quality and methods used to derive dietary patterns. Results from studies relating dietary patterns with disease or other health outcomes are described as well in order to gain insight into the validity and usefulness of these patterns or patterning methods.

[1] DNCFS-1 (VCP-1) was held in 1997/98, DNCFS-2 (VCP-2) in 1992, and DNCFS-3 (VCP-3) in 1997/98.

More insight in and a better understanding of dietary patterns and their potentials will facilitate the possible development and implementation of a dietary index that can be used for the Dutch population in a next step.

1.2 Outline of the report

In order to better understand the rationale behind dietary pattern analysis this issue is further explored in chapter 2. In this chapter both the limitations of relating individual dietary factors with disease and the potentials of considering dietary patterns instead are discussed briefly. Chapter 3 and 4 deal with indexes of diet quality that have been defined beforehand, based on current nutrition knowledge. First, in chapter 3, an overview of existing indexes is provided and similarities and differences between the indexes are discussed. Then, in chapter 4, study results of the associations of the various indexes with health outcome are reported.
Likewise chapter 5 and 6 describe and evaluate dietary patterns that have been derived empirically, making use of dietary intake data. Two methods, factor and cluster analysis, are described, and resulting patterns and their relation with health outcome are evaluated.
In chapter 7 a few other statistical methods to derive patterns used sporadically so far are described briefly.
Final conclusions and recommendations for the use of dietary patterns in the Dutch situation can be found in the last chapter, chapter 8.

2. Evaluating diet quality: individual dietary components or dietary patterns

Unlike other behavioral risk factors like smoking, eating is not optional. The question is not whether to eat, but how to eat for optimal health. Thousands of studies have been conducted to gain insight into the role of diet and dietary constituents in the development of disease.
In nutrition research focus is generally on the role of single nutrients in diet-disease relations. This view has led to important steps forward in identifying relationships of dietary components and several health outcomes. Nevertheless, this 'reductionist' approach passes over the complexity of the true relationship between diet and disease.

2.1 The complexity of the diet

The complex nature of the diet makes it extremely difficult to study the relationship between dietary factors and health outcome. Almost everyone eats fat, fiber, and folate, for example. Besides people eat foods not nutrients and are generally not aware of the content of the foods eaten.
Studying diet and disease we should therefore be aware of the fact that intake of nutrients may be related. It is often difficult to separate the specific effects of nutrients or foods. For example, diets high in fiber tend to be high in vitamin C, folate, and various carotenoids. When an association is detected between fiber and disease risk, is it certain that the relationship is not a consequence of folate or carotenoid intake? Although the use of foods or food groups instead of nutrients might help to capture a part of this complexity, similar problems exist. For example, when whole-grain intake is found to be associated with lower disease risk, is it certain that the association is not due to differences in e.g. red meat or fruit and vegetable consumption? When intakes are highly correlated adjusting for intakes of other nutrients or foods may not produce satisfying results.
Moreover analyses of individual nutrients and foods often ignore the many potential interactions between components of a diet and disease risk. Additionally, by trying to find the effect of certain dietary components, one might miss associations between diet and disease. It might in practice not be possible to detect small differences in for example disease risk from single nutrients.
An endeavor is therefore warranted to evaluate diet quality, considering the diet as a whole, in which dietary patterns, and not single nutrients, are related to health outcome.

2.2 Dietary patterns and public health

Also from a public health perspective it seems more relevant to study dietary patterns instead of individual foods or even nutrients. People do not consume nutrients nor single foods, but combinations of several foods that contain both nutrient and non-nutrient substances. Dietary pattern analysis would thus resemble more closely the real world, in which nutrients and foods are consumed in combination.
Studying dietary patterns could have important public health implications because the overall patterns of dietary intake might be easier to interpret or translate into diets. In fact, dietary guidelines depart from dietary patterns. Studying dietary patterns in relation to disease outcomes thus provides a practical way to evaluate the health effects of adherence to dietary guidelines by individuals. It can also enhance our understanding of dietary practice, and provide guidance for nutrition intervention and education.

2.3 Dietary pattern analysis

Dietary pattern analysis has increased substantially in the past two decades and many studies using this alternative method have been published. Two kinds of dietary pattern analysis can be distinguished: beforehand defined dietary patterns and empirically derived dietary patterns. They will be discussed successively in the following chapters.

3. Theoretically defined indexes of diet quality

Theoretically defined indexes of diet quality consist of nutritional variables, most often foods and/or nutrients, that are grouped according to proposed criteria of nutritional health. The index variables are quantified and summed to provide an overall measure of dietary quality.

In order to find publications on diet quality measures PubMed was searched (to June 2004). PubMed is a service of the US National Library of Medicine including over 15 million citations for biomedical articles. These citations are from Medline, a database that contains more than 11 million references to journal articles in the health sciences, and additional life science journals. Key words included diet(ary) quality, diet(ary) patterns, diet score, diet index, food groups, dietary diversity, dietary variety, and Mediterranean diet. In addition references cited were reviewed.

3.1 Rationale and composition

Theoretically defined dietary patterns generally have been created *'a priori'* or beforehand by a research group in order to rank eating behavior that is assumed to be more or less healthy. The definition of diet quality depends on attributes selected by the investigator and are built upon current nutrition knowledge or theory.
For example, in the past, diets that met needs for nutrients such as protein or selected vitamins and minerals may have been defined as high quality. Given the current focus on reducing the risk of chronic diseases, dietary attributes associated with risk reduction may be considered as contributing to a healthy diet. Indexes often include variables that represent current nutrition guidelines or recommendations.

Instead of dietary guidelines creation of indexes of diet quality can also be based on a diet that has proven healthful. The Mediterranean diet has received increased attention in recent years because of a suggested association with reduced risk of coronary heart disease and several forms of cancer for people consuming such diet (53; 53; 90-93). Several indexes have been developed based on the Mediterranean diet.

Dietary variables contained in the index are generally nutrients and foods or food groups that are assumed to be either healthful or detrimental. In addition to dietary components, dietary variety is also considered to contribute to a healthy diet and can be an individual index item. Frame 3.1 provides an overview of the characteristics of predefined indexes of diet quality.

Frame 3.1: Characteristics of theoretically defined indexes of overall diet quality

- created beforehand ('a priori')
- researcher selects attributes:
  nutrients, foods or food groups, and/or an indicator of dietary variety
- built upon current nutrition knowledge
- often represents nutrition guidelines or recommendations
- *or* based on diet that has proven healthful (e.g. Mediterranean diet)

3.2 Dietary Variety Scores

Several investigators have used dietary variety on itself to evaluate food consumption by computing a Dietary Variety Score. Generally this score is calculated as the number of different foods consumed over a given period. If food consumption data originate from food frequency questionnaires, all different food items on the questionnaire can contribute to the score. Some researchers however assigned foods to more comprehensive food groups and calculated the score as the number of different food groups consumed.
A modification was proposed by Kant en Thompson (44) who divided foods in nutrient-dense and nutrient-poor (energy-dense) foods and calculated a variety score for recommended foods. Several researchers followed this example and calculated Recommended Food Scores (RFS).

3.3 Existing indexes of diet quality

From the above it may not be surprising that many different predefined indexes of overall diet quality have been constructed. Table 3.1a and b give an overview of existing theoretically defined indexes of overall diet quality and dietary variety scores. In appendix A the exact composition and make-up of the scores has been summarized for all indexes mentioned in table 3.1. Several indexes have been adapted and modified by other researchers. These revised indexes have also been described.
The Healthy Eating Index (46), the Diet Quality index (77), the Healthy Diet Indicator (37) and the Mediterranean Diet Score (92) are the indexes that have been referred to and/or validated most extensively.

*Table 3.1a: Overview of existing indexes of overall diet quality and studies in which they have been used and/or evaluated**

Index	references
Based on dietary guidelines	
Diet Quality Index[1]	**Patterson et al., 1994 (77)**
	Seymour et al., 2003 (84)
	Dubois et al., 2000 (14)
Diet Quality Index Revised (DQI-R)	**Haines et al., 1999 (27)**
	Newby et al., 2003 (69)
Diet Quality Index International (DQI-I)	**Kim et al., 2003 (48)**
Other indexes adapted from DQI	Drewnowski et al., 1996 (13)
	Drewnowski et al., 1997 (12)
	Lowik et al., 1999 (56)
Healthy Eating Index (HEI)[2]	**Kennedy et al., 1995 (46)**
	McCullough et al., 2000 (62)
	McCullough et al., 2000 (64)
	Dubois et al., 2000 (14)
	Kennedy et al., 2001 (45)
	Hann et al., 2001 (29)
	McCullough et al., 2002 (63)
	Weinstein et al., 2004 (97)
Alternative Healthy Eating Index (AHEI)	**McCullough et al., 2002 (63)**
Healthy Diet Indicator (HDI)[3]	**Huijbregts et al., 1997 (37)**
	Huijbregts et al., 1997 (40)
	Huijbregts et al., 1998 (38)
	Dubois et al., 2000 (14)
	Haveman-Nies et al., 2001 (32)
Dietary guidelines index	**Harnack et al., 2002 (30)**
Based on Mediterranean diet	
Mediterranean Diet Score (MDS)	**Trichopoulou et al., 1995 (92)**
	Osler and Schroll, 1997 (75)
	Kouris-Blazos et al., 1999 (50)
	Lasheras et al., 2000 (55)
	Woo et al., 2001 (99)
	Haveman-Nies et al., 2001 (32)
	Bosetti et al., 2003 (4)
MDS adapted	**Haveman-Nies et al., 2002 (31)**
MDS + fish	**Trichopoulou et al., 2003 (91)**
	Knoops et al., 2004 (49)
Mediterranean Diet Quality Index (MDQI)	**Gerber et al., 2000 (23)**
	Scali et al., 2001 (82)
Food-based	
Food-based quality index	**Lowik et al., 1999 (56)**
Healthy Food Index (HFI)	**Osler et al., 2001 (73)**
	Osler et al., 2002 (74)
Nutrient-based	
Nutrient Adequacy Ratio (NAR/MAR)[4]	**Madden and Yoder, 1972 (57)**

*Bold: Publication in which index has first been published
[1] based on US dietary recommendations
[2] based on US dietary recommendations, recommended servings of USDA Food Guide Pyramid
[3] based on 1990 WHO dietary guidelines
[4] These scores have been used in several studies a.o. to evaluate indexes of diet quality

*Table 3.1b: Overview of Dietary Variety Scores and studies in which they have been used and/or evaluated**

Index	references
Dietary Variety Score (DVS)	**Fanelli and Stevenhagen, 1985 (15)**
	Fernandez et al., 1996 (17)
	Drewnowski et al., 1996 (13)
	Drewnowski et al., 1997 (12)
	La Vecchia et al., 1997 (54)
	Slattery et al., 1997 (85)
	Fernandez et al., 2000 (18)
	Bernstein et al., 2002 (3)
Dietary Variety Score for Recommended Foods (DVSR)	**Kant and Thompson, 1997 (44)**
or **Recommended Food Score (RFS)**	**Kant et al., 2000 (42)**
	Michels and Wolk, 2002 (65)
	McCullough et al., 2002 (63)
Dietary Diversity Score (DDS)	**Kant et al., 1993 (43)**
	Drewnowski et al., 1996 (13)

*Bold: Publication in which index has first been published

3.4 Index components

3.4.1 Index items: foods and nutrients

Dietary variables contained in the index are generally nutrients and foods or food groups that are assumed to be either healthful or detrimental. Some indexes consist solely of food groups or foods (Food-based quality index, HFI), others only of nutrients (adapted DQIs). Most indexes however comprise both food groups and nutrients. Frame 3.2 gives an overview of index components or attributes found to be included in the indexes in Appendix A.
Main food groups included in the various indexes are vegetables and fruits, cereals or grain, and meat and meat products. Some indexes also incorporated legumes, milk and dairy products, fish, olive oil, bread, potatoes, and cheese. As for nutrients: fat, saturated fat (SFA), or the ratio of mono-unsaturated fatty acids (MUFA) to SFA, cholesterol, and alcohol are included in many indexes. (Complex) carbohydrates, protein, and fiber are comprised in some scores. A few indexes have included the micronutrients sodium or calcium. Also iron and vitamin C can be found in one index. In addition to foods and nutrients, a number of researchers have included a variable representing dietary variety in their index.
The units in which intake is expressed differs between indexes and between nutrients. As intake of total fat or SFA is usually expressed in energy percent, for other nutrients other appropriate units are used. Micronutrients are expressed in micrograms or in percentage of the recommended dietary allowance. Intake of foods can be conveyed in grams, but is often expressed as number of servings.

