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Special Article

Review of a priori dietary quality indices in relation to their construction criteria

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A multitude of indices measure the healthiness of dietary patterns. Because validation results with respect to health outcomes do not sufficiently facilitate the choice of a specific dietary quality index, the decision of which index to use for a particular research objective should be based on other criteria. This review aims to provide guidance on which criteria to focus upon when choosing a dietary index for a specific research question. A review of 57 existing specifications of dietary quality indices was conducted, taking explicitly into account relevant construction criteria explicated in the Organisation for Economic Co-operation and Development handbook on constructing composite indicators. Index construction choices regarding the following criteria were extracted: theoretical framework, indicator selection, normalization and valuation functions, and aggregation methods. Preferable features of dietary indices are discussed, and a summarizing toolbox is provided to help identify indices with the most appropriate construction features for the respective study aim and target region and with regard to the available database. Directions for future efforts in the specification of new diet quality indices are given.

INTRODUCTION

In recent years, multiple indices that measure the healthiness of dietary patterns have been created. Overall, 2 approaches to defining dietary patterns can be distinguished: the a posteriori and the a priori approach (see, eg, Kant[1]). The a posteriori approach derives dietary patterns through statistical methods using dietary intake data at hand. Such exploratory post hoc techniques aggregate intake variables into factors to reveal common underlying food consumption patterns within a population.[2,3] Because a posteriori–defined dietary patterns are derived specifically for the population under consideration, they are often not reproducible across populations.[1] Furthermore, a posteriori–defined patterns do not necessarily define the healthiest patterns because they are not derived from current nutritional knowledge or evidence-based diet–health relationships.[4]

Dietary indices based on the a priori approach, on the other hand, are based on current nutrition knowledge and determine conceptually defined dietary components, which are considered important for the promotion of health, and which reflect risk gradients

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for major diet-related diseases. These individual components are then quantified and aggregated to an overall measure of dietary quality (DQ).[5,6] However, the accuracy of an a priori index approach is limited by the current level of dietary knowledge regarding the diet–health relationship, as well as uncertainties accompanying the index construction process.

The choice of an appropriate a priori index for the analysis of DQ has to be motivated—together with practicability, sensitivity, and reliability criteria—by its empirical validation with health outcomes and mortality. However, empirical studies have shown that validated a priori indices appear to have more or less the same predictive capacity for the risk of chronic diseases.[1,6–10] Furthermore, differences in the design of validation studies regarding the length of follow-up periods, dietary measurement methods, and approaches for adjusting for confounders such as body mass index (BMI), physical activity, age, or education hamper the choice of an index primarily based on validation results.[6,10]

Hence, it is proposed that a DQ index be chosen based on consideration of key issues of index construction. According to the Organisation for Economic Co-operation and Development (OECD) handbook on constructing composite indicators, relevant key issues are as follows: 1) the theoretical framework considering index purpose and index structure; 2) indicator selection; 3) normalization methods considering scaling procedures, cutoff points, and valuation functions; and 4) methods to weight and aggregate index components.[11] Thus, judging the soundness of the theoretical framework and the fitness of the methodology for the study purpose should help researchers and practitioners to select the most suitable index out of the large pool of existing composite DQ indices. However, until now the discussion on index construction criteria has been rather unsystematic and not comprehensive in regard to the above-mentioned index construction criteria.[11] Previous discussions had a strong focus on indicator selection, scaling techniques, and cutoff points (see, eg, Waijers et al.,[6] Nutrition Evidence Library,[9] or Wirt and Collins[10]), whereas little attention has been given to the other relevant key issues of index construction.

This paper contributes to the existing literature by providing a critical narrative review of a priori DQ indices, taking explicitly into account relevant index construction criteria explicated in the OECD handbook on constructing composite indicators. It provides an overview of existing a priori DQ indices and presents a methodological discussion of key index construction criteria. Furthermore, a summarizing toolbox is offered, which aims at helping researchers identify those indices whose construction is most appropriate for their respective study aim. Based on this summarizing toolbox, conclusions are derived.

IDENTIFICATION OF EXISTING A PRIORI DIETARY QUALITY INDICES

To identify relevant a priori DQ indices of human diets, a review of published English-language literature was conducted. The electronic database MEDLINE was searched using the following search terms: "diet," "dietary," "food," "eating," "nutrition," or "nutritional," in combination with "habit," "pattern," "patterns," or "quality," together with "index," "score," "measure," or "indicator." Furthermore, reference lists were searched for further relevant studies. Subsequently, indices with the following specific criteria were excluded from consideration: 1) indices on animal feeding; 2) indices with <2 DQ dimensions, such as the Recommended Food Score by Kant et al.[12] or the Not Recommended Food Score by Michels and Wolk,[13] as well as indices exclusively measuring diversity patterns (eg, the Dietary Variety Score by Bernstein et al.[14]); 3) indices for specific population groups, such as the Diet Quality Score for Pregnancy by Bodnar and Siega-Riz[15] or the Diet Quality Index for American Preschoolers by Kranz et al.[16]; 4) indices developed for the prevention of specific diseases, such as the adherence to Dietary Approaches to Stop Hypertension (DASH diet) by Fung et al.[17] or the Heart Disease Prevention Eating Index by Lee et al[18]; and 5) indices not exclusively based on the assessment of overall DQ, such as the Dietary Guideline Index (DGI-2002) by Harnack et al.[19] or the Dutch Healthy Diet Index by van Lee et al.,[20] both of which include dietary intake components and components on physical activities, or the Overall Nutritional Quality Index by Katz et al.,[21] which is designed for food labeling purposes. Indices developed for the prevention of a specific disease were excluded because they are designed for people with specific health risks but are likely to be inappropriate for assessing and guiding overall dietary quality of individuals in an unspecified population.

Table 1[5,8,22–74] provides an overview of all relevant indices, with the main indices ordered alphabetically. If indices are modifications of an originally defined index, these modified indices are then ordered with regard to content-related proximity with the original index, and then chronologically.

A total of 57 indices or their variations have been identified; they are primarily based on the Diet Quality Index,[25] the Healthy Eating Index,[42] and the Mediterranean Diet Score.[58]

COMPARATIVE DISCUSSION OF DIETARY QUALITY INDEX CHARACTERISTICS

Theoretical framework

Information sources and index purpose. The quality of a composite index and the soundness of its message

