Use of Dietary Indexes among Children in Developed Countries[1,2]

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ABSTRACT

In this article, we review studies that have used dietary indexes to assess different aspects of diet in relation to health outcomes and sociodemographic factors in childhood populations of developed countries. Eighty-four papers published from 1980 to mid-2010 including 90 unique dietary indexes were reviewed. Seventy-two indexes were developed (or have been adapted) specifically for childhood populations; 38 of these were used to assess diet-disease associations, mostly of diet and obesity. In the majority of these studies, small inverse associations between dietary indexes and obesity indexes were shown. Children who were younger, female, and from high-income families had better dietary quality scores. Forty-nine indexes (of 90) were compared with other aspects of dietary intakes or behaviors, with correlations ranging from very low to modest ($\sim r = 0.05$–0.50). Only 2 validation studies compared an index with nutritional biomarkers, and correlations were quite weak for most plasma nutrients ($P < 0.10$). Overall, a large number of indexes have been created and used, but the majority of studies are descriptive. Fewer analytic studies on index-health associations have been performed, and most analyses insufficiently adjusted for confounders. Thus, prospective and intervention research in diverse populations is needed to further test these tools. In conclusion, indexes are potentially useful methods for dietary assessment, because they offer valuable information on overall dietary patterns in children. However, understanding the advantages and limitations when applying them in research and public health settings is important, and more research is needed to further develop their utility. *Adv. Nutr. 2: 295–303, 2011.*

Introduction

Analysis of overall dietary patterns is an approach that has been used in nutritional epidemiology, especially during recent years, and aims to measure the human diet as a whole (1,2). Specifically, pattern analysis permits the assessment of the combined effect of the diet, including interactive and synergistic relationships among and between nutrients, foods, and eating habits.

Dietary indexes are one of the methodological tools that permit a holistic assessment of diet (3–5). A major advantage of using this approach over empirical methods such as principal components, cluster analysis, or reduced rank regression analyses is the ease of interpretability. Specifically, an index yields a summary score that represents the level of adherence to dietary recommendations and/or reflects the overall quality of diet. Thus, the results of dietary assessment via this method are more easily understood and interpreted by consumers and nondietetic health professionals (e.g. general practitioners and nurses) as well as by various stakeholders such as policy makers. Although the latter group may not have specialized nutrition- or health-related knowledge, they make decisions regarding public health policies and thus need to be provided with scientifically accurate, easily comprehensible information to correctly address population needs.

Dietary indexes have been widely used in adult populations (3,4). As a result, some important relationships of diet to chronic diseases risk factors and mortality have been revealed (4). Several papers have also reviewed associations between diet indexes, diet quality, and disease (3–12). In children, however, the use of dietary indexes has been rather limited. Their application in developed countries has been aimed mainly at the assessment of diet quality (13–17) and only recently at the investigation with diet-related diseases or chronic disease risk factors (18–21). In contrast to developed countries, the development and use of dietary indexes for childhood populations in developing countries have generally been designed to assess nutritional

[1] Author disclosures: C. Lazarou and P. K. Newby, no conflicts of interest.

[2] Supplemental Tables 1–3 are available from the "Online Supporting Material" link in the online posting of the article and from the same link in the online table of contents at advances.nutrition.org.

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adequacy and growth, which are the major nutritional concerns in those countries (22,23). Although dietary indexes in developing countries have been reviewed (22,23), to our knowledge, a comprehensive review of dietary indexes among children in developed countries has not yet been performed.

Because the use of dietary indexes is relatively new in nutritional epidemiology, criteria need to be developed that guide users in the selection of a suitable index. The first step is to evaluate the outcome for which the index was constructed to measure. Second, the evidence on which the index was developed needs to be critically assessed (5,24,25). The final step is to determine whether rigorous methods were used to create and evaluate the index.

Such techniques include the application of specific weights to the index's components to reflect each component's relative importance to what an index measures (26) and/or the assessment of the index's performing characteristics (i.e. validity and reliability) (27). Finally, the discriminative power of an index may be influenced by the inherent characteristics of the study sample. It is thus important to recognize that certain population subgroups with distinct sociodemographic characteristics might exhibit significant differences in diet characteristics and thus the utility an index may be varied accordingly (28).

