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Nutrient Requirements and Optimal Nutrition

The Infant Diet Quality Index Predicts Dietary and Adiposity Outcomes in US Children 2 to 4 years old☆

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A B S T R A C T

Background: Healthy nutrition during the first year of life is critical for optimal growth and development. Limited techniques are available to assess diet quality in infancy, and few have been shown to be predictive of dietary and adiposity outcomes in low-income children.
Objective: The objectives of this study were to construct an Infant Diet Quality Index (IDQI) to assess the diet quality from birth to 12 mo and to determine whether the IDQI exhibits predictive validity by estimating the longitudinal associations of IDQI scores with diet quality and weight status at 2 to 4 y.
Design: Data were analyzed from the longitudinal Women, Infants, and Children Infant and Toddler Feeding Practices Study-2 (unweighted, n = 2858; weighted. N = 392,439) using one 24-h dietary recall and survey responses during infancy. The newly constructed IDQI consists of 16 equally-weighted components: *1)* breastfeeding duration; *2)* exclusive breastfeeding; age of first introduction of: *3)* solids, *4)* iron-rich cereals, *5)* cow milk, *6)* sugar-sweetened beverages, *7)* salty/sweet snacks, *8)* other drinks/liquids, and *9)* textured foods; frequency of consuming *10)* fruit or *11)* vegetables; frequency of consuming different *12)* fruit or *13)* vegetables; *14)* nonrecommended bottle-feeding practices; *15)* use of commercial baby foods; and *16)* number of meals and snacks. Regression analysis was used to estimate associations between the total IDQI score (range, 0–1) and Healthy Eating Index-2015 (HEI-2015) scores and body mass index z-scores (BMIz) at 2 to 4 y of age, adjusted for covariates (e.g., child age, sex and race/ethnicity; maternal education level, etc.)
Results: The total IDQI score was positively associated with HEI-2015 at the age of 2 y (β = 16.7; 95% CI: 12.6, 20.9; $P < 0.001$), 3 y (β = 14.5; 95% CI: 8.1, 21.0; $P < 0.001$), and 4 y (β = 15.4; 95% CI: 8.4, 22.4; $P < 0.001$); and negatively associated with BMIz at the age of 2 y (β = -1.24; 95% CI: -2.01, -0.47; $P = 0.002$) and 4 y (β = -0.92; 95% CI: -1.53, -0.30; $P = 0.003$).
Conclusions: The IDQI has predictive validity for diet quality and weight status in low-income US children.

Keywords: Infant Diet Quality Index, adiposity, WIC, children, HEI, BMIz, complementary feeding

Introduction

Child obesity has increased in the last decade and remains high [1], especially among children from low-income families [2–4]. For example, close to 14% of low-income young children enrolled in the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) are obese [5]. Low-income children disproportionately shoulder the burden of weight-related morbidity and mortality, disparities which start at a very young age [6–8]. These disparities may be mitigated through improved nutritional assessment in the first 1000 d, or the period from conception to 24 mo [9,10], especially for nutritionally at-risk children, such as those in WIC.

The WIC program is in an important position to improve complementary feeding during the first year of life, a critical developmental period for establishing lifelong eating habits [11]. WIC serves about half of all infants in the US, in addition to low-income women and children, making it the third largest federal nutrition assistance program in the US [12–14]. A federal requirement of WIC is to identify nutritional risk of children while

Abbreviations: BMIz, body mass index z-score; CFUI, Complementary Feeding Utility Index; DGA, Dietary Guidelines for Americans; HEI-2015, Healthy Eating Index-2015 score; IDQI, Infant Diet Quality Index; WIC, Special Supplemental Nutrition Program for Women, Infants, and Children; WIC ITFPS-2, WIC Infant and Toddler Feeding Practices Study-2.

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providing nutrition education and a nutritious food package during the key developmental life stages of pregnancy, infancy, and early childhood [15]. The effectiveness of this counseling is directly related to the effectiveness of their nutrition assessment measures. Few tools have been specifically designed; however, for low-income populations who face disparities in dietary quality compared with high-income populations [16,17].