There seems to exist unanimity on the fact that fat intake should be considered: almost all indexes contain one or more fat-related variable. In Mediterranean indexes the ‘ratio of MUFA to SFA’ is, next to alcohol, the only nutrient-derived variable included. Total fat is included in the majority of indexes, but also SFA and cholesterol are often simultaneously included.
It should be noticed that most indexes have been created several years ago and that nutrition science has not stand still since. There is increasing awareness of the risks associated with high intakes of trans fatty acids (TFA). This variable may therefore also be candidate for inclusion in an index of diet quality.
What accounts for fat also accounts for vegetables and fruit. They are incorporated in the majority of indexes, either grouped together or separately. Some indexes contain an additional attribute legumes. Nuts are sometimes added to the fruit group or to the legumes.

Frame 3.2: Overview of attributes included in theoretically defined indexes of diet quality

Nutrients

- fat-related variables: total fat, saturated fat, cholesterol, MUFA/SFA
- carbohydrates: (complex) carbohydrates, mono- and disaccharides, sucrose
- dietary fiber
- protein
- micronutrients: sodium, calcium, iron, vitamin C
- alcohol

Foods or food groups

- Vegetables and fruit: vegetables, vegetables and fruit, fruit, fruit and nuts, legumes, legumes and nuts, etc.
- meat (and meat products)
- cereals or grain
- milk (and dairy)
- others: fish, olive oil, cheese

Dietary diversity or dietary variety

Dietary moderation

3.4.2 Dietary variety as an index item

Several composite indexes contain a variable indicating dietary variety. Dietary variety is generally made operational as the quantity of different foods or food groups consumed in a given period of time. As most indexes contain several different foods (and nutrients) only with a varied diet it is possible to score high on all these items. Nevertheless 'dietary variety' or 'dietary diversity' is additionally included in many indexes.

3.4.3 Assigning foods to food groups

Dietary data used to calculate diet scores can stem from either food frequency questionnaires (FFQs) or from other methods used to collect food consumption data, like diet records or dietary recalls.

Following the choice of the index variables, foods have to be assigned to an item. For many foods this might not be disputable, but nevertheless choices have to be made. It should be realized that the dietary assessment method used influences the outcome. A food frequency questionnaire contains a limited number of foods or food groups, whereas a dietary history is generally more elaborate. As mentioned, also in order to calculate dietary variety the researcher can choose to assign foods to specified food groups.

3.5 Scoring

Once the attributes to be included in the index have been selected, they need to be quantified. Many options exist. Most straightforward is to use a cut-off value for each component and to attribute a score of ‘0’ if consumption is lower than this value (or higher if an unfavorable component is concerned) and ‘1’ if consumption is higher (or lower) than the cut-off. The question remains however how the cut-off value should be chosen. It is also possible to create several cut-offs. Or would it be better to assign a graduate score as the consumption level of a variable becomes more favorable? In addition, it may be justifiable to assign different weights to the diverse components if a certain variable is assumed to contribute more to a (un)healthy diet than another.

It may be clear that again many decisions have to be made. Although based on current nutrition knowledge, it is finally the (subjective) choice of the researcher. Below, scoring within the various indexes, and thus choices made by the researchers, will be compared.

3.5.1 Choosing a cut-off value

The first step in the quantification procedure is to determine an intake cut-off or range for each index variable in order to distinguish between healthy and less desirable consumption levels. There are different ways to do so.

In Mediterranean indexes the group median intake of each variable serves as a cut-off value. Taking the group median as a cut-off might not seem a rational choice, as it has in fact no relation with a healthy level of intake perse. The advantage however of doing so follows from the definition of ‘median’: half of the subjects will score positively and half will score negatively on each index item, ensuring that each index item distinguishes well and exactly similar between subjects.

In all other indexes index items are categorized or scaled based on current insights on what is supposed to be a healthy level of intake. Often they are based on dietary guidelines. This approach might seem more appealing. However if for example for a certain food or nutrient intake remains below the desired (cut-off) level for almost all subjects in a group, this index item will not contribute to the scores power of discernment and could just as well be left out. It is therefore likely that researchers do take into consideration the median intake levels for the variables they want to incorporate in their index when assigning intake categories or cut-offs. Cut-off values are therefore generally population specific.

Frame 3.3: The consecutive steps and choices for the researcher in the construction of an index of overall diet quality

- Choosing the index items (§ 3.4.1 and frame 3.2)
- Assigning foods to food groups (§ 3.4.3)
- Choosing cut-off values (§ 3.5.1)
- Quantifying index components (§§ 3.5.1 and 3.5.2)
- Weighting index items (§ 3.5.3)
- Handling energy intake (§ 3.5.4)

Haveman-Nies et al. have used the MDS to quantify diet quality (32).They have used both Greek medians (GMDS) and study-specific medians (FS-MDS) as cut-offs. Individuals should only score high on the MDS if they do really consume a diet that can be characterized Mediterranean, for the Mediterranean diet has proven 'healthy'. Therefore it seems reasonable to use the cut-offs of the Greek population. However, as consumption patterns differ considerably between cultures, using these cut-off values it might not be possible to discern well between individuals. Although mean total GMDS scores for non-Mediterranean populations were considerably lower than mean total FS-MDS scores, the authors did not report a poorer distinguishing power. When relating the diet scores to the individual components both the GMDS and the FS-MDS appeared reliable indicators of diet quality. In this study the Greek medians were successfully applied as cut-offs for a Western population. This might however not always be the case.

For some indexes the researchers have specified just one cut-off value and positively appraised those individuals with an intake level at the desirable side of the cut-off (MDS, HDI, adapted DQIs, Food-based quality index, HFI). Several other indexes contain for example a lower cut-off, an intermediate range, and an upper boundary (DQI, MDQI, DQI-R, Dietary guidelines index). A third option was the score for each item to be proportional to the extent to which for example the dietary guideline was met (HEI, AHEI, DQI-I). This may allow the total score to better represent the degree to which the individuals satisfy the recommendations, especially for those with intakes near the cut-offs. Consequently the range of the score was also increased, instead of '0' or '1' individuals can score from '0' to '10' on an item.

Several indexes that have been adapted from the DQI (12; 13; 56) are essentially similar, containing only the nutrient-components of the original index. All these indexes had a low discriminating power; most persons yielded very low scores and fell within the same (low-score) category. This shows the importance of well chosen cut-offs.

3.5.2 Quantification of variables that are both beneficial and detrimental

'Meat' and 'dairy', but also 'alcohol', are particularly complex variables. Consumed in moderate quantities they are assumed to be beneficial (or even elemental). However, their intake should not be exaggerated, as high consumption levels are considered unfavorable. Consequently both non-consumers and individual with excessive intakes should have a low or no score on these items. Theoretically one can therefore not confine to a straight cut-off value to categorize consumption of these variables.
Moderate alcohol (especially wine) intake might be protective for cardiovascular disease. Alcohol intake in higher doses is well known to be harmful. High consumption of meat (and meat products) and dairy (products) is thought to be detrimental, because of their relatively high (saturated) fat content and presence of other less favorable substances. For example red meat contains nitrosamines and meat cooked at high temperatures contains other potential mutagens in the form of heterocyclic amines (HCAs) and polycyclic aromatic hydrocarbons (PAHs), consumption of which is believed to increases cancer risk. However, these food groups contribute importantly to our intake of protein and calcium and are generally recommended to be included in the diet. Omission of these foods from the diet could result in severe insufficiencies for an individual if no major effort is done to compensate. We should therefore take a closer look at how these variables are being quantified.

All Mediterranean indexes, the HEI and the Food-based quality index include the variable 'meat'. The Mediterranean indexes have a cut-off value (most often the median) and no scoring is awarded if consumption is above this value. In contrast, the HEI departs from a minimum of servings, and consumption below this minimum is not credited, whereas there is no deduction for being beyond this level. Only the food based quality index contains a consumption interval for meat: if consumption falls within a certain range the score is '1', else '0'.
Most indexes that do not incorporate meat, do (instead) contain protein. Either a cut-off value is used (DQI) or an interval (HDI) to calculate the score. When dairy is included in the index generally intakes below a certain cut-off value are positively appraised. For the adapted MDS and the Food-Based Quality Index an interval has been determined.
Alcohol has been included in the Mediterranean indexes. It seems that in the original MDS the group median intake is used as a lower cut-off. The adapted Mediterranean Diet Scores have specified an intake range.

From the above it becomes clear that, especially for meat, inconsistency exists as how to handle these items that are considered both beneficial and detrimental. Using an range to assess their intake seems most appealing as in that way both insufficient as excessive intakes are penalized.

3.5.3 Quantification of cereals, vegetables and fruits

Most indexes contain either a carbohydrate rich food group, generally ‘cereals’ or ‘grain’, or they contain ‘carbohydrates’ or a related nutrient. Consumption of cereals, grains or carbohydrates is generally positively appraised, with no deduction for high consumption levels. Also dietary variety scores generally include the food group ‘grain’.
The HDI has included the variables ‘dietary fiber’ and ‘complex carbohydrates’ for both of which a certain intake range is positively appraised, but both consumption levels below or above this range are not rewarded. However the upper limit for complex carbohydrates is as high as 70 energy percent. For ‘mono- and disaccharides’ the intake ranges from 0 to 10 energy percent.
Thus, there seems to exist agreement regarding the consumption of cereals or grain (products), but also (complex) carbohydrates and fiber. High intake ranges are considered beneficial. Whether to choose for foods (cereals) or nutrients (carbohydrates) also depends on the composition and aim of the index.
Consumption of foods from the vegetable and/or fruit group is generally assumed to be healthful. Intake of fruits and vegetables has been associated with a lower risk of cardiovascular disease as well as a lower risk of many diet-related cancers, chronic diseases prevailing highly in Western societies. It seems therefore that vegetable and fruit can not be lacking in an index aimed to evaluate overall diet quality.
These index components may however need to be more narrowly defined. Dark green and deep yellow fruits and vegetables, citrus fruits, and tomatoes may be more strongly associated with reduced risk of many chronic diseases than other fruits and vegetables (87). This distinction is not found in indexes of diet quality.

3.5.4 Energy intake: a confounder

Individuals with high energy needs and consequently a high total consumption will more easily meet requirements for a number of food group servings or a specific cut-off value. They may therefore have a high index score, whereas relative to their needs their consumption may not be more balanced or in the desired direction. Fat consumption does not pose a problem in this respect, as it is expressed in energy percent. But intake of other variables does generally not account for energy intake. Dietary variety faces the same problem. Individuals with high intakes will more easily consume a larger variety of foods.
Some scores have allowed for energy intake. Calculating the MDS, intake of each component is adjusted to daily intakes of 2500 kcal for men en 2000 kcal for women. The HEI and DQI-R have handled this issue in a different way. In these scores the recommended number of servings depends on recommended energy intakes. For all index items scores reflect intake as a proportion of the number of servings recommended for the appropriate energy intake level, based on sex and age. Three energy intake levels have been discerned following the 1992 US Food Guide Pyramid.

3.5.5 Mutually weighting the individual index components

Another complex and important issue, but not frequently addressed, is the relative contribution, as determined by the researchers, of the different index items to the total score. In most indexes all individual variables have the same weight, i.e. they contribute equally to the total score. It is not plausible though that all index variables do have the same health impact. It seems therefore better to ascribe greater weights to those items that affect our health to a greater extent.

However, to be able to correctly do so, information is needed on the individual health effects of the index items and especially on their relative impact. Not only is 'health impact' a complex concept, as many different health outcomes can be considered and the various dietary factors are related to different health outcomes. It is extremely difficult to do statements on the relative contribution of different dietary components to health outcome.

In this respect it should also be noted that many indexes include several items encompassing 'similar' or strongly correlating dietary variables, so that in fact these variables contribute more heavily to the score. This is for example the case for dietary fat. Some indexes include more than one fatty variable, for example 'total fat' and 'saturated fat'. Additionally high consumption of some foods (e.g. meat) can be negatively appraised, to a large extent due to their fat content.

An additional remark concerns the contribution of the individual items to the discriminating power of the total score. The discrimination power depends on the extent to which the constructed variables can distinguish between individuals, as has been discussed previously. This aspect however does not only determine the discriminating power of the index score, but also influences the relative contribution of the individual variables to the total score.