Therefore, the main objectives of this review were to present dietary indexes that have been developed and utilized for childhood populations in developed countries and discuss associations of these indexes with overall diet quality, sociodemographic characteristics, and health outcomes in children. We also examined the potential use of diet quality indexes and delineated the research implications and future research directions in this area.

Methods

An extensive search of the scientific databases PubMed, Scopus, ProQuest, Heal-Link, and HighWire, as well as Google, was performed. The following English key terms were used: "dietary indexes (indices)/index (es)/score(s)," "diversity indexes(indices)/index (es)/score(s)" combined with the following terms "child/children," "obesity/weight/height/BMI/growth/anthropometric," "asthma/blood pressure/blood lipids/LDL-cholesterol/HDL-cholesterol/TG/biomarkers/blood test/risk/chronic disease factors," and "nutrient status/nutrition/diet quality/dietary patterns/habits." In addition, links from the original Web sites and article reference lists were checked to identify additional articles of relevance. Publications were searched from January 1980 through August 2010.

Exclusion criteria for papers were: *1*) indexes from nondeveloped countries; *2*) indexes that were not examined in relation with either sociodemographic, dietary, anthropometric, disease risk factors, or health and disease outcomes; *3*) publications in languages other than English; *4*) studies where the sample included adults and no separate results were reported for children; *5*) indexes that focused on other lifestyle factors (even if they included diet as well); *6*) indexes that targeted clinical conditions and hospitalized children and were not applied in the general population; *7*) nutrient density scores, because they do not evaluate total dietary patterns (29); and *8*) publications that were available only in abstract form from conference proceedings.

Of note, there are several psychometric tools that measure behavioral aspects of diet and eating behavior, such as the Child Eating Behavior Questionnaire (30), Adolescent Food Habits Checklist (31), Dutch Eating Behavior Questionnaire (32), and the Three Factor Questionnaire (33). These tools are scored according to the definition given for dietary indexes (i.e. each answer is scored and the result of the evaluation is expressed in the format of an arithmetic score) and have been used to assess the relationship to dietary quality (31) and diet-related diseases (32). Thus, these tools could arguably be regarded as types of dietary indexes. No previous review of dietary indexes has included them (3–12). Therefore, we also largely omitted these publications in this review and included only those that specifically facilitated discussion about the possible applications and uses of dietary indexes in public health.

In total, we retrieved 128 articles; 84 of these met the inclusion criteria and were selected for review.

Data presentation and organization

Table 1 presents an overview of the indexes reviewed, grouped by intended use as reported in the paper. The number of indexes by each category along with general characteristics of their components and scoring system are summarized.

Further details of the indexes reviewed here are presented in **Supplemental Table 1**. The acronym for the index and its full name are provided, alongside a brief description of the components, its scoring system, and the year of publication. Because there are several publications that may refer to the same index, Supplemental Table 1 presents the first use of a given index, with additional publications that employ the same index are provided as references in the table footnotes.

Key results of studies that have applied diet quality indexes are presented in **Supplemental Table 2** and **3**. Results were grouped into 2 tables based on whether the dietary index was examined in association with nutritional health, growth, diet quality, and/or socio-demographic factors (Supplemental Table 2) or diet-related diseases or chronic disease risk factors and biomarkers (Supplemental Table 3).

Table 1. Dietary indexes used among childhood populations in developed countries, grouped by intended use

Intended use	Index components and scoring characteristics	Number of indexes	Reference
Assess dietary quality	Most indexes are based on foods, food groups, dietary guidelines, food variety, and dietary/meal habits. Some include or are based on nutrients and ratio of macronutrients. In 12 indexes, the scoring system or optimal score is not defined. In most other indexes, a higher score represents the most healthful diet.	50	(13–21), (34–55), (57–95)
Assess dietary habits and beliefs	Based on dietary habits, attitudes, beliefs and emotions toward food, food knowledge, and factors that promote or discourage healthy eating habits. In 14 indexes, the scoring system or optimal score is not defined. In most other indexes, a higher score represents the most healthful dietary attitudes/beliefs/habits.	32	(30–32), (56), (96–102)
Assess association to diet-related diseases/risk factors	Based on dietary factors (including foods, food groups, dietary/meal habits, attitudes, beliefs and emotions toward food) that may be related to diet-associated diseases. In 3 indexes, the scoring system or optimal score is not defined. In most other indexes, a higher score represents the most healthful dietary habits.	8	(21), (103–106)