The *2020–2025 Dietary Guidelines for Americans* (DGA) was the first edition to provide comprehensive dietary guidance for infants and toddlers [11] and is the basis of dietary guidance for programs, such as the WIC. This birth to 24-mo period is critically important because healthy nutrition during the complementary feeding period is essential for optimal growth and development [11] and evidence show that by 3 to 5 y of age, most children have established dietary habits that impact long-term weight and health [18,19]. Although the impact of diet during pregnancy and modes of early infant feeding on children's health and development have been investigated [20,21], better understanding of the influence of complementary feeding and eating behaviors on obesity in more diverse populations is needed. Most studies examining early childhood feeding have focused on breastfeeding [22], timing of introduction of solids [23], or single foods or nutrients [24], with most longitudinal studies including relatively high income, largely White populations [25–27]. Although numerous techniques have been developed to assess the diet quality among older children and adults [28], few studies have examined diet quality in infants and toddlers [16,17]. To our knowledge, even fewer longitudinal studies have examined the diet quality during infancy and examined associations with health outcomes, such as adiposity, and have shown mixed results [29–32].

In 2018, Au et al. [33] adapted the Complementary Feeding Utility Index (CFUI), originally developed by Golley et al. [25] for the US population, but did not examine its association with later health outcomes. The original CFUI assessed the degree of adherence to feeding guidelines based on a review of recommendations from Australia, New Zealand, North America, and the United Kingdom, and these guidelines included nutritional, developmental, and behavioral components of feeding. The original CFUI has been shown to be positively associated with intakes of healthier foods and a better nutrient profile at 3 y [25]. In addition, the original CFUI has been positively associated with higher intelligent quotient scores at 8 y, negatively associated with waist circumference and diastolic blood pressure at 7 y, and not associated with BMI or other cardiovascular risk factors [30]. Thus, the objectives of this study were to construct an Infant Diet Quality Index (IDQI) to assess the diet quality from birth to 12 mo and to determine whether the IDQI exhibits predictive validity by estimating the longitudinal associations of IDQI scores with diet quality and weight status at the age of 2 to 4 y. A better understanding of diet quality during the first year of life that contributes to healthy weight maintenance can inform pediatric intervention strategies to lower obesity and other related chronic diseases.

Methods

Participants

The WIC Infant and Toddler Feeding Practices Study-2 (WIC ITFPS-2) is a national, longitudinal study of mothers (>16 y) and their children aged ≤ 9 y. WIC ITFPS-2 is designed to examine feeding practices, the associations between WIC services and those practices, and the health and nutrition behaviors of children receiving WIC [34]. In 2013, study mothers were recruited in person from 80 WIC sites across 27 states and territories. WIC sites were selected among sites enrolling at least 30 eligible participants per month using a stratified 2-stage sampling approach [34]. The participants received a prenatal interview and up to 14 postnatal interviews during the first 4 y (1, 3, 5, 7, 9, 11, 13, 15, 18, 24, 30, 36, 42, and 48 mo). Telephone interviews were conducted by trained interviewers in English or Spanish. Interview questions included sociodemographic information, prenatal beliefs, breastfeeding initiation, introduction of complementary foods, and other feeding practices. In addition, a 24-h dietary recall was collected at each time period.

WIC ITFPS-2 participants were enrolled in 1 of 2 samples: the core longitudinal sample (n = 3503) or the supplemental sample (n = 864). The core sample was designed to be an equal probability sample of all new enrollees at the 80 WIC sites, and the supplemental sample was designed to focus on subpopulations of interest, such as African Americans. Inclusion criteria included enrolling in WIC for the first time for that pregnancy or infant, and the ability to complete interviews in either English or Spanish. Exclusion criteria included: children aged ≥2.5 mo at the time of recruitment; adolescent mothers aged <16 y; mothers in foster care at the time of enrollment; foster parents enrolling foster infants. The study will observe children until age 9 y, but the current analysis focuses on publicly available data of the core and supplemental samples through 4 y. This national study was approved by the Westat Institutional Review Board and the US Office of Management and Budget. This national study is registered at clinicaltrials.gov as NCT02031978.

