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Review Article

A critical review of predefined diet quality scores

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The literature on predefined indexes of overall diet quality is reviewed. Their association with nutrient adequacy and health outcome is considered, but our primary interest is in the make-up of the scores. In total, twenty different indexes have been reviewed, four of which have gained most attention, and many others were based on those four. The various scores differ in many respects, such as the items included, the cut-off values used, and the exact method of scoring, indicating that many arbitrary choices have been made. Correlations in intake between dietary components may not be adequately addressed. In general, diet quality scores show an association with mortality or disease risk, but these relations are generally modest. Existing indexes do not predict morbidity or mortality significantly better than individual dietary factors. Although conclusions from the review may provide guidance in the construction of a diet quality score, it is questionable whether a dietary score can be obtained that is a much better predictor of health outcome.

Diet quality index: Diet score: Dietary assessment: Review

In nutritional epidemiology focus has long been directed towards the impact of single dietary components. Such a ‘reductionist’ approach can reveal the role of individual nutrients or foods in the development of disease, but it has its limitations (Willett, 1998). Dietary patterns have gained considerable attention in the past two decades. The main argument for this shift is that intakes of nutrients and foods are related, as people do not consume nutrients or single foods but combinations of foods. In addition, dietary components may interact, complicating the search for associations between single dietary factors and disease (Hu, 2002).

Many studies have now been published in which diet has been considered in a more holistic way. Two approaches to dietary patterning can be distinguished: theoretically defined dietary patterns and empirically derived dietary patterns. The latter consist of patterns statistically derived ‘a posteriori’ from collected food consumption data based on correlations in intakes of the various dietary components. A comprehensive review on dietary patterns from factor and cluster analysis has been published (Newby & Tucker, 2004). Theoretically defined dietary patterns, however, are created ‘a priori’ based on current nutrition knowledge. They consist of nutritional variables, generally foods and/or nutrients considered to be important to health, that are quantified and summed to provide an overall measure of dietary quality.

In the present review we focus on these predefined indexes of overall diet quality, or diet quality scores. Several have been proposed and validated by relating the index score to health outcome. A review of indexes of overall diet quality by Kant (1996) was followed eight years later by a review of dietary patterns, both empirically derived and theoretically defined, and health outcome (Kant, 2004). However, little attention has been paid to their actual composition, the differences (and similarities) between the various indexes, and the many choices in the creation of a score. Yet these issues are of essential importance to assess the usefulness and validity of a specific index, and of diet quality scores in general, as a tool for dietary assessment. Therefore, we have critically reviewed existing indexes of diet quality and their relation to health outcome. In particular, we consider the composition of the various existing scores and the rationale behind them. In this way we aim to reveal common principles, but also differences and limitations.

Methods

PubMed was searched (to September 2005) to find publications on predefined diet quality scores, using the key words diet(ary) quality, diet(ary) patterns, diet score, diet (quality) index, food groups, and Mediterranean diet. In addition, cited references were reviewed.

Results

We found 20 distinct indexes of overall diet quality, as listed in Table 1. The Healthy Eating Index (HEI; Kennedy *et al.*

Abbreviations: NNR, Nordic Nutrition Recommendations.

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1995), the Diet Quality Index (DQI; Patterson *et al.* 1994), the Healthy Diet Indicator (HDI; Huijbregts *et al.* 1997*a*) and the Mediterranean Diet Score (MDS; Trichopoulou *et al.* 1995) are the four 'original' diet quality scores that have been referred to and/or validated most extensively. The composition of these four scores is detailed in the Appendix. Several indexes have been adapted and modified. In particular, many variations on the MDS have been proposed; four distinct adaptations are all referred to as adapted MDS (MDS-a).

Most indexes include variables that represent current nutrition guidelines or recommendations, such as the DQI, the HEI and the HDI, and also the Dietary Guidelines Index (DGI; Harnack *et al.* 2002). The Mediterranean diet has received increased attention in recent years because of a suggested association with reduced risk for CHD and several forms of cancer (Kushi *et al.* 1995; Trichopoulou *et al.* 1995, 2000, 2003, 2005*a*; Trichopoulos & Lagious, 2004).

As the consumption of a greater variety of foods is considered beneficial compared to a monotonous diet, many investigators have used a Dietary Variety Score (DVS) to evaluate food consumption (Fanelli & Stevenhagen, 1985; Fernandez *et al.* 1996, 2000; Drewnowski *et al.* 1997; La Vecchia *et al.* 1997; Slattery *et al.* 1997; Bernstein *et al.* 2002). In general, dietary variety is calculated as the number of different foods consumed over a given period. Some researchers first 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 & Thompson (1997), who divided foods into 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; McCullough *et al.* 2002; Michels & Wolk, 2002). Although we considered that DVS deserved to be discussed briefly, we decided to focus the present review on diet quality scores.

Make-up of diet quality scores

Composing an index of overall diet quality involves many choices (Table 2) related to the variables or index items to be included, the cut-off values, and their scoring.

Index items. Dietary variables contained in the diet quality scores are nutrients and foods or food groups that are assumed to be either healthy or unhealthy. The Food-Based Quality Index (FBQI; Lowik *et al*. 1999), the Healthy Food Index (HFI; Osler *et al*. 2001, 2002) and the Food Pyramid Index (FPI; Massari *et al*. 2004) consist solely of food groups or foods. The MDS mainly contain food groups, supplemented with a ratio reflecting the fatty acid composition of the diet and alcohol, whereas two adapted MDS contain foods only (Schroder *et al.* 2004; Pitsavos *et al.* 2005). By contrast, the adapted DQI contain nutrients only. All other indexes, including the original DQI, HEI and HDI, comprise both food groups and nutrients. Table 3 gives an overview of the index components or attributes included in the diet quality scores listed in Table 1.