Results and discussion

Overview of findings

Ninety dietary indexes presented in 84 publications have been evaluated in this review (Table 1), because they met the published definition criteria for an index (5,7–9,11,12). However, several of these indexes are subscales of some questionnaires [e.g. the Child Eating Behavior Questionnaire (96)] or are subindexes of an overall index [e.g. the Electronic Kids Index and its 3 subindexes (106)]. In addition, some are adaptations of indexes first developed for adults (such as the Mediterranean Diet Score by Trichopoulou et al. (107)], with different versions when applied to children (76,77,93,95).

Four of the indexes measure overall dietary variety (59,60,61,89). In this review, all of these have been counted as distinct indexes, because they meet the definition criteria of an index (5,7–9,11,12) and our inclusion criteria. It should be noted that some publications evaluate more than one dietary index or several papers evaluate the same index; thus, 84 papers in total are presented in Supplemental Tables 1–3.

Seventy-two of the 90 indexes presented in Supplemental Table 1 were developed (or adapted) for use in childhood populations. Thirty-eight of these were used to examine diet-disease associations, mostly on diet and obesity. Only 18 of those were developed with the goal of assessing a specific diet-related disease or condition, as follows: *1*) dental caries [one index (103)]; *2*) obesity/overweight [16 indexes in total (96,73,104,106)]; and *3*) inflammation [one index (105)]. Of note, the 16 indexes that were developed with the aim of examining associations with obesity or overweight were from only 4 studies (96,73,104,106). Specifically, one study used 8 scales of a single questionnaire [the Child Eating Behavior Questionnaire (96)]; 3 were parental feeding questionnaires scores from one study (104); 4 were the 3 subindexes and their overall index from another study (the Electronic Kids Dietary Index and its 3 subindexes) (106); and the last was a revised index [the Revised Overall Diet Quality Index for Children (73)]. The remaining indexes were originally developed to assess diet quality and food behaviors but were later applied to examining diet-disease relationships.

These observations perhaps suggest why some dietary indexes were more effective than others in showing associations of indexes with disease and risk factors. It may be partly due to the fact that most of the dietary indexes were initially constructed to assess overall diet quality and very few were actually constructed to assess the association with a specific diet-related health outcome. When indexes were specifically developed to address a certain health outcome, they were, in general, more likely to be significantly associated with that outcome. However, given that most studies are descriptive, it should be noted that the number of analytical studies (i.e. studies examining an association with an outcome) are limited and more research is needed.

Because the main purpose of dietary indexes is to summarize the overall diet quality or selected aspects of diet quality, we next discuss how effectively dietary indexes in children achieve this goal.

Are dietary indexes in children good indicators of overall dietary quality?

The majority of the 69 publications [46 (71%)] that assessed associations of dietary indexes in children with demographic and nutrient intakes or diet quality (Supplemental Table 1) reported significant associations. However, the majority of studies were cross-sectional. Diet-related characteristics included other than the index used diet quality markers (significant associations in 27 of 69 studies), food behaviors (significant associations in 14 of 69 studies), nutrition knowledge (significant associations in 3 of 69 studies), self-rated health status (1 of 69), and dietician's rated diet quality (1 of 69). Other studies showed associations with plasma nutrients, mean adequacy ratio scores, and/or dietary intakes of nutrients and food groups. Finally, food beliefs and behaviors examined included neophobia, food variety, empirically derived dietary patterns (using principal components or cluster analyses), other dietary indexes, and meal habits. Correlations ranged mostly from very low ($r < 0.10$) to modest ($r = 0.30$–0.50).