Dietary intake

Each interview after the prenatal interview included a 24-h dietary recall, administered over the phone, using the *USDA Automated Multiple Pass Method* [35]. Before the interview, participants received a package by mail of measuring guides to help them report their child's portion sizes during the interview. During the *Automated Multiple Pass Method*, a caregiver was asked to recall all their child's dietary intake for the previous day, which could include the weekday or weekend. The caregiver was asked to report all foods, beverages (including infant formula and breastfeeding), and dietary supplements for each eating event during the 24-h period [36]. Nutrient values were taken from the *USDA Food and Nutrient Database for Dietary Studies*, 5.0 [37]. The caregiver reported what the child ate for daycare foods. Additional questions related to breastfeeding, formula feeding, and complementary feeding practices (e.g., age of first introduction of solids) were also completed during the telephone interview.

Adiposity and dietary outcomes measured at 2 to 4 y of age

Body mass index z-scores (BMIz)

Weight and length/height measurements of the WIC ITFPS-2 children were collected at birth, 6 mo, 1 y, 2 y, 3 y, and 4 y. As part of regular clinic visits, WIC sites directly measure most enrolled infants using standardized protocols. For participants who have left WIC, the study attempts to collect the weight and length information from the child's health care provider. The main outcome, BMIz, was calculated at 2 to 4 y using the *Centers for Disease Control age- and sex-specific growth charts* [38].

Healthy Eating Index-2015 (HEI-2015)

For predictive validity testing with dietary intake at 2 to 4 y, HEI-2015 total scores were computed using the population ratio method. The HEI has been revised to reflect [39] and is considered a valid tool for assessing the diet quality among individuals aged >2 y [40,41]. The *2015–2020* DGA emphasizes a variety of food groups, thereby improving nutrient density and food and beverage choices within calorie needs. The HEI-2015 consists of 13 components; 9 components assess dietary adequacy (total fruits, whole fruits, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant proteins, and fatty acids) and 4 assess overconsumption (refined grains, sodium, added sugars, and saturated fats).

Covariates

Demographic characteristics of the study child, including sex, birth weight, and race/ethnicity were collected from the mother at the first postnatal interview. Other sociodemographic variables collected from the study mother at the first study visit, unless otherwise noted, included maternal age at child's birth, maternal race/ethnicity, marital status, maternal education level, maternal employment status at the 7-mo visit, maternal weight, maternal depression score at the 3-mo visit, gestational diabetes, household size at the 7-mo visit, and household income.

Creating the Infant Diet Quality Index

The adapted CFUI for a US setting [33] included the following 14 components: *1)* breastfeeding duration; age of first introduction of: *2)* solids, *3)* iron-rich cereals, *4)* cow milk, *5)* protein foods, *6)* sugar-sweetened beverages, *7)* salty or sweet snacks, *8)* teas or broths, and *9)* textured foods; frequency of consuming *10)* fruit or *11)* vegetables; *12)* feeding breastmilk or formula on demand; *13)* nonrecommended bottle-feeding practices (i.e., mixing formula with more or less water, using an infant feeder or bottle with an extra-large nipple hole, or adding cereal to the bottle); and *14)* number of meals and snacks (i.e, number of eating occurrences). To create the IDQI, additional candidate index components were considered based on 2 primary conditions. First, they could be reliably and validly measured using WIC ITFPS-2 dietary surveys based on consultation with experts involved with the surveys. Second, they could be plausibly associated with later diet quality or risk of obesity based on a literature review, which included the 2020–2025 DGA recommendations for birth to 24 mo [11] and consultation with WIC researchers. These included examining the following variables for possible inclusion: *15)* use of commercial infant foods [42]; *16)* food insecurity [43]; frequency of consuming different *17)* fruit [44] and *18)* vegetables [45,46]; *19)* use of responsive feeding [47]; and *20)* age of weaning from the bottle [48,49]. The process for selecting components and calculating the IDQI is described below.

The newly constructed IDQI consisted of 16 components: *1)* breastfeeding duration; *2)* exclusive breastfeeding; age of first introduction of *3)* solids, *4)* iron-rich cereals, *5)* cow milk, *6)* sugar-sweetened beverages, *7)* salty or sweet snacks, *8)* other drinks or liquids (e.g., teas or broths), and *9)* textured foods; frequency of consuming *10)* fruit or (*11)* vegetables; frequency of consuming different *12)* fruit or *13)* vegetables; *14)* nonrecommended bottle-feeding practices; *15)* use of commercial baby foods; and *16)* number of meals and snacks.