Nutrients. Nutrients found in many scores are: total fat, SFA or the ratio of MUFA to SFA, cholesterol and alcohol. Sodium, (complex) carbohydrates, dietary fibre and protein are also found in various scores. The units in which intake is expressed differ between indexes and between nutrients. While intake of total fat or SFA is usually expressed in energy per cent (energy %), other units are used for other nutrients. Micronutrients are expressed in micrograms or in percentage of the recommended dietary allowance.

Fat. Most indexes contain one or more fat-related variable. However, it should be recognized that including 'total

Table 1. Overview of existing diet quality scores and studies in which they have been used and/or evaluated

Index	Authors (year)
Based on dietary guidelines	
Diet Quality Index (DQI)*	Patterson *et al.* (1994)
	Seymour *et al.* (2003)
	Dubois *et al.* (2000)
Diet Quality Index Revised (DQI-R)	Haines *et al.* (1999)
	Newby *et al.* (2003)
	Fung *et al.* (2005)
Diet Quality Index International (DQI-I)	Kim *et al.* (2003)
Other indexes adapted from the DQI	
DQI-a I	Drewnowski *et al.* (1996)
DQI-a II	Drewnowski *et al.* (1997)
DQI-a III	Lowik *et al.* (1999)
Healthy Eating Index (HEI)*	Kennedy *et al.* (1995)
	McCullough *et al.* (2000*a*)
	McCullough *et al.* (2000*b*)
	Dubois *et al.* (2000)
	Kennedy *et al.* (2001)
	Hann *et al.* (2001)
	McCullough *et al.* (2002)
	Weinstein *et al.* (2004)
	Fung *et al.* (2005)
Alternative Healthy Eating Index (AHEI)	McCullough *et al.* (2002)
	Fung *et al.* (2005)
Healthy Diet Indicator (HDI)†	Huijbregts *et al.* (1997*a,b*)
	Huijbregts *et al.* (1998)
	Dubois *et al.* (2000)
	Haveman-Nies *et al.* (2001)
Dietary guidelines index (DGI)	Harnack *et al.* (2002)
Based on Mediterranean diet	
Mediterranean Diet Score (MDS)	Trichopoulou *et al.* (1995)
	Osler & Schroll (1997)
	Kouris-Blazos *et al.* (1999)
	Lasheras *et al.* (2000)
	Woo *et al.* (2001)
	Haveman-Nies *et al.* (2001)
	Bosetti *et al.* (2003)
Mediterranean Diet Quality Index (MDQI)	Gerber *et al.* (2000)
	Scali *et al.* (2001)
MDS + fish (MDS-f)	Trichopoulou *et al.* (2003)
	Knoops *et al.* (2004)
	Trichopoulou *et al.* (2005*b*)
Other indexes adapted from the MDS	
MDS-a I	Haveman-Nies *et al.* (2002)
MDS-a II	Schroder *et al.* (2004)
MDS-a III	Fung *et al.* (2005)
MDS-a IV	Pitsavos *et al.* (2005)
Food-based	
Food-Based Quality Index (FBQI)	Lowik *et al.* (1999)
Healthy Food Index (HFI)	Osler *et al.* (2001)
	Osler *et al.* (2002)
Food Pyramid Index (FPI)	Massari *et al.* (2004)
Nutrient-based	
Nutrient Adequacy Ratio (NAR/MAR)‡	Madden & Yoder (1972)

Publications in which the index was first published are shown in bold.
* Based on US dietary recommendations.
† Based on 1990 WHO dietary guidelines.
‡ Nutrient Adequacy Ratio (NAR) is the ratio of intake of a nutrient relative to its Recommend Dietary Allowance (RDA). The Mean Adequacy Ratio (MAR) is computed by averaging the sum of the NAR. These scores have been used in several studies, and also to evaluate diet quality scores.

Table 2. Key issues in the construction of a diet quality score

- Choice of the index components to include in the score
- Assigning foods to food groups
- Choice of cut-off values
- Exact quantification of the index components judged against cut-off values
- Adjustment (or not) for energy intake
- Decision on the relative contribution of the individual components to the total score

fat' in the score is very distinct from considering the fatty acid composition. Total fat is a macronutrient and, with particular regard to the risk of obesity, intake of the three macronutrients fat, carbohydrates and protein should be balanced. For that reason we suggest that two macronutrients should be included in a diet quality score.

The fatty acid composition of the diet is considered to be an important health determinant. Intake of SFA is generally recognized to be deleterious, and is included as a single item in the DQI, HEI, Mediterranean Diet Quality Index (MDQI), HDI and DGI. Higher consumption of MUFA and PUFA has been reported to be associated with reduced CVD risk (Chan *et al.* 1993; Roche *et al.* 1998; Hu *et al.* 1999; Oh *et al.* 2005; Solfrizzi *et al.* 2005). The MDS contain 'the ratio of mono-unsaturated fatty acids to saturated fatty acids' as an index item, whereas the Alternative Healthy Eating Index (AHEI) contains 'the ratio of poly-unsaturated fatty acids to saturated fatty acids'. Recently, a modification of the MDS has been suggested for use in an international context. PUFA were added to the numerator (Trichopoulou *et al.* 2005*b*). However, it is questionable whether the health effects of MUFA and PUFA, and even of n-3 and n-6 PUFA, are equivalent (Hu *et al.* 2001). Besides, calculating a ratio introduces a very complex variable, and it can be questioned whether this is desired in a dietary score. Therefore, we favour the inclusion of simple variables, such as SFA and MUFA for example.

The risks associated with high intakes of trans fatty acids are now generally acknowledged (Hu *et al.* 2001). This variable may therefore also be a candidate for inclusion in an index of diet quality.