Table 1 **A priori indices of dietary quality**

Index (Abbreviation)	Reference
Baltic Sea Diet Score (BSDS-M-2014)	Kanerva et al. (2014)[22]
Baltic Sea Diet Score (BSDS-Q-2014)	Kanerva et al. (2014)[22]
Danish Healthy Diet Index (D-HDI-2003)	Dynesen et al. (2003)[23]
Danish Diet Quality Index (D-DQI-2012)	Knudsen et al. (2012)[24]
Diet Quality Index (DQI-1994)	Patterson et al. (1994)[25]
Diet Quality Index (DQI-2003)	Seymour et al. (2003)[8]
Diet Quality Index-Revised (DQI-R-1999)	Haines et al. (1999)[26]
Diet Quality Index-Revised (DQI-R-2003)	Newby et al. (2003)[27]
Diet Quality Index-International (DQI-I-2003)	Kim et al. (2003)[28]
Diet Quality Index-Swedish Nutrition Recommendation (DQI-SNR-2011)	Drake et al. (2011)[29]
Chinese Diet Quality Index (CH-DQI-2000)	Stookey et al. (2000)[30]
Mediterranean Diet Quality Index (Med-DQI-2000)	Gerber et al. (2000)[5]
Mediterranean Diet Quality Index including tobacco use (Med-DQI-f-2000)	Gerber et al. (2000)[5]
Mediterranean Diet Quality Index (Med-DQI-2006)	Gerber (2006)[31]
Diet Quality Score (DQS-2002)	Fitzgerald et al. (2002)[32]
Diet Quality Score (DQS-2007)	Toft et al. (2007)[33]
Dietary Behavior Score (DBS-2009)	Kant et al. (2009)[34]
Dietary Guidelines for Americans Adherence Index (DGAI-2005)	Fogli-Cawley et al. (2006)[35]
Dietary Quality Index Nutrient Based (DQINB-1999)	Löwik et al. (1999)[36]
German Food Pyramid Index (GFPI-2012)	von Ruesten et al. (2010)[37]
Healthy Diet Indicator (HDI-1997)	Huijbregts et al. (1997)[38]
Healthy Diet Indicator (HDI-2011)	Cade et al. (2011)[39]
Healthy Diet Indicator (HDI-2013)	Berentzen et al. (2013)[40]
Healthy Diet Score (HDS-2005)	Maynard et al. (2005)[41]
Healthy Eating Index (HEI-1995)	Kennedy et al. (1995)[42]
Healthy Eating Index-2005 (HEI-2005)	Guenther et al. (2008)[43]
Healthy Eating Index-2010 (HEI-2010)	Guenther et al. (2013)[44]
Healthy Eating Index-2015 (HEI-2015)	National Cancer Institute[45]
Healthy Eating Index-Frequency Questionnaire (HEI-f-2000)	McCullough et al. (2000)[46], McCullough et al. (2000)[47]
Alternate Healthy Eating Index (AHEI-2002)	McCullough et al. (2002)[48]
Alternate Healthy Eating Index (AHEI-2010)	Chiuve et al. (2012)[49]
Canadian Healthy Eating Index (C-HEI-2005)	Shatenstein et al. (2005)[50]
Diet Quality Index adjusted for energy requirement (DQI-a)	Jaime et al. (2010)[74]
Healthy Food Index (HFI-2001)	Osler et al. (2001)[51]
Healthy Food and Nutrient Index (HFNI-2006)	Bazelmans et al. (2006)[52]
Italian Mediterranean Index (IMI-2011)	Agnoli et al. (2011)[53]
Mediterranean Adequacy Index (MAI-1999)	Alberti-Fidanza et al. (1999)[54]
Mediterranean Adequacy Index (MAI-2006)	Knoops et al. (2006)[55]
Mediterranean Adherence Diet Screener (MEDAS-2011)	Schröder et al. (2011)[56]
Mediterranean Adherence Diet Screener (MEDAS-2013)	Domínguez et al. (2013)[57]
Mediterranean Diet Score (MDS-1995)	Trichopoulou et al. (1995)[58]
Mediterranean Diet Score (MDS-2001)	Haveman-Nies et al. (2001)[59]
Mediterranean Diet Score (MDS-2002)	Haveman-Nies et al. (2002)[60]
Mediterranean Diet Score (MDS-2003)	Trichopoulou et al. (2003)[61]
Mediterranean Diet Score (MDS-2004)	Knoops et al. (2004)[62]
Mediterranean Diet Score (MDS-2011)	Cade et al. (2011)[39]
Modified Mediterranean Diet Score (mMDS-2005)	Trichopoulou et al. (2005)[63]
Modified Mediterranean Diet Score (mMDS-2014)	Yang et al. (2014)[64]
Alternate Mediterranean Diet Score (aMED-2005)	Fung et al. (2005)[65]
Mediterranean Dietary Pattern (MDP-2002)	Sanchez-Villegas et al. (2002)[66]
Mediterranean Food Pattern (MeDiet-2008)	Sánchez-Taínta et al. (2008)[67]
Mediterranean Score (MS-2003)	Goulet et al. (2003)[68]
Mediterranean-Style Dietary Pattern Score (MSDPS-2009)	Rumawas et al. (2009)[69]
Recommendation Compliance Index (RCI-2008)	Mazzocchi et al. (2008)[70]
Relative Mediterranean Diet (rMED-2009)	Buckland et al. (2009)[71]
Relative Mediterranean Diet (rMED-2010)	Buckland et al. (2010)[72]
Adapted Relative Mediterranean Diet (arMED-2013)	Buckland et al. (2013)[73]

depend heavily on the appropriateness of the theoretical framework.[11] A theoretical framework defines the respective latent construct with its conceptual dimensions and structural assumptions, which provide the basis for the subsequent selection and composition of indicators.

Concerning the index purpose, it is important to distinguish between indices that are used to guide an individual's diet in the context of public health promotion programs and indices that aim to assess and monitor the DQ of populations.[6] The first mentioned group of indices definitely asks for simpler food group indicators and is often based on a direct translation of common dietary guidelines into index components (see, eg, Healthy Diet Indicator [HDI]–2013). The latter group of applications justifies more detailed scores because a higher degree of elaboration (ie, more detailed index scores resulting from a higher amount of relevant index components and/or more differentiated component scores) tends to increase the indices' power to distinguish among different levels of overall DQ within a population. Indeed, Wirt and Collins,[10] as well as Waijers et al.,[6] show that more elaborate indices, which consider the latest results on epidemiological associations and are constructed with a more detailed scoring range (eg, Alternate Healthy Eating Index [AHEI]–2002, AHEI-2010), are better health risk predictors than those indices developed to simply measure direct adherence to dietary guidelines with a strong health promotion purpose (eg, HDI-2013).

Furthermore, most DQ indices have been created to address diet-related chronic diseases that are most prevalent in developed countries, such as the United States (eg, HEI-2005, Diet Quality Index [DQI]–1994, Dietary Guidelines for Americans Adherence Index [DGAI]–2005) or the Mediterranean region (eg, Mediterranean Diet Score [MDS]–1995, modified MDS [mMDS]–2005). For example, the DGAI-2005 has been developed for the US population with a focus on problems of overconsumption and energy density.[35] Further, Gerber et al.[5] apply the Mediterranean Diet Quality Index (Med-DQI)–2000 to assess the DQ of the population of southern France. Given the pervasiveness of cardiovascular diseases and cancer in the target region, the authors focused on diet components important for these health outcomes. By contrast, the Diet Quality Index-International (DQI-I)–2003 and the Chinese Diet Quality Index (CH-DQI)–2000 accommodate coexisting problems relating to both under- and overnutrition. In particular, the DQI-I-2003 aims to assess DQ across diverse countries at different stages of nutrition transition and is supposed to provide a global tool for exploring different aspects of DQ.[28]

Dimensions of dietary quality. The purpose of an index is closely connected to the question of which dimensions of DQ have to be addressed during index construction. Generally, 4 dimensions of DQ can be distinguished: 1) adequate intakes of foods and/or nutrients, 2) moderate intakes of foods and/or nutrients that increase the risk of chronic diseases, 3) overall balance of macronutrients and specific micronutrients, and 4) variety of foods consumed.

All existing DQ indices that follow this multidimensional approach involve at least the adequacy and moderation dimensions. Adequacy refers to the sufficient intake of dietary elements beneficial to health, whereas moderation means limiting the intake of foods or nutrients detrimental to health (ie, dietary elements that increase the risk of chronic diseases if consumed in excess). Additionally, some indices consider a balance dimension, which addresses the proportionality of the energy-yielding macronutrients (carbohydrates, proteins, and fats) and/or fatty acids (saturated fatty acids [SFAs], monounsaturated fatty acids [MUFAs], and polyunsaturated fatty acids [PUFAs]). This is because nutrient recommendations, such as the acceptable macronutrient distribution ranges, demonstrate the importance of balanced macronutrient intake. Regarding the balance among fatty acids, partial replacement of SFAs with PUFAs and/or MUFAs is associated with lower health risks.[6,75,76]

Several indices (eg, DQI-Revised [DQI-R]–2003, DQI-I-2003, HEI-1995) take into account food variety (or diversity) as a further dimension. Dietary variety is a possible dimension of overall DQ because it is positively associated with adequate nutrient intake (eg, Foote et al.,[77] Isa et al.,[78] or Royo-Bordonada et al.[79]). Hence, several studies indicate that a higher level of variety within specific food groups may reduce a number of health risks.[78,80,81]

However, Waijers et al.[6] argue against the need for food group variety because of the close link between variety and adequacy, which may lead to problems of unaccounted component correlations with the related problem of potential double-counting. This is because DQ indices generally contain a great number of adequacy indicators, which can only be successfully achieved with a varied diet. Furthermore, variety is often negatively associated with a moderate nutrient intake because increased dietary diversity generally increases daily energy intakes and thus decreases the level of moderation (eg, Jayawardena et al.[82] or Lyles et al.[83]). Nevertheless, it is important to note that not all relevant adequacy indicators can possibly be considered in an index construction, which may make the practical variety indicator a helpful measure. Moreover, overconsumption is mostly related to excessive intake quantities of few specific food types (such as fats), rather than the consumption of too many food types in general. This fact makes the inclusion of variety, especially of the within–food group variety (without considering the fat group), beneficial as long as possible intercorrelation problems are accounted for.