Statistical analysis

All analyses were weighted to address nonresponsiveness and support national estimates to represent WIC participants who met the ITFPS-2 study enrollment criteria: pregnant or early (<3 mo) postpartum, aged ≥ 16 y, spoke either English or Spanish, and enrolled in WIC for the first time for that pregnancy or child at a clinic expected to enroll at least 30 prenatal women per month. Longitudinal weights were used to have the sample represent the population and compensate for both the unequal sampling probabilities and nonresponse [10]. In addition estimation incorporated the balanced replicated weights as recommended by WIC ITFPS-2 study data use guidelines.

The WIC ITFPS-2 study enrolled 4367 study participants. Participants were excluded for the following reasons: 85 were born prematurely and had very low birth weight, 324 reported at any interviews up to 2 y that their babies had long-term medical problems that could affect eating, and 1100 were excluded for having no HEI-2015 or BMI data collected at either 2, 3, or 4 y of age. Premature infants and those with long-term medical problems were excluded because they have special dietary requirements that are specific to their medical situation and may be unfairly characterized as having poor diets. Unlike the previous study by Au et al. [33], this study conducted conditional multiple imputation to incorporate information from individuals with partial data using conservative count of 10 imputations for each analysis. Normally distributed continuous variables were described using mean ± SD while skew variables were presented using median (Q1, Q3). Categorical variables were described with event counts and proportions.

The process for creating the diet quality index began with converting each candidate index component to a partial utility following the methodology used to develop the CFUI [50]. This method used the von-Neumann and Morgenstern utility theory [51] to convert the variable into a utility ranging from nonadherence to guidelines (value of 0) to complete adherence to guidelines (value of 1) for each individual component. Preference was given to the utility functions that were based on dietary recommendations rather than sample distributions so that a participant's score would be consistent regardless of the dataset being considered and population scores would be comparable over time (Supplemental Table 1).

Each individual candidate index component was then assessed for association with HEI-2015 and BMI z-scores (BMIz) at 2, 3, and 4 y using bivariate linear regression accounting for survey design using survey procedures and available participant weights. Candidate index components found to be marginally associated ($P < 0.1$) with at least 1 of the outcomes retained for inclusion in the final IDQI, which yielded 16 components (Supplemental Table 2). To compute the final IDQI with a maximum possible total score of 1, the displaced ideal method using the Euclidean distance metric was used, mirroring the method used to develop the CFUI [50]. This method has the advantage of assigning high scores to individuals with more consistent scores than the individuals only adhering to individual guidelines.

For predictive validity, regression analysis was used to estimate associations between the total IDQI score (range 0 to 1) and HEI-2015 and BMIz at 2 to 4 y, unadjusted and adjusted for covariates. Analysis was conducted in R version 4.1.1 and SAS version 9.4.

Results

Maternal and child demographic characteristics are shown in Table 1 for the unweighted (n = 2858) and weighted (N = 392,439) samples. Based on the weighted sample, close to half of the mothers were Hispanic (48%) and more than 3-quarters spoke English (78%). Most mothers were overweight or obese (54%) and lived at or below 75% of poverty levels at baseline (62%). Most children were born at a normal birth weight (93%) and close to half were female (47%). More children received some formula (97%) compared with any breastfeeding (84%).

The median IDQI score was 0.36 (Q1, Q3 range: 0.30–0.43, possible range: 0–1.0). Over half of the infants achieved the maximum score for having zero exposures to nonrecommended bottle-feeding practices by 7 mo of age (67%), introducing other drinks or liquids at 12 mo or later (62%), and introducing cow milk at 12 mo or later (62%) (Table 2). Few infants met the maximum score for exclusive breastfeeding (4%), introducing solids between 6 and 7 mo (3%), and consuming ≥4 types of vegetables at 9 mo (2%). Many infants were not introduced to textured foods by 9 mo (56%) and were introduced to sugary sweetened beverages, including soda and non-100% fruit juices, before 12 mo (66%).