Table 3. Overview of the attributes included in the diet quality scores of Table 1

Nutrients	
Total fat	DQI, DQI-R, DQI-I, DQI-a I–III, HEI, DGI
SFA	DQI, DQI-R, DQI-I, DQI-a I–III, HEI, HDI, MDQI, DGI
Ratio of MUFA or PUFA to SFA	DQI-I, AHEI, MDS, MDS-f, MDS-a I, MDS-a III
PUFA	HDI
Trans fatty acids	AHEI
Protein	DQI, DQI-I, HDI
Carbohydrate	DQI-a I–III
Complex carbohydrates	DQI, HDI
(Cereal) fibre	DQI-I, AHEI, HDI
Mono- and disaccharides	DQI-a III, HDI
Sucrose	DQI-a I
Cholesterol	DQI, DQI-R, DQI-I, DQI-a I–III, HEI, HDI, MDQI, DGI
Alcohol	MDS, MDS-f, MDS-a I, III, IV, AHEI, DGI
Sodium	DQI, DQI-I, DQI-a II, HEI, DGI
Calcium	DQI, DQI-R, DQI-I
Iron	DQI-R, DQI-I
Vitamin C	DQI-I
Ratio of carbohydrates to protein to fat	DQI-I
Foods	
Fruit and vegetables	DQI, MDQI, MDS-a I, HDI
Fruits (and nuts)	DQI-R, DQI-I, HEI, AHEI, MDS, MDS-f, MDS-a II–IV, FBQI, HFI, DGI
Vegetables	DQI-R, DQI-I, HEI, AHEI, MDS, MDS-f, MDS-a II–IV, FBQI, HFI, DGI
Legumes (and nuts and seeds)	MDS, MDS-f, MDS-a I–IV, HDI
Nuts (and soya)	AHEI, MDS-a II, MDS-a III
(Whole) cereals/grains (Coarse) bread	DQI-R, DQI-I, HEI, all MDS, MDQI, HFI, DGI FBQI, HFI
Meat (and meat products)	HEI, MDS, MDS-f, MDQI, MDS-a I–IV, FBQI, DGI
Ratio of white to red meat	AHEI
Red and processed meat	MDS-a III
Poultry	MDS-a IV
Fish	MDS-f, MDS-a II–IV, MDQI
Milk (and dairy products)	HEI, MDS, MDS-a I, FBQI, DGI
High fat dairy	MDS-a II, IV
Olive oil	MDS-a IV, MDQI
Potatoes	MDS-a IV, FBQI
Cheese	FBQI
Red wine	MDS-a III
Butter, margarine, animal fat	HFI
Sweets/sweet beverages	DGI
Dietary variety	DQI-R, DQI-I, HEI, DGI
Dietary moderation	DQI-R

DQI, Diet Quality Index; DQI-R, Diet Quality Index Revised; DQI-I, Diet Quality Index International; HEI, Healthy Eating Index; AHEI, Alternate Healthy Eating Index; DGI, Dietary Guidelines Index; MDS, Mediterranean Diet Score; MDQI, Mediterranean Diet Quality Index; HDI, Healthy Diet Indicator; FBQI, Food-Based Quality Index; HFI, Healthy Food Index.

Food items. Main food groups included in (almost) all food-containing indexes in Table 1 are fruits and vegetables, either grouped or separately, and cereals or grain. Meat and meat products are also contained in many scores, and legumes, milk (and dairy products), fish, and nuts (and soya) were included in some indexes. Other food items used were olive oil, bread, potatoes, red and processed meat, poultry, and cheese. The selected foods clearly reflect nutritional knowledge at that particular time. For example, fish has only been included in most recent indexes. Intake of foods can be expressed in grams, but is often expressed as number of servings. Alcohol can be included either as a food (number of glasses per day) or as a nutrient (grams of ethanol per day). Both methods have been used and in our opinion can be considered equally.

Fruit and vegetables. Although there may be discussion on the exact way of inclusion in the score, there is no dispute on the importance of an adequate amount of fruits and vegetables in the diet. All indexes except those that only contain nutrients include the components fruits and vegetables, either grouped together (DQI, MDQI, MDS-a I, HDI) or separately (all other indexes). The MDS contain an additional attribute ‘legumes’. The HDI contains an item ‘pulses, nuts and seeds’. If not considered individually, nuts are added to the fruit group (MDS, some MDS-a) or to the legumes. As fruits and vegetables supply us independently with important dietary constituents, we favour including them separately.

Complex v. refined foods. There are health benefits of whole grains in contrast to refined grains (Fung *et al.* 2002; McKeown *et al.* 2002; Liu, 2003; Jensen *et al.* 2004). Fibre is recognized to be a beneficial dietary component (Brennan, 2005). Unfortunately, the DQI, HEI, MDS and HDI do not distinguish between whole and refined cereals. The HDI, in addition to ‘complex carbohydrates’, includes the item ‘dietary fibre’. Cereal products are not the only foods that provide dietary fibre. Moreover, the health effect of whole grains is not attributed to fibre alone, but also to the micronutrients, antioxidants and non-nutritive dietary constituents such as phyto-oestrogens in wheat bran, and beta-glucans in oats (King, 2005). We therefore suggest that in a dietary score, whole-grain products should be distinguished from refined foods.

Dairy, meat, and alcohol. Dairy and meat, but also alcohol, are complex variables to include in a diet quality index. Dairy has been shown to reduce risk for several chronic diseases, including osteoporosis, hypertension, obesity and type 2 diabetes (Pereira *et al.* 2002; Zemel & Miller, 2004; Choi *et al.* 2005). However, some compounds in milk, primarily lactose, cause negative effects in susceptible individuals. In addition, full-fat dairy products contain high quantities of saturated fat and should preferably be distinguished from skimmed milk and dairy products.