Thus, although the adequacy, moderation, and balance dimensions should be included in a composite DQ index, including the within–food group variety dimension depends on the consideration of potential correlations between the variety dimension and certain adequacy or moderation components.

Index structure. Although composite scores may be useful to provide a first overview of DQ, it is usually considered beneficial for more in-depth analyses and increased transparency if the index construction is structured in a way that the composite is easily decomposable. Such a structure can be achieved if indicators are nested in subindices, which in turn aggregate to the overall index. Such hierarchical structure is possible, provided that the subindices are defined in a way that satisfies appropriate separability assumptions.[11] For example, the DQI-I-2003 assesses 4 major aspects of a heathy diet by 4 subindices: adequacy, moderation, variety, and overall balance. Likewise, the Mediterranean Adequacy Index (MAI)–2006 is divided into the 2 subindices of Mediterranean food groups and non-Mediterranean food groups.

A nested structure of several subindices allows one to determine which aspect of the diet requires additional attention.[11,84] In contrast, indices that simply aggregate adequacy and moderation components, for example, make it impossible for the researcher to determine whether a low DQ score is due to deficits in adequacy components or excessive intake in moderation components because the process of aggregating cancels out important information of deficient and excessive intakes (eg, Kim et al.[28], Thiele et al.[84]). Therefore, a nested structure of several subindices within the composite is desirable to more effectively and efficiently target with nutritional intervention programs those aspects of a population's DQ that have been assessed as critical. Furthermore, when analyzing causes of unhealthy diets, information loss might arise if subindices are affected by the same influencing factors, albeit in different directions, resulting in insignificant estimated effect sizes on overall DQ.[85] For example, increasing incomes have been found to increase the consumption of animal products, which possibly improves nutrient adequacy (eg, iron intakes) but, at the same time, most likely worsens SFA moderation.[86,87]

Indicator selection

Food group versus nutrient indicators. To operationalize the selected dimensions of DQ, suitable indicators have to be selected. Usually one differentiates between intake indicators based on food groups, nutrients, or a combination of these (eg, Kant[88]).

The strength of food group indicators is that they are relatively easy to handle and interactions of nutrients within products are taken into account. For example, an indicator based on whole-grain products considers that the health effect of whole grains is not attributed to fiber alone, but also to other nutrients, antioxidants, and nonnutritive dietary constituents.[6] Regarding food group indicators, the reviewed indices often assess the adequacy of whole-grain intakes. The weakness of food group indicators is that an index exclusively based on a small number of widely defined food groups might result in composites that are probably unable to keep track of the large heterogeneity within the considered food groups.[6] For example, although the intake of fruits and vegetables is associated with a lower risk of cardiovascular disease and many diet-related cancers, different fruits and vegetables vary in terms of how protective they are.[8]

Furthermore, it is quite difficult for most food items to be classified into healthy foods for assessing the adequacy dimension and unhealthy foods for assessing the moderation dimension. Meat consumption, for example, might contribute substantially to an adequate level of iron intake, whereas, at the same time, frequent meat consumption, especially of processed meat, is assumed to be associated with an increased risk for colorectal cancer, cardiovascular diseases, diabetes, and chronic kidney diseases.[89–93] Along these lines, some indices consider the aggregated consumption of meat (often including red and processed meat) in their adequacy dimension (eg, HEI-1995 and HEI-2005), whereas other indices consider meat aggregates (eg, Mediterranean Dietary Pattern [MDP]–2002 and MDS-2003) or only red and processed meats (eg, AHEI-2010, and Alternate Mediterranean Diet Score [aMED]–2005) in their moderation dimension. Even the consumption of functional and convenience foods would be difficult to assess with food group–based indices because these foods are not per se healthier or unhealthier than other foods. This heterogeneity aspect makes index specifications based on widely defined food groups overly restrictive, whereas using a sufficiently large number of narrowly defined food items is likely impractical.

In summary, the major weakness of food group indicators is that foods generally involve a combination of nutrients that are supposed to be healthy and nutrients that increase the risk of chronic diseases if consumed in excess. Thus, it seems essentially more appropriate to use nutrient indicators to concentrate on the dosage of nutrient intakes and their effects on health rather than on foods per se. However, nutrient indicators are much more data-demanding because converting food intake into nutrient intake requires the quantities of the specific foods to be assessed. Furthermore, the conversion into nutrient intakes may introduce additional measurement error through the use of improper food composition tables.

Nevertheless, even though the choice between food group and nutrient indicators is not straightforward, some guiding principles can be derived that account for the strengths and weaknesses of each approach. If an index is supposed to guide an individual's diet in the context of public health promotion programs rather than monitoring a population's DQ, then food group indicators seem to be the preferred choice because they are more practical and easier to comprehend.[6] However, if the applied index aims to assess the DQ of a population (or different population strata), nutrient indicators are often beneficial if relevant and valid nutrient intake data are accessible. Furthermore, nutrient-based indices are preferable if they are to be applied to populations whose food group compositions are likely to differ substantially from the population that food group–based indices were gauged on. Finally, even if primarily nutrient-based indicators are considered, it is often favorable to use some food group indicators, such as the whole-grain food group in the adequacy dimension and the empty-calorie food group in the moderation dimension. Such a combination of nutrient and food group indicators can be explained by practicability reasons and to account for the interactions of various healthy nutrients such as in the whole-grain food group (see, eg, DQI-I-2003).

Specific indicators per diet quality dimension. Overall, indicator selection has to be based on the latest epidemiological evidence, current nutrition standards, and considerations of the country-specific situation.[36] With respect to the adequacy dimension, the systematic reviews covered in Nutrition Evidence Library[9] provide strong or moderate evidence that the adequate intakes of fruits, vegetables, whole grains, nuts, legumes, and unsaturated oils, as well as low-fat dairy, poultry, and fish, are associated with a decreased risk of several disease outcomes across different countries. Hence, the adequate intake of these food groups seems to be beneficial in DQ index constructions for international applications. Yet, as mentioned above to more appropriately cope with the heterogeneity of nutrient supply within these food groups, many index constructions are based on nutrient indicators. Thereby, country-specific empirical results regarding nutrients that are at risk of deficient intakes should be considered when selecting nutrient-based adequacy indicators. For example, in their DQ analysis, Murphy et al.[94] use those 8 nutrients whose intakes fall below two thirds of the corresponding US reference intake values: protein, calcium, iron, thiamine, riboflavin, preformed niacin, vitamin A, and vitamin C.

With respect to the moderation dimension, composite indices often consider the moderate intake of (processed) meat, sugar-sweetened foods and drinks, salt, (high-fat) dairy products, and alcoholic drinks.[9] Nevertheless, the detrimental effects of these moderation food groups can be more appropriately analyzed when considering their embodied nutrients. Generally, SFA is an often-applied moderation indicator because of the verified association between SFA intakes and the incidence of chronic diseases.[6,76] Furthermore, intake of trans fatty acids may be another indicator candidate for the moderation dimension because the risks associated with high intakes of trans fatty acids are generally acknowledged (see, eg, DGAI-2006). The frequently used total fat indicator (see, eg, DQI-I-2003) should not be considered as a moderation indicator because the effects of total fat consumption on cardiovascular diseases, type 2 diabetes, and cancer could not be generally confirmed.[76] Additionally, cholesterol intake is often considered as a moderation indicator[9] even though cholesterol in foods shows only a weak relationship with blood cholesterol levels.[95–97]

Furthermore, a positive association between the risk of nutrition-related chronic diseases and the intakes of sugar and salt is generally assumed to justify sugar and salt intakes as recommendable moderation indicators.[98–100] Nevertheless, salt and sugar indicators are often limited in practical applications because of problems with accurately determining salt and sugar intakes.[38,101] Alcohol is used in many indices, although including alcohol as part of nutrition rather than as a confounding lifestyle factor is not without criticism[37] and the association between alcohol consumption and the respective health effect is not straightforward. Along these lines, some indicators assign the highest score to a zero or low alcohol intake (eg, DGAI-2005), whereas others assign the highest score to alcohol intake within a specific intake range (eg, Italian Mediterranean Index [IMI]–2011).