All IDQI components were positively related ($P < 0.05$) to HEI-2015 scores in at least 1 point in childhood (2, 3, or 4 y), except for exclusive breastfeeding, age of first introduction of other drinks and liquids, and frequency of consuming different vegetables (Table 3). Breastfeeding duration, exclusive breastfeeding, age of first introduction of cow milk, age of first introduction of sugar-sweetened beverages, age of first introduction of other drinks and liquids, frequency of consuming fruit, and frequency of consuming different vegetables was negatively related to BMIz at 2, 3, or 4 y. The total IDQI score was positively associated with HEI-2015 at 2 y (β = 16.7; 95% CI: 12.6, 20.9; $P < 0.001$), 3 y (β = 14.5; 95% CI: 8.1, 21.0; $P < 0.001$), and 4 y (β = 15.4; 95% CI: 8.4, 22.4; $P < 0.001$); and negatively associated with BMIz at 2 y (β = -1.24; 95% CI: -2.01, -0.47; $P = 0.002$) and 4 y (β = -0.92; 95% CI: -1.53, -0.30; $P = 0.003$).

Discussion

This study examined the predictive validity of a diet quality index during the critical complementary feeding period in low-income US infants. Complementary feeding during infancy is an important period because tastes and food preferences are being established and can often carry over to later childhood and adulthood [52,53]. The IDQI score was negatively associated with BMIz at the age of 2 and 4 y and positively associated with

TABLE 1
Characteristics of participants in the Special Supplemental Nutrition Program for Women, Infants and Children Infant Toddler Feeding Practices Study-2.

Characteristic[1]	Unweighted n = 2858	Weighted N = 392,439
Maternal age at child birth (n, %) [2]		
16–19 y	333 (11.7)	45786 (11.7)
20–25 y	1174 (41.1)	158039 (40.3)
≥26 y	1351 (47.3)	188614 (48.1)
Maternal race (n, %)		
Hispanic	1159 (40.6)	190059 (48.4)
Non-Hispanic White	833 (29.1)	102456 (26.1)
Non-Hispanic African American	708 (24.8)	77484 (19.7)
Non-Hispanic Other	158 (5.5)	22440 (5.7)
Predominant language preference (n, %)		
Spanish	545 (19.1)	86659 (22.1)
English	2313 (80.9)	305780 (77.9)
Marital status at screening (n, %)		
Married	866 (30.3)	133314 (34.0)
Not married[4]	1992 (69.7)	259125 (66.0)
Maternal education level at screening (n, %)		
Less than high school	698 (24.4)	97323 (24.9)
High school	1076 (37.7)	145115 (37.1)
More than high school	1071 (37.5)	148718 (38.0)
Maternal employment status at 6 mo child age (n, %)[3]		
Full-time	537 (21.5)	71097 (20.0)
Part-time	504 (20.2)	68275 (19.2)
Not working for pay	1455 (58.2)	215534 (60.7)
Maternal BMI at screening (n, %)		
Normal or underweight (<25.0 kg/m^2)	1286 (45.0)	180923 (46.1)
Overweight (25.0 to <30.0 kg/m^2)	783 (27.4)	97100 (24.7)
Obese (≥30.0 kg/m^2)	789 (27.6)	114416 (29.2)
Household size at 6 mo child age (n, %)[3]		
2 people	222 (8.9)	29955 (8.4)
3 people	679 (27.1)	95356 (26.8)
4 people	680 (27.1)	100331(28.2)
5 or more people	917 (36.6)	128491 (36.1)
Household poverty level at enrollment (n, %)[3,5]		
≤75% of poverty guideline	1830 (64.0)	242930 (61.9)
>75% but <130%	751 (26.3)	106580 (27.2)
>130% of poverty guideline	277 (9.7)	42928 (10.9)
Child birth weight (n, %)		
Low (<2.5 kg)	152 (5.3)	22810 (5.8)
Normal (2.5 kg to ≤4.5 kg)	2668 (93.4)	364952 (93.0)
High (>4.5 kg)	38 (1.3)	4677 (1.2)
Child sex, female (n, %)	1389 (48.6)	185443 (47.3)
Any breastfeeding (n, %)[6]	2340 (81.9)	328718 (83.8)
Any formula use (n, %)[6]	2728 (95.5)	379326 (96.7)

[1] Values are means ± SDs or frequency (percentage)
[2] Maternal includes other primary caregiver if not mother (<1% of respondents are caregivers other than the baby's biological mother at the time of enrollment).
[3] Because of missing values, the total n is not the same for all variables.
[4] Not married includes divorced, widowed, or separated.
[5] Income at 100% of the Federal Poverty Level was $23,550 for family of 4 in 2013.
[6] The breastfeeding and formula categories do not add up to 100 percent due to coding the participants that consumed *both breast milk and formula* answers in the *any breastfeeding* category and the *any formula use* category.