The association of meat and alcohol consumption with health can be described as U-shaped. In moderate quantities they are assumed to be beneficial. However, their intake should not be too high, as high consumption levels are considered unfavourable. This explains why in some indexes consumption of meat and dairy is valued positively (HEI, DGI) and in others negatively (MDS, MDS-f, MDS-a, MDQI). Both non-consumers and individuals with excessive intakes should have a low score on these items. Therefore, a simple cut-off value cannot be used to categorize consumption of these variables. Only the FBQI contains a consumption interval for both meat (115–130 g/day) and dairy (2–3 glasses). If consumption falls within the interval, the score is ‘1’, otherwise ‘0’.

Alcohol has been included in the Mediterranean indexes. The group median intake was used as a lower cut-off in the original MDS (Trichopoulou *et al.* 1995). In two adaptations of the MDS, an intake range has been specified (Haveman-Nies *et al.* 2002; Fung *et al.* 2005).

From the above it becomes clear that inconsistency exists as how to handle items that are considered both beneficial and detrimental. Using a range to appraise the intake of meat, dairy and alcohol seems most appropriate because in that way both insufficient and excessive intakes are not rewarded.

Creating food groups. In the case of food groups, particular foods should be assigned to an item. For many foods this may be straightforward, but this is not always the case. For example, should nuts be added to the fruit (and vegetable) group, and does a food group labelled ‘milk and dairy’ also include cheese? It should furthermore be realized that the dietary assessment method used influences the outcome. An FFQ contains a limited number of foods or food groups, whereas a dietary history is generally more elaborate.

Dietary variety. In addition to foods and nutrients, some researchers have included a variable representing dietary variety in their index (Kennedy *et al.* 1995; Haines *et al.* 1999; Harnack *et al.* 2002), reflecting the number of different foods or food groups consumed over a given time period. 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 several indexes (the Diet Quality Index Revised (DQI-R), the Diet Quality Index International (DQI-I), the HEI and the DGI). We think this is superfluous if it concerns variety in food groups. When variety *within* food groups is considered, as in the DGI, which contains ‘variety of grains’, ‘variety of fruit’ and ‘variety of vegetables’ as individual index items, this may be different. However, this approach results in a very large number of index items, which may not be desirable. Therefore, we suggest that dietary variety should not be included in the score. However, to calculate a DVS or an RFS in addition to the index score could be an interesting method of evaluating the dietary index afterwards.

Cut-off values and scoring. Once the attributes to be included in the index have been selected, they need to be quantified. The most straightforward method 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 unfavourable component is concerned) and ‘1’ if consumption is higher (or lower) than the cut-off. However, this is a rather black-and-white approach, and the question remains how to choose the cut-off value.

In most MDS the group median intake of each variable serves as a cut-off value. Taking the group median as a cut-off value may not be related to a healthy level of intake per se, and will differ between population(s sample)s. The advantage then 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 item distinguishes well and in the same way between subjects.

In the other indexes items are categorized or scaled based on current views on what is a healthy level of intake. Often they are based on dietary guidelines. This approach may seem more appealing. However, if, for example, intake for a certain food or nutrient remains below the desired (cut-off) level for almost all subjects in a group, this index item will not contribute extra discriminating power and could just as well be left out. Therefore, it is likely that researchers did take into consideration the intake levels in the population for the variables they included when they assigned intake categories or cut-offs.

Haveman-Nies *et al.* (2001) have compared the use of study-specific medians and Greek medians as a cut-off to calculate the MDS in a multicentre European study. Individuals should only score high on the MDS if they consume a diet that can be characterized as ‘Mediterranean’, as the Mediterranean diet has proved to be ‘healthy’. Therefore, it seems reasonable to use the cut-offs of the Greek population. However, as consumption patterns differ considerably between cultures, by using these cut-off values it might not be possible to discriminate well between individuals. Although mean total Greek median scores for non-Mediterranean populations were considerably lower than mean total population specific scores, the authors did not mention a poorer discriminating power (Haveman-Nies *et al.* 2001).

In general, there will always be the dilemma between scientific knowledge of healthy levels of intake on the one hand, and the power to discriminate and related to the contribution of the index item to the total score on the other.

Instead of just one cut-off value (MDS, HDI, DQI-a, FBQI, HFI), several indexes contain a lower cut-off, an intermediate range, and an upper boundary (DQI, MDQI, DQI-R, DGI), or let the score for each item be proportional to the extent to which the dietary guideline is 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.

The three DQI-a categories (Drewnowski *et al.* 1996, 1997; Lowik *et al.* 1999) are essentially similar, containing only nutrient-components of the original index. All these indexes had a low discriminating power, as most persons yielded very low scores and fell within the same (low-score) category. This stresses the importance of well-chosen cut-off values.

Confounding by energy intake. 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 generally expressed in energy per cent, but for other variables energy intake is generally not accounted for. 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. When calculating the MDS, intake of each component is adjusted to daily intakes of 2500 kcal for men and 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 US Food Guide Pyramid (1992). Such methods are possible ways to adjust for energy intake and are important to consider.

Relative contribution of the individual index components to the score. Another important, but not frequently addressed, issue is the relative contribution of the different items to the total score. In most indexes all individual variables have the same weight, that is they contribute equally to the total score.

From the indexes of diet quality listed in Table 1, only the DQI-I has attributed different weights to different items (Kim *et al.* 2003). Unfortunately, the authors of the DQI-I do not explain how their scores for each of the four discerned main categories were derived. They only state that ‘current worldwide and individual national dietary guidelines … provided a basic rationale for the construction of the DQI-I’.

It is not plausible that all index components have the same health impact. Therefore, it seems better to ascribe greater weights to those items that affect our health to a greater extent. However, to be able to 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, but it is also extremely difficult to make statements on the relative contribution of different dietary components to health outcome. More important, if published relative risks of individual index components would be used for this purpose, existing correlations and interactions between the individual dietary components are ignored – the ‘raison d’être’ of diet quality scores.