Regarding the overall balance dimension, the proportions of the macronutrients protein, fat, and carbohydrates are often addressed by preferred intake ranges—that is, the intake recommendations for these macronutrients are provided as lower and upper intake limits expressed as a percentage of total energy intake. For example, the majority of indices consider an optimal fat intake range (eg, DGAI-2005, CH-DQI-2000, HDI-2011) and/or an optimal carbohydrate intake range (eg, CH-DQI-2000, HDI-2011, DQS-2002). Only some indices address the overall macronutrient balance dimension by the intake ratio of carbohydrates, proteins, and fats rather than separate intake ranges (eg, DQI-I-2003). Although the macronutrient balance is mainly referred to by recommended intake ranges, the fatty acid balance is primarily referred to by intake ratios of SFAs, MUFAs, and/or PUFAs (eg, AHEI-2002, DQI-I-2003).

The variety dimension of DQ indices is often operationalized by count measures—that is, the number of different foods consumed during a certain period of time.[102] The foods counted toward the variety score of DQ indices are either food items or broader food groups. Based on this distinction, 3 types of variety measures exist: the number of unique food groups reported (between-group variety); the number of unique food items within particular food groups reported (within-group variety); and the total number of unique food items reported (overall variety).[77] Thereby, food items from the fat and oil group should not be part of the variety measure because greater variety within this food group is likely to increase energy intakes and thus the risk of overweight and obesity.[103]

Despite extensive research efforts regarding the most effective indicators for each DQ dimension, many questions remain unresolved and should be addressed in future research, especially regarding the relative importance of PUFAs and/or MUFAs versus SFAs.[76]

Moreover, the specification of indicators in DQ indices, particularly of most adequacy and moderation indicators, requires using intake measures that are adjusted for variations of energy intake. As pointed out by Willett (Ch. 11),[104] this is because, for many nutrients, the amount of the nutrient in relation to total caloric intake is epidemiologically more relevant than the absolute amount of the nutrient. Energy adjustment tries to ensure that health effects of foods and nutrients reflected in DQ indices are not confounded (or their variance is not inflated) by variations in total energy intake. The DQ index specifications that use energy-adjusted indicators reviewed here measure micronutrients as intake quantity per kilocalorie or express macronutrient intakes as percentage of total caloric intake. This approach is simple and practicable but has potential pitfalls for disease risks that are associated with total caloric intake.[104] Alternatives, such as the adjustment of measured intakes to the estimated intakes at the daily recommended energy intakes or the residual method, might be considered, as long as suitable intake data are available. Some indices use unadjusted indicators but account for differing energy intakes by using cutoff values that differ among groups of individuals with different energy requirements, defined by sex, age, weight, and/or physical activity level (see "Cutoff values" below).

Normalization and valuation function

Scaling procedure. Normalization of the reported data is required because dietary variables often have different measurement units, such as grams or liters, number of servings, or percentage of energy contributed.[1] Because normalization can be achieved by different methods (eg, ranking, standardization, distance to reference measure, ordinal categorization), the selection of a suitable normalization method is critical, and special attention should be given to potential scale adjustments or transformations, particularly for highly skewed variables.[11] For example, normalization by classification into very few scored categories results in crude scoring increments and information losses, possibly resulting in less statistical power to distinguish among different levels of DQ and hence a lower predictive capacity of future health outcomes.[6,10,29,105] The specific loss of information depends on the distribution of the variable and the kind of association with health outcomes (eg, linear or decreasing effects). In particular, the dichotomization of an originally continuous variable into scores of 0 and 1 discards most of the original information. In this line, for the HFI-2001, which has an aggregated discrete scoring scale of 0 to 4 (based on 4 dichotomous indicators), no or only a low association has been found with all-cause mortality after controlling for potential confounding factors or with the risk of coronary heart disease or cardiovascular mortality.[51,106] Moreover, dichotomization results in a moderate-to-substantial decrease in measurement reliability because the remaining information might be quite different from the original.[107]

In summary, if the index construction aims to predict future health outcomes and if appropriate indicator data are available, more detailed scoring ranges are preferable because they increase discriminating ability and predictive power. For this reason, the DQI-1994, with its discrete scoring scale ranging from 0 for the healthiest diet to 16 for the least healthy diet, was revised by the DQI-R-1999 to have a more detailed scoring scale ranging from 0 to 100, with 100 indicating the healthiest diet pattern.

Cutoff values. Cutoff values to normalize data should be country or region specific to use the best scientific knowledge available for the population under scrutiny.[28] Furthermore, cutoff values should be specific to groups defined by age, sex, weight, and physical activity level in as much as such groups differ with regard to their total or energy-adjusted nutrient requirements. For example, the HEI-1995 provides cutoff values for 5 different energy intake levels,[42] and the CH-DQI-2000 provides separate standards for higher and lower intake categories. Some DQ indices, such as the MAI-1999 or the HEI-2005, apply nutrient density measures to account for different energy intakes.

Moreover, applied cutoff values in existing indices can be grouped into normative and percentile cutoffs. Normative cutoffs are derived from current evidence regarding diet–health relationships that reflect dietary requirements of healthy individuals in a particular life stage and sex group. For example, for the United States and Canada, information for the respective normative cutoff values is compiled in Dietary Reference Intake tables[108–112] and is also published by the Food and Nutrition Information Center.[113] Hence, normative cutoff values for adequate nutrient intakes are often based upon the availability of recommended intake values, such as the recommended dietary allowances (RDA). For nutrients with no RDAs available, adequate intake levels, which are approximations of nutrient intakes by groups of healthy people, are applied. For moderation indicators, reference values like the tolerable upper intake levels are often used as normative cutoff values in index constructions. A tolerable upper intake level is the highest level of daily nutrient intakes likely to pose no risk of adverse health effects to almost all individuals in the general population (eg, Institute of Medicine[108]). Some indices apply even more stringent cutoff values than those found in official recommendations (eg, DQI-I-2003 for total fat intake).[28] For the overall balance dimension, cutoffs such as the acceptable distribution ranges are often used, with the intakes specified as a percentage of total energy intakes.[112]

In contrast with normative cutoffs, percentile cutoffs (eg, median or quartile cutoffs) simply indicate the intake values below which a given percentage of observations in a certain population sample fall. Therefore, percentile cutoffs, such as the often-used median cutoff, depend on the analyzed dataset and may not necessarily be related to healthy intake levels.[6] Despite this weak diet–health relationship, indices with dichotomous scaled indicators usually use median cutoffs to ensure significant discriminatory power (eg, MDS-2003 and MDS-2011). Even more discriminatory power is achieved using quartile cutoff values. Nevertheless, if the intake values get normalized proportionally with regard to the normative cutoff levels, resulting in metric-scaled indicators (eg, a score of 0.75 for a 75% achievement of the adequate fiber intake value), then normative cutoff values generally provide the most sufficient discriminatory power regarding the healthiness of the respective intake levels.

In summary, cutoff values within DQ models should be region-specific they should also be target group–specific unless sufficient accounting for differing energy requirements is already achieved through energy adjustment of the respective indicators. Moreover, normative cutoffs ought to be preferred for continuous scales if intake recommendations are available. Percentile cutoffs might be used only if intake recommendations are not available or a large proportion of the population would receive a score of 0, leading to low discriminatory power of the indicator.