From the indexes described in appendix A only the Diet Quality Index International (DQI-I) has contributed different weights to their variables (48). The authors of the DQI-I do not argue how they have come to the attribution of a score for each of the four discerned main categories and thus how they have assessed their relative importance. They only state that 'current worldwide and individual national dietary guidelines… provided a basic rationale for the construction of the DQI-I' .

The Dietary guidelines index[1] may seem to have differently weighted its attributes, however 'the scoring system was based on the premise that each major guideline should contribute equally to the total dietary guidelines index score' (30).

It is a shortcoming that most researchers have not well addressed this topic concerning the relative importance of the individual index attributes and therefore their relative contribution to the total score.

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[1] The Dietary guidelines index also contains non-dietary variables ('Aim for fitness'), and therefore actually falls outside the scope of this report. However, because of its interesting construction, and to be complete, it has been included.

Although it is deemed essential to consider the relative effects of the individual index items, it is very tricky to substantiate choices for different weights of the attributes. Yet, deciding to leave out such weighting, because of the complexity discussed above, will result in equal weights for all index components. And that is also a choice that needs to be accounted for.

One way to weight the index items could be to let the weights depend on the size of the items association with morbidity and/or mortality. However, the exactness with which associations can be determined based on study results is questionable and might for some foods or nutrients be more reliable than for others. But more important, 'la raison d'être' of an index of overall diet quality is not taken into account when individual foods or nutrients are considered: existing correlations and interactions between the individual dietary components.

3.6 Composing an index of overall diet quality: conclusions

Composing an index of overall diet quality involves many choices for the researchers. Choices are related to the variables or index items to be included, the cut-off values, and their scoring (frame 3.3).

The first question that may arise is whether it is actually possible to sum the extent to which a desired intake level of fat is satisfied with that of cereals or alcohol for instance. Who finds this approach irrational may consider indexes of overall diet quality not relevant to assess diet quality. However, although skepticism is understandable, the only alternative is doing what has been done for years: relating individual nutrients and foods to disease or other health outcomes. And as discussed earlier, this approach has many limitations. Indexes of diet quality might therefore be a good endeavor to consider the diet as a whole.

The question remains of course what the best approach would be. *How* can overall diet quality be quantified best? Several indexes have been proposed (summarized in appendix A). As many choices have to be made, a large degree of subjectivity exists.

However the various indexes have similarities. Based on these similarities it can be concluded that some agreement exist upon the index components to be included. Indexes generally contain one or more fat-related variables, several food groups: generally cereals or grain, vegetables and/or legumes, fruits, and sometimes meat, or, if not, protein.
In addition dietary variety may be a relevant component of the score. Its operationalization should however be well contemplated.
Inclusion of macro-nutrients like total fat and carbohydrates or protein seems sound to ensure that consumption is overall balanced. It would not be necessary to include all three macronutrients as they are complementary. SFA, or the ratio of MUFA to SFA, but also alcohol and cholesterol are included because high intakes are regarded deleterious. Most

other components are considered beneficial and intake should therefore exceed a specified level. If the index consists of a sufficient number of dietary components it also implies that the diet should be varied, because otherwise intakes for all the specified index items cannot be satisfied. Inclusion of micronutrients seems less defensible as translation into consumption patterns is difficult. Besides it undermines the base of the idea of considering the diet as a whole.
We therefore think that a diet quality index should be merely food-based. Such index is also more practical if it is aimed to be a tool that should ultimately lead to intervention or health education purposes. A few macronutrients could be included to assure the diet to be overall balanced, and a few nutrients that are regarded fairly deleterious may also be comprised.

Except for the Mediterranean indexes most indexes are based on dietary recommendations. Both the DQI and the HEI are based on US guidelines and composition and cut offs are therefore alike. Cut-off values for total fat (30 E%) and saturated fat (10 E%) are the same for almost all indexes.
The choice for the cut-off also depends on what the index is used for. If the objective is to divide individuals in subgroups with different diet quality in order to relate diet quality to health outcome then most important is that the index distinguishes well between subjects. If, on the other hand, it is intended to evaluate the quality of the overall diet, to what extent all dietary guidelines are met and, for example, to discern risk groups for whom diet quality is considerably less than desired, it is important that cut-off values are based upon nutritional knowledge as to what is considered a healthy diet.
Using an intake range instead of a simple cut-off to appraise intake levels seems appealing, especially for those foods or nutrients that are essential or beneficial in lower quantities, but detrimental if intakes become too high. In a way this may account for most items, as excessive intakes are seldom healthful.
Total consumption or energy intake may be an important confounder and its influence should therefore be seriously considered. A possible way to handle this problem is to let the intake cut-off, or intake range, depend on energy intake or to adjust intake of each component to specific daily energy intakes.
Furthermore the relative weights of the individual index components should be addressed and the researcher should defend his or her choice. Although this is an arduous task, it is highly important and may determine to a large extent the index' predictive capacity, and consequently its validity.

4. Predefined dietary patterns and health outcomes

Chapter 3 has provided an overview of predefined indexes of overall diet quality. Several existing indexes have been summarized and their composition, and thus the choices of the researchers have been discussed. Although it can be argued that some choices are more rational than others, composing an index remains a complex matter with a large degree of subjectivity. Therefore validation of the indexes is desired.
To gain insight into the validity of the various indexes, thus the extent to which they are able to distinguish between individuals, the indexes can be related to either nutrient adequacy or health outcome. In this chapter results of validation studies will be discussed.

It should first be mentioned that results from the various studies are difficult to compare. Exact values but also significance of the relative risks depends largely on the testing procedure, especially the variables adjusted for. Reported associations between diet quality and mortality in some studies may be greatly attenuated if additional potentially confounding factor were taken into account. Also the way in which energy intake has been dealt with may influence the results. In addition interpretation and presentation of the results differs considerably between researchers. In some studies relative risks are reported for example for the lowest versus the highest quintile of index score, whereas in others relative risks are given for a certain increment in score. Furthermore some authors report 'strong associations' or 'high predictivity' whether others may report 'marginal predictivity' with similar results.

4.1 Socio-demographic factors and nutrient adequacy

Diet scores have been related to socio-demographic factors, nutrient adequacy, and health outcome. Female gender, older age, and higher income or education were generally predictors of better diet scores.
Six studies have examined associations between biological markers of dietary exposure and diet quality. Sixteen studies have related diet scores to overall and/or cause-specific mortality. An overview of studies that have examined associations between overall diet scores with nutrient adequacy and health outcome and their major findings is given in appendix B.

4.2 Mediterranean Diet Score (MDS) and health outcome

Adherence to the Mediterranean diet was reported to predict survival in 5 studies. Participants were Greek adults (91; 92), Danish elderly (75), Anglo-Celts and Greek-Australian elderly

(50), and elderly from 11 European countries (49). Lower mortality was also reported among French adults following a Mediterranean diet in intervention studies (8; 9).
Havemann-Nies et al. reported an association between the three life style factors physical activity, smoking and diet with mortality, but found no significant association for diet alone (31). In a study among Spanish elderly a relation between MDS and mortality was only observed in persons older then 80 years (55).
In a recent large study among European elderly from 9 different countries participating in the EPIC project, a significant reduction in overall mortality was found with increasing diet score. Yet, no association could be found between the MDS and overall, cancer, and CHD-mortality within the Dutch sub-cohort consisting of 122 men and 4031 women (unpublished results, oral communication Marga Ocké).

Osler and Schroll reported that plasma carotene was associated with MDS, but they did not find an association for plasma cholesterol, HDL, and vitamin E with the score (75).
It is important to consider cultural differences in eating patterns. One can wonder whether it is pertinent to calculate a Mediterranean Score for Western Europeans. Often this problem is dealt with by choosing a country-specific cut-off value (31; 49; 75). However, as mentioned before, it is questionable what exactly is being measured when doing so.

It is likely that the Mediterranean diet is beneficial in composition. Yet results are inconsistent. The MDS seems able to predict mortality especially in European Mediterranean populations and it may be a valid score for use in these countries. For Western populations like the Dutch, it may however be better to either adapt or develop a score that is more tailored for the local diet.

4.3 Healthy Eating Index (HEI) and health outcome

The HEI was reported to be associated with a wide range of nutritional biomarkers of micronutrients in two studies (29; 97). It should be noted that those biomarkers mostly represented nutrients from fruit and vegetables and thus consumption of these food groups. Both studies did not find an association with cholesterol.
The HEI was found to have a higher correlation with the mean adequacy ratio (MAR) of several nutrients than DQI and HDI (14).

We did not find any study that has related the HEI score with mortality. Four studies have examined the relationship between HEI and disease risk (30; 62-64). No association of the HEI with cancer incidence could be detected (30). McCullough and colleagues reported a weak inverse association between HEI score and chronic disease risk in a large study in men (62), but did not find an association with overall chronic disease risk in women (64), only a weak inverse association with CVD risk.

The authors consequently developed an Alternative Healthy Eating Index (AHEI), and reported it to be inversely associated with major chronic disease, primarily with CVD (63). Although the AHEI has adapted some components from the original HEI it differs considerably from the HEI (see appendix A) and therefore these scores cannot be compared. The authors state that some components of the AHEI were already known to be protective in the cohort. But they argue that associations between components of the AHEI and disease risk have ‘strong biological justification’ as they have been observed in other epidemiological studies. Besides the population, consisting of participants in the Health Professional’s Follow-up Study and the Nurses’ Health Study, is homogenous and health-conscious. The AHEI has not been validated in other studies.

The HEI has been constructed according to US dietary guidelines. It does therefore measure the extent to which individuals follow these guidelines. This does however not mean that the HEI is a good predictor of health status or can well predict health outcome. To our knowledge the HEI score has not been validated by relating the index score to mortality. The index does not seem well able to predict disease risk, although the index score does show correlations with plasma biomarkers.

4.4 Healthy Diet Indicator (HDI) and health outcome

The HDI, developed in the Netherlands according to the World Health Organizations guidelines for the prevention of chronic diseases, has been reported to be inversely associated with all-cause mortality in men from 3 European countries, including the Netherlands (37) and in Dutch elderly men, but not in women (40). Reported risk reductions were relatively small (13 %) for the European men (40), but considerably higher (44 %) for the Dutch elderly men (37). Furthermore HDI was suggested to correlate inversely with cognitive impairment (38). However HDI score was found to be only very marginally correlated with MAR (14), and no association was found between HDI score and serum albumin, Hb, or waist circumference (32).

4.5 Diet Quality Index (DQI) and health outcome

DQI was shown to be only marginally correlated with nutrient adequacy (MAR) (14).
We only found one study that tried to validate the DQI by relating its score to mortality (84). The authors state that ‘the DQI may have limited ability to predict mortality’, however they reported a multi-variately adjusted rate ratios for the relation of DQI and all-cause mortality up to 1.31 (significant) for women and 1.19 for men consuming a medium-low quality diet (DQI-score 8-10 on scale of 16) versus a high quality diet (DQI-score 0-3 on scale of 16).

CVD-mortality was also lower for persons consuming a high quality diet, but cancer mortality was not found to be associated with DQI. The model contained many potential confounders, when adjusting for age only associations were much stronger.

The DQI Revised (DQI-R) has shown significant correlations with several plasma biomarkers representing micronutrient intake. This index had not been studied in relation to morbidity or mortality.

The DQI-I has also been adapted from the DQI (48). Differences are however considerable. The DQI-I is not only more extensive, it has also attributed different weights to the individual index components. It has divided the index into four major components: variety, adequacy, moderation, and empty calorie foods. Many nutrients showed strong relationships with the index score. The authors state that the DQI-I can identify dietary problem areas.

Several other indexes have been adapted from the DQI (12; 13; 56), one of which calculated the score for Dutch adults (56). These indexes are essentially similar, containing only the nutrient-components of the original index. All these indexes however had a low discriminating power; most persons yielded very low scores and fell within the same (low-score) category.

4.6 Food-based indexes and health outcome

Osler and colleagues found no association of their Healthy Food Index, a four-item food-based index, with all-cause mortality nor with CHD-risk in a Danish population (73; 74). Food consumption of Dutch adults (from the DNFCS) was evaluated using a 7-item Food-based Quality Index (56). It was concluded that the index was associated with an increase in food consumption without clear relevance for dietary quality.