Furthermore, many indexes include several items encompassing ‘similar’ or strongly correlated dietary variables, so that in fact these variables contribute more heavily to the score. In addition, the extent to which the constructed variables can distinguish between individuals not only determines the discriminating power of the score, as discussed earlier, but also influences the relative contribution of the individual variables to the total score.

Most researchers do not address this topic. The reason may be that it is very difficult to substantiate choices for different weights of the index items, yet not weighing results in equal weights for all index components, a choice that also needs to be supported.

Diet quality scores and health outcome

In the first part of this paper we have provided an overview of predefined indexes of overall diet quality and discussed their composition. Although it can be argued that some scores tend to have higher content validity, composing an index remains a complex matter with a large degree of subjectivity. To validate the diet quality scores, they can be related to nutrient adequacy or health outcome. Table 4 provides an overview of the thirty-nine studies that have examined associations between overall diet scores with nutrient adequacy and health outcome and their major findings. Results are arranged by diet quality score to enable comparison between the various scores. This is quite delicate. Exact values, but also significance of the relative risks, depend largely on the testing procedure, especially on the variables adjusted for. Reported associations between diet quality and mortality in some studies may be attenuated if additional potentially confounding factors had been taken into account.

Table 4. Associations of dietary indexes and scores with nutrient adequacy, biomarkers of health, disease outcome or mortality

Authors (year)	Index	Subjects	Follow-up	Dietary method	Outcome measure	Results
Diet Quality Index (DQI) and adapted scores*						
Patterson *et al.* (1994)	DQI	5484 US adults	cs	24-h recall and 2-d record	Nutrient adequacy	Lower index scores positively associated with vitamin and mineral intakes and negatively associated with fat intake
Dubois *et al.* (2000)	DQI	2103 Canadian adults	cs	24-h recall	Nutrient adequacy	Correlation with MAR 0·001 (men −0·008; women 0·031)
Seymour *et al.* (2003)	DQI	63109 elderly women 52724 elderly men	4 y	68-item FFQ	CVD mortality, cancer mortality, all mortality	Medium-low *v.* high quality diet: 19 % (men) and 31 % (women) increase in all mortality, 86 % increase in CVD mortality in women only (multivariately adjusted). No association with cancer mortality
Haines *et al.* (1999)	DQI-R	3202 US men	cs	24-h recalls (2 repeated days)	Nutrient adequacy	Moving from lowest to highest group of scores: significant improvement in all components of DQI-R
Newby *et al.* (2003)	DQI-R	127 US men (40–75 y)	cs	Two 131-item FFQ (1-y interval) and diet records (2)	Biomarkers	Positive correlation of DQI-R from FFQ with alpha-carotene (0·43), beta-carotene (0·35), lutein (0·31), alpha-tocopherol (0·25). Inverse correlation with total cholesterol (0·22). Correlation of biomarkers with DQI-R from diet record was higher
Fung *et al.* (2005)	DQI-R	660 US women	cs	140-item FFQ	Biomarkers for CVD (and correlation of scores)	DQI-R not significantly associated with any of the biomarkers
Kim *et al.* (2003)	DQI-I	8269 Chinese adults 9218 US adults	cs	Three consecutive 24-h recalls Two 24-h dietary recalls	Nutrient adequacy	Many nutrients showed strong relationships with index score
Lowik *et al.* (1999)	DQI-a	1493 Dutch adult women (DNFCS)	cs	Two diet records	Nutrient adequacy and	DQI associated with improved intake of the nutrients included in the index
Healthy Eating Index (HEI) and adapted scores						
Kennedy *et al.* (1995)	HEI	7443 US subjects (>2 y)	cs	24-h recall and	Nutrient adequacy	HEI positively correlated with intake of nutrients
McCullough *et al.* (2000*b*)	HEI	62272 US women (30–55 y)	12 y	2-d record 116-item FFQ	Chronic disease risk	Lowest *v.* highest HEI-score quintile RR for major chronic diseases 0·97, RR for CVD 0·86. No association of HEI with cancer risk
McCullough *et al.* (2000*a*)	HEI	51 529 US men (40–75 y)	8 y	131-item FFQ	Chronic disease risk	Lowest *v.* highest HEI-score quintile: RR for major chronic diseases 0·89, RR for CVD 0·72. No association of HEI with cancer risk
Dubois *et al.* (2000)	HEI	2103 Canadian adults	cs	24-h recall	Nutrient adequacy	Correlation with MAR 0·287 (men 0·197; women 0·391)
Hann *et al.* (2001)	HEI	340 US women (21–80 y)	cs	3-d record	Biomarkers	Correlation of HEI with EI 0·21, alpha-carotene 0·40, beta-carotene 0·30, beta-cryptoxanthin 0·41, lutein 0·24, vitamin C 0·33, folate 0·26
Weinstein *et al.* (2004)	HEI	16 467 US adults	cs	24-h recall	Biomarkers	Crude correlation of HEI with serum folate 0·25, ery-folate 0·27, vitamin C 0·30, vitamin E 0·21, serum carotenoids 0·17 to 0·27. Correlations were attenuated, but still significant when adjusted for additional factors. No correlation with among other things TAG, cholesterol