Valuation function. Normalization procedures should take into account the objectives of the composite indicator through a valuation function because the intake of several nutrients and foods is only an auxiliary instrument to value the health impact of the respective nutrient or food intake.[114] Hence, a valuation function has to represent the association between each (normalized) indicator value and its assumed health impact. A specific valuation function is always necessary if it is assumed that a specific intake indicator exhibits increasing or diminishing marginal health effects.

Epidemiological research often suggests a U-shaped association between food/nutrient intakes and various health outcomes, such as those for iron,[115,116] folate,[117] fat and protein,[75,118] and sodium.[119] Because of these U-shaped associations, it seems appropriate to assume nonlinear valuation functions. For example, the valuation function of vitamin and mineral intake indicators might be specified as being increasing with diminishing marginal health effects until the adequacy cutoff level (eg, RDA) is reached. Beyond the adequacy cutoff level, valuation scores are often restricted to a maximal achievable score instead of being decreasing for nutrient oversupply. This is adequate for vitamin and mineral intakes because their content in a diet without supplements is generally assumed to be below a potentially unhealthy oversupply. However, for existing DQ indices, index functions often reveal an underlying assumption of constant health returns yielding a proportional valuation function without further explanation. More work on this topic is necessary.

The variety dimension of DQ indices is generally assessed by count measures for foods. However, count measures count food items or food groups regardless of their respective intake shares. This is problematic because the health effects of food variety are determined not only by the number of foods but also by their respective distribution. When additional distribution aspects are considered, which is particularly appropriate in the case of within-group variety, variety scores will also increase if food items are more equally consumed rather than being more concentrated. For example, a simple count measure would assign the same scores to the consumption of broccoli and iceberg lettuce within the vegetables group, with either consumption shares of 50% and 50%, or consumption shares of 5% and 95%, respectively. Such a count measure would disregard the fact that the more concentrated vegetable consumption is nearly exclusively composed of iceberg lettuce and therefore less appropriate. To consider distribution aspects, which seem to be especially appropriate for the within-group variety, different approaches exist. Some indices consider a food component in a variety score conditional on a minimum intake of at least half a serving size per day. More elaborate approaches are the Berry Index,[120] the Gollop-Monhan-Index,[121] and the Healthy Food Diversity Index.[102,122]

Weighting and aggregation

After normalization and valuation, the indicators have to be combined into the composite score. Because compensability of indicators is generally assumed, the predominant aggregation technique in existing DQ index constructions is linear aggregation. When such a linear aggregation technique is applied, the most naive method of constructing a composite index is obtained with equally weighted indicators. This method yields a robust composite index, but validity could be suboptimal if some indicators or dimensions are more effectively related to future health outcomes than others.[11]

Furthermore, if indicators are grouped into subindices, which are further aggregated into the composite, then equal weighting of the indicators implies an unequal weighting of the subindices if the number of indicators per subindex differs.[11] For example, the MDS-2004 consists of the following equally weighted indicators: 1 fatty-acid-balance indicator, 5 adequacy indicators, and 2 moderation indicators. Therefore, the MDS-2004 results in an indirect relative weighting of the balance, adequacy, and moderation dimension of 12.5%, 62.5%, and 25%, respectively. Additionally, regarding potential correlation among indicators, the question arises of whether individual indicators measure distinct aspects of the DQ construct and therefore bear equal weights. If this is not the case, it is permissible to give positively correlated indicators lower weights.[11]

If weights shall be assigned to the indicators of the composite, weights have to relate variations in nutrient intake levels to population-level variations in health outcomes. This might be achieved via statistical methods such as regression analysis of index components with later health outcomes or subjective expert considerations if statistical evidence is missing.[21] Furthermore, indicators that are highly correlated with each other should receive lower weights to correct their heavier contribution to the (sub)index score. However determining the acceptable level of correlation among indicators is highly subjective, and future research regarding this issue is necessary. For example, Huijbregts et al.[38] excluded the macronutrient indicators carbohydrate and total fat intake from their HDI-1997 to avoid correlations with the selected protein intake indicator. Drake et al.[29] adjusted the Dietary Quality Index - Swedish Nutrition Recommendations 2011 (DQI-SNR-2011) for intercorrelation problems by excluding MUFAs from the index because of a strong correlation between SFAs and MUFAs ($r = 0.65$). Nevertheless, they did not adjust the DQI-SNR–2011 for the nearly similar correlation between dietary fiber intake and fruit and vegetable consumption ($r = 0.63$). Furthermore, in the DGAI-2006, the indicators fiber intake and percentage of whole grains from total grain intake are equally weighted, although both indicators are possibly highly correlated.

The majority of hitherto existing DQ indices uses equal weighting (eg, HEI-1995) to reduce conscious interferences to a minimum and as a consequence of the lack of sufficient information. However, when weights are assigned within the pool of existing DQ indices, they are exogenously attributed on the basis of subjective expert information or a cause-and-health relationship between dietary exposure and disease. For example, Domínguez et al.[57] weight each item of the Mediterranean Adherence Diet Screener (MEDAS)–2013 by evidence-based contribution factors of each component to coronary heart diseases. Kim et al.[28] deduce weights for their adequacy, moderation, overall balance, and variety dimensions of the DQI-I-2003 based on the available literature. However, the authors failed to establish a documentary method, which would make the rationale for their weighting system more controllable by intersubjective comprehensibility and verifiability. Determining a favorable weighting approach would improve the rigor of future index applications.[9] A systematic approach of determining weights based on an explicit theoretical concept was followed during the construction of the Overall Nutritional Quality Index (ONQI).[21] However, the context differed from the topic of the present review because the ONQI rates specific food products according to their healthiness. Table 2 highlights preferable features of an a priori DQ index for assessing and monitoring a population's dietary quality based on major composite index construction criteria.

OVERVIEW OF DIETARY QUALITY INDICES AND THEIR CONSTRUCTION CHARACTERISTICS

Table 3[5,8,22–74] provides an overview of existing composite DQ indices, taking into consideration theoretical framework, indicator selection, normalization, and aggregation techniques. Preferable features of indices assessing DQ are shaded gray.

Twenty-one of the 57 indices were constructed to reflect dietary patterns observed in Mediterranean countries. These patterns were used as a guideline for index construction because they are considered largely responsible for the low prevalence of major noncommunicable diseases in Mediterranean countries. Thirty-six indices were compiled from dietary guidelines/

Table 2 **Preferable features of an a priori dietary quality index based on major composite index construction criteria**

Feature category	Construction criteria	Recommendations[a]
Theoretical framework		
Index dimensions	Adequacy Moderation Balance Variety	Adequacy, moderation, and balance should be included. (Within-food group) variety only if not strongly correlated with adequacy and/or moderation dimension or the correlation is accounted for
Index structure	Unordered Ordered Nested	Nested structure should be preferred, capturing the different DQ dimensions with their specific indicators
Indicator selection		
Index components	Number and definition of components	Find balance between necessary level of accuracy and practicability, as well as feasibility, regarding available data source. See text for specific recommendations
Component types	Food-group indicators Nutrient indicators Combination of food-group and nutrient indicators	Nutrient indicators (and specific food-group indicators) preferable if index is used to assess DQ in populations Food group indicators preferable if index application is communicated with individuals in health guidance
Normalization methods		
Scaling procedure	Dichotomous Ordinal Metric	Metric measures should be preferred over ordinal and dichotomous measures for DQ assessment
Cutoff values	Normative Percentile	Normative cutoff values preferable
	Uniform Group-specific	Energy-adjusted cutoffs should be preferred to account for group-specific nutrient requirements (if indicators are not energy-adjusted)
Valuation function	Linear Nonlinear	Nonlinear functions preferred, reflecting assumed diet–health relationships (eg, U-shaped function)
Weighting and aggregation		
	Unweighted linear Weighted linear	Weighted aggregation preferable to account for component-specific health impacts and correlations among components

Abbreviations: DQ, dietary quality.

[a] Depending on the features of the analyzed dataset.

recommendations based on current knowledge on diet–health relationships. Of these indices, the Med-DQI-2000, Med-DQI-f-2000, and the Med-DQI-2006 are based on the DQI-1999 but have been further adapted to Mediterranean patterns. The indices were designed for or validated in a range of geographic regions, including Europe ($n = 31$) and North America ($n = 18$), with 3 explicitly designed for international applications.