4.7 Dietary Variety Scores (DVS) and health outcome

Dietary variety has been made operational in various ways and scores were used to evaluate diet quality (3; 12; 13; 43; 44) (17; 18; 85). Often either a distinction is made between recommended and non-recommended foods, or only recommended food or food groups have been selected to contribute to the variety score. Regardless of how a variety score has been calculated, most authors report dietary variety to be beneficial.
Three studies examined the association between dietary variety and overall mortality (42; 43; 65). They all reported important reductions in overall mortality associated with a more varied diet. Reduced cancer and CHD mortality were also reported (42; 65). In addition, Michels

and Wolk calculated a Non-Recommended Food Score and found it to be associated positively with cancer mortality, but not with CHD- and overall mortality.
Overall dietary variety, and especially variety in fruit and vegetable intake, was also reported to reduce risk of various forms of cancer (17) (18; 41; 54). Dietary variety was also found to be associated with improved nutrient adequacy, as an additional component of dietary quality that is not captured by energy intake (19). An association of overall variety with colon cancer risk was not found by Slattery and colleagues (85), they reported however that intake of fruit, plant food, and meat was associated with colon cancer risk.

Dietary variety seems to contribute importantly to a healthy diet. Considering dietary variety alone would however pass over many other aspects of the diet. Yet, regarding the presented evidence overall dietary variety and/or variety within food groups should be taken into account in a composite score. The question remains how exactly it should be operationalized. Total food consumption and therefore energy intake can be an important pitfall in the operationalization of dietary variety. Another important issue is that several individual components of the score may be related, i.e. scoring high on a particular item may involve a high score on another item. For dietary variety this phenomenon may even be more extreme. In order to have a high score on the overall index containing several foods or food groups, the diet already needs to be varied.

4.8 Predefined dietary patterns and health outcome: conclusions

Most of the published indexes tend to relate positively to the intake of micronutrients. Associations between biological markers of dietary exposure and diet quality generally result from higher micronutrient intakes in better-quality diets.

Evidence regarding the association of mortality and CVD risk in relation to healthful dietary patterns from diet indexes was more consistently positive. The magnitude of the protective effect was moderate in most published studies. In several studies the dietary pattern and health association was markedly attenuated by control for confounders. Most studies did not show an association between risk of incident cancer at most sites and dietary patterns.

Considering the results of validation studies of the HEI, DQI, and HDI the question can be raised whether an index based purely on dietary guidelines can adequately describe consumption patterns that are associated with reduced risk of chronic disease and mortality. These indexes had only marginal predictive capacity.
An index of diet quality should always consider existing, culturally defined dietary patterns. The Mediterranean diet may be truly beneficial regarding the associations reported in several studies. However the MDS is not appropriate for use in the Dutch population. Beneficial

aspects of the Mediterranean diet can of course be kept in mind when a diet score is being constructed.
Several studies in which dietary variety has been calculated have reported considerable and significant associations with morbidity or mortality. A measure of dietary variety should therefore be included in the overall index.

5. Empirically derived dietary patterns

Another way of examining dietary patterns is an '*a posteriori'* approach, in which patterns have not been defined in advance, but are derived empirically. Statistical methods are used to generate patterns from collected dietary data. Empirically derived eating patterns therefore do not depend on how the authors define a healthful pattern. In nutritional epidemiology, factor and cluster analyses are two commonly used methods to derive eating patterns.

To identify studies that have used pattern analysis, PubMed was searched using the terms 'factor analysis' and 'diet', 'cluster analysis' and 'diet', 'eating patterns', and 'dietary patterns'.
Newby and Tucker have recently (May 2004) reviewed studies having derived dietary patterns empirically, using either factor or cluster analysis (72). As their work seemed comprehensive and complete we will refer to their published results (tables 1, 2 and 3 of the article) for an overview of epidemiological studies using factor analysis or cluster analysis to derive eating patterns.

5.1 Dietary patterns from factor analysis

Factor analysis, as a generic term, includes both principal component analysis (PCA) and common factor analysis. Principal component analysis is generally used to define dietary patterns. It is driven by the idea that correlated variables can be grouped, thus that correlated variables belong together, and that they should be recognized as distinct from groups of variables with which they are not correlated. Factor analysis thus reduces data into patterns based upon intercorrelation between dietary variables.
Factor analysis distinguishes between variables, not between individuals. Individuals have a score on each factor. A summary score for each pattern can be derived and can be used in either correlation or regression analysis to examine relationships between various eating patterns and the outcome of interest, such as nutrient intake, cardiovascular risk factors, and other biochemical indicators of health.

Although factor analysis is 'data-driven'; dietary patterns are derived empirically, it does involve a degree of subjectivity. We will therefore discuss the main steps involved when conducting factor (or rather PC) analysis and note the kind of subjectivity encountered at each step. A summary of these steps and the choices for the researcher is given in frame 5.1.

An overview of epidemiological studies using factor analysis can be found online: *http://www.ilsi.org/file/Newby.tab1.pdf* ; this is table 1 from the article by Newby and Tucker (72).

5.1.1 Selecting and adjusting the variables

The first step in the procedure is selection of the variables to examine. Depending on the dietary assessment method used, the number of foods available for analysis can be enormous. Generally these foods are assigned to several specified foods or food groups for entry into the factor analysis. It should be noticed that the type of data collected, for example food frequency data or intake data from a dietary history, influences the factor solution.
Although selection of the foods and food groups will be based on sound arguments from the researchers, it is a subjective process. The number of foods or food groups as well as their choice directly influences the resulting factor solution. Thus different investigators can combine foods from a same dataset into different groups, developing different dietary variables. Likewise the final models will vary by researcher.
Furthermore bias in either inclusion or deletion can be problematic: inclusion of unrelated variables can affect formation of the factors, whereas deletion of variables in order to simplify the factorial structure can lead to erroneous conclusions (59).
In most of the studies in which dietary data had been analyzed using factor analysis, the originally measured dietary items were collapsed into a smaller number of input variables, usually food groups. Some studies however entered all individual food items from the primary method into a factor analysis.
Depending on the dietary assessment method used, intakes were measured in several ways, including frequency (number of servings), weight (gram per day), or daily percent energy contribution.
A next step before the actual analysis can be a further adjustment of the intake variables. Although in several studies input variables were further adjusted, more often input variable have not been treated further. Adjustments were done for energy intake and occasionally for sex. Some authors have reported logtransformation, or treating the variables as ordinal.

5.1.2 Choices in the analysis procedure

Once the input variables have been prepared, they can be entered into the factor analytical procedure. In this step the dietary patterns are identified. In the majority of studies principal components analysis (PCA) was conducted. This method permits as many factors as there are variables in the analysis. Usually however, only a few of these factors are considered important. In most studies, a factor is taken to be relevant if its eigenvalue is greater than 1, i.e. if the factor explains more of the variance in the correlation than is explained by a single variable. This number can however be arbitrarily set at another value. Eigenvalues >1.5 and >2.0 were used in a few studies to derive factors, particularly when large numbers of factors had eigenvalues >1.
Principal component solutions are often rotated to achieve a simple structure of the factor loadings. Rotation is aimed at generating an easily interpretable solution. It does however not improve the degree of fit of the factor structure to the data. The choice of the rotation is similarly arbitrary. Generally varimax rotation is used, resulting in orthogonal (uncorrelated) factors. Only one study did not rotate and in two studies oblique rotation was used.

Rationally, only factors with high corresponding eigenvalues should be chosen. However, any lower bound for eigenvalues, whether predetermined or determined by a scree plot, is arbitrary.

Frame 5.1: Analytical steps in factor analysis and choices for the researcher

1. (Dietary assessment method)

2. Selection of foods or food groups
- selection of foods or food groups for entry into the factor analysis
- assigning foods to food groups
- adjusting (or not) input variables (e.g. for energy intake)

3. Identification of dietary patterns from factor analysis
- choice of eigenvalue
- choice of rotation

4. Interpretation of the results
- factor loadings
- labeling the factors

5.1.3 Interpreting and labeling the factors

Once the analysis has been performed, the resulting factors need to be interpreted and labeled. Although generally the factor loadings are reported in the published results, so that the reader can determine for himself what the factors represent, labeling does play a critical role in the interpretation.
The majority of patterns has been named according to specific combinations of foods. Often the label represents a certain level of perceived healthfulness. Many authors labeled factors as ‘western’, ‘prudent’, or ‘healthy’. The extent to which similar patterns are seen in diverse populations may be an indicator of reproducibility. Caution is however warranted. Such conclusion can only be drawn by comparing the actual factor loadings. A factor labeled ‘western’ in one study can differ largely in composition from a factor with the same name in another study.
Other patterns have been named according to the input variable with the highest factor loading, (e.g. fruits, vegetables, cereals, or meat) or according to quantitative descriptions of dietary composition (e.g. high-fat, high-energy density).
Although dietary variables are intercorrelated, their intercorrelations are generally modest. This is of importance when factor loadings are considered. If for example a criterion of 0.20

is used as the lower limit for a meaningful factor loading, two variables with a predicted correlation of only 0.04 could be considered to load on the same factor (59). One variable can in addition load equally (with modest loadings) on two factors. This can make it difficult to interpret the factors.
Therefore not only the loadings of individual foods within one factor should be considered, they must also be compared between factors. For example, the loading for sweets on a factor called 'sweets and drinks' may be less than that on a factor called 'cereals' if, next to cereals, sweets by incidence also have a high loading on this factor.

5.1.4 General conclusions comparing factor analysis studies

Table 1 from Newby and Tucker (72) summarizes factor solutions from 58 studies.
The number of food groups entered into the factor analysis varied from 16 to more than 100, but in the majority of studies between 20 and 50 food groups were entered. Most of the researchers had first collapsed dietary items (stemming mainly from FFQs) into a smaller number of food groups. The majority of factor analysis studies had applied principal components analysis, orthogonal rotation, and eigenvalues >1.
Newby et al. reported that within the reported 58 studies, the number of derived factors ranged from 2 to 25, and percent variance explained ranged from 15 to 93 percent (72). For most studies the total of variance explained by all factors was limited, generally ranging from 15 to 40 percent. It can be questioned what a factor represents if it explains only a few percent of total variance in intake between individuals.
It is important to notice that, whereas the first factor is usually quite similar in many studies, factors 2 and 3 from a 6-factor solution may be different from factors 2 and 3 from a 3-factor solution. Yet Balder et al. reported that identified dietary patterns were robust for number of factors extracted, distribution of input variables and energy-adjustment (2).
Hu et al. have reported reasonable reproducibility and validity of the major dietary patterns defined by factor analysis (35). They identified two major eating patterns, which were qualitatively similar across FFQs and diet records. The correlations ranged from 0.45 to 0.74 for the two patterns. Although reproducibility may indeed be called 'reasonable' it becomes clear that the dietary assessment method used does seriously influence the results.
It is apparent that the number of food groups entered into the factor analysis can seriously influence the resulting factor solution. It is however less clear how eigenvalues cut points and rotation affect factor solutions.

5.2 Dietary patterns from cluster analysis

Cluster analysis is another method for characterizing dietary patterns 'a posteriori'. In contrast to factor analysis, cluster analysis does not aggregate intake variables (food groups), but individuals into relatively homogeneous subgroups (clusters) with similar diets. Cluster analysis thus reduces data into patterns based upon individual differences in mean intakes. As factor analysis it is an exploratory method; it classifies individuals in such a way that groups are internally as homogenous as possible and mutually divergent.

Cluster analysis resembles discriminant analysis. They differ in this respect that discriminant analysis departs from existing groups. It aims to gain insight in what characteristics differ between the existing groups, whereas cluster analysis does not depart from existing groups, but tries to distinguish subgroups exploratively based on (dis)similarities between individuals.

The consecutive steps in the cluster analytical process resemble somewhat those in the process of factor analysis. Again some degree of subjectivity exists at each step. A summary of these steps and the choices for the researcher is given in frame 5.2.

An overview of epidemiological studies using cluster analysis can also be found online: *http://www.ilsi.org/file/Newby.tab2.pdf* ; this is table 2 from the review of Newby and Tucker (72).

5.2.1 Selecting and adjusting the variables

As many of the choices that need to be made in cluster analysis resemble those in factor analysis, they will be discussed only briefly.
Departing from the dietary intake data generally stemming from a food frequency questionnaire or a dietary record, first thing is to select the food groups to use for the analysis. For this purpose foods can be attributed to food groups.
In addition input variables can be treated in different ways. Cluster analysis is very sensitive to outliers. When dietary variables have different ranges or scales variables with larger values will outweigh those with smaller values. More often than in factor analysis cluster studies treated the input variables as percent energy contribution and/or Z-scores[1]. However not all authors reported such adjustments of the input variables.