TABLE 2
Median Infant Diet Quality Index scores for children (7-12 mo) in the Special Supplemental Nutrition Program for Women, Infants and Children Infant Toddler Feeding Practices Study-2 (unweighted n = 2858, weighted N = 392,439)

Index component	Scoring[1]		Results		
	Criteria for minimum score (variable)	Criteria for maximum score (1)	Minimum score, weighted N (%)	Maximum score, weighted N (%)	Median (Q1, Q3) (range 0-1)
Breastfeeding duration	Never breastfed	Breastfed for 12 mo or longer	63721 (16.3)	71268 (18.3)	0.17 (0.02, 0.67)
Exclusive breastfeeding	Introduced formula at birth	Introduced formula at age 7 mo or later	21318 (5.7)	14487 (3.8)	0.14 (0.02, 0.93)
Age of first introduction of solids	Introduced at birth or after 12 mo	Introduced between 6 and 7 mo	34809 (9.0)	11459 (3.0)	0.39 (0.20, 1.00)
Age of first introduction of iron-rich cereals	Introduced at birth or after 12 mo	Introduced between 6 and 7 mo	8524 (2.3)	135682 (36.2)	0.64 (0.36, 1.00)
Age of first introduction of cow milk	Introduced before 12 mo	Introduced at 12 mo or later	139159 (38.5)	222171 (61.5)	1.00 (0.00, 1.00)
Age of first introduction of sugar-sweetened beverages	Introduced before 12 mo	Introduced at 12 mo or later	236264 (66.0)	121709 (34.0)	0.00 (0.00, 1.00)
Age of first introduction of salty or sweet snack	Introduced before 6 mo	Introduced at 12 mo or later	95518 (25.6)	43702 (11.7)	0.25 (0.03, 1.00)
Age of first introduction of other drinks or liquids	Introduced before 6 mo	Introduced at 12 mo or later	51905 (15.2)	213792 (62.4)	1.00 (0.25, 1.00)
Age of first introduction of textured foods	Not introduced by 9 mo	Introduced by 9 mo	177611 (55.5)	142440 (44.5)	0.00 (0.00, 1.00)
Frequency of consuming fruit[2]	Consumed none at 9 mo	Consumed 2 or more times in a day at 9 mo	61093 (16.6)	175093 (47.4)	1.00 (0.50, 1.00)
Frequency of consuming vegetables[2]	Consumed none at 9 mo	Consumed 2 or more times in a day at 9 mo	83999 (22.8)	136726 (37.0)	0.50 (0.50, 1.00)
Frequency of consuming different fruits[2]	Consumed none at 9 mo	Consumed 2 or more types at 9 mo	80925 (21.9)	36772 (10.0)	0.50 (0.50, 0.50)
Frequency of consuming different vegetables[2]	Consumed none at 9 mo	Consumed 4 or more types at 9 mo	84151 (22.8)	5703 (1.5)	0.30 (0.30, 0.60)
Exposure to nonrecommended bottle-feeding practices	2 or more exposures by 7 mo of age	0 exposures by 7 mo of age	25383 (6.9)	245269 (67.0)	1.00 (0.50, 1.00)
Use of commercial baby food	Used for 5 or more food types	Never used	70186 (21.9)	42243 (13.2)	0.40 (0.20, 1.00)
Number of meals or snacks[2]	0 or 1 in a day	5 or more in a day	18369 (5.0)	161575 (43.8)	0.75 (0.75, 1.00)

Values are median (Q1, Q3) or frequency (%)
[1] Utility functions were used to derive a unit-free component score (range, 0–1). The function selected achieved scores for each of the 16 components that were bounded between a minimum score (variable) (indicating poor adherence to guideline) and 1 (indicating adherence with guideline). See Supplemental Table 1 for formulae.
[2] Derived from one 24-h dietary recall at 9 mo. All other components derived from surveys repeated over time.