All of the 57 DQ indices reviewed consider indicators of the adequacy and the moderation dimension. The balance dimension is included in 25 indices, in most cases characterizing ratios among fatty acids. A variety dimension is present in 8 indices; it is represented by simple count measures despite advantages of alternatives that account for distributional aspects.

With regard to the dimensional structure, only 4 indices provide the advantage of a nested structure with subindices (DQI-I-2003, CH-DQI-2000, MAI-1999, and MAI-2006). The majority of indices (30 of 57) do not have a nested structure with fixed subindices, but they do provide a specific order of their index components within the index construction based on the underlying DQ dimensions to allow for an easy calculation of the corresponding subindices by interested users (eg, HEI-2015, mMDS-2005). Along these lines, indicators are sometimes already denoted in a way that suggests compiling useful aggregates, such as “adequacy of fruit and vegetable intakes” and “adequacy of whole grain intakes,” which can be aggregated into an adequacy sub-index. The remaining 23 reviewed indices provide their indicator scores in an order that seems to be independent of the respective DQ dimensions.

Regarding the type of indicators, 39 of 57 DQ indices include a combination of nutrient and food group indicators, such as the DQI-I-2003, MDS-2003, and the AHEI-2010. Many of the indices consider primarily nutrient indicators, but they often use the whole-grain food group in the adequacy dimension and the empty-calorie food group in the moderation dimension. Sixteen indices—for example, the DBS-2009, DQS-2007, HFI-2001, mMDS-2014, and the MEDAS-2013—consist solely of food-group indicators. By contrast, only 2 indices, the DQINB-1999 and the DQS-2002, contain nutrient indicators only.

The DQ indices reviewed are heterogeneous with regard to the scaling procedure applied to

Table 3 **Index construction criteria**

Index	Theoretical framework			Dimensions				Dimensional structure	Indicator selection		Normalization		Aggregation technique
	Recommendations	Mediterranean diet	Target region (analyzed region)	Adequacy	Moderation	Balance	Variety	Nested Ordered Not ordered	Data base	Food groups Nutrients Both	Dichotomous Ordinal Metric Ordinal/metric	Scoring range	Weighted
BSDS-M-2014, Kanerva et al. (2014)[22]	×		Nordic countries (Finland)	×	×	Ratio PUFA/(SFA+ trans-fatty acids)		Ordered	131-item FFQ	Both	Dichotomous	[0; 9]	Equally by indicators
BSDS-Q-2014, Kanerva et al. (2014)[22]	×		Nordic countries (Finland)	×	×	Ratio PUFA/(SFA+ trans-fatty acids)		Ordered	131-item FFQ	Both	Ordinal[a]	[0; 25]	Equally by indicators
D-HDI-2003, Dynesen et al. (2003)[23]	×		Denmark	×	×			Ordered	13-item short FFQ	FG	Ordinal	[0; 15]	Equally by indicators
D-DQI-2012, Knudsen et al. (2012)[24]	×		Denmark	×	×			Not ordered	Food diary	Both	Metric	[0; 6]	Equally by indicators
DQI-1994, Patterson et al. (1994)[25]	×		USA	×	×			Not ordered	24-h recall + 2 d food record	Both	Ordinal	[0; 16][b]	By number of indicators per recommendation
DQI-2003, Seymour et al. (2003)[8]	×		USA	×	×			Not ordered	68-item FFQ	Both	Ordinal	[0; 16][b]	By number of indicators per recommendation
DQI-R-1999, Haines et al. (1999)[26]	×		USA	×	×		×	Ordered[c]	24-h recall method	Both	Ordinal/metric	[0; 100]	Equally per main component
DQI-R-2003, Newby et al. (2003)[27]	×		USA	×	×		×	Ordered[c]	131-item FFQ + 2 1-wk food record	Both	Ordinal/metric	[0; 100]	Equally per main component
DQI-I-2003, Kim et al. (2003)[28]	×		Global	×	×	Ratio CH/PR/FA and PUFA/MUFA/SFA	×	Nested	24-h recall method	Both	Ordinal/metric	[0; 100]	By indicators and subscores
DQI-SNR-2011, Drake et al. (2011)[29]	×		Sweden	×	×	PUFA range		Not ordered	Modified DHM	Both	Dichotomous	[0; 6]	Equally by indicators
CH-DQI-2000, Stookey et al. (2000)[30]	×		China	×	×	FA and CH range	×	Nested	24-h recall method	Both	Ordinal/metric	[−74; 56]	By indicators
Med-DQI-2000, Gerber et al. (2000)[5]	×	(×)	South France	×	×			Ordered	162-item FFQ	Both	Ordinal	[0; 14][b]	Equally by indicators
Med-DQI-f-2000, Gerber et al. (2000)[5]	×	(×)	South France	×	×			Ordered	162-item FFQ	Both	Ordinal	[0; 16][b]	Equally by indicators
Med-DQI-2006, Gerber (2006)[31]	×	(×)	Mediterranean region (France)	×	×			Ordered	134-item FFQ	Both	Ordinal	[0; 14][b]	Equally by indicators
DQS-2002, Fitzgerald et al. (2002)[32]	×		North America (Canada)	×	×	CH range		Ordered	24-h recall method	Nutrients	Dichotomous	[0; 17]	Equally by indicators

(continued)

Table 3 **Continued**

Index	Theoretical framework			Dimensions				Dimensional structure	Indicator selection		Normalization		Aggregation technique
	Recommen-dations	Mediterranean diet	Target region (analyzed region)	Adequacy	Moderation	Balance	Variety	Nested Ordered Not ordered	Data base	Food groups Nutrients Both	Dichotomous Ordinal Metric Ordinal/metric	Scoring range	Weighted
DQS-2007, Toft et al. (2007)[33]	×		Denmark	×	×			Ordered	48-item FFQ (validated by 198-item FFQ)	FG	Ordinal	[0; 12]	Equally by indicators
DBS-2009, Kant et al. (2009)[34]	×		USA	×	×			Ordered	124-item FFQ	FG	Ordinal	[0; 36]	Equally by indicators
DGAI-2005 Fogli-Cawley et al. (2006)[35]	×		USA	×	×	FA range		Not ordered	126-item FFQ	Both	Ordinal	[0; 20]	Equally by indicators[d]
DQINB-1999, Löwik et al. (1999)[36]	×		Nether-lands	×	×			Not ordered	2-d food records	Nutrients	Dichotomous	[0; 5]	Equally by indicators
GFPI-2010, von Ruesten et al. (2010)[37]	×		Germany	×	×			Ordered	148-item FFQ	FG	Metric	[0; 110]	Equally by indicators
HDI-1997, Huijbregts et al. (1997)[38]	×		(Europe)	×	×	PR, CH, and PUFA range		Not ordered	Cross-check DHM	Both	Dichotomous	[0; 9]	Equally by indicators
HDI-2011, Cade et al. (2011)[39]	×		(UK)	×	×	FA, CH, PR, and PUFA range		Not ordered	219-item FFQ	Both	Dichotomous	[0; 10]	Equally by indicators
HDI-2013, Berentzen et al. (2013)[40]	×		(Nether-lands)	×	×	PR and PUFA range		Not ordered	FFQ (79 main foods/178 foods)	Both	Dichotomous	[0; 7]	Equally by indicators
HDS-2005, Maynard et al. (2005)[41]	×		UK	×	×	PR, CH, and PUFA range		Not ordered	113-item FFQ	Both	Dichotomous	[0; 12]	Equally by indicators
HEI-1995, Kennedy et al. (1995)[42]	×		USA	×	×		×	Ordered	24-h recall + 2-d food record	Both	Metric	[0; 100]	Equally by indicators
HEI-2005, Guenther et al. (2008)[43]	×		USA	×	×			Ordered	24-h recall	Both	Metric	[0; 100]	By indicators
HEI-2010, Guenther et al. (2013)[44]	×		USA	×	×	Ratio (PUFA+MUFA)/SFA		Ordered	Not specified	Both	Metric	[0; 100]	By indicators
HEI-2015, National Cancer Institute[45]	×		USA	×	×	Ratio (PUFA+MUFA)/SFA		Ordered	Not specified	Both	Metric	[0; 100]	By indicators
HEI-f-2000, McCullough et al. (2000)[46,47]	×		USA	×	×		×	Ordered	131-item FFQ / 116-item FFQ	Both	Metric	[0; 100]	Equally by indicators
AHEI-2002, McCullough et al. (2002)[48]	×		USA	×	×	Ratio PUFA/SFA		Not ordered	≈130-item FFQ	Both	Metric[e]	[2.5; 87.5]	Equally by indicators[e]
AHEI-2010, Chiuve et al. (2012)[49]	×		USA	×	×			Not ordered	FFQ	Both	Metric	[0; 110]	Equally by indicators