[1] Factor scores are always Z-scores

Frame 5.2: Analytical steps in cluster analysis and choices for the researcher

1. (Dietary assessment method)

2. Selection of foods or food groups
- selection of foods or food groups for entry into the cluster analysis
- assigning foods to food groups
- adjusting (or not) input variables (e.g. for energy intake)

3. Identification of dietary patterns from cluster analysis
- choice of clustering method
- choice of distance between subjects

4. Interpretation of the results
- choice of the number of clusters
- labeling the clusters

5.2.2 Choices in the analysis procedure

Two key steps within cluster analysis are measuring distances between variables and grouping the variables based upon the resultant distances: the clustering method used. The distances provide a measure of similarity between variables and may be measured in a variety of ways. Euclidean and squared Euclidean distances but also Manhattan metric distance are often reported[1].

Two types of clustering methods are often used: hierarchical methods which build up or break down the data row by row, and partitioning methods which break the data into a pre-specified number of groups. Partitioning methods are used most for larger data sets. These methods are computationally efficient and their output is much easier to interpret when many items are being clustered. K-Means method, a partitioning method, and Ward's Method, a hierarchical method, are often used in dietary epidemiology. Ward's optimizes the minimum variance within clusters. In K-Means clustering the most distance between clusters is created. Few studies have examined which of these methods is better, although it is common to use K-means clustering when a large number of input variables is being entered into the analysis. One study used the partitioning around method (PAM) and compared it with the K-Means method (5). The K-Means method derives clusters based upon the mean intakes of the input variables, whereas the PAM uses the median and is therefore less sensitive to outliers. Campain et al. concluded that the PAM algorithm produced clusters that were more consistent with literature published in their field (of dental epidemiology) (5)

.

5.2.3 Interpreting and labeling the clusters

Ultimately a decision must be made as to which solution is most meaningful and will be reported. This decision is driven both by the plain cluster solution as by the (dietary) interpretability of the clusters derived.
For the K-Means method the researcher must specify the number of clusters in advance. However most researchers run the analysis for a range of solutions, to see which solution makes the most sense. The selection of the best number of clusters can be based on a scree plot, in which the variance that remains within the clusters is portrayed against the number of clusters. When the plot levels off, no additional reduction of the within cluster variance is achieved. The number of clusters corresponding with this point is often selected. But also other methods are applied to select the cluster solution that is considered the most appropriate. Analysis of variance can be used to identify cluster solutions with well separated clusters. And generally the size of the clusters and the differences in food consumption across individual clusters from each run is examined for their interpretability.
Like factors, resulting clusters are labeled. A similar line of reasoning can be followed (see paragraph 5.13).

5.2.4 General conclusions comparing cluster analysis studies

35 studies that have applied cluster analysis to derive eating patterns are presented in table 2 from Newby and Tucker (72). In 17 studies dietary intake data did not stem from food frequency questionnaires, but from food records or, occasionally, a dietary history.
As in factor analysis most studies formed a reduced set of food groups from the primary data. The number of food groups ranged from 10 to 74 (an outlier to above), but most studies did not depart from more than 40 food groups. The average number of food groups entered into the cluster analysis was apparently smaller than in factor analysis studies. In five studies not food groups but (a small number of) nutrients was departed from.
The number of resulting clusters ranged from 2 (only once) to 8. As for the clustering method, K-Means method was most often used, but Ward's Method was also regularly applied. Newby and Tucker conclude that it is not clear from looking at the studies in table 2 which method is preferable for use with dietary variables.

5.3 Deriving dietary patterns empirically: conclusions

Conducting factor or cluster analysis the researcher has to make several (subjective) choices. However, that subjectivity exists, does not mean that these methods should be abandoned. Decisions should however be well documented. At this moment there is not yet enough insight in to what extent outcomes are influenced by choices including treatment of the input

[1] For more technical infromation on cluster analysis we refer to specific statistical handbooks.

variables (e.g. servings per day, standardized, energy adjusted), the factor or clustering method used, and the other choices summed in frames 5.1 and 5.2. Variables are standardized to enable the comparison of variables and to minimize the bias in weighting that may result from differing measurement scales and ranges. However, standardizing variables may dilute differences between clusters and may cause correlations between variables to be ignored (26; 98).
It is difficult to do any statements on the reproducibility of the resulting factor and clustering solutions. Very few validation studies of eating patterns have been performed. Confirmatory factor analysis for factors and discriminant analysis for clusters may be used to test the internal validity of a pattern solution. Internal validation can also be performed by splitting the study sample and repeating the analysis.

Many studies show that eating patterns are associated with other characteristics, including sex, age, socioeconomic status, and general health habits (e.g. smoking, drinking). Newby and Tucker summarized that more women than men have been shown to have a healthier eating pattern, and socioeconomic associations were in the expected direction (72). Age has been associated both directly and inversely with a healthier pattern. Eating patterns are also associated with other health behaviors. A healthy eating pattern group usually has the highest percentage of nonsmokers, exercisers, and vitamin users. Patterns high in alcohol, which are observed in many studies, using either factor or cluster analysis, usually contain a greater percentage of men than women and more smokers (72).
An important concern is whether patterns should be separately derived for different subgroups, for example men and women, or whether it is sufficient to derive patterns in a mixed population and then explore the relation with sex through the analysis. The majority of studies contained both men and women included together in the analysis. In studies that have derived patterns separately for men and women many of the patterns were similar across sex groups. Reproducibility between men and women within a study and between studies suggests similar patterns among men and women.

Data-driven methods to discern dietary patterns suggest objectivity. However, from this chapter it may have become clear that the researcher has to make several choices in the analysis procedure that may significantly influence the resulting solution: the dietary patterns derived. How exactly these choices affect the outcome of the analysis is still unclear. When greater consensus exists to guide decision-making in patterning methods, decisions can become more standardized, decreasing the subjectivity and increasing the reproducibility of factoring and clustering methods.

6. Empirically derived eating patterns and health outcome

Newby and Tucker have presented results from 65 studies that have examined the relationship between eating patterns derived from either cluster or factor analysis and a biomarker or disease outcome. Outcomes included indicators of cardiovascular or coronary heart disease, anthropometric measures, overweight and obesity, many different cancers, symptoms of the metabolic syndrome, type 2 diabetes, and all-cause mortality. The studies are presented in table 3 in the review by Newby and Tucker (72).

6.1 Associations of dietary patterns and health outcome

Several studies examined the relation between eating patterns and anthropometry, including overweight, obesity, and waist circumference. Findings were inconsistent. Modification of the effects by sex or age may explain (part of) the inconsistencies. Although this has to be further examined, one should be aware of these interactions.

It should first be noted that it is delicate to compare results of the diverse studies, as extracted factors and clusters differ in composition. Various factors or clusters carry the same label, e.g. 'Western pattern' or 'Healthy pattern', and their composition, i.e. the variables contributing to these factors, may be to some extent comparable. Nevertheless these factors are never exactly the same, more often they may differ to a larger extent. It may therefore not be reasonable to compare associations between factor or cluster solutions and health outcomes between different studies.
However, whether eating patterns can reliably predict disease is an important indicator of their validity and consequently their utility. Several studies do report factor or cluster solutions that are significantly associated with many different disease outcomes and plasma biomarkers.
Associations of derived eating patterns with metabolic disorders, the metabolic syndrome, and cardiovascular outcomes were generally in the expected direction. More healthy eating patterns were often associated with better health status or lower disease risk and/or unfavorable patterns were found to be associated oppositely (10; 16; 21; 22; 25; 26; 28; 36; 39; 47; 52; 60; 61; 66; 67; 70; 71; 73; 74; 76; 78; 80; 86; 88; 95; 96; 98). Several studies however reported that the relation between eating patterns and lipids was modified by sex.
For many of the individual cancer outcomes, very few (often only one) patterning studies have been performed. Most studies reported no significant associations. If relationships were significant they were generally in the expected direction (28; 58; 61; 76; 86; 89). Patterns high in fruits and vegetables were often found to be associated with lower cancer risk (58; 76; 88). Dixon et al. reported that dietary patterns from factor analysis were associated with

colon and rectal cancer risk in some cohorts, but not in the Dutch cohort (Netherlands Cohort Study) (11).
However other studies that have related empirically derived dietary patterns to health outcome could not find odds ratios that were significantly different from one (6; 20; 73; 74; 79; 81; 83; 94).

6.2 Empirically derived dietary patterns and health outcome: conclusions

Many studies in which dietary patterns have been derived by factor or cluster analysis have reported positive and/or negative associations between certain patterns and a measure of health outcome. These patterning methods therefore seem able to distinguish healthy and less healthy eating patterns.
However, if a dietary pattern obtained by either factor or cluster analysis turns out to be a risk factor for a specific disease, an explanation is often difficult to find. Although we know which food groups substantially contribute to the factor, food groups loading high on a particular factor can be diverse.
In addition several studies could not find any association between any of the factors or clusters derived and health outcome. A reason is that explaining as much variation in food intake as possible does not mean that much variation in important nutrients will be explained. It could be put forward that it would be wiser to focus on the variation in nutrients that presumably affect the incidence of disease. But applying principal components analysis to these nutrients is not attractive since patterns are then defined as linear functions of nutrients and are therefore not directly related to dietary habits because individuals consume foods not nutrients.

Factor and cluster analysis may be well able to identify the major dietary patterns of a particular sample, but these patterns do not necessarily represent ideal diets. They represent combinations of foods that tend to occur together in a given population as results of different cultural, social and economic situations. Whether or not they can predict disease, they represent dietary behaviors that are of interest by themselves.
Factors or clusters that do show an association with a particular health outcome allow us to identify combinations of foods that can be considered less healthy. Results from such analysis could lead to further research into the actual cause. They could also give insight in how nutritional education should be directed.

7. Other statistical methods to derive dietary patterns

In the previous chapters approaches two derive dietary patterns have been described and evaluated. Chapter 3 and 4 provide insight in 'a priori' or theoretically defined dietary patterns, whereas in chapter 5 and 6 patterns derived 'a posteriori' by factor or cluster analysis are being discussed. These approaches have gained considerable attention in nutritional epidemiology and many studies have been published in which either (or both) of these methods have been applied.
As discussed however, both approaches have their limitations. In this chapter two other statistical methods that can be used to derive dietary patterns are described. These methods have seldom been proposed for use in this respect, but they might provide another means to evaluate the overall diet.

7.1 Multiple, Logistic and Proportional Hazard Regression

Regression analysis is a very commonly performed statistical procedure in nutritional epidemiology. It is generally used to predict a dependent variable (e.g. incidence of disease, or mortality) on the basis of a set of independent variables (e.g. dietary variables). Also the independents are ranked according to their relative importance, their interaction can be assessed, and the percent of variance in the dependent variable explained by the independents can be determined. In normal linear or multiple regression both the independent and the dependent variables are continuous, whereas in logistic regression the independent variable is dichotomous. Cox proportional-hazards regression allows analyzing the effect of several risk factors on survival.
Often regression analysis, e.g. Cox proportional hazard regression, is used to estimate the association between smoking, physical activity, dietary habits etc. and disease outcome or mortality. However we could not find any study that used regression analysis to actually derive dietary patterns that are associated with, or rather, predictive of a specific health outcome.
On the other hand some researchers have used regression analysis to predict disease risk from specific risk factors. For example Baan et al. have developed a predictive model to identify individuals with an increased risk for undiagnosed diabetes using stepwise logistic regression (1). Risk factors included age, sex, presence of obesity, physical inactivity, BMI, and family history of diabetes. Similarly Conroy et al. have used a Weibull proportional hazards model to develop a risk estimation system for estimating cardiovascular risk from a series of cardiovascular risk factors (7). Both models were reasonably well able to estimate disease risk from the specified risk factors.
There are no obvious reasons why regression analysis could not be employed in a similar way to derive dietary patterns that are associated with for example mortality.

7.2 Reduced Rank Regression

Reduced Rank Regression (RRR) or maximum redundancy analysis is a statistical method that determines linear functions of predictors (for example foods) by maximizing the explained variation in responses (for example disease-related nutrients). Hoffmann and colleagues were the first to apply RRR in nutritional epidemiology (33). RRR is neither an a priori nor a purely exploratory method, but since it uses both information sources, data from the study and prior information for defining responses, it represents an a posteriori method.