HEI-2015 at the age of 2, 3, and 4 y. These findings support that adherence to complementary feeding guidelines may influence adiposity and dietary outcomes in low-income children.

The IDQI provides a summary diet quality score that includes nutritional, developmental, and behavioral complementary feeding guidelines. Similar to Golley et al. [25], utility functions were created to combine items with different measurement scales and units. Unlike Golley et al. [25], the utility functions were created to be independent of children within the sample, which previously rewarded children in larger categories and assumed that most children were following complementary feeding guidelines. Thus, the IDQI allows an infant's score to be consistent regardless of the dataset being considered, and in addition, population scores are comparable over time.

Our study demonstrated that over half of the infants had no exposures to nonrecommended bottle-feeding practices by 7 mo of age, which included mixing formula with more or less water, using an infant feeder or bottle with an extra-large nipple hole, or adding cereal to the bottle. In addition, most infants were first introduced to other drinks and liquids, such as teas and broths, and cow milk at 12 mo or later, as is recommended. However, other infant feeding practices needed improvement, such as exclusive breastfeeding, delaying timing of solids introduction, and greater exposure to different types of vegetables. Both exclusive breastfeeding and exposure to different types of vegetables were independently related to lower BMIz scores in childhood, showing particular importance to adhering to these guidelines in this at-risk population.

This study supports that early diet quality affects later adiposity, consistent with previous literature [54–56]. A higher IDQI predicted lower BMIz scores at 2 and 4 y of age, but not at the age of 3 y. This finding was in contrast to the study by Golley et al. [30] which found a relationship between the CFUI and lower waist circumference, but not BMI at the age of 7 y [30]. The predicted effect size of IDQI on BMIz was large, reflecting a z-score difference of 1.24 at 2 y and 0.92 at 4 y across the total possible range of IDQI score (i.e., 0–1, reflecting no adherence to total adherence to infant feeding guidelines). The effect size of this difference can be best understood through an example. For a 2-y-old girl in this study, the median BMI was 17.0 kg/m^2, which approximately corresponded to the 70th percentile based on the *Centers for Disease Control and Prevention growth charts* [57]. The

TABLE 3

Associations between Infant Diet Quality Index (IDQI) scores and outcomes for children (7–12 mo) in the Special Supplemental Nutrition Program for Women, Infants and Children (WIC) Infant Toddler Feeding Practices Study-2 (unweighted n = 2858; weighted N = 392,439)

Index component	BMIz 24 mo	BMIz 36 mo	BMIz 48 mo	HEI 24 mo	HEI 36 mo	HEI 48 mo
Breastfeeding duration	**	**	**	*	**	**
Exclusive breastfeeding	**	**	**			**
Age of first introduction of solids				**	**	**
Age of first introduction of iron-rich cereals				**	**	**
Age of first introduction of cow's milk			**	**	**	**
Age of first introduction of sugar-sweetened beverages			**	**	**	**
Age of first introduction of salty or sweet snack				**	**	**
Age of first introduction of other drinks or liquids	**				**	
Age of first introduction of textured foods			*	**	**	
Frequency of consuming fruit	**			*		*
Frequency of consuming vegetables				**		
Frequency of consuming different fruits						**
Frequency of consuming different vegetables			**			
Exposure to non-recommended bottle-feeding practices					**	**
Use of commercial baby food				**	**	**
Number of meals or snacks					**	*
Index total						
Constructed IDQI	**		**	**	**	**
Constructed IDQI – covariate adjusted models[1]	**		**	**	**	**

Dark grey indicates an association with lower BMIz or higher HEI while grey indicates higher BMIz or lower HEI. * indicates p < 0.10 in survey design linear regressions while ** indicates p < 0.05.
[1]Adjusted for child age, child sex, child birth weight, child race/ethnicity, maternal age, maternal race/ethnicity, marital status, maternal education level, maternal depression score, maternal weight, maternal employment status, household size, household income, and gestational diabetes.