Table 4. *Continued*

Authors (year)	Index	Subjects	Follow-up	Dietary method	Outcome measure	Results
Fung *et al.* (2005)	HEI, AHEI	660 US women	cs	140-item FFQ	Biomarkers for CVD	HEI not significantly association with any of the biomarkers, AHEI significantly inversely associated with most biomarkers
McCullough *et al.* (2002)	AHEI	38615 US men 67271 US women	8–12 y	130-item FFQ	Chronic disease risk	Highest *v.* 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 association of HEI with cancer risk
Harnack *et al.* (2002)	DGI	34708 US post-menopausal women	13 y	127-item FFQ	Cancer incidence	Highest *v.* lowest quintile: 15 % reduction in all cancer risk. Similar association for colon, lung, bronchus, breast, uterus cancer. No association with ovarian cancer but when excluding non-diet factors from the index, associations were not significant
Mediterranean Diet Score (MDS) and adapted scores						
Trichopoulou *et al.* (1995)	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 & Schroll (1997)	MDS	202 Danish elderly	6 y	3-d diet record and frequency checklist	All mortality	21 % reduction in mortality for 1 unit increase in the 7-point score
					Biomarkers	Plasma carotene significantly associated with score. No association of cholesterol, HDL, HDL/cholesterol, vitamin E with score
Kouris-Blazos *et al.* (1999)	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)	MDS	161 Spanish elderly	>9 y	FFQ	All mortality	No association in subjects <80 y In subjects >80 y: 31 % reduction in mortality for 1 unit increase in the 8-point score
Haveman-Nies *et al.* (2001)	MDS	828 US elderly	cs	126-item FFQ	Biomarkers	No association of serum albumin, Hb or BMI with MDS. Waist circumference significantly associated with MDS
		1282 European elderly		3-d record and frequency checklist		
Bosetti *et al.* (2003)	MDS	598 + 304 + 460 cases *v.* 1491 + 743 + 1088 controls	Rs		Upper aero-digestive tract cancer	60 % reduction in pharyngeal cancer risk, 74 % reduction in oesophageal cancer risk, 77 % reduction in laryngeal cancer risk
Haveman-Nies *et al.* (2002)	MDS-a I	1281 European elderly	10 y	3-d history and frequency checklist	All mortality	No significant association of MDS with all mortality
Trichopoulou *et al.* (2003)	MDS-f	25917 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
Knoops *et al.* (2004)	MDS-f	European elderly: 1507 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 %
Schroder *et al.* (2004)	MDS-a	3162 Spanish adults	cs	165-item FFQ	BMI, obesity	Significant inverse association of score with BMI and obesity risk
Fung *et al.* (2005)	MDS-a	660 US women	cs	140-item FFQ	Biomarkers for CVD	MDS-a significantly inversely associated with most biomarkers
Trichopoulou *et al.* (2005b)	MDS-m	74607 elderly Europeans	<10 y	EPIC-FFQ	All mortality	8 % reduction in mortality for 2-unit increase in the 9-point score

[*continued overleaf*]

Table 4. *Continued*

Authors (year)	Index	Subjects	Follow-up	Dietary method	Outcome measure	Results
Pitsavos *et al.* (2005)	MDS-a	3042 Greek adults	cs	156-item FFQ	Biomarkers for CVD	Highest *v.* lowest score tertile: 11 % increase in total anti-ox. capacity, 19 % decrease in LDL-cholesterol level
Gerber *et al.* (2000)	MDQI	146 French adults	cs	162-item FFQ	Biomarkers	Significant inverse association between vitamin E, n-3 FA, beta-carotene and score. No association of cholesterol with score
Healthy Diet Indicator (HDI)						
Huijbregts *et al.* (1997*a*)	HDI	3045 European (Netherlands, Italy, Finland) men (50–70 y)	20 y	Diet history	All mortality	Large variation in intake between three countries
						Highest *v.* lowest group: HDI > 2 *v.* HDI < 2 for NL, F, and HDI > 4 *v.* HDI >3 for I: 13% reduction in mortality (similar within each country)
Huijbregts*et al.* (1997b)	HDI	272 Dutch elderly (~ 70 y)	17 y	Diet history	All mortality	HDI >2 *v.* HDI < 2: 44 % reduction in mortality risk in men. No association for women
Huijbregts *et al.* (1998)	HDI	1049 European men (70–91 y)	cs	Diet history	Cognitive impairment	19 % and 25 % reduction in cognitive impairment in Dutch (not significant) and Italian cohorts respectively
Dubois *et al.* (2000)	HDI	2103 Canadian adults (18–74 y)	cs	24-h recall	Nutrient adequacy	Correlation with MAR 0·079 (men 0·0·061; women 0·101)
Haveman-Nies *et al.* (2001)	HDI	828 US elderly	cs	126-item FFQ	Biomarkers	No association of serum albumin, Hb or waist circumference with HDI. BMI significantly associated with HDI
		1282 European elderly		3-d record and frequency checklist		
Food-based indexes						
Lowik *et al.* (1999)	FBQI	1493 Dutch adult women (DNFCS)	cs	Two diet records	Nutrient adequacy	Score positively associated with EI and nutrient density
Osler *et al.* (2001)	HFI	7316 (30–70 y)	15 y	26-item FFQ	CHD and all mortality	No significant association after adjustment
Osler *et al.* (2002)	HFI	7316 (30–70 y)	15 y	26-item FFQ	CHD incidence	No significant association
Massari *et al.* (2004)	FPI	7665 Italian adults	cs	32-item FFQ	Five CHD risk factors	Men: positive association between FPI and all five risk factors Women: only significant association for serum cholesterol and glucose

DQI, Diet Quality Index; DQI-R, Diet Quality Index Revised; DQI-I, Diet Quality Index International; HEI, Healthy Eating Index; AHEI, Alternate Healthy Eating Index; DGI, Dietary Guidelines Index; MDS, Mediterranean Diet Score; MDQI, Mediterranean Diet Quality Index; HDI, Healthy Diet Indicator; FBQI, Food based Quality Index; HFI, Healthy Food Index; FPI, Food Pyramid Index; cs, cross-sectional; rs, retrospective; RR, relative risk; y, years; MAR, Mean Adequacy Ratio.

* Lower score indicative of a healthier diet.