(continued)

Table 3 **Continued**

Index	Theoretical framework			Dimensions				Dimensional structure	Indicator selection		Normalization		Aggregation technique
	Recommendations	Mediterranean diet	Target region (analyzed region)	Adequacy	Moderation	Balance	Variety	Nested Ordered Not ordered	Data base	Food groups Nutrients Both	Dichotomous Ordinal Metric Ordinal/metric	Scoring range	Weighted
C-HEI-2005, Shatenstein et al. (2005)[50]	×		Canada	×	×		×	Ordered	73-item FFQ	Both	Metric	[0; 100]	Equally by indicators[f]
DQI-a-2010, Jaime et al. (2010)[74]	×		Brazil	×	×		×	Ordered	24-h recall	Both	Metric	[0; 100]	Equally by indicators
HFI-2001, Osler et al. (2001)[51]	×		(Denmark)	×	×			Ordered	26-item FFQ	FG	Dichotomous	[0; 4]	Equally by indicators
HFNI-2006, Bazelmans et al. (2006)[52]	×		Belgium	×	×	PR, CH, and PUFA range		Not ordered	1-d food record	Both	Dichotomous	[0; 8]	Equally by indicators
IMI-2011, Agnoli et al. (2011)[53]		×	Italy	×	×			Ordered	140-, 188-, and 217-item FFQ	FG	Dichotomous	[0; 11]	Equally by indicators
MAI-1999, Alberti-Fidanza et al. (1999)[54]		×	Mediterranean region (Italy)	×	×			Nested	DHM + weighted record method	FG	Ordinal/metric	[0; 99.99]	Equally per food groups
MAI-2006, Knoops et al. (2006)[55]		×	(Europe)	×	×			Nested	DHM	Both	Metric	Not normalized	Equally by indicators
MEDAS-2011, Schröder et al. (2011)[56]		×	(Spain)	×	×			Not ordered	MEDAS- questionnaire (screener)	FG	Dichotomous	[0; 14]	Equally by indicators
MEDAS-2013, Domínguez et al. (2013)[57]		×	Mediterranean region (Spain)	×	×			Not ordered	136-item FFQ	FG	Dichotomous	[0; 13]	By indicators (the number of Bradford Hill criteria met by each component)
MDS-1995, Trichopoulou et al. (1995)[58]		×	Mediterranean region (Greece)	×	×	Ratio MUFA/SFA		Not ordered	190-item FFQ	Both	Dichotomous	[0; 8]	Equally by indicators
MDS-2001, Haveman-Nies et al. (2001)[59]		×	Western countries (USA, Europe)	×	×	Ratio MUFA/SFA		Not ordered	Modified DHM or FFQ	Both	Dichotomous	[0; 8]	Equally by indicators
MDS-2002, Haveman-Nies et al. (2002)[60]		×	Western countries (Europe)	×	×	Ratio MUFA/SFA		Not ordered	Modified DHM	Both	Dichotomous	[0; 7]	Equally by indicators
MDS-2003, Trichopoulou et al. (2003)[61]		×	(Greece)	×	×	Ratio MUFA/SFA		Ordered	150-item FFQ	Both	Dichotomous	[0; 9]	Equally by indicators
MDS-2004, Knoops et al. (2004)[62]		×	Western countries (Europe)	×	×	Ratio MUFA/SFA		Not ordered	DHM	Both	Dichotomous	[0; 8]	Equally by indicators
MDS-2011, Cade et al. (2011)[39]		×	(UK)	×	×	Ratio MUFA/SFA		Ordered	219-item FFQ	Both	Dichotomous	[0; 10]	Equally by indicators
mMDS-2005, Trichopoulou et al. (2005)[63]		×	Mediterranean and non-Mediterranean region (Europe)	×	×	Ratio (MUFA+PUFA)/SFA		Ordered	FFQ, FFQ + food record	Both	Dichotomous	[0; 9]	Equally by indicators
mMDS-2014, Yang et al. (2014)[64]		×	Non-Mediterranean region (USA)	×	×			Not ordered	Lifestyle questionnaire with 15 questions on diet	FG	Ordinal	[0; 42]	Equally by indicators[f] (+ wine scores)

(continued)

Table 3 **Continued**

Index	Theoretical framework			Dimensions				Dimensional structure	Indicator selection		Normalization		Aggregation technique
	Recommen-dations	Mediterranean diet	Target region (analyzed region)	Adequacy	Moderation	Balance	Variety	Nested Ordered Not ordered	Data base	Food groups Nutrients Both	Dichotomous Ordinal Metric Ordinal/metric	Scoring range	Weighted
aMED-2005, Fung et al. (2005)[65]		×	(USA)	×	×	Ratio MUFA/SFA		Not ordered	140-item FFQ	Both	Dichotomous	[0; 9]	Equally by indicators
MDP-2002, Sanchez-Villegas et al. (2002)[66]		×	Mediterranean region (Spain)	×	×	Ratio MUFA/SFA		Ordered	FFQ	Both	Metric	[0%; 100%]	Equally by indicators
MeDiet-2008, Sánchez-Taínta et al. (2008)[67]		×	Mediterranean region (Spain)	×	×			Not ordered	14-item MeDiet questionnaire	FG	Dichotomous	[0; 14]	Equally by indicators
MS-2003, Goulet et al. (2003)[68]		×	World-wide (French Canada)	×	×			Ordered	91-item FFQ	FG	Ordinal	[0; 44]	Equally by indicators
MSDPS-2009, Rumawas et al. (2009)[69]		×	Non-Mediterranean region (USA)	×	×			Not ordered	126-item FFQ + further items possible	FG	Metric[g]	[0; 100]	Equally by indicators
RCI-2008, Mazzocchi et al. (2008)[70]	×		(World-wide)	×	×	FA, PR, and CH range		Ordered	Food Balance Sheets (FAO)	Both	Metric	[0; 1]	Alternative sets of weights
rMED-2009, Buckland et al. (2009)[71]		×	Mediterranean region (Spain)	×	×			Ordered	DHQ	FG	Ordinal[a]	[0; 18]	Equally by indicators
rMED-2010, Buckland et al. (2010)[72]		×	Mainly non-Mediterranean countries (Europe)	×	×			Ordered	DHQ, FFQ, or FFQ + food record	FG	Ordinal[a]	[0; 18]	Equally by indicators
arMED-2013, Buckland et al. (2013)[73]		×	Mainly non-Mediterranean countries (Europe)	×	×			Ordered	DHQ, FFQ, or FFQ + food record	FG	Ordinal	[0; 16]	Equally by indicators

The sign × indicates a fit with the respective construction criterion. Gray shading indicates preferable features of dietary quality indices. For balance only ranges of fat, protein, or carbohydrates as well as ranges of saturated fatty acids, monounsaturated fatty acids or polyunsaturated fatty acids are considered. Recommendations include also recommendations by dietary guidelines or food pyramids.