RRR determines combinations of food intake that explain as much response variation as possible. The number of factors that can be extracted equals the number of response variables. Similar as for factor and cluster analysis, the coefficients of the factor scores are study specific.
To apply RRR, disease-specific response variables, intakes of nutrients, and predictors, intakes of food groups, are requested. Like principal component analysis, RRR also extracts successive linear combination of the predictors. However the goals of these methods differ. The classic PCA method selects factors that explain as much predictor variation as possible. In contrast, RRR extracts factors that explain as much response variation as possible. Another method, partial least squares (PLS) is a compromise between PCA and RRR, it balances the two goals of explaining predictor variation and explaining response variation.
Just as accounts for PCA, the factors obtained by RRR and PLS are sorted by decreasing eigenvalues. The first factor of RRR explains more variation in response than any other linear function of predictors, but possibly explains only a moderate fraction of predictor variation (in contrast to PCA). On the other hand PLS maximizes the covariance between linear combination of predictors and responses (33).

Hoffmann and colleagues applied RRR to extract dietary patterns from 49 food groups, specifying four diabetes-related nutrients and nutrient ratios as responses. They chose the responses to be nutrients that are presumed to be important in the development of type 2 diabetes. They selected the following responses: the ratio of polyunsaturated fat to saturated fat (PUFA:SFA) intake, fiber intake, magnesium intake, and alcohol consumption. They conducted PCA, RRR, and PLS to explain variation in 49 predefined food groups and (or) in the four response variables in a pooled data set of 578 cases and controls.
The four factors extracted by RRR explained 93.1 percent of response variation, whereas the first four factors obtained by PCA accounted for only 41.9 percent. The authors concluded that RRR extracted a significant risk factor for diabetes.
The responses, in this study disease-related nutrients, need to be selected by the researchers based on current nutrition knowledge (published research results). The extent to which intake of the selected nutrients are actually associated with the disease largely determines the validity of the results. The authors of above mentioned study for example found that the crude means of the four selected responses did not differ significantly between cases and

controls. Only after adjustment for the other three response variables were the means significantly different, but, contrary to their assumption, magnesium intake and PUFA:SFA intake were on average higher for cases than for controls (33). One can therefore wonder whether the selected response variables were well chosen. Of the factors obtained by RRR, only the fourth was found to be a risk factor for type 2 diabetes, when the factor scores were entered as independent variables in a logistic regression model.

In a subsequent study from the same research group, 5 biomarkers for coronary artery disease (CAD) were used as responses in RRR (34). The results of this study were more consistent than that of the former study. The first factor was taken of interest, and although it explained only 7.8% of the total variation of all 5 biomarkers, the adjusted relative risks across increasing quintiles of the dietary pattern score were 1.0, 1.4, 3.2, 6.5, and 11.4.
This study showed the potential of RRR to identify dietary patterns that simultaneously affect the concentrations of, in this case, known CAD biomarkers and the risk of developing CAD.

8. Conclusions and recommendations

In the previous chapters several approaches have been discussed to evaluate diet quality in a holistic way. Dietary intake can be judged (scored) using 'objective' criteria set beforehand, or it can be evaluated afterwards using statistical methods like factor and cluster analysis to derive dietary patterns from collected food consumption data.

8.1 Is a holistic approach warranted?

In the first place the question needs to be answered if in fact we should want to use dietary pattern analysis in any kind, to evaluate diet quality. The answer is yes: it should be used *not instead* of the alternative and common approach of considering individual components, *but in addition.* As explained in chapter 2, a 'reductionist' approach can reveal the role of individual nutrients in the development of disease, but it also has its limitations. Evaluating diet quality in a holistic way is another approach to gain insight into the relation between diet and health that takes into account the often high correlations in intakes of foods and nutrients. The simple fact remains that people have diets: they do not consume nutrients but combinations of foods.

8.2 Theoretically defined indexes: conclusions

In chapter 3 an overview is given of existing predefined indexes of diet quality and their composition. The choices for the researcher have been discussed elaborately. Although diet-quality scores will account for current scientific evidence, many choices remain subjective. Nevertheless, from the overview and the results presented in chapters 3 and 4, some conclusions can be drawn that may guide choices for adapting or developing an index of diet quality.

First of all it should be taken into account that diet is culturally determined. The general dietary habits within a population should therefore be considered when the index items and their cut-offs are chosen.
Most of the evaluated predefined indexes of diet quality show a relation with nutrient adequacy or health outcome. However, these associations are generally moderate, casting doubts on the validity of the existing indexes.

Based on the findings in this report we propose that, if an index of diet quality is to be constructed, it should in principle be food-based. Nonetheless the index may contain two

macronutrients to assure an overall balance. And also certain nutrients that are rather deleterious can be included. Candidates are alcohol, cholesterol, and saturated fatty acids, that have been included in most dietary indexes, and trans fatty acids, that has gained considerable attention in recent years because of its adverse health effects.
The index should further and primarily consist of foods or food groups though.
Given the scientific evidence that has proven its relevance, dietary variety should be considered. Overall dietary variety can be an individual index item, but the index could also be constructed in such a way that in order to obtain a high index score dietary variety is assured. Also variety within food groups, for example within the vegetables and fruit group could be considered. Of course, the composite score should be a better predictor of health outcome than dietary variety alone.
It may be preferable to design scoring ranges instead of simple cut-off values. Not only because they are more subtle, but also because they make it easier to judge intakes of foods or nutrients that are both beneficial (in low quantities) and detrimental (in too high quantities).
To avoid confounding by energy intake scores should depend on or be adjusted for energy intake.
The relative contribution of the individual index components to the total score remains a delicate and complex issue that should be further examined. Nutrient adequacy and associations between individual dietary components and morbidity and/or mortality may play a role.

A predefined index of diet quality may be helpful to evaluate the diet of a population (sample) and to monitor changes. It could also be used to compare the quality of the diet between subgroups within the population. Ideally the index would be a strong predictor of health outcome and the individual index components would contribute to the index as they contribute to ‘healthiness’. In that case diet quality could be assessed quantitatively, providing us with a tool to monitor the diet and changes in eating patterns within a population, so that policy priorities can be set.
Previously mentioned aspects, may be helpful in developing an index with reasonably high predicting ability specific for the Dutch or Western population. It will remain a difficult task though, involving arbitrary decisions. Therefore it may be possible to construct an index in a slightly different manner, but based on these insights. This will be further discussed in the last paragraph of this chapter.

8.3 Factor and cluster analysis: conclusions

In contrast to predefined indexes, dietary patterns can also be derived from collected food consumption data, using factor or cluster analysis. Correlation in intakes of the various foods serves as a starting point. Chapter 5 went into the factoring and clustering methods and the choices involved, and in chapter 6 reported associations of dietary patterns with health outcome have been evaluated.

Although patterns are derived empirically, a substantial degree of subjectivity exists concerning treatment of the input variables, the factor or clustering method used, and other methodological choices. The degree to which these choices affect the outcome is still unclear. Furthermore derived dietary patterns are generally population specific.

Several studies have reported dietary patterns from factor or cluster analysis to be associated with disease. However, factor and clustering methods may be able to identify dietary patterns in a population, these patterns do generally not represent optimal diets. They are based on food consumption data and correlations in intakes between foods and ignore prior knowledge completely.
These methods may therefore not be very useful to evaluate diet quality, but do allow us to gain insight into existing food consumption patterns within the population and patterns that may be associated with increased (or decreased) health risk.

Thus factor or cluster analysis may be used to gain insight into correlations in intakes between foods and in prevailing eating patterns. But we do not think that either factor or cluster analysis can contribute significantly to the construction of an overall diet quality score.

8.4 Additional methods to derive dietary patterns: conclusions

Although predefined indexes of diet quality and factor and cluster analysis have been widely described and used to gain insight into dietary patterns, these methods do not provide the only means of assessing the quality of the overall diet.
With (logistic) regression or proportional hazard regression it would be possible to discern foods that predict disease or mortality risk best. Reduced Rank Regression may determine combinations of foods that explain as much response variation as possible. The response variables can for example be biomarkers for a specific disease. This latter approach only makes sense if the response variables are good predictors of the disease. Or it could be focused on more general measures of health outcome, like nutrient adequacy or a series of nutritional biomarkers.
Compared with regression analysis Reduced Rank Regression may take better account of correlation in intakes of different foods (and nutrients). The method sounds appealing to identify existing dietary patterns that are directly predictive for a specific disease. To our knowledge only two studies applying Reduced Rank Regression have been published so far with moderate results. It may be interesting to further explore its potential.

8.5 Dietary pattern analysis for use in the Netherlands

Three large scale Dutch National Food Consumption Surveys (DNFCS) have been conducted in 1987/88, 1992, and 1997/98, consisting of a sample of about 6,000 individuals (1 to 75 years) from the Dutch population. In these DNFCS food consumption was measured using 2-day dietary records. In 2003 a food consumption survey was held among a smaller sample of 750 younger adults, using two independent computerized 24-hour dietary recalls. It is expected that this new approach will be used for future national food consumption surveys. These national food consumption surveys are aimed at monitoring food consumption of and nutrient supply to the Dutch population. Until now intake of nutrients and consumption of several food groups have been assessed individually. This literature study was aimed to evaluate the use of dietary patterns to assess the diet as a whole and its application in the Netherlands, making use of data from the national food consumption surveys.

A predefined index of overall diet quality could serve as a tool to assess the diet of the Dutch population. The index could be used to do statements on the overall healthfulness of the diet, and to monitor dietary changes. The index could also be used to distinguish subgroups with differing diet quality (target groups) within the population. Such an index should be adapted to the Dutch diet and it should be validated for its association with morbidity and/or mortality, or e.g. plasma biomarkers.
The problem is however that predefined indexes of diet quality focus on selected aspects of diet and do not consider the fact that intakes of foods and nutrients are correlated. Moreover, the many subjective choices and lack of insight in particularly the relative contribution of the individual index components to the score has so far resulted in marginal predictive capacity of the existing indexes.

We therefore propose the following:
A framework for diet quality score could be developed in line with the suggestions in paragraph 8.2. Also it should be considered to link to the new Dutch Guidelines for a Healthy Diet ('Richtlijnen Gezonde Voeding') that will be developed by the National Health Council in 2005.
In a next step Proportional Hazard Regression or survival analysis can be applied to establish the final model. The index items would be the independent variables and overall mortality, or if desired another measure of health outcome, the dependent variable. So the items to be finally included can be selected objectively and the relative weights of the individual index items can be determined in accordance with the regression coefficients. In this way correlations between the dietary components are taken into account. Another option would be to conduct a sensitivity analysis, varying index items and a.o. their weights in order to find out which index is the best predictor of mortality. Additionally Reduced Rank Regression can be applied to explore the potential of this method.

For this purpose an appropriate Dutch cohort is needed. The Dutch cohorts that seem the most suitable candidates are the Prospective Netherlands Cohort Study on Diet and Cancer (NLCS)[1], the MORGEN[2] study or the combined MORGEN and Prospect-EPIC[3] cohorts (Dutch contribution to the EPIC study[4]), and the (local) Rotterdam study (ERGO)[5].
This should result in a final model that can be used as a tool to assess the quality of the overall diet and to monitor changes based on data from the Dutch National Food Consumption Surveys.

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[1] Population survey iniated in 1986 among 120,852 Dutch men and women aged 55-70y at baseline.
[2] Population survey (Monitoring Project on Risk Factors and Health in the Netherlands) among 23,100 individuals from three towns in the Netherlands, aged 20-59y at baseline (1993-1997)
[3] Population survey among 17,500 women living in Utrecht and surroundings, aged 50-70y at baseline (1993-1997)
[4] European Prospective Investigation into Cancer and Nutrition (EPIC): Large international study with 519,978 participants from 23 centers in 10 European countries
[5] Population survey among all inhabitants >55y at baseline (1990-1993) living in a suburb of Rotterdam. In total 7,983 subjects partcipated, in 2002 another 3,011 were added to the cohort.