Diet Quality Index. The DQI was shown to be only marginally correlated with nutrient adequacy (Dubois *et al.* 2000). We found only one study that validated the DQI by relating its score to mortality, reporting multivariately adjusted rate ratios for overall mortality of 1·31 (95 % CI 1·04, 1·65) for women and 1·19 (95 % CI 0·94, 1·.49) for men (Seymour *et al.* 2003). CVD mortality, but not cancer mortality, was lower for persons consuming a high-quality diet. The model contained many potential confounders, and when adjusting for age only, associations were much stronger.

The DQI-R was shown to correlate significantly with several plasma biomarkers representing micronutrient intake (Newby *et al.* 2003) but not with markers of inflammation and endothelial dysfunction (Fung *et al.* 2005). This can be explained by the non-specificity of fat and carbohydrate quality in the score. This index has not been studied in relation to morbidity or mortality, but the lack of association of the score with CVD risk factors may indicate limited capacity to predict CVD risk. This should be studied further.

Healthy Eating Index. The HEI was reported to be associated with a wide range of nutritional biomarkers of micronutrients in two studies (Hann *et al.* 2001; Weinstein *et al.* 2004). It should be noted that those biomarkers mostly represented nutrients from fruit and vegetables and hence consumption of these food groups. Neither of the studies found any association with serum cholesterol. The HEI had a higher correlation with mean adequacy ratio (MAR) of several nutrients compared with the DQI and HDI (Dubois *et al.* 2000).

We did not find any study that has related the HEI score to mortality. Four studies have examined the relationship between HEI and disease risk (McCullough *et al.* 2000*a*,*b*, 2002; Harnack *et al.* 2002). No association of the HEI with cancer incidence could be detected (Harnack *et al.* 2002). A weak inverse association (RR highest *v*. lowest quintile 0·89) between HEI score and chronic disease risk was observed in men (McCullough *et al.* 2000*a*) but not in women (McCullough *et al.* 2000*b*). Consequently, the AHEI was developed, and the AHEI score was reported to be inversely associated with major chronic disease (relative risk (RR) highest *v*. lowest quintile in men 0·80, in women 0·89), primarily CVD (RR in men 0·61, in women 0·72), but some components of the AHEI were already known to be protective in the cohort (McCullough *et al.* 2002). Fung *et al.* (2005) also reported a significant inverse association of the AHEI, but not the HEI, with several biomarkers of CVD risk. The AHEI contains items that have been shown to be protective for CVD, such as the ratio of PUFA to SFA and trans fat. The association of the HEI and AHEI with all-cause mortality should still be studied to appreciate their ability to assess diet quality in relation to health outcome.

Mediterranean Diet Scores. The Mediterranean diet has gained considerable attention recently and adherence to this diet has been studied extensively. As a result, several adaptations of the original MDS have been proposed. We found 14 publications in which an MDS has been related to health outcome. Adherence to the Mediterranean diet was reported to predict survival in six studies. Participants were Greek adults (Trichopoulou *et al.* 1995, 2003), Danish elderly (Osler & Schroll, 1997), Anglo-Celts and Greek-Australian elderly (Kouris-Blazos *et al.* 1999), and European elderly populations (Knoops *et al.* 2004; Trichopoulou *et al.* 2005*b*). Lower mortality was also reported among French adults following a Mediterranean diet in intervention studies (de Lorgeril *et al.* 1998, 1999).

By contrast, Haveman-Nies *et al.* (2002) found no significant association for diet alone and mortality among European elderly adults. In a study among Spanish elderly individuals, an association between MDS and mortality was only observed in persons older than 80 years (Lasheras *et al.* 2000). Although for all nine countries participating in EPIC-Elderly, the MDS was associated with increased survival, the score did not show an association with mortality for elderly populations from France, Italy, the Netherlands and Germany (Trichopoulou *et al.* 2005*b*). The association was strongest for Greek elderly adults. The MDS has been proposed by Greek researchers.

Osler & Schroll (1997) reported that plasma carotene, but not plasma cholesterol, HDL and vitamin E, was associated with the MDS. In all studies medians specific for the study population were used as cut-off values.

Differences between the various MDS may seem small, but changes in the score may have considerable effect on the classification of individuals and therefore the predicting ability of the score. Correlation coefficients between the various scores and correlation of the various scores with health outcome should be studied to determine which MDS is the best predictor of health outcome.

It is likely that the Mediterranean diet is beneficial in composition (Trichopoulou *et al.* 1995, 2003; Osler & Schroll, 1997), but data are not entirely consistent (Haveman-Nies *et al.* 2002). The MDS seems to predict mortality in Mediterranean populations. It is debatable whether it is pertinent to calculate an MDS for Northern Europeans. As mentioned earlier, it is uncertain what exactly is being measured if population-specific medians for Northern European populations are used as cut-off values.

Healthy Diet Indicator. The HDI, developed according to the WHO guidelines for the prevention of chronic diseases, has been reported to be inversely associated with all-cause mortality in men from three European countries, including the Netherlands (Huijbregts *et al.* 1997*a*), and in Dutch elderly men but not women (Huijbregts *et al.* 1997*b*). Reported risk reductions were relatively small (13 %) for Dutch elderly (Huijbregts *et al.* 1997*a*) but considerably higher (44 %) for Italian men. HDI was also suggested to correlate inversely with cognitive impairment (Huijbregts *et al.* 1998). The HDI score was only very marginally correlated with MAR (Dubois *et al.* 2000), and no association was found between HDI score and serum albumin, Hb or waist circumference (Haveman-Nies *et al.* 2001).

Food-based indexes. Osler *et al.* (2001, 2002) found no association of their HFI, a four-item food-based index, with all-cause mortality, nor with CHD risk. Food consumption of Dutch adults (from the Dutch National Food Consumption Survey) was evaluated using a seven-item FBQI (Lowik *et al.* 1999). It was concluded that the index was associated with an increase in food consumption without clear relevance for dietary quality. The FPI, summarizing the relative proportion of fatty to non-fatty foods, was associated with five CHD risk factors in men, but with only two in women.