Abbreviations: BMIz, body mass index z-score; IDQI, Infant Diet Quality Index; HEI, Healthy Eating Index.
Dark grey indicates an association with lower BMIz or higher HEI whereas grey indicates higher BMIz or lower HEI.
* indicates $P < 0.10$ in survey design linear regressions while ** indicates $P < 0.05$.
[1]Adjusted for child age, child sex, child birth weight, child race/ethnicity, maternal age, maternal race/ethnicity, marital status, maternal education level, maternal depression score, maternal weight, maternal employment status, household size, household income, and gestational diabetes.

average difference in BMI between infants who adhered to IDQI guidelines completely compared with no adherence was about 1.8 kg/m^2. For girls of median height, shifting an individual from a BMI of 17.0 to 15.2 corresponds to a shift of approximately 1.36 z-scores or 49 percentile points. Furthermore, these relationships were observed even after adjusting for an extensive list of demographic variables, which included maternal weight and infant birth weight.

A higher IDQI score was also positively associated with later diet quality in childhood. Similar to the findings with BMIz, the effect sizes were large, with an increase of between 15 and 17 points out of 100 points in the HEI-2015 score if the IDQI was shifted from 0 to 1. These findings are consistent with Golley et al. [25], which found that the CFUI was positively associated with healthy dietary patterns and inversely associated with unhealthy dietary patterns at 3 y of age in a United Kingdom sample of 6065 children. Similarly, in a study of 1162 US children, healthier complementary feeding behaviors at the age of 1 y was associated with high diet quality at 3 y of age [27]. This also further supports the research that shows that by toddlerhood, most children have established dietary habits that impact long-term weight and health [18,19].

This study examines the predictive validity of the newly constructed IDQI in low-income US infants. A single 24-h dietary recall at each time period was reported by parents, who tend to over-report total energy [58]. Owing to the single 24-h dietary recall at each time period, the HEI-2015 population ratio method was used which represents unusual intakes. A strength of this study, however, is that dietary recalls were collected over multiple time periods to assess the diet quality longitudinally from ages 2 to 4 y. Alternative methods such as replicate 24-h dietary recalls at each period, observation of child intake by researchers, or weighing foods was beyond the budgetary scope of this study. In addition, a valid measure of physical activity was not available in this study. Infants born prematurely and who had a very low birth weight, as well as infants who had a long-term medical problem that could affect eating, were excluded from the analysis because their special dietary needs might have unfairly characterized their diet quality; therefore, the IDQI may not be applicable to these groups. Additionally, close to a third of the sample was excluded for not having BMIz or HEI-2015 scores at either 2, 3, or 4 y of age. The use of survey weights to recreate the original sample and conditional multiple imputation to preserve the sample size helped this study to incorporate information from individuals with partial data. The findings may be representative of women who enrolled in WIC shortly before or after a child's birth and other study criteria but may not be representative of children on WIC at later ages because our study includes participants that no longer remained on WIC.

In conclusion, the IDQI was associated with adiposity and dietary outcomes in early childhood in a sample of US infants from low-income families. Future research should consider using the components of the IDQI as a starting point for extending the healthy eating index or other diet quality indices for infants. In addition, findings from this study may be used to improve WIC nutrition screening assessments and accompanying nutrition education, as well as general pediatric nutrition screening measures. A better understanding of diet quality during the first year of life that contributes to healthy weight maintenance can inform pediatric interventions to lower obesity and improve nutritional outcomes in childhood.

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Author Contributions

The authors' responsibilities were as follows – LEA, LDR, EAF: designed research; LEA, LDR, EAF, CDA: conducted research; CDA: analyzed data; LEA, CDA: wrote the paper; LEA: had primary responsibility for final content. All authors read and approved the final manuscript.

Data Availability

Data described in the manuscript and code book, will be made publicly and freely available without restriction at: https://data.nal.usda.gov/dataset/wic-infant-and-toddler-feeding-practices-study-2-wic-itfps-2-prenatal-infant-year-second-year-third-year-and-fourth-year-datasets-0. Analytic code is available upon request.

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Author disclosures

The authors report no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tjnut.2023.01.037.

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