Abbreviations: AHEI, Alternate Healthy Eating Index; aMED, Alternate Mediterranean Diet Score; BSDS, Baltic Sea Diet Score; C-HEI, Canadian Health Eating Index; CH, carbohydrates; CH-DQI, Chinese Diet Quality Index; D-HDI, Danish Healthy Diet Index; D-DQI, Danish Diet Quality Index; DBS, Dietary Behavior Score; DGAI, Dietary Guidelines for Americans Adherence Index; DHM, diet history method; DHQ, diet history questionnaire; DQI, Diet Quality Index; DQI-a, Diet Quality Index adjusted for energy requirement; DQI-I, Diet Quality Index-International; DQI-R, Diet Quality Index-Revised; DQI-SNR, Diet Quality Index-Swedish Nutrition Recommendation; DQINB, Dietary Quality Index Nutrition Based; DQS, Diet Quality Score; FA, fat; FAO, Food and Agriculture Organization of the United Nations; FG, food groups; FFQ, food frequency questionnaire; GFPI, German Food Pyramid Index; HDI, Healthy Diet Indicator; HDS, Healthy Diet Score; HEI, Healthy Eating Index; HEI-f, Health Eating Index-Frequency Questionnaire; HFI, Healthy Food Index; HFNI, Healthy Food and Nutrient Index; IMI, Italian Mediterranean Index; MAI, Mediterranean Adequacy Index; MDP, Mediterranean Dietary Pattern; MDS, Mediterranean Diet Score; Med-DQI, Mediterranean Diet Quality Index; MEDAS, Mediterranean Adherence Diet Screener; MeDiet, Mediterranean Food Pattern; mMDS, Modified Mediterranean Diet Score; MS, Mediterranean Score; MSDPS, Mediterranean-Style Dietary Pattern Score; MUFA, monounsaturated fatty acids; PR, proteins; PUFA, polyunsaturated fatty acids; RCI, Recommendation Compliance Index; rMED, Relative Mediterranean Diet; SFA, saturated fatty acids.

[a] This is valid except for alcohol.

[b] Higher scores indicate less healthy diets.

[c] Thereby, total fat, saturated fat, and cholesterol intakes are not part of a predefined moderation subindex.

[e] This is valid except for multivitamin use.

[d] This is valid except for half weights on low-fat dairy and low-fat meat indicators.

[f] This is valid except for combined fruit and vegetable group with a doubled score.

[g] This is valid except for olive oil.

operationalize indicators. Twenty-two indices are exclusively based on dichotomous indicators (eg, Baltic Sea Diet Score [BSDS]–M-2014, DQI-SNR-2011, HDI-2013, and MDS-2003), whereas 15 indices are based on ordinal categorical indicators. Fifteen indices are solely based on metric indicators normalized by linear scaling technique (eg, HEI-2005), whereas 5 indices contain a mixture of both metric and ordinal indicators (eg, DQI-R-2003 and DQI-I-2003).

The majority of indices with metric scaling of indicators use normative cutoffs (eg, DQI-2003 and AHEI-2010), whereas indices with dichotomously scaled indicators use mainly median cutoffs (eg, MDS-2003 and MDS-2011). Examples of an index with exclusively dichotomous scaling but normative cutoffs are the MEDAS-2011 and MEDAS-2013. Other indices with ordinal categorization choose both normative and percentile cutoffs. For example, the Med-DQI-2000 uses normative cutoffs when recommended intake levels are available and tertile cutoffs otherwise.[5]

In 6 cases, weighting of the index components according to the strength of their effects on health is implemented by indicator-specific setting of the maximum score achievable for the respective indicator (eg, DQI-I 2003, HEI-2005, HEI-2010, and HEI-2015). For 2 indices (DQI-1994 and DQI-2003), the implicit weighting by the number of indicators per DQ recommendation is explicitly emphasized as the means of accounting for the relative importance of different DQ recommendations for health. Further, the Recommendation Compliance Index 2008 (RCI-2008) is provided with alternative weight functions. The remaining indices implement linear aggregation with equal weights per indicator without explicitly explaining the rationale.

Using the summarizing toolbox of Table 3[5,8,22–74], researchers and practitioners are now able to choose an appropriate index construct for monitoring DQ of populations considering the most suitable construction criteria, the particular target region, and the database at hand.

Although a greater adherence to a Mediterranean diet has been shown to be associated with a reduction in the risk of several chronic diseases and mortality,[123–125] Table 3[5,8,22–74] shows that none of the observed Mediterranean DQ indices seems to properly conform to most of the aforementioned methodological requirements of an appropriate index construction. Indices measuring Mediterranean DQ are generally not nested, have mainly food-group indicators, use (with few exceptions) mainly percentile cutoffs, and often have a considerably less detailed scoring range. Some of these critiques may be explained by data restrictions, especially in cases when Mediterranean DQ index constructions are based on intake data from short food-frequency questionnaires. The question thus arises of whether association results of Mediterranean indices with health outcomes would be even stronger if more methodological finesse was used in constructing them.

For the assessment of US dietary patterns, the HEI-2010 (as well as the HEI-2015, which has not yet been officially published) meets nearly all of the aforementioned preferable key issues of index construction, and it can surely be adjusted to account for country-specific intake recommendations in other Western countries. The HEI-2010 considers the adequacy, moderation, and balance dimension within an ordered index structure. Based on national dietary guidelines, as well as additional expert knowledge, the weighted metric food and nutrient indicators of the HEI-2010 sum up to a metric scoring range of 0–100. However, it would be more beneficial if the ordered structure of the HEI-2010 were enhanced by a nested structure with predefined subindices, which would show problematic areas of dietary quality and perhaps provoke more detailed subsequent analyses.

Furthermore, the DQI-I-2003 seems to be the most appropriate index for international analyses. In contrast with other indices created to account for diet-related concerns of developed countries, the DQI-I-2003 accounts for dietary aspects in relation to not only chronic diseases but also problems of deficient nutrient intakes typical for emerging and developing countries. The DQI-I-2003 is derived from international and national nutrient guidelines and accounts for advantages and disadvantages of the DQI-1994, DQI-R-1999, and the CH-DQI-2000. The DQI-I-2003 describes a population's diet quality as an aggregated DQ measure, and, at the same time, the nested structure of the DQI-I-2003 enables the researcher to pinpoint exactly those forms of nutritional deficiencies that need to be most improved. Additionally, this index is very detailed, with a mixture of metric and ordinal scaled indicators that sum up to a total scoring range between 0 and 100 points. Finally, indicator selection and cutoff points are based on dietary guidelines and additional epidemiological evidence.

Despite its various advantages, some construction aspects of the DQI-I-2003 might be improved. For instance, for the calculation of the DQI-I-2003, a number of metrically reported nutrition variables need to be mapped on 3-level categorical indicators, implying a considerable loss of information and discriminatory power. Further, the development of weights is not intersubjectively comprehensible and verifiable. Finally, the DQI-I-2003 considers total fat as a moderation indicator and applies a count measure of the variety dimension, ignoring the distributional aspect of dietary variety and potential problems of double-counting adequacy aspects.

CONCLUSION

Even though validating the association with health outcomes should be the major criterion in choosing a specific a priori DQ index, current empirical evidence does not sufficiently facilitate this choice. Heterogeneity in sample populations, datasets, measurements, and index compositions makes it almost impossible to derive solid recommendations for the multitude of existing indices based on validation results. Therefore, this review focuses on discussing existing a priori DQ indices in relation to their construction criteria, considering theoretical considerations and recent knowledge about diet–health relationships. The discussion is based on relevant aspects of the OECD handbook on constructing composite indicators[11] and aims to be both more systematic and more comprehensive than previous studies. Inclusion of the adequacy, moderation, and balance dimensions were identified as necessary to provide an overall picture of DQ. Further, it was shown why a nested index structure and metric indicator scales or a combination of metric and ordinal indicator scales with indicators based on nutrients or a combination of nutrients and food groups seem favorable for DQ assessment. Finally, a weighting system has to take into account variations in nutrient intake levels relative to population-level variations in health outcomes and the potential problems of double-counting because of strong correlations between indicators. As a result of this discussion, a summarizing toolbox has been developed that might help researchers and practitioners identify those indices whose concept of index construction is most appropriate for their respective study aim, target region, and the restrictions of the available database. For future work, researchers might pay more attention to the derivation of valuation functions and weighting systems, which ought to be internally consistent and intersubjectively comprehensible and verifiable.

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