Discussion

Most of the published indexes tend to relate positively to the intake of micronutrients. Evidence regarding the association of mortality and CVD risk in relation to healthy dietary patterns from diet indexes is often positive. The predictive capacity of the various scores seems to be in the same range, although these results cannot be easily compared across studies, as different reference groups have been used. In addition, confounders adjusted for vary between the studies.

However, the magnitude of the protective effect was modest in most published studies. In comparison, dietary variety alone was shown to be associated with nutrient adequacy, biomarkers, and lower disease and/or mortality risk to a similar or even greater extent in various studies (Kant *et al.* 1993; Drewnowski *et al.* 1996; Fernandez *et al.* 1996; Kant & Thompson, 1997; La Vecchia *et al.* 1997; Fernandez *et al.* 2000; Bernstein *et al.* 2002). For example, Kant *et al.* (2000) reported a reduction in overall mortality of the third and fourth quartile compared to the lowest quartile of the RFS of 29 % and 31 %, respectively. For fruit and vegetables alone, reported risk reductions for the highest *v.* the lowest quintile were 20 % for CHD (Joshipura *et al.* 2001), 31 % for stroke (Joshipura *et al.* 1999) and around 20 % for several types of cancer (International Agency for Research on Cancer, 2003).

Considering the results of validation studies of the (A)HEI, DQI(-R) and HDI, the question can be raised of whether an index based 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. They measure the extent to which individuals follow the guidelines, but that does not necessarily mean that they are good predictors of health (morbidity or mortality) in the context of a diet quality index.

In fact most existing indexes are able to predict health outcome to some extent, but the associations were generally modest for all dietary scores, casting doubts on their validity. This may be explained by the many arbitrary choices in the development of an index and the lack of insight into the consequences of these choices.

The main choices relate to the components to include in the score, the cut-off values to compare intake with, and the exact method of scoring. In addition, diet quality scores may still not adequately deal with the main reasons for a holistic approach: the correlations in intake of various dietary factors and existing nutrient–nutrient interactions.

From the findings in the first part of this review some conclusions can be drawn that may guide choices in the construction of another diet quality score. However, it should first be clear what the score intends. Is it aimed to measure absolute diet quality or to evaluate adherence to dietary guidelines? Or will the index be used for health promotion purposes? If the latter is the case, the dietary index should in principle be food based, as people consume (combinations of) foods, not nutrients. Furthermore, the strength of a food-based score is that interaction of dietary components within products is taken into account. A disadvantage may be the large heterogeneity within food groups.

The index should contain two macronutrients (fat, carbohydrate or protein) to ensure an overall balance. Given the scientific evidence that has proven its relevance, dietary variety should also be considered. However, dietary variety need not necessarily be included as an index item. The index could be constructed in such a way that dietary variety is ensured to obtain a high score.

It is preferable to design scoring ranges or let the score be proportional to intake, instead of using simple cut-off values, not only because this is more subtle but also with regard to foods that have shown a U-shaped correlation with health outcome. Furthermore, 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 complex issue that needs to be further examined.

It must always be taken into account that diet is culturally determined. Therefore, the general dietary habits within a population need to be considered when the index items and their cut-offs are chosen.

However, it is still questionable whether, following these recommendations, a dietary score as a measure of diet quality can be obtained that is an adequate predictor of morbidity or mortality. It may have become clear that the development of such a score is extremely complex and many issues are still unresolved. If a diet quality index is aimed to assess diet quality in relation to health outcome, a measure of health outcome, for example mortality, should be allowed for in the construction of the score.

Predefined diet quality indexes aim to assess the overall diet and divide individuals according to the extent to which their eating behaviour is ‘healthy’. We have compared and evaluated existing indexes, their composition and their validity.

Development of an index demands many arbitrary choices to be made and correlations in intake between dietary components may not be adequately addressed. As a result, existing indexes do not predict disease or mortality significantly better than individual dietary factors. That does not mean that predefined diet quality scores should be abandoned. They can be useful to measure the extent to which individuals adhere to dietary guidelines, but these scores need to be used and interpreted with care, and authors should pay more attention to the limitations of such a score.

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Appendix: Composition of predefined indexes of diet quality

Diet Quality Index (DQI*; Patterson *et al.* 1994)

Component	Scoring	
Total fat	< 30 energy %	0
	30–40 energy %	1
	>40 energy %	2
Saturated fatty acids	< 10 energy %	0
	10–13 energy %	1
	>13 energy %	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	< 2400 mg	0
	2400–3400 mg	1
	>3400 mg	2
Calcium	≥ RDA	0
	2/3 RDA	1
	< 2/3 RDA	2

*Based on US recommendations from *Diet and Health* (National Research Council. Committee on Diet and Health, 1989)

Mediterranean Diet Score (MDS; Trichopoulou *et al.* 1995)

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)

Healthy Diet Indicator (HDI; Huijbregts *et al.* 1997*a*)

Nutrient or food group	Scoring	
SFA	0–10 energy %	1 (else: 0)
PUFA	3–7 energy %	1 (else: 0)
Protein	10–15 energy %	1 (else: 0)
Complex carbohydrates	50–70 energy %	1 (else: 0)
Dietary fibre	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 disaccharides	0–10 energy %	1 (else: 0)
Cholesterol	0–300 mg/d	1 (else: 0)

Healthy Eating Index (HEI; Kennedy *et al.* 1995)

	Scoring		
Component	Criteria for score 0	Criteria for score 10*	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 energy %	< 30 energy %	0–10
Saturated fatty acids	>15 energy %	< 10 energy %	0–10
Cholesterol	>450 mg	< 300 mg	0–10
Sodium	>4800 mg	< 2400 mg	0–10
Variety	≤ six different food items/3d	16 different food items/3d	0–10

* Depending on energy intake.