A few patterns were observed when reviewing these studies. First, there was no clear tendency of stronger or weaker associations of dietary indexes to a specific diet-related characteristic. Interestingly, indexes derived from parentally administered tools (75,98) did not show better results compared to indexes that were derived from child-administered tools. Surprisingly, no clear patterns emerged regarding associations across age groups. Dietary reporting errors and the possible effect of body weight on the association of indexes to diet-related characteristics was considered in fewer than 10 studies; 9 studies adjusted for BMI or obesity status (20,44,53,66,68,83,87,88,102) and 8 studies adjusted or excluded dietary misreporters (40,51,53,58,63,64,71,93). However, results from studies that accounted for reporting errors or adjusted for obesity were not different from other studies that did not make those adjustments. Other differences across studies included heterogeneous populations, the number and type of variables used in adjustments, and the type of indexes used, which makes comparison across studies difficult. It is thus evident that more work is needed in this area. For example, using the same index and same adjustment variables in a number of studies that refer to same age groups will shed more light in this area.

Are dietary indexes associated with sociodemographic characteristics?

Sociodemographic factors are important correlates of diet quality in children (108–110). It is therefore important for any dietary assessment tool, such as an index, to discriminate diet quality of groups or individuals across these characteristics. In this review, 54% percent of studies (37 of 69) reported significant associations between indexes and various sociodemographic variables, including age, gender, race/ethnicity, income, parental education, socio-economic status, place of living, and marital status of parents. Effect

sizes (as determined by correlation coefficients) were mostly fair to low ($r < 0.30$). The most consistent associations appeared to be with age, family income, and gender. In general, children of younger ages (13 studies) and those coming from families with high incomes (3 studies) had significantly better scores. Also, girls often had higher quality scores compared to boys. Sixteen of 23 studies observed significant associations with diet indexes and gender, but correlations were generally modest ($r < 0.30$); only 3 of those 16 studies showed that males had better scores, whereas the remaining 13 showed better diet scores for females. There was no other evident pattern between index scores and socio-demographics in any of the age groups. Of note, only 23 of the 69 publications (presented in Supplemental Table 1) adjusted for potential confounders; thus, some findings may be spurious associations that need to be replicated with more rigorous analyses. That said, the direction of the findings were consistent with available evidence, especially income (111–113), even though detected relationships were generally modest. In children, literature on the relationship of gender to diet quality are mixed (113–117), although many studies usually are based on single food groups or nutrients and therefore comparability with those examining total diet quality is difficult. Besides the above factors, other sociodemographic and family-related factors were examined in a few studies, including ethnicity (5 studies), region of living (5 studies), type of school (2 studies), parental education (2 studies), and household type and parents' divorce (1 study). Although additional research on the above factors would be helpful, including various other important variables, e.g. culture, occupation, family size, urban/rural environment, geographic characteristics, it would be useful to better understand correlates of high diet quality among children.

Are dietary indexes associated with health and disease outcomes?

Thirty studies (using 40 indexes) reported associations between dietary indexes and diet-related diseases, disease risk factors, and/or biomarkers (Supplemental Table 2). All studies were cross-sectional. Most studies (22 of 30) examined relationships between dietary indexes and anthropometric factors (e.g. BMI, fat percentage, abdominal obesity). In 13 of 22 papers (67%), small but significant inverse associations with BMI or other obesity indexes were shown and the rest did not show any significant association. Almost one-half of the papers (12 of 30) presented associations of dietary indexes with other risk factors or health outcomes, as follows: blood pressure ($n = 2$; $P < 0.05$ for both), asthma and related symptoms ($n = 5$; $P < 0.05$ for all), blood lipids or inflammation factors ($n = 1$; $P < 0.05$), and dental caries ($n = 2$; $P < 0.05$ for 1 study). Of note, only 20 of those 30 publications (67%) adjusted for a few potential confounders, but many of these were not mulitivariable adjusted.

It is therefore evident that few studies have examined the associations between diet indexes and health/disease outcomes among children. Although the relationships observed here were weak to modest, the results were consistent with evidence from the available literature in adults on various outcomes (e.g. obesity, asthma, blood lipids, inflammation, insulin resistance, and blood pressure), as comprehensively reviewed by Kant (4).