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Appendix A Composition of predefined indexes of diet quality

Diet Quality Index (DQI)[1]

Patterson et al., 1994 (77)

Component	Scoring	
Total fat	<30 E%	0
	30-40 E%	1
	>40 E%	2
SFA	<10 E%	0
	10-13 E%	1
	>13 E%	2
Cholesterol	<300 mg	0
	300-400 mg	1
	>400 mg	2
Fruit and vegetables	5+ servings	0
	3-4 servings	1
	0-2 servings	2
Complex carbohydrates	6+ servings	0
	4-5 servings	1
	0-3 servings	2
Protein	=<100% RDA	0
	100-150% RDA	1
	>150% RDA	2
Sodium	<2,400 mg	0
	2,400-3,400 mg	1
	>3,400 mg	2
Calcium	=>RDA	0
	2/3 RDA	1
	<2/3 RDA	2

[1] based on US recommendations from 'Diet and Health',
National Research Council. Committee on Diet and Health, 1989 (68)

Diet Quality Index Revised (DQI-R)
Haines et al., 1999 (27)

Component	Scoring	
Total fat	<30 E%	10
	30-40 E%	5
	>40 E%	0
SFA	<10 E%	10
	10-13 E%	5
	>13 E%	0
Cholesterol	<300 mg	10
	300-400 mg	5
	>400 mg	0
Fruit[1]	% of recomm servings	0-10
Vegetables[1]	% of recomm servings	0-10
Grain[1]	% of recomm servings	0-10
Calcium[1]	% of AI	0-10
Iron[1]	% of RDA	0-10
Dietary Diversity[1]	weighted average of scores from 4 main food groups (containing in total 23 food groups)	0-10
Dietary moderation (consumption of added sugar, discretionary fat, sodium, alcohol) [1]	weighted average of score for each component	0-10

[1]score is continuous variable proportional to recommended range of intake

Diet Quality Index International (DQI-I)
Kim et al., 2003 (48)

Component	**Scoring**	
Variety		*0-20*
Overall food group variety	servings from different groups	0-15
Within-group variety	servings from different sources	0-5
Adequacy		*0-40*
Vegetable group	0-3(5) servings	0-5
Fruit group	0-2(4) servings	0-5
Grain group	0-6(11) servings	0-5
Fiber	0-20(30) g/d	0-5
Protein	0-10 E%	0-5
Iron	% RDA/AI	0-5
Calcium	% RDA/AI	0-5
Vitamin C	% RDA	0-5
Moderation		*0-30*
Total fat	30-20 E%	0-6
SFA	10-7 E%	0-6
Cholesterol	400-300 mg/d	0-6
Sodium	3400-2400 mg/d	0-6
Empty calorie foods	10-30 E%	0-6
Overall balance		*0-10*
Macronutrient ratio	CH:protein:fat	0-6
FA ratio	P/S and M/S	0-4

DQI adapted and modified

a Drewnowski et al., 1996 (13)

Component	Scoring	
Total fat	<30 E%	1 (else: 0)
SFA	<10 E%	1 (else: 0)
Cholesterol	<300 mg/d	1 (else: 0)
Carbohydrate	>50 E%	1 (else: 0)
Sucrose	<10 E%	1 (else: 0)

b Drewnowski et al., 1997 (12)

Component	Scoring	
Total fat	<30 E%	1 (else: 0)
SFA	<10 E%	1 (else: 0)
Cholesterol	<300 mg/d	1 (else: 0)
Carbohydrate	>50 E%	1 (else: 0)
Sodium	< 2,400 mg/d	1 (else: 0)

c Lowik et al., 1999 (56)[1]

Component	Scoring	
Total fat	< 35 E%	1 (else: 0)
SFA	< 10 E%	1 (else: 0)
Cholesterol	< 33 mg/MJ	1 (else: 0)
Carbohydrate	> 50 E%	1 (else: 0)
Mono- and disacharides	< 25 E%	1 (else: 0)

[1] based on Dutch dietary guidelines

Healthy Eating Index (HEI)
Kennedy et al., 1995 (46)

Component	Scoring		
	Criteria for score 0	Criteria for score 10[1]	Range
Grains	0 servings	6-11 servings	0-10
Vegetables	0 servings	3-5 servings	0-10
Fruits	0 servings	2-4 servings	0-10
Milk	0 servings	2-3 servings	0-10
Meat	0 servings	2-3 servings	0-10
Total fat	>45 E%	<30 E%	0-10
Sat fat	>15 E%	<10 E%	0-10
Cholesterol	>450 mg	<300 mg	0-10
Sodium	>4,800 mg	< 2,400 mg	0-10
Variety	≤6 diff food items /3d	16 diff food items /3d	0-10

[1] depending on energy intake

Alternative Healthy Eating Index (AHEI)
McCullough et al., 2002 (63)

Component	Scoring		
	Criteria for score 0	Criteria for score 10	Range
Vegetables	0 servings	5 servings	0-10
Fruit	0 servings	4 servings	0-10
Nuts and soy	0 servings	1 serving	0-10
Ratio of white to red meat	0	4	0-10
Cereal fiber	0 gram	15 gram	0-10
Trans fat	>4 E%	<0.5 E%	0-10
PUFA:SFA	≤0.1	≥1	0-10
duration of multivitamin use[1]	<5 y	≥5 y	0-10
Alcohol men:	0 or ≥3.5 servings	1.5 – 2.5 servings	0-10
women:	0 or ≥2.5 servings	0.5 - 1.5 servings	

[1]For multivitamins, the minimum score was 2.5 and the maximum score was 7.5

Mediterranean Diet Score (MDS)

Trichopoulou et al., 1995 (92)

Nutrient or food group	Scoring	
MUFA : SFA	> median	1 (else: 0)
Legumes	> median	1 (else: 0)
Cereals	> median	1 (else: 0)
Fruits and nuts	> median	1 (else: 0)
Vegetables	> median	1 (else: 0)
Meat and meat products	< median	1 (else: 0)
Milk and dairy products	< median	1 (else: 0)
Alcohol	< median	1 (else: 0)

MDS + fish

Trichopoulou et al., 2003 (91)

Nutrient or food group		Scoring	
MUFA : SFA		> median	1 (else: 0)
Legumes		> median	1 (else: 0)
Cereals		> median	1 (else: 0)
Fruits and nuts		> median	1 (else: 0)
Vegetables		> median	1 (else: 0)
Meat and meat products		< median	1 (else: 0)
Milk and dairy products		< median	1 (else: 0)
Fish		> median	1 (else: 0)
Alcohol	men:	10-50 gram	1 (else: 0)
	women:	5-25 gram	

MDS adapted

Haveman-Nies et al., 2002 (31)

Nutrient or food group		Scoring	
MUFA : SFA		> median	1 (else: 0)
Legumes, nuts and seeds		> median	1 (else: 0)
Cereals		> median	1 (else: 0)
Vegetables and fruits		> median	1 (else: 0)
Meat and meat products		< 130 gram (~75th perc)	1 (else: 0)
Milk and dairy products		>25th perc and <75th perc	1 (else: 0)
Alcohol	men:	< median	1 (else: 0)
	women:	< 8 gram (75th perc)	

Mediterranean Diet Quality Index (MDQI)

Gerber et al., 2000 (23); Scali et al., 2001 (82)

Component	Scoring		
	Gerber et al.	*Scali et al.*	
SFA	<10 E%	idem	0
	10-13 E%		1
	>13 E%		2
Cholesterol	<300 mg	idem	0
	300-400 mg		1
	>400 mg		2
Meat	<200 g	<25 g	0
	200-400 g	25-125 g	1
	>400 g	>125 g	2
Olive oil	>15 ml	idem	0
	15-5 ml		1
	<5 ml		2
Fish	>60 g	idem	0
	60-30 g		1
	<30 g		2
Cereals	>300 g	idem	0
	300-100 g		1
	<100 g		2
Fruit and vegetables	>700 g	idem	0
	700-400 g		1
	<400 g		2
Cigarettes	<10	not included	0
	10-20		1
	>20		2

Healthy Diet Indicator (HDI)
Huijbregts et al., 1997 (37)

Nutrient or food group	Scoring	
SFA	0-10 E%	1 (else: 0)
PUFA	3-7 E%	1 (else: 0)
Protein	10-15 E%	1 (else: 0)
Complex carbohydrates	50-70 E%	1 (else: 0)
Dietary fiber	27-40 g/d	1 (else: 0)
Fruits and vegetables	>400 g/d	1 (else: 0)
Pulses, nuts and seeds	>30 g/d	1 (else: 0)
Mono- and disacharides	0-10 E%	1 (else: 0)
Cholesterol	0-300 mg/d	1 (else: 0)

Food-based Quality Index[1]

Lowik et al., 1999 (56)

Component	Scoring	
Bread (incl breakfast cereals)	5-7 slices	1 (else: 0)
Potatoes (incl rice, pasta and pulses)	3-5 pieces	1 (else: 0)
Vegetables	3-4 serving spoons	1 (else: 0)
Fruit	2 pieces	1 (else: 0)
Milk and milk products	2-3 glasses	1 (else: 0)
Cheese	1-2 slices	1 (else: 0)
Meat, fish and eggs	115-130 g	1 (else: 0)

[1]based on recommended quantities of basic food groups formulated by the Netherlands Bureau for Nutrition Education

Healthy Food Index

Osler et al., 2002 (74)

Component	Scoring	
butter, margarine, animal fat	not at all	1 (else: 0)
vegetables	at least once a day	1 (else: 0)
coarse bread	at least once a day	1 (else: 0)
fruit	at least once a day	1 (else: 0)

Dietary Guidelines Index

Harnack et al., 2002 (30)

Index item	Scoring	
Aim for fitness		
weight	BMI<25	2
	25<BMI<30	1
	BMI>30	0
physical activity	>4 times/wk	2
	2<times/wk<4	1
	<2 times/wk	0
Consumption		
grains	>6 servings	0.4
	<6 servings	0
vegetables	>3 servings	0.4
	<3 servings	0
fruits	>2 servings	0.4
	<2 servings	0
milk	>2 servings	0.4
	<2 servings	0
meat	>2 servings	0.4
	<2 servings	0
Variety		
variety of grains	>6 different grain food items	1
	4-5 different grain food items	0.5
	<3 different grain food items	0
whole grains	>3 servings	1
	1-2 servings	0.5
	<1 servings	0
variety of fruit	>7 different fruit items	1
	5-6 different fruit items	0.5
	<4 different fruit items	0
variety of vegetables	>10 different grain food items	1
	7-9 different grain food items	0.5
	<6 different grain food items	0
Sensible choice		
total fat	<30 kcal from fat	0.67
	>30 kcal from fat	0
saturated fat	<10 kcal from fat	0.67
	>10 kcal from fat	0
cholesterol	<300 mg	0.67
	>300 mg	0
sweets/sweet beverages	0-1 servings	2
	2-3 servings	1
	>4 servings	0
sodium intake	<2400 mg	2
	>2400 mg	0
alcohol	<1 drink	2
	>1 drink	0

Dietary Variety Scores

Dietary Variety Score (DVS) and Dietary Variety Score for Recommended foods (DVSR)
Dietary Diversity Score (DDS)
Recommended Food Score (RFS) and Non-Recommended Food Score (NRFS)

Component	Scoring	Reference
DVS	Number of different (nutrient-dense) foods consumed over a given period	Fanelli and Stevenhagen, 1985 (15) Kant and Thompson, 1997 (44)
DDS	Number of different food groups (dairy, meat, grain, fruit, and vegetable) consumed daily. Max score is 5	Kant et al., 1993 (43)
DVSR =RFS	Number of different recommended foods consumed over a given period	Kant and Thompson, 1997 (44) Kant et al., 2000 (42)
RFS and NRFS	Number of different recommended foods consumed over a given period Number of different non-recommended foods consumed over a given period	Michels and Wolk, 2002 (65)

Nutrient Adequacy indexes (NAR & MAR)[1]
Madden and Yoder, 1972 (57)

Component	Scoring
NAR	Ratio of intake of a nutrient relative to RDA
MAR	Average of NARs

[1]These scores are often used to evaluate indexes of diet quality

Appendix B Associations of dietary indexes and scores with nutrient adequacy, biomarkers of health, disease outcome, or mortality. Sorted by index and year of publication

Diet Quality Index (DQI)[2] and adapted scores

Authors, year	Score	Subjects	Follow up[1]	Dietary assessment method	Outcome measure	Results
Patterson et al., 1994 (77)	DQI	5,484 US adults	cs	24-h recall & 2-d record	nutrient adequacy	Lower index scores pos. ass. with vitamin and mineral intakes and neg. ass. with fat intake
Dubois et al., 2000 (14)	DQI	2,103 canadian adults	cs	24-h recall	nutrient adequacy	corr. with MAR 0.001 (men –0.008 ; women 0.031)
Seymour et al., 2003 (84)	DQI	63,109 elderly women and 52,724 elderly men	4 y	68-item FFQ	CVD-mortality, cancer mortality, all mortality	Medium-low vs. high quality diet: 19% (men) and 31% (women) increase in all mortality, 86% increase in CVD-mortality in women only (multivar-adjusted). No ass. with cancer mortality
Haines et al., 1999 (27)	DQI-R	3,202 US men	cs	24-h recalls (2)	nutrient adequacy	Moving from lowest to highest group of scores: sign. improvement in all components of DQI-R
Newby et al., 2003 (69)	DQI-R	127 US men (40-75y)	cs	2 131-item FFQs (1y interval) & diet records (2)	biomarkers	Pos. corr. of DQI-R from FFQ with alpha-carotene (0.43), beta-carotene (0.35), lutein (0.31), alpha-tocopherol (0.25). Inv corr. with total cholesterol (0.22). Corr. of biomarkers with DQI-R from diet record were higher
Kim et al., 2003 (48)	DQI-I	8,269 Chinese adults 9,218 US adults	cs	3 consec 24-h recalls 2 24-h dietary recalls	nutrient adequacy	Many nutrients showed strong relationships with index score
Lowik et al., 1999 (56)	adapted DQI	1,493 Dutch adult women (DNFCS-	cs	2 diet records	nutrient adequacy and food consumption	DQI ass. with improved intake of the nutrients included in the index, and lower cheese, fats and oils, meat (products), and higher fruits and vegetables consumption

Healthy Eating Index (HEI) and adapted scores						
Authors, year	**Score**	**Subjects**	**Follow up[1]**	**Dietary assessment method**	**Outcome measure**	**Results**
Kennedy et al., 1995 (46)	HEI	7,443 US subjects (>2 y)	cs	24-h recall and 2-d record	nutrient adequay	HEI pos corr. with intake of nutrients
McCullough et al., 2000 (64)	HEI	62,272 US women (30-55y)	12 y	116-item FFQ	chronic disease risk	Lowest vs highest HEI-score quintile: RR for major chronic diseases 0.97, RR for CV disease 0.86. No ass. of HEI with cancer risk
McCullough et al., 2000 (62)	HEI	51,529 US men (40-75y)	8 y	131-item FFQ	chronic disease risk	lowest vs highest HEI-score quintile: RR for major chronic diseases 0.89, RR for CV disease 0.72. No ass. of HEI with cancer risk
Dubois et al., 2000 (14)	HEI	2,103 canadian adults	cs	24-h recall	nutrient adequacy	corr. with MAR 0.287 (men 0.197 ; women 0.391)
Kennedy et al., 2001 (45)	HEI	10,014 US adults	cs	24-h recalls (2)	ass. with popular diets	People with high carbohydrate intake have higher HEI score
Hann et al., 2001 (29)	HEI	340 US women (21-80y)	cs	3-d record	biomarkers & socio-demogr. characteristics	Corr. of HEI with EI 0.21, alpha-carotene 0.40, beta-carotene 0.30, beta-cryptoxanthin 0.41, lutein 0.24, vit C 0.33, folate 0.26. No ass. with cholesterol. HEI pos. ass. with age, marriage, education, income
Weinstein et al., 2004 (97)	HEI	16,467 US adults	cs	24-h recall	biomarkers	Crude corr. of HEI with serum folate 0.25, ery-folate 0.27, vit C 0.30, vit E 0.21, serum carotenoids 0.17 to 0.27. Corr were attenuated, but still sign. when adj. for additional factors. No corr. with a.o. triglycerides, cholesterol.
McCullough et al., 2002 (63)	AHEI	38,615 US men 67,271 US women	8-12 y	130-item FFQ	chronic disease risk	Highest vs. lowest quintile: RR for chronic disease 0.80 in men and 0.89 in women, for CVD risk: 0.61 in men and 0.72 in women. No ass of HEI with cancer risk.
Harnack et al., 2002 (30)	DGI	34,708 US post menopausal women	13 y	127-item FFQ	cancer incidence	Highest vs. lowest quintile: 15% reduction in all cancer risk. Similar ass. for colon, lung, bronchus, breast, uterus cancer. No ass. with ovarian cancer BUT when excl non-diet factors from index, ass. were not- sign.

Mediterranean Diet Score (MDS) and adapted scores						
Authors, year	**Score**	**Subjects**	**Follow up[1]**	**Dietary assessment method**	**Outcome measure**	**Results**
Trichopoulou et al., 1995 (92)	MDS	182 Greek elderly	4 y	190-item FFQ	all mortality	17% reduction in mortality for 1 unit increase in the 8-point score
Osler and Schroll, 1997 (75)	MDS	202 Danish elderly	6 y	3-d diet rec. & freq checklist	all mortality	21% reduction in mortality for 1 unit increase in the 7-point score
					biomarkers	Plasma carotene sign. ass. with score. No ass. of cholesterol, HDL, HDL/chol, vit. E with score
Kouris-Blazos et al., 1999 (50)	MDS	141 Anglo-Celts and 189 Greek- Australian elderly	4 y	250-item FFQ	all mortality	17% reduction in mortality for 1 unit increase in the 8-point score
Lasheras et al., 2000 (55)	MDS	161 Spanish elderly	> 9 y	FFQ	all mortality	No ass. in subjects <80 y In subjects >80y: 31% reduction in mortality for 1 unit increase in the 8-point score
Woo et al., 2001 (99)	MDS	1,689 Chinese adults	cs	266-item FFQ	socio-demogr. characteristics	Women scored higher than men. Age and geographic location were associated with MDS
Haveman-Nies et al., 2001 (32)	MDS	828 US elderly 1,282 European elderly	cs	126-item FFQ 3-d record & freq checklist	socio-demogr. characteristics & biomarkers	Diets varied widely across centers No ass. of serum albumin, Hb or BMI with MDS. Waist circ. sign. ass with MDS
Bosetti et al., 2003 (4)	MDS	598 + 304 + 460 cases vs. 1491 + 743 + 1088 controls	rs		upper aerodigestive tract cancer	60% reduction in pharyngeal cancer risk, 74% reduction in esophageal cancer risk, 77% reduction in laryngeal cancer risk
Haveman-Nies et al., 2002 (31)	MDS adapted	1,281 European elderly	10 y	3-d history & freq checklist	all mortality	No sign. ass. of MDS with all mortality
Trichopoulou et al., 2003 (91)	MDS + fish	25,917 Greek adults	3.7 y	150-item FFQ	CHD, cancer, and all mortality	25% reduction in all mortality, 33% in CHD mortality, 24% in cancer mortality for 2 unit increase in the 9-point score

Authors, year	Score	Subjects	Follow up[1]	Dietary assessment method	Outcome measure	Results
Knoops et al., 2004 (49)	MDS + fish	European elderly; 1.507 men and 832 women	12 y	diet history	all cause and cause-specific mortality	Low risk group (MDS≥4): reduction in all mortality 23%, CHD mortality 39%, cancer mortality 10%.
Gerber et al., 2000 (23)	MDQI	146 French adults	cs	162-item FFQ	biomarkers	Sign. inv. ass. between vit E, N-3 FA, beta-carotene and score. No ass. of cholesterol with score[2]
Scali et al., 2001 (82)	MDQI	964 French adults	cs	162-item FFQ	socio-demogr. characteristics	Higher score ass. with non-smoking, higher age, rural residence

Healthy Diet Indicator (HDI)

Authors, year	Score	Subjects	Follow up[1]	Dietary assessment method	Outcome measure	Results
Huijbregts et al., 1997 (37)	HDI	3,045 European (Nl, I, F) men (50-70y)	20 y	diet history	all mortality	Large variation in intake between 3 countries. Highest vs. lowest group: 13% reduction in mortality (similar within each country)
Huijbregts et al., 1997 (40)	HDI	272 Dutch elderly (~70y)	17 y	diet history	all mortality	HDI>2 vs. HDI<2: 44% reduction in mortality risk in men. No ass. for women
Huijbregts et al., 1998 (38)	HDI	1,049 European men (70-91y)	cs	diet history	cognitive impairment	19 and 25% reduction in cogn. impairment in Dutch (not sign.) resp. Italian cohort.
Dubois et al., 2000 (14)	HDI	2,103 canadian adults (18-74y)	cs	24-h recall	nutrient adequacy	corr. with MAR 0.079 (men 0.0.061 ; women 0.101)
Haveman-Nies et al., 2001 (32)	HDI	828 US elderly 1,282 European elderly	cs	126-item FFQ 3-d record & freq checklist	socio-demogr. characteristics & biomarkers	diets varied widely across centers. No ass of serum albumin, Hb or waist circ. with HDI. BMI sign ass with HDI

Food-based indexes

Authors, year	Score	Subjects	Follow up[1]	Dietary assessment method	Outcome measure	Results
Osler et al., 2001 (73)	HFI	7,316 (30-70y)	15 y	26-item FFQ	CHD and all mortality	No sign. ass. after adjustment
Osler et al., 2002 (74)	HFI	7,316 (30-70y)	15 y	26-item FFQ	CHD incidence	No sign. ass.
Lowik et al., 1999 (56)	Food-based quality index	1,493 Dutch adult women (DNFCS)	cs	2 diet records	nutrient adequacy and food consumption	Score pos. ass. with EI and nutrient density. Score ass. with increase in food consumption without clear relevance for dietary quality

Various Scores indicating Dietary Variety (DVS, DDS, RFS)						
Authors, year	**Score**	**Subjects**	**Follow up[1]**	**Dietary assessment method**	**Outcome measure**	**Results**
Fernandez et al., 1996 (17)	DVS	1,326 Italian cancer cases and 2,024 controls	rs		colorectal cancer risk	Highest vs. lowest quartile: total diversity OR for colon and rectal cancer 0.7, diversity within vegetables OR 0.6.
Drewnowski et al., 1997 (12)	DVS	24 (20-30y) and 24 (65-75y) US adults	cs	24-h recall & 14 diet records	nutrient adequacy	DVS pos. ass. with vit C, neg ass. with sodium, sugar, and SFA intake
La Vecchia et al., 1997 (54)	DVS	746 gastric cancer cases and 2,053 controls			gastric cancer risk	Highest vs. lowest quartile: total diversity OR for gastric cancer 0.7, diversity within vegetables OR 0.5, within fruit OR 0.6)
Slattery et al., 1997 (85)	DVS	1,993 cases and 2,410 controls		diet history	colon cancer risk	No ass. of total diversity with colon cancer risk
Fernandez et al., 2000 (18)	DV	1,225 Italian colon and 728 rectum cancer cases; 4,154 controls	rs	79-item FFQ	colorectal cancer risk	Highest vs lowest quintile: OR colon cancer 0.65 (men) , 0.85 (women). Within vegetables highest vs lowest quintile: OR colon cancer 0.66, rectal cancer 0.71
Bernstein et al., 2002 (3)	DVS	36 US elderly men, 87 women (72-98y)	cs	3-d weighed record	biomarkers and medical history	DVS and variety in fruit&vegetable intake pos. ass. with HDL and folate, and neg. ass. with VLDL and triglycerides in men. DVS pos ass with BMI and body K, and variety in fruit&vegetable intake pos. ass. with BMI, MUAC, MUAMA in women. DVS inv. ass. with cancer and gastroint cancer history
Kant and Thompson, 1997 (44)	DVS(R)	10,799 US adults	cs	68-item FFQ	nutrient adequacy	DVS and DVSR pos. ass. with EI, Ca, vit C, carotenoid intake. DVSR inv. ass. with E%-fat intake.
Kant et al., 2000 (42)	RFS	42,254 US women (~61y)	5.6 y	62-item FFQ	all and cause-specific mortality and nutrient adequacy	Reduction in mortality highest vs 2nd quartile 18%, vs 3rd quartile 29%, vs lowest quartile 31% Also strong reduction in cause-specific mortality (all cancer, CHD, stroke) highest vs lowest quartile at least 30% RFS pos ass with EI, protein, E%-CH intake, micronutrient intake, inv. ass. with E%-fat intake.

Michels and Wolk, 2002 (65)	RFS and NRFS	59,038 Swedish women (40-76y)	9.9 y	60-item FFQ	all and cause-specific mortality and nutrient adequacy	Highest. vs. lowest RFS group: 42% reduction in all mortality. 24% reduction in cancer mortality, 53% in CHD mortality, 60% in mortality from stroke. NRFS not ass with all mortality or CHD mortality, but pos ass. with cancer mortality RFS pos. ass. with EI, alcohol, nutrient density, E%-CH, E%- protein and inv. ass. with E%-fat intake
McCullough et al., 2002 (63)	RFS	38,615 US men 67,271 US women	8-12 y	130-item FFQ	chronic disease risk	Reduction in chronic disease risk 7% (not sign.) and CVD risk 23% in men. No ass. in women
Kant et al., 1993 (43)	DDS	4,160 US adult men and 6,264 women	14 y	24-h recall	all mortality	Highest vs. lowest DDS group: increase in mortality risk 50% in men, 40% in women

[1] cs = cross-sectional, rs = retrospective
[2] lower score indicative of healthier diet