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The Relationship between Diet Costs and Dietary Adequacy: A Scoping Review of Measures and Methods with a Focus on Cost Estimation using Food Supply Data

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A B S T R A C T

Background: "Diet cost" refers to a methodological approach developed by Drewnowski et al. to estimate individual daily diet costs, where cost vectors are derived by matching prices from food supply data to the food sources of reported intakes from dietary assessment tools. The dietary assessment method and food price collection approach have been found to vary diet cost estimates. There is a need to better understand how food supply prices might be better standardized and attached to price individuals' diets.

Objectives: To conduct a scoping review to examine Drewnowski's diet cost method, with a focus on a detailed description and charting of cost estimation measures and methods used to price individuals' consumed diets.

Methods: Five databases were searched from the inception of each database to March 2023. Included articles comprised analyses of individual-level dietary assessment data matched to food prices to assign estimates of individual daily diet costs.

Results: A total of 55 articles were included, published between 1999 and 2022 from 17 countries. In all studies, cost estimates were intended to be representative of price exposures among individual respondents' dietary assessment data. All studies derived cost estimates from separately collected food prices. 34 (62%) of included articles collected food prices from retail (supermarket) audits. A minority of studies (19, 35%) reported the number of food prices used to cost diets, and those varied widely, ranging from 57 to nearly 4600 distinct food prices per study.

Conclusions: In the absence of a standardized approach to study the relationship between diet costs and dietary adequacy, this scoping review has described methodological concepts and parameters used to price individuals' consumed diets. Our review shows that despite common arithmetic to calculate cost vectors, there is substantial variation in the methods used to select and attach prices from the food supply to self-reported dietary intake assessments.

Keywords: diet cost, diet quality, dietary intake, dietary adequacy, food prices

Introduction

Dietary causes are a leading risk of noncommunicable diseases [1], responsible for over 8 million deaths and 188 million years of life lost to disability globally [1,2]. The cost of food is an important influence in diet and has been identified as a driver of dietary disparities [3–9]. It is generally agreed upon in the literature that on average, healthier diets tend to cost more, whereas less healthy diets tend to cost less [4–8,10,11]. However, our understanding of why this relationship exists remains incomplete [12]. One prominent explanation has been the foods themselves, within an unhealthy food environment: that is, a

Abbreviations: CNPP, Center for Nutrition Policy and Promotion; FFQ, food frequency questionnaire; HEI, Healthy Eating Index; SNAP, Supplemental Nutrition Assistance Program.

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proliferation of cheap and widely available foods that tend to be energy dense and nutrient poor [13–16].

The term “diet cost” began to be used in the nutrition literature in a set of studies by Drewnowski, Darmon, and colleagues [8,17–19]. Darmon and Drewnowski proposed that by attaching standard food prices or individual-level expenditures to individual-level dietary intake data, they could examine the costs of the foods comprising individuals' consumed diets [20,21]. Incorporating principles from development economics to study diet costs [22], they specifically investigated the relationship between diet cost and energy intake or energy density of intake [17,23], and concluded that higher dietary energy density predicts lower diet costs (measured as energy cost) [23]. Distinctively, these early studies proposed poverty and obesity hypotheses, arguing that poverty results in dietary intakes that are energy dense and nutrient poor [14,19,24,25], positioning the cost of healthy eating as a driver of obesity. These findings were countered, however, by other studies employing modeling approaches such as linear programming to show, theoretically, that a nutritious diet need not necessarily cost more [26–30]. However, the acceptability of these healthier lower cost diets among the general population was low, whereas the feasibility remains unknown [31,32].

The methodological foundation of Drewnowski's diet costing approach, on which the diet cost-dietary adequacy association was proposed, was the secondary analysis of previously collected dietary assessments, from population-based cohorts of adults, or costing of population-representative nutritional surveillance datasets such as those from health surveys conducted periodically by governments [4–9]. Darmon and Drewnowski referred to themselves as “early adopters” of this novel technique and emphasized its methodological importance as a way to study real-world costs incurred by individuals to achieve their consumed diets [20,21]. The estimation of diet costs was accomplished by attaching cost vectors to individuals or household respondents, derived by matching prices from food supply data, to the food sources of reported intakes from dietary assessment tools [11].

Soon after their diet cost approach was introduced, several methodological challenges were raised. One line of critique was about the relative differences in energy density (price per calorie) of different food sources [22,33], which raised the possibility that energy autocorrelation between the cost and intake vectors had resulted in a spurious association. Yet to date little is known about the food prices that can be used in diet cost estimation conducted based on Drewnowski's method. A few methodological diagnostic efforts in the diet cost literature have attempted to compare diet cost estimates by dietary assessment method [34–37]. The dietary assessment method, and the source of food prices used in the diet cost estimation, have both been found to vary diet cost estimates and its relationship to dietary adequacy [34–37]. Furthermore, the one study that varied the diet cost estimation method with a consistent dietary assessment tool found that depending on the number and type of food prices matched to diets and the geographic specificity of those food prices, diet costs significantly varied [37]. This suggests that the methods for selecting among food supply prices and attaching them to the intake data may have direct implications for our understanding of the strength and direction of the relationship between diet costs and dietary adequacy.

No review of the literature to date has examined the cost estimation component of diet cost methodology, in particular the techniques used to select a “standard” [4–8,10,11] set of food supply prices that could be attached to dietary assessments. To our knowledge, the only meta-analysis to date in the diet cost literature, by Rao et al. [11], identified that on average, those with the healthiest food-based dietary patterns spend an extra \$1.50 per person per day (or ~\$550 per person annually) as compared with the least healthy dietary pattern [11]. However, when examining the price of food among food groups, meats/protein had largest price differences: healthier options cost \$0.29/serving (95% confidence interval: \$0.19, \$0.40) and \$0.47/200 kcal (\$0.42, \$0.53) more than less healthy options [11]. Heterogeneity in diet costs may arise from two dimensions: the absolute price of foods and the relative prices of different food products; as well as the food budget available to individuals to allocate to different foods. Although Rao et al.'s [11] review and meta-analysis distinctively addressed heterogeneity, it combined varied dietary studies (using individual dietary assessments) as well as market-based studies reporting on the mean retail price of foods, that is, analyzing diet costs and food costs. This means that Rao et al. [11] meta-analyzed studies that costed consumed diets, as well as those studies employing a theoretical cost of consuming those foods in the food supply.

Our objective was a scoping review [38] to revisit Drewnowski's diet cost method, with a return to their original focus on pricing individuals' consumed diets. A scoping review can support answering “how” questions about the conduct of studies in a field to clarify its concepts and parameters, an indicator for choosing a scoping review over other knowledge synthesis designs [39]. The following review systematically describes and charts in a tabular format the cost estimation parameters and techniques used in the application of Drewnowski's technique to draw together the state of knowledge. We aimed to explore in detail how the collection and use of food source data for cost estimation in dietary assessment-based diet costing impacts our understanding of diet costs, and its implications for our understanding of the association between diet costs and dietary intakes and adequacy. Our diet cost review is the first, to our knowledge, to focus on the significance of this individual consumed-diet method in detail in the dietary literature specifically. Two other newer reviews have explored food supply pricing alone [40,41], that is, the cost of discrete food items and food groups, which remain theoretical costs of what an individual could buy rather than the cost of their dietary intakes. To focus our inquiry, we specifically examined the measures and methods that encompass the handling and precision of food sources and food supply price data to derive individual daily diet costs, as originally defined by Drewnowski and Darmon [8,17–19]. Diet costs were thus defined as the amount of money an individual would have been required to spend to consume the foods reported through dietary assessment. In doing so, we also extend upon Rao et al. [11], adding the subsequent decade of literature. A scoping review for these purposes is a better choice than a systematic review, because scoping reviews are intended to descriptively map and clarify concepts in a literature that can then be critically discussed [39].

Methods

This scoping review followed the Joanna Briggs Institute evidence synthesis method for scoping reviews [42], and the findings are reported as guided by the PRISMA extension for scoping reviews [43]. Consistent with best practice for scoping reviews, a detailed, a priori plan for the review including search strategy was created in consultation with a librarian scientist; scoping reviews are not routinely registered and remain ineligible for Prospective Register of Systematic Reviews registration [44,45].

The search was conducted in CINAHL, PsycInfo, Academic Search Premier, Food Science and Technology Abstracts, Social Work Abstracts, CAB Abstracts, and Medline with slight syntax modifications, to identify peer-reviewed articles published from the beginning of each database to January 2022, and updated in March 2023. The search strategy captured diet and cost search terms as identified and tested in collaboration with a librarian scientist and utilized a title-abstract-keyword search strategy. The search strategy was created to balance search quality and quantity so as to maximize the number of relevant articles returned while limiting irrelevant articles. A complete search strategy for all databases can be found below.

Medline search (performed 22 July, 2021 and updated 6 March, 2023)

TI-AB-KEY ((nutrient* OR energy OR diet*) N3 (quality OR value OR dens*)) AND (cost* OR price* OR pricing OR economic* OR expen*)).

CINAHL search that includes all the other databases (performed 22 July, 2021 and updated 6 March, 2023)

S1. TI ((nutrient* OR energy OR diet*) N3 (quality OR value OR dens*)) OR AB ((nutrient* OR energy OR diet*) N3 (quality OR value OR dens*)) OR SU ((nutrient* OR energy OR diet*) N3 (quality OR value OR dens*))

S2. TI (cost* OR price* OR pricing OR economic* OR expen*) OR AB (cost* OR price* OR pricing OR economic* OR expen*) OR SU (cost* OR price* OR pricing OR economic* OR expen*)

S3. S1 AND S2

Inclusion criteria

Table 1 outlines the Population, Intervention, Comparison, Outcomes and Study criteria for study selection. To be included, articles had to comprise an analysis of diet costs, not food prices, such that the cost of consumed diets (and not theoretical diets) were estimated. Included studies used individual-level dietary assessment data to measure dietary intake, described the entirety of an individual's diet over a period of time, and derived estimates of individual-level diet costs, defined as the amount of money an individual would have needed to spend to be able to consume the foods. Short communications were accepted with new empirical analyses. The included studies must have described how food prices were collected and used to derive diet costs and outline the food price matching process, which refers to any technique in which prices of foods from a food supply source (for example, retail audits, scanner data) were assigned to reported food sources of intakes consumed in an individual's diet. No restrictions were placed on the age, sex, gender, socioeconomic status, race or ethnicity of the study population, or country of study. The full text of each study must have been published in English.

TABLE 1
PICOS criteria for study selection.

Parameter	Inclusion criterion	Exclusion criterion
Population	Any age, sex, gender, socioeconomic status, race or ethnicity, or country of study were included with the full-text published in English	Studies that did not measure freely chosen diets of respondents
Intervention	Not applicable	
Comparison	Measure the difference in cost between dietary intake/quality levels or the difference in dietary intake/quality between different levels of diet cost	When diet costs methods did not allow for the pricing of individual consumed food items (e.g., receipt data or income used as a proxy for diet costs)
Outcome	≥1 of the following 3 outcome measures: dietary intake, dietary quality, and/or diet cost	Any other outcomes
Study design	Cross-sectional or cohort study designs	Systematic or scoping reviews, interventions, commentaries, conference abstracts, or research protocols

Abbreviation: PICOS, Population, Intervention, Comparison, Outcomes and Study.

Exclusion criteria

Studies were excluded if they were systematic or scoping reviews, interventions, commentaries, conference abstracts, or protocols. Studies that did not measure freely chosen diets of respondents [for example, participants in the United States' Supplemental Nutrition Assistance Program (SNAP)], or that were restricted to dietary intakes from a given setting (for example, cafeterias), were excluded. Articles on associations at the ecological level (for example, neighborhoods or households) were excluded, as were those that used income or food prices (to measure theoretical diets) as a proxy for diet costs. Articles that used exclusively individuals' own receipt data to measure individual/household food expenditures, and no other researcher-assembled food supply data, were excluded [35]. The use of annotated receipts is an important approach in dietary research to quantify individual and household food expenditures. However, receipts measure types and quantities of food products purchased by individuals, not those eaten, and contain costs for only those foods in the receipts and selected by that individual from the larger food supply. Matching of food sources in receipts to food sources in self-reported dietary intakes thus introduces several unique reliability, missing data, and estimation-related methods topics about cost estimation, and were deemed outside the feasible scope of this review [35].

Study selection, extraction, and charting

The review plan was completed before and decided upon before completing the review. Four reviewers were involved in the study selection and extraction process. Each article in the title-abstract and full-text screen was independently reviewed by 2 reviewers (HW or LJK were the first reviewers and GL was the second reviewer). Conflicts were reviewed and resolved by a fourth reviewer (CLM). Additionally, reference lists of two key diet cost reviews [11,40] were searched by two reviewers (HW or LJK) and verified by a third (GL) to obtain any missed articles ($n = 3$). Finally, two reviewers (HW or LJK) independently extracted half of the included articles each using a piloted form, and the third reviewer (GL) verified the extraction in consultation with the fourth reviewer. The extraction form collected information on the following variables:

- Study design, distinguished by sampling. Population-representative studies were defined as those whose sampling methodology ensured that the sample was representative of the underlying population distribution (for example, by sex, age, and region) and relied on a published/described sampling frame to systematically recruit participants. Population-based studies used less rigorous sampling strategies, such as a random or purposive sample of a previously recruited cohort.
- Type and quantity of dietary assessment tool(s) used. Using these data, we reported commonly used dietary assessment tools and compared the potential error introduced by each tool when used for diet costing.
- Dietary adequacy measure(s) (intakes of food groups, foods, food components or nutrients, and/or diet quality indices based on energy or other food-based diet pattern). These data were collected to understand the types of dietary adequacy measures of importance in the diet cost literature and to examine the impact of the unit of measurement (for example, grams compared with g/kcal) on estimating diet costs.
- Food supply source for item prices and all available pricing characteristics, including location, medium, and source of pricing (for example, retail, scanner, government). Using these data we estimated the ratio of researcher collected prices, to numbers of food items reported by respondents in their dietary assessment data, to examine the degree to which diet cost estimates reflected a flattening of the "true" variation in food items in respondents' diets (for example, all sources of "apples" in a diet being assigned a single price for a generic food supply "apple"). The three types of food price collection methods were defined as follows: *1*) retail—prices from food retail audits conducted in-store or online, *2*) consumer scanner data/market research—prices collected from in-store scans at the cash register or in-home scans of products purchased by individuals, and *3*) government—food price data collected from government-sourced national food prices.
- Matching process between dietary intakes and food prices. We collected details about how dietary intakes were matched to food prices to examine any bias that may have been introduced in the diet costing process (for example, number of food prices, handling missing food prices, level of aggregation for food prices and dietary intake when matching products).
- Diet cost derivation and measure (for example, \$/d, \$/kcal). We reported on the diet cost measure to identify any biases that may be introduced when matched with the dietary adequacy measure.

This scoping review was intended to characterize the state of methodology, and was not an outcomes synthesis. No exclusions of studies based on study quality were undertaken. Because the objective of our scoping review was to explore the scope of methods and measures in this field of study to clarify its concepts and parameters [39], we have described authors' varied approaches using their own terminology and reasoning wherever possible, in contrast to a rank-ordering or classification of the constituent articles as of higher and lower quality on methodological grounds.

Results

Of 11,907 articles returned from the search, after removal of duplicates ($n = 1{,}037$), 10,870 articles were screened by title and abstract. In total, 235 articles underwent full text review; 184 did not meet the inclusion criteria. Four articles were added at the update in March 2023 resulting in 55 included articles, comprising 41 (75%) unique datasets (Figure 1 and Table 2).

Time and origin of the included articles

Included articles were published between 1999 and 2022. Table 2 is organized by date to illustrate temporal evolution. The largest proportion of included articles were from the United States ($n = 15$) [4,7,25,51,56–58,61,63,66,74,77,78,83,84]. The remaining studies were from France [8,15,23,46–48] and Japan

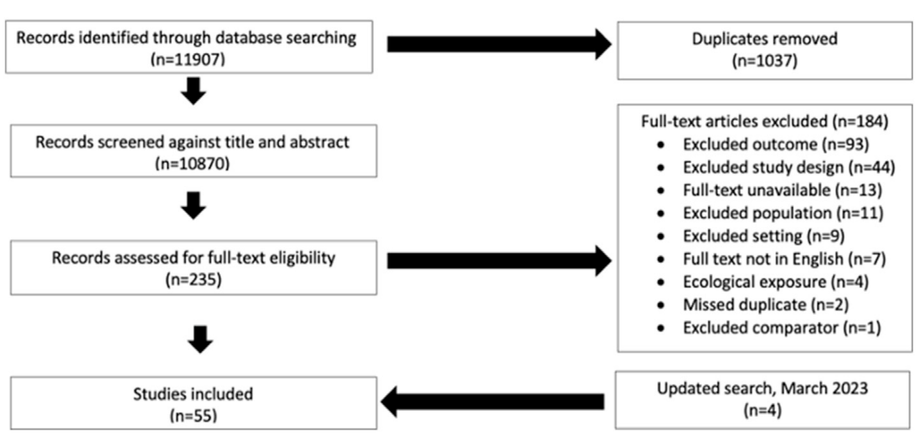

FIGURE 1. PRISMA flow diagram, diet cost review, 1999–2022.

[7,49,52,53,68,79] ($n = 6$ each), Spain ($n = 5$), [6,50,67,69,86], the United Kingdom ($n = 5$) [9,64,65,72,80], Mexico ($n = 3$) [70, 88,89], the Netherlands ($n = 3$) [55,76,82], Germany ($n = 2$) [59,62], and Belgium ($n = 2$) [85,81], Canada [81], China [75], Greece [54], Malaysia [73], Sweden [12], Taiwan [60], South Africa [90], and Portugal [87] ($n = 1$ each).

Study design and participants

The vast majority of analyses were secondary analyses on previously collected dietary data ($n = 48$, 87%). Several articles reported on diet-cost analyses with newly collected primary data examining other empirical questions, such as the Seattle Obesity Study ($n = 6$). The remaining 7 (13%) studies collected all their data specifically for the diet cost study.

By study design, the minority of studies (26, 47%) used dietary datasets based on a population-representative sampling design (for example, United States NHANES, Japanese National Health and Nutrition Survey, or Encuesta Nacional de Salud y Nutrición 2012). The largest number of studies (29, 53%) used sociodemographic and dietary intake data from other population-based designs, such as: the UK Women's Cohort Study, the Nurses' Health Study, the Seattle Obesity Study series (I, II, and III), the Osaka Maternal and Child Health Study, and the Dortmund Nutritional and Anthropometric Longitudinal.

Of the total 55 studies included in the review, 2 articles (4%) comprising cohort studies analyzed their data longitudinally [74, 67]; the remaining 53 (96%) studies conducted cross-sectional analyses on existing or new data, with 25 of these from population-representative samples.

The inferential analyses that comprise these diet cost studies have been based on an exceedingly wide range of sample sizes, from 130 to 78,191 respondents: <1000 ($n = 12$, 22%), 1001–5000 ($n = 35$, 65%), 5001–10,000 ($n = 3$, 5%), 10,001–20,000 ($n = 3$, 5%), >20,000 ($n = 2$, 4%). Most studies examined individuals 15 y and older ($n = 44$, 80%). The remaining studies examined diet costs in children/youth ranging from 2 to 24 y old (9, 16%) and older adults over 65 (2, 4%).

Of the included studies, 9 (17%) used sociodemographically defined subpopulation samples, such as low-income individuals. Several population-representative studies excluded subpopulations within their sampling designs (for example, pregnant or breastfeeding women).

Main outcome

Included studies examined the association between diet costs and dietary intakes/adequacy in both directions, with 25 studies (45%) examining dietary intakes/adequacy as the main outcome and 29 studies (53%) examining diet cost as the outcome. Eight (15%) studies examined specific dietary intakes as the primary outcome, and 17 (31%) examined diet quality (for example, dietary patterns). Dietary adequacy measures were reported as energy-adjusted intake ratios, such as sodium expressed as a percentage of energy (% energy), intake quantity (for example, g or mg), or intake quantity per energy (for example, g/1000 kcal). Other dietary adequacy measures included energy density, energy intake, holistic indicators of diet [that is, Healthy Eating Index (HEI) scores], intakes of food groups (that is, fruits, vegetables, beverages, fats and oil), and nutrients (that is, sodium, potassium, vitamins and minerals). Diet cost outcomes were expressed as daily diet costs ($/d or $/wk or $/mo, $n = 11$), energy-adjusted diet costs ($/kcal, $n = 12$), or both ($n = 6$). One study descriptively examined both diet quality (HEI-2015 score) and energy-adjusted diet costs as outcomes [88].

More than half of the reviewed studies ($n = 30$, 55%) reported excluding certain food and beverage items, from both dietary intake and diet cost estimates, frequently, water ($n = 24$), alcoholic beverages ($n = 22$), and coffee/tea ($n = 7$), and for diverse data quality reasons, such as poor recall, high variability and unreliability of the food supply prices for such foods, or low energy density (for water, tea/coffee) [48,92]. Only three studies explicitly described these exclusion criteria [15,23,70].

Dietary assessments

Data collection tools

The most common instrument was a semiquantitative food frequency questionnaire (FFQ) ($n = 31$, 56%). Of the 31 studies, 28 described the number of foods that were collected from the FFQ to be priced ranging from 73 foods to 1247 items: <100 items ($n = 2$), 101–300 items ($n = 17$), 301–500 items ($n = 8$), and >500 items ($n = 1$).

The second most used dietary assessment tool was a 24-h dietary recall ($n = 15$, 27%) followed by food records/diaries ($n = 13$, 24%) and biomarkers ($n = 1$, 2%). Four studies used a combination of instruments to obtain less biased estimates of usual intakes: for example, parallel FFQ and a single 24-h recall [55]; repeated measures (for example, two 24-h dietary recalls) [85,91]; or biomarkers (with FFQ) [52].

Assigning food sources of dietary intakes

The majority ($n = 39$, 71%) of articles used national food databases/food composition tables only to assign food sources of intakes, such as the General Food Composition Database [88,89]. Two studies employed a national food database and expert judgment for items not easily matched using the database alone [8,25]. Another two studies collected food composition information from a survey-specific nutrient database and supplemented remaining food item information from other national food composition databases [47,48]. Nine studies used a nutrient database that was developed specifically for an FFQ [51,56,58, 64,72,76–78,83]. A final three studies used researcher-created or third-party nutrient composition databases [6,61,87].

Handling implausible or missing data

In 22 articles, the authors explicitly addressed underreporting, based on energy ($n = 21$) and/or food/nutrient ($n = 8$) intakes. Eighteen articles excluded implausible diets from the final set of observations, for energy using Willett (for example, <500 kcal and >3500 or 5000 kcal) or Goldberg (for example, based on Basal Metabolic Rate and physical activity) cutoffs as appropriate [93,94]. One study removed respondents who left >10 items on the FFQ blank [7], another removed responses based on implausible nutrient intakes [88], and 6 removed respondents with "incomplete dietary data" [75,85,88,89,90,91].

Sources and collection of food prices

In all studies, a separate food price dataset was used, developed, or adapted to match prices to food sources of dietary intakes. Prices were derived from more than one of the following three food supply sources: online or in-person retail audits ($n =$

TABLE 2

Description of included studies that examined the relationship between diet cost and dietary intake/quality ($n = 55$).

First author	Year	Country	Study name	Target population	Food price collection method	Diet cost measure	Dietary intake tool	Dietary intake measure	Covariates	Outcome measure	Main analysis
Cade [9]	1999	United Kingdom	UK Women's Cohort Study	Adults (women)	Government, retail	$/d	FFQ	WHO healthy eating indicator	Age, highest level of household education, BMI	Dietary quality	Ordinal logistic regression
Darmon [23]	2004	France	Val-de-Marne Dietary Study	Adults	Government	$/d	FFQ	Food groups, Energy density	Age, gender	Diet cost	Linear regression
Drewnowski [15]	2004	France	Val-de-Marne Dietary Study	Adults	Government	$/kcal	FFQ	Food groups, Nutrients	Age, gender	Diet cost	Linear regression
Andrieu [46]	2006	France	Enquete Individuelle et Nationale sur les Consommations Alimentaires (INCA)	Adults	Government, retail, scanner	$/kcal	7-d food diary/ record	Nutrients, Energy density, energy intake	Age, gender	Dietary intake	ANOVA
Schroder [6]	2006	Spain	N/A	Adults	Government	$/d	FFQ	Energy density, HEI, Mediterranean Diet Score	Age, sex, energy consumption, leisure-time physical activity, smoking	Dietary quality	Linear regression
Maillot [47]	2007	France	Enquete Individuelle et Nationale sur les Consommations Alimentaires (INCA)	Adults	Scanner	$/kcal	7-d food diary/ record	Nutrients, Food groups	Sex	Dietary quality	ANOVA
Maillot [48]	2007	France	Enquete Individuelle et Nationale sur les Consommations Alimentaires (INCA)	Adults	Government, retail, scanner	$/d	7-d food diary or record	Energy density, Nutrients	Age, energy intake	Diet cost	General linear model analysis
Murakami [49]	2007	Japan	N/A	Adults	Government	$/kcal	Diet history questionnaire (FFQ)	Nutrients, food groups	Age, sex, region or province, household size, smoking, alcohol consumption, height, weight, rate of eating, currently trying to lose weight	Dietary intake	Linear regression
Drewnowski [8]	2007	France	Enquete Individuelle et Nationale sur les Consommations Alimentaires (INCA)	Adults	Government, retail, scanner	$/wk	7-d food diary/ record	Energy density	Age, energy intakes	Diet cost	Linear regression
Lopez [50]	2009	Spain	Seguimiento Universidad de Navarra (SUN) study	Adults (university graduates)	Government	$/kcal	FFQ	Food groups, Mediterranean Diet Score, "Western" diets	Age, sex, years of education, marital status, employment	Diet cost	Linear regression
Monsivias [51]	2009	United States	N/A	Adults (university faculty)	Retail	$/kcal	FFQ	Nutrients, Energy density	Age, household income, highest level of household education	Dietary quality	Linear regression
Murakami [52]	2009	Japan	The Japan Dietetic Students' Study for Nutrition and Biomarkers	Adults (female university students)	Government, retail	$/kcal	Biomarkers, Diet history questionnaire (FFQ)	Nutrients	Survey year	Dietary intake	Linear regression
Murakami [53]	2009	Japan	Osaka Maternal and Child Health Study (OMCHS)	Adults (pregnant women who did not work outside of the home)	Government, retail	$/d	Diet history questionnaire (FFQ)	Nutrients, food groups, Energy density	Age, household income, highest level of household education, gestational age, parity, cigarette smoking, change in diet in the previous month, physical activity	Dietary intake	Linear regression

(continued on next page)

TABLE 2 (*continued*)

First author	Year	Country	Study name	Target population	Food price collection method	Diet cost measure	Dietary intake tool	Dietary intake measure	Covariates	Outcome measure	Main analysis
Townsend [25]	2009	United States	N/A	Adults	Retail	$/kcal	FFQ	Nutrients, Energy density	None	Dietary intake	ANOVA
Bernstein [7]	2010	United States	The Nurses' Health Study	Adults (female nurses)	Government, retail	$/d	FFQ	AHEI	Age, highest level of household education, race/ethnicity, marital status, living arrangement, employment status	Dietary quality	Linear regression
Vlismas [54]	2010	Greece	The ATTICA study	Adults	Retail	$/wk	FFQ	Mediterranean Diet Score	Age, gender, household income, highest level of household education, smoking, physical activity, CVD history	Dietary quality	T-test
Waterlander [55]	2010	the Netherlands	The Amsterdam Growth and Health Longitudinal Study (AGHLS, measured in 2000) and Longitudinal Ageing Study Amsterdam (LASA, measured in 2007)	Adults	Retail	$/kcal	FFQ or 24-HR	Energy density	None	Diet cost	ANOVA
Aggarwal [56]	2011	United States	The Seattle Obesity Study (S.O.S) I	Adults	Retail	$/kcal	FFQ	Energy density, Nutrients	Age, gender, race/ethnicity, household size, total energy intake	Diet cost	Linear regression with mediation analyses
Rehm [57]	2011	United States	National Health and Nutrition Examination Survey (NHANES 2001–2002)	Adults	Government	$/kcal	24-HR	HEI-2005	Age, sex, highest level of household education, race/ethnicity, income-to-poverty ratio	Dietary quality	Linear regression
Ryden [12]	2011	Sweden	Riksmaten – children	Children	Government, retail	$/kcal	4-d food diary/record	Energy density, HEI-2005	None	Diet cost	Linear regression
Aggarwal [58]	2012	United States	The Seattle Obesity Study (S.O.S) I	Adults	Retail	$/d	FFQ	Nutrients	Age, gender, race/ethnicity, total caloric intake	Diet cost	Linear regression
Alexy [59]	2012	Germany	Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study	Children	Retail	$/d	3-d food diary/record	Energy density	Age, gender, energy density	Diet cost	Linear mixed effects regression models
Lo [60]	2012	Taiwan	Elderly Nutrition and Health Survey (1999–2000)	Older adults	Government, retail	$/d	24-HR	Dietary Diversity Score	Gender, age, personal education, working status, personal income, household income	Diet cost	Linear regression
Monsivais [61]	2012	United States	The Seattle Obesity Study (S.O.S) I	Adults	Retail	$/d	FFQ	Nutrients	Dietary energy, age, gender, race	Dietary intake	General linear models
Alexy [62]	2014	Germany	Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study	Children	Retail	$/d, $/kcal	3-d food diary/record	Nutrient Quality Index (NQI), Healthy Nutrition Score for Kids and Youth (HuSKY)	Age, gender, parental overweight, total energy intake	Diet cost	Linear mixed effects models
Beydoun [63]	2015	United States	Healthy Aging in Neighborhoods of Diversity across the Life Span Study (HANDLS)	Adults	Government	$/d	24-HR	Nutrients, HEI-2010	Age, sex, highest level of household education, race/ethnicity, marital status, poverty status, current smoking status, % energy consumed at home	Dietary quality	Linear regression
Mackenbach [64]	2015	United Kingdom	Fenland Study	Adults	Retail	$/kcal	FFQ	Fruit and vegetable intake	Individual education, household income,	Dietary intake	General linear models

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TABLE 2 (*continued*)

First author	Year	Country	Study name	Target population	Food price collection method	Diet cost measure	Dietary intake tool	Dietary intake measure	Covariates	Outcome measure	Main analysis
									household size, age, sex		
Timmins [65]	2015	United Kingdom	National Diet and Nutrition Study (NDNS)	Adults	Retail	$/d, $/kcal	4-d food diary/record	Food groups	Age, sex, food energy, BMI, cigarette consumption, household income, marital status, individual education, household size, occupation, alcohol consumption	Diet cost	Linear regression
Rehm [4]	2015	United States	National Health and Nutrition Examination Survey (NHANES 2007–2010)	Adults	Government	$/kcal	24-HR	HEI-2010	Gender, race/ethnicity	Dietary quality	Linear regression
Drewnowski [66]	2015	United States	National Health and Nutrition Examination Survey (NHANES 2001–2002)	Adults	Government	$/kcal	24-HR	Nutrients	Age, race/ethnicity, gender, income-to-poverty ratio (IPR), education	Diet cost	Linear regression
Schröder [67]	2016	Spain	N/A	Adults	Government, retail	$/kcal	FFQ	Energy density, Mediterranean Diet Score Diet Score	Sex, age, smoking, energy intake, education, leisure-time physical activity	Diet cost	Linear regression
Okubo [68]	2016	Japan	Comprehensive Survey of Living Conditions and the National Health and Nutrition Survey	Adults	Government	$/kcal	Food diary/record	Nutrients, Energy density	Age, sex, household income, highest level of household education, household size, marital status, home ownership	Dietary intake	Linear regression
Schröder [69]	2016	Spain	enKid Study	Children	Government, retail	$/d, $/kcal	24-HR	Mediterranean Diet Score	Age, sex, region/province, community size, maternal education, energy over- and underreporting	Diet cost	Linear regression
Mendoza [70]	2017	Mexico	Encuesta Nacional de Salud y Nutrición (ENSANUT 2012)	Adults	Government	$/kcal	FFQ	Nutrients, Energy density	None	Diet cost	Bivariate regression analysis
Shiraki [71]	2017	Japan	Three-generation study of women on diets and health	Adults (women)	Government, retail	$/kcal	Diet history questionnaire (FFQ)	Nutrients, Food groups	Survey year, residential area, weight, smoking, alcohol, supplement use, medication, physical activity, living status, eating out, dietary reporting stats, education, marital status, age	Diet cost	Linear regression
Mackenbach [72]	2017	United Kingdom	Fenland study	Adults	Retail	$/kcal	FFQ	DASH dietary accordance	Age, sex, individual educational attainment, energy intake, household income, distance to nearest supermarket	Dietary quality	Logistic regression
Pondor [73]	2017	Malaysia	N/A	Adults	Government	$/kcal	FFQ	HEI	Age, individual income	Dietary quality	Linear regression
Beydoun [74]	2018	United States	Healthy Aging in Neighborhoods of Diversity across the Life Span (HANDLS)	Adults	Scanner	$/d	2 × 24-HR	Nutrients, HEI-2010	Age, sex, highest level of household education, race/ethnicity, literacy,	Dietary quality	Linear regression

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TABLE 2 (*continued*)

First author	Year	Country	Study name	Target population	Food price collection method	Diet cost measure	Dietary intake tool	Dietary intake measure	Covariates	Outcome measure	Main analysis
									poverty status, current smoking status, current drug use		
Zhang [75]	2019	China	Dietary Quality During Childhood study (DQDC)	Children	Government, retail	$/kcal	3 × 24-HR	Energy density, Chinese Children Dietary Index score	Age, gender, family location, parental education level, family income level	Diet cost	Linear regression
Mackenbach [76]	2019	the Netherlands	HELIUS study	Adults	Retail	$/kcal	FFQ	Dutch Healthy Diet index (DHD15-index) – 2015	Age, sex, energy intake, individual education, physical activity and smoking	Dietary quality	Linear regression
Aggarwal [77]	2019	United States	Seattle Obesity Study series (I and II)	Adults	Retail	$/kcal	FFQ	Plant-based compared with animal-based proteins	Age, gender, race/ethnicity, household income, individual education, percentage of energy from animal proteins, percentage of energy from plant proteins	Diet cost	Linear regression
Rose [78]	2020	United States	Seattle Obesity Study III (SOS III)	Adults	Retail	$/kcal/mo, $/mo	FFQ	HEI-2015	Age, gender, individual education, race/ethnicity, marital status, food assistance use	Dietary quality	Linear regression
Kojima [79]	2020	Japan	Japanese National Health and Nutrition Survey (NHNS)	Adults	Government	$/d, $/kcal	1-d food diary/record	Nutrients, Food variety score (FVS), Dietary diversity Score (DDS)	None	Diet cost	ANOVA
Hobbs [80]	2020	United Kingdom	UK National Diet and Nutrition Survey years 1–4	Adults	Retail	$/d	4-d food diary/record	Nutrients, Alternative Healthy Eating Index Score (AHEI)-2010	Age, sex, total energy intake	Diet cost	ANCOVA
Bukambu [81]	2020	Canada	2014 REALKids Alberta survey	Children	Retail	$/kcal	FFQ	Diet Quality Index (DQI)I, Canada's Food Guide food group recommendations	Gender, household income, highest level of household education, food security status, energy intake, urbanization status, and body weight status	Diet cost	Linear regression
Hoenink [82]	2020	the Netherlands	EPIC-NL Cohort	Older adults	Retail	$/d	FFQ	Dutch Healthy Diet Index, DASH diet	Age, sex, study center, energy intake, individual and household education level	Dietary quality	Linear regression
Gupta [83]	2021	United States	Seattle Obesity Study III (SOS III)	Adults	Retail	$/kcal/mo	FFQ	HEI-2015, nutrients	Age, sex, highest level of household education, race/ethnicity, property value	Dietary quality	Linear regression
Conrad [84]	2021	United States	National Health and Nutrition Examination Survey (NHANES 2005–2016)	Adults	Government	$/d	24-HR	Food groups, Alternative Healthy Eating Index-2010	Age, sex, household income, highest level of household education, race/ethnicity	Diet cost	Linear regression
Pedroni [85]	2021	Belgium	Belgian National Food Consumption Survey, 2014–2015	Adults	Scanner	$/d	1xFFQ and 2 × 24-HR	Mediterranean Diet Score, Healthy Diet Indicator	Age, sex, highest level of household education, region/province, total energy intake	Diet cost	Linear regression

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TABLE 2 (*continued*)

First author	Year	Country	Study name	Target population	Food price collection method	Diet cost measure	Dietary intake tool	Dietary intake measure	Covariates	Outcome measure	Main analysis
Pastor [86]	2021	Spain	N/A	Children	Government	$/d, $/kcal	3 × 24-HR	Mediterranean Adequacy Index (MAI)	Age, sex, school location, energy intake	Diet cost	Logistic regression
Alves [87]	2022	Portugal	Portuguese National Food, Nutrition, and Physical Activity Survey (IAN-AF 2015–2016)	Adults	Retail	$/d	2 × 24-HR or 2 × 1-d food diary/ record	Mediterranean Diet Score	Age, sex, individual education level, region	Diet cost	Linear/Poisson regression
Curi-Quinto [88]	2022	Mexico	Encuesta Nacional de Salud y Nutrición (ENSANUT 2012)	Adults	Government	$/kcal	FFQ	Healthy Eating Index Score (HEI)-2015	None	Diet cost, Dietary quality	T-test
Curi-Quinto [89]	2022	Mexico	Encuesta Nacional de Salud y Nutrición (ENSANUT 2012)	Adults	Government	$/kcal	FFQ	Healthy Eating Index Score (HEI)-2015	Sociodemographic variables	Dietary quality	Linear regression
Mulabisano [90]	2022	South Africa	Data from 4-pooled studies	Children	Retail	$/d, $/kcal	24-HR	Mean adequacy ratio (MAR), Dietary diversity score (DDS), Average nutrient density (Ave-ND)	None	Diet cost	Median regression
Pedroni [91]	2022	Belgium	Belgian National Food Consumption Survey, 2014–2015	Children	Scanner	$/d	24-HR or 1-d diet diary	Kidmed Index Score	Sex, age, household type, household education, country of birth, region, total energy intake	Diet cost	Linear regression

Underlined terms highlight socioeconomic covariates discussed in the review.
Unless otherwise specified, the dietary assessment tool was only administered at 1 timepoint.
ANCOVA, Analysis of Covariance; ANOVA, Analysis of Variance; CVD, Cardiovasular disease; FFQ, food frequency questionnaire; HEI, Healthy Eating Index.

34, 62%), government-sourced national food prices (n = 30, 55%), or consumer scanner data/market research (n = 7, 13%).

Government-sourced national food price data were largely based on economic monitoring of the food supply by the government's statistics department (for example, Consumer Price Indices). As such, this food supply price source typically had no direct correspondence between its constituent food items and the items used within nutritional surveillance dietary assessments. The sole exception appeared to be the USDA's Center for Nutrition Policy and Promotion (CNPP) food price database, the only purpose-built government administrative food price dataset identified [95], which used Nielsen Homescan Consumer panel data corresponding to food items in the 2001–2002 cycle of the NHANES population nutrition surveillance survey; this dataset was never updated as far as we know [95].

Where online or in-person retail food supply sources were used, audits were administered specifically for the given survey without reporting of the area sampling frames used to access retail outlets. Consumer/market research food price sources comprised third-party retail or at-home scanner data. In some instances (n = 13, 24%), multiple food supply sources of food prices were used in the same analysis, such as market data, with the French National Institute of Statistics, and supermarket websites [46]. In all cases, the final food price dataset was intended to be representative of the population who completed the dietary assessment surveys; however, the match to area or household sampling frames or representativity in relation to dietary assessments was typically not reported. The vast majority of retail prices used were supermarket prices, with the rationale that retail food supply sources comprised the predominant purchased food exposure and limitations in capture of eating-out locations were noted. Six studies collected fast-food establishment prices alongside retail prices [49,52,53,71,75]. There were no further details provided about how the fast-food prices were integrated into the FFQ responses to price food items. One additional study by Conrad et al. [84] priced food consumed away from home separately from foods consumed at home by creating a food away from home coefficient for all major food groups to convert food prices from retail outlets to food a food away from home price for foods reported in the 24-h recalls as being consumed away from home.

A minority of studies ($n = 19$, 35%) explicitly mentioned how many food prices were used by researchers to cost the food items in respondents' diets. There was a very wide distribution of ratios of food prices-to-numbers of items reported, from 57:1 to nearly 4600:1; $n = 6$ used <500, 501–1000 ($n = 9$), >1000 ($n = 4$).

Calculation of diet cost estimates

Respondent diet costs were computed the same way in all articles included in this review. Daily diet costs were computed by multiplying the quantity (g) of each food item reported in the dietary assessment tool by the unit price ($/g) of that food item and then summed across all items consumed. Similarly, in some studies energy-adjusted diet costs were computed by multiplying the energy (kcal) of each food item reported by the energy cost of that item ($/kcal) summed across all items consumed and standardized to a certain number of calories (for example, $/2,000 kcal). Other studies computed energy-adjusted diet costs using crude estimates by dividing daily diet costs ($/day) by the total number of calories the respondent consumed and multiplying that number by a standard number of calories (i.e., 2,000kcal). Depending on the dietary assessment tool used, the method by which food prices were matched to the type and quantity of food reported in the dietary assessment tool differed. For instance, the type and quantity of dietary intakes collected via 24-h recalls and diet diary/record were directly matched to food prices to compute diet costs [57,84]. For FFQs, well-established methods that take into account the frequency of consumption, time period of collection, and the types of foods reported are used to compute diet costs [7,23,49,52,53,71]. In just over half of articles (29, 53%), food prices were corrected for waste and slink factors such that diet costs reflected the quantity of food purchased to consume the amount of food reported considering waste and other refuse. The included articles did not compare diet costs to food budgets/income but rather explored the relationship between diet costs and dietary adequacy with or without socioeconomic factors including income.

Covariate adjustment, in particular socioeconomic factors

Several covariates were explored, most frequently age, sex/gender, highest level of household education, race/ethnicity, and household income measures; others included region/rurality, household size, physical activity level, smoking status, car ownership, food security status, alcohol intake, BMI, and consuming food away from home. Seventeen (31%) articles adjusted for income: of those, 15 used total annual household income, 1 used both household and individual annual income, and 2 used an income-to-poverty ratio. Three articles that controlled for household income also adjusted for household size. Twenty-three (42%) studies adjusted for education, typically based on attainment (individual and/or household). Ten (18%) studies included effect modification/mediation analyses to examine the relationship between diet costs and dietary intakes by income, education, region, ethnicity, age, and sex [4,56,57,59,64,76,82,85,87,89].

Discussion

Our review captured 55 articles published between 1999 and 2022 that examined the relationship between individual daily diet costs and dietary adequacy, operationalized as either dietary intakes and/or diet quality, using dietary assessment data. No other scoping reviews to date have examined the methodological foundations of the diet cost literature, and our focus here was to examine the cost estimation techniques to derive individual daily diet costs on the basis of secondary analyses of dietary assessments, a literature stemming from the developments of Drewnowski, Darmon, and colleagues [8,17–19]. This scoping review focuses on the diet cost approach that matches food sources of intakes from collected population dietary assessments, to representative lists of food prices, separately collected, and/or derived from food supply data, which permits the estimation of a diet cost for each individual or respondent, then used to examine the relationship between diet costs and dietary intakes and/or quality.

Our review shows that despite common arithmetic to calculate cost vectors, there is substantial variation in the methods used to select and attach prices from the food supply to self-reported dietary intake assessments. We found that diet costs were most commonly derived from retail audits and government sources of national food prices, and the majority were conducted in adult populations and employed cross-sectional population-based studies. FFQs accounted for just over half of the dietary assessment tools used to collect dietary intake information. Together with the dietary assessment method, the combination of dietary intake tools with food price tools to estimate diet costs can introduce potential sources of error that would not arise from the use of each tool alone.

Potential sources of error in the derivation of diet costs, arising from cost estimation

Over half of the included studies in our review were based on a semiquantitative FFQ (n = 31, 56%), and of these, 9 studies used a nutrient database developed specifically for the FFQ [51,56,58,64,72,76–78,83]. Use of FFQs in diet costing requires the assembly of a single price list for all respondents, on the basis of the FFQ food item list. Hence, any cost variation experienced by each respondent is actually eliminated through the population-level assignment of a standardized price for the item they chose, and even if adjusted for group-level characteristics of respondents to examine between-person variation cannot account for individual, or within-person, variation in food sources—and hence food prices [96]—that comprise what respondents reported they ate. This diminishes a principal advantage of using respondent-level dietary data for the estimation of diet costs, in contrast to observational assessments of the food supply, that is, food cost analyses.

Diet cost literature has evolved using other self-report dietary assessment tools [52,55,85,91], such as 24-h diet recalls, diet diary/records, and corroboration with biomarkers. These methods allow the proximal assignment of costs, such as food item selections and quantity (g) consumed [97]. Our review indicates, however, that the opportunity to assign proximal and precise costs is underused. The assembly of food prices and their matching to intakes in this review varied widely, with variation in reporting, and little agreement on what might point to a future gold standard. The majority of articles in this review (n = 47, 85%) selected a single assumed consumer purchasing location, supermarkets, for the assignment of prices.

Furthermore, to overcome the measurement error introduced with the administration of a dietary assessment tool at a single time point (most commonly 24-h dietary recalls), a minority of studies administered repeated measures of the dietary assessment tools. In these cases, intakes and prices were averaged across the repeated measures [75], or multiple tools used to discern usual intakes (such as 24-h dietary recalls with an FFQ) [85]. One study that was not captured in this review employed a novel method to capture usual diet costs by applying the National Cancer Institute (NCI) method to both diet costs and dietary intakes in their analysis [98].

A few studies considered the representativity of food prices; for instance, in Townsend's analysis, eight supermarkets (one large supermarket chain and one small independent market in each county) were selected to be representative of participants' food shopping habits of four counties in California [25]. No study has examined the assumptions in use of government price monitoring of commodified economically important groups of foods.

There was no agreement across the literature on the geographical area precision needed or quantification of error when food supply sources are matched to intake data. More than half of the articles ($n = 33$, 60%) included in the present review used (secondary) food price data that were collected ad hoc, without assessing correspondence to food items in the dietary assessment used.

Of note, the few existing food price databases that were used were not created for the express purposes of the diet costing research. Two studies described the method by which food prices were inflated to match the year of dietary intake data collection [84,70], but temporal rationales for food supply price source match to intakes were lacking. Prices may have combined online or in-person retail food audits, national economic monitoring data such as retail consumer price indices, or using private sector (market-based) consumer scanner data, with few studies examining those sources' competing biases in pricing that may under- or overestimate price.

For example, in retail audits, a common practice is to capture the least expensive, smallest package size, whereas in scanner data, exact prices paid by consumers may be utilized in a given sampling frame [95,99–101]. Geographic scale of retail audits, in relation to the consolidation of the market food supply, can shape cost estimates by biasing price collection toward or away from regional commonly consumed and supermarket own-brand products [96]. Scanner-based data or price indices are business surveillance tools, and the priority is to price items commonly purchased, blunting the price dispersion that may be part of true population distributions of food cost burdens [95]. Correlated error may also be introduced, because national economic monitoring itself relies on periodic collection of food prices through either retail audits or scanners. Error in certain sources of prices may also be correlated with the nutritional quality of the diet. For instance, if individuals purchased two different varieties of a product (for example, white bread and whole grain bread), one price may be used for both products if only the commonly consumed white bread was audited [102]. Emerging studies of prices within the consumer food environment have shown that such details about the method of food price collection are important to understand, because they may be associated with representativity of price assignment to individuals' dietary intakes, and consequently diet cost estimation [102].

In one of the most thorough instances of a food price list assembled with nutritional surveillance in mind (that is, the CNPP database), food prices were derived based on the popularity of consumer purchases weighted to a specific population distribution [95]. However, the CNPP database still lacks regional weighting and seasonality, omits nutritionally significant food groups (for example, alcoholic beverages), has a differing sampling frame to that of its counterpart dietary assessment tool, and does not weight prices by individual characteristics in relation to food purchases (for example, do all those who identify as White males purchase foods the same way?). Only 2 studies in Mexico addressed the known food environment issue of regional disparities in food prices, using location of residence to match prices to intakes [88,89].

A minority of studies (19, 35%) identified the number of food prices available to match to dietary intake data. The majority of studies that used FFQs reported the number of food items that needed to be matched. A recent analysis of the utility of the Canadian Consumer Price Index to estimate diet costs showed that the specificity of pricing varied by food group: meat and milk product prices were well differentiated (that is, many prices), whereas price variation was limited for monitored snacks, fruits, vegetables, and sweets [102]. This has implications for examining diet quality because prices may differ both between and within food groups based on their nutritional value.

Diet costs analyses by Rehm et al. [57] and Bernstein et al. [7] have developed and applied a systematic process to match food prices to food sources. One Belgian study identified that 70% of the items had prices attached to them and developed a protocol to account for the missing prices by attaching a price of an item with similar nutritional composition [85]. Another study in China priced items from a variety of sources including both national sources and local supermarkets [75]. Murakami et al. ($n = 3$) [49,52,53] supplemented national retail price data with food prices for missing items from nationally distributed supermarket and fast-food chains in major Japanese cities. No study has yet investigated or quantified the biases that might arise from mixing food supply sources to address missing data. Increasing our understanding of the ways in which combining food price sources and accounting for missing food prices impacts the estimations of diet costs and their relationship to dietary intake is imperative to understand the type and magnitude of error that might be introduced in the process by which food prices are matched to dietary intakes.

The use of socioeconomic covariates

Briefly, the use of socioeconomic covariates bears discussion. Twenty-seven of the included studies (49%) included more than one measure of socioeconomic status as part of their models, with the most common, total annual household income. However, only 3 studies included a covariate such as household size to adjust for the impacts of total income at the household level. This is a potentially significant gap: for instance, a total annual household income of $60,000 has different implications on spending behaviors based on household size (for example, 1-person household compared with a 4-person household). In the included studies, lower income tended to be associated with lower diet costs and poorer diet quality; however, 2 studies identified that this relationship did not always hold true. For instance, an analysis among British adults found that income was an effect modifier: at the lowest diet cost, low income predicted lower fruit and vegetable intake, whereas at the highest diet cost, low income predicted higher fruit and vegetable intake [64]. A second study among Taiwanese older adults identified a subpopulation of elders with the highest dietary diversity score despite spending the equivalent cost per day outlined by the World Bank as an indicator of poverty [60]. Careful consideration of socioeconomic covariates is paramount to be able to disentangle the relationship between diet cost and dietary adequacy, especially with socioeconomic variables that can be measured both at the individual and household level.

Implications of the focus on cost estimation in diet costing

By focusing on the measures and analytical techniques used in cost estimation, this review has implications for related literature in population dietary assessment as well as the diet-related behavioral outcomes of food supply interventions. The feature that brings these methodological literatures together is the dedicated consideration of the use of food supply variables, with an eye to the need to potentially price them. This review also has, ultimately, some pressing significance for policy; with record global food inflation, the results of diet costs studies are increasingly important to a breadth of food policy, social policy, and food affordability research and interventions [103]. A recent systematic review of experimental studies to evaluate dietary responses to fiscal (food price) interventions showed large differences in price sensitivity by individual/household factors [104]. Cost estimation is critical to disentangle in the daily diet cost-diet quality association, particularly as our review shows that our existing understanding of cost-related variation in diet quality may have been detected at the expense of limiting true, and multilevel, population variation in prices paid for their diets by survey respondents. Improving our understanding of cost estimation biases is moreover important to refine our ability to detect heterogeneity in the diet cost association for the many subpopulations who bear a greater burden of nutritional vulnerability, such as the growing socioeconomic and structural factors influencing household material deprivation and which predict food insecurity status.

Strengths and limitations

This is the first review, to our knowledge, to critically examine the methods used in diet cost studies, and has focused on providing a detailed "how" of the methodology, specifically, describing cost estimation hindrances and gaps. This is a novel contribution that brings together the important methodological interconnectedness between food price, consumer food environments, and diet costs subfields. This scoping review does not attempt to create definitive field-specific definitions, only to report the terms, definitions, measures, and methods as closely as we could to the original language used by those who have employed the cost estimation techniques developed by Drewnowski, Darmon, and others. This review had a number of limitations. First, the majority of included studies were conducted in European or North American countries among otherwise free-dwelling, healthy, and socioeconomically secure individuals in population-based cohorts. Additionally, only studies published in English were included. Hence, the generalizability of these diet cost results may be limited, and this limitation hence carried through our synthesis. Second, in an effort to focus on the implications for population research, our exclusion criteria may have omitted salient methodological developments, as a consequence of excluding studies in select populations (for example, hospital settings, SNAP/Special Supplemental Nutrition Program for Women, Infants, and Children programs) and in which a number of studies used receipt data to measure proximal expenditures. Fourth, although we were able to characterize gaps in the cost estimation process, we were unable to quantify the resulting magnitude of error. Neither the cost estimation methods of each study were presented uniformly across studies nor the foundation for cost estimation methods decisions; for instance, nearly two-thirds of included studies did not include features such as the number of foods used to price diets. As such, we decided that it would be most informative to examine the features of cost estimation through description and charting guided by the scoping review method; future research and meta-analyses could elaborate upon the impact of differences in cost estimation approaches. Finally, some relevant studies may have been missed as result of the search strategy used. The diet cost literature does not use consistent terminology that makes it difficult to capture the breadth of the literature. With the assistance of a librarian we created a search strategy that balanced quality of returned searches with quantity. To minimize missed studies, we reviewed the reference list of 2 key reviews in the diet cost literature.

Conclusion

In the absence of a standardized approach to study the relationship between diet costs and dietary adequacy, we have sought to summarize concepts and parameters used in the individual dietary assessment method known as diet costing. Our review suggests that diet cost methods continue to be of interest to nutritional epidemiology, but attention should be invested toward developing transparent and consistent methods for cost-estimation approaches, because this literature's significance expands beyond its subfield in population dietary assessment. By improving these methods we can refine our understanding of how diet costs are associated with dietary adequacy to support achievement of healthier diets within and among diverse population groups.

Author contributions

The authors' responsibilities were as follows – GL, CLM: coled the formulation of the research question and study design, interpretation, and share responsibility for final content; GL: led the data collection, analysis, and writing of the manuscript; CLM: contributed to the analysis and writing of the manuscript; LJK, HW: contributed to the data collection; LEC, MH, LJK, HW, YY, VT: contributed to the data interpretation and editing of the manuscript; and all authors: read and approved the final manuscript.

Conflict of interest