Dietary indexes used in children: summary of strengths and limitations

Apart form the main observations above regarding associations of dietary indexes to diet-related characteristics, sociodemographic factors, and health outcomes, we noted a number of major strengths and weaknesses of the dietary indexes we reviewed. In our view, the 4 overall strengths of the extant literature include the following: *1*) the ability to translate successfully a set of dietary guidelines or evidence into a single, comprehensible assessment tool that reflects adherence to a healthful diet prototype; *2*) indexes were associated with a wide variety of dietary characteristics; *3*) indexes were associated with important sociodemographic characteristics.; and *4*) indexes were associated with some meaningful health outcomes. There are also a number of major weaknesses that we observed. There was a large variety of indexes used in the literature, with relatively few studies within any given age group. The quality of the primary dietary assessment tools used to derive the dietary indexes (e.g. FFQ, diet record, etc.) varied considerably, making comparisons across studies difficult. Most results were from descriptive analyses and most analytic studies showed weak associations, with limited if any adjustment for potential confounders. In addition, only a handful of studies compared different indexes to determine which was better associated with a given outcome; thus, it is unclear which indexes are better than others. Finally, only 2 validation studies were performed. It is to this final critical point, validation, that we now turn.

Are dietary indexes in children valid assessment tools?

Dietary indexes are a relatively new tool in nutritional epidemiology and very few validation studies have been performed in children, with modest results. Many studies (47 of 90 in Table 1 and Supplemental Table 1) simply compared the index with other aspects of diet measured using the same dietary assessment method. For example, 29 studies compared the index with mean adequacy ratio, nutrient intakes, food frequency intakes, or empirically derived dietary patterns. In other studies, indexes were compared with nutrition knowledge ($n = 2$), self-rated health status ($n = 1$), dietician's rating ($n = 1$), dieting scale or other behavioral nutrition measures ($n = 3$), or menus developed by experts ($n = 1$). Four studies compared the index with an independent method. Two studies compared the index score using 2 different self-reported dietary assessment methods. Only 2 validation studies compared the index with nutritional plasma biomarkers (59,90), considered an objective, gold standard of dietary validation, but correlations were quite weak for most nutrients ($r < 0.10$).

Across all of these studies, the magnitude of the effect size of the correlations was on average ~0.3–0.5. Some of these indexes have been compared with multiple dietary assessment methods over time. For example, the Dietary Variety Index created by Bordonada et al. (59) was validated using both nutrient biomarkers and reported food intakes. Another example is the Healthy Eating Index-2005 (80–83), which has been compared with total energy intake (118) and expert-developed menus (27), although results in the latter study were not reported separately for children. The most extensively studied index is the (original) Healthy Eating Index (n = 15 studies), which has been compared with single nutrient intakes (n = 9), dietary patterns and food practices (n = 3), self-rated status (n = 1), and food frequency intakes (n = 5) in childhood populations from 3 different countries (United States, Greece, and Spain). In all of these reports, correlations were similar and ranged from ~0.10 to 0.70. Most correlations were of medium effect size (r = 0.30–0.50).

In summary, it is difficult to draw conclusions, because the reference methods used in the above studies vary and the number of studies conducted is so few. However, it seems that the magnitude of effect sizes (low- to medium-size correlations) is comparable to other similar studies using single nutrients and foods using FFQ in children (119,120). Critically important, however, is the need for more validation studies that compare diet quality indexes in children with gold standard methods such as nutritional biomarkers.

Future research directions

Future attempts to develop new indexes should first focus on further improving the development and discriminative power of an index and second on testing and establishing its validity and reliability. Two main factors should be taken into consideration in working toward this direction. First, the application of more robust methods to create indexes and more rigorous methods to measure discriminative power may increase the content validity of those tools. Those methods may include: *1*) applying specific weights to each component scale of the index on the basis of relative importance (24,25,27); *2*) grouping index components according to the domain of the dietary behavior they assess (e.g. diet composition, beliefs, behaviors) (106); *3*) conducting proper statistical tests to evaluate the discriminating characteristics and abilities of the index, such as sensitivity, specificity, c-statistic values, positive/negative predictive values, and others; and *4*) performing additional tests beyond multivariate regression analyses to reveal any potential heterogeneity in index performance (106), including latent class analysis (106,121), structural equation modeling (122), and data mining (123).

Second, future validation studies must use a superior method for comparison rather than relying upon internal, relative validity using the same dietary assessment method, as has been done in the vast majority of the studies reviewed here. Optimally, validation of dietary assessment tools should be evaluated with methods having uncorrelated errors, ideally nutritional biomarkers and/or a more accurate, gold standard method of self-report dietary assessment such as dietary records (124,125). The collection of biomarkers is costly and may be prohibitive, and only 2 studies in this review used this method (59,90). Comparison with a superior dietary assessment method, such as multiple days of diet records, may be more feasible and would also provide greater confidence in the soundness of these indexes. Also, additional studies are needed to establish the reliability (or reproducibility) of indexes over time to better understand how diet quality changes as children age and how to use diet indexes in longitudinal studies; only 3 studies (15,35,96) we reviewed examined the reproducibility of diet quality in children. Importantly, validity and reproducibility of any index should be tested in various racial/ethnic populations to have a clearer understanding of its utility alongside its discriminatory and predictive ability in diverse groups of children.

Applications in public health settings

Dietary indexes have a number of potential uses and purposes in public health. For example, scores could be used to rank and/or compare within and between individuals or groups of individuals (such as school populations or certain subgroups within a population), with the goal of identifying individuals who have poorer dietary quality and hence need dietary counseling. They also may be helpful as monitoring tools to evaluate how well children comply with dietary recommendations, monitor changes in dietary patterns over time, or evaluate the effectiveness of public health nutrition programs. Moreover, individual components of an index can be used to determine specific areas and goals for improvement. As a result, dietary counseling and interventions may be better tailored to meet specific individual needs.

Additionally, some diet quality indexes that are formatted as questionnaires (17,31,106) can easily be used by nondietetic health professionals such as pediatricians, general practitioners, and nurses in their everyday clinical practice to guide nutrition counseling. Also, simple, user-friendly indexes, such as those based on key food intakes and/or dietary behaviors, may, e.g., potentially be used as educational and self-monitoring tools by parents or teachers. Several indexes reviewed here are readily available in electronic format, thus further easing their use. A good example of such an index is the KIDMED (Mediterranean Diet Quality Index in Children and Adolescents Index). KIDMED is an electronic diet quality index based on 16 yes/no questions aimed to evaluate adherence to the Mediterranean diet; the tool can be easily completed by children as young as 6 y old (17,126). After completing the index, a child receives a score alongside personalized feedback and guidance designed to help the child improve his/her score, as needed; information is also provided to parents. Electronic indexes can be made even more attractive to children if they are based on interactive games, such as "Blast off" used in the USDA's MyPyramid (127) and "Feed the Monster" used by the US Dairy Council (128). Finally, because most index scores are easily interpretable, they may be better poised

than findings from single nutrient and food studies to inform policy makers and key stakeholders about overall diet quality of population subgroups.

Conclusions

In summary, the majority of studies reviewed had notable methodological weaknesses, but in general higher diet quality scores were associated with more favorable nutrient and food intakes, more healthful dietary behaviors, lower chronic disease risk factors, more favorable body weight, less obesity, and fewer asthma-related conditions among children in the developed world. In conclusion, dietary indexes are useful, practical tools for dietary assessment, because they offer valuable information on overall dietary patterns in children that are simple and comprehensible. However, certain measures and techniques may improve the diagnostic accuracy of these indexes and increase the robustness of results. Prospective and intervention research in diverse populations and additional validation studies are needed to strengthen the utility of these tools in understanding dietary quality in children and showing associations with meaningful health outcomes.

Acknowledgments

We thank Associate Professors Demosthenes Panagiotakos and Antonia-Leda Matalas of Harokopio University of Athens, Greece, who provided useful suggestions for the preparation of this manuscript. C.L. developed the concept for the article, conducted the literature search, and wrote the paper; P.K.N. supervised the work, helped draft the manuscript; and critically reviewed the paper. Both authors read and approved the final manuscript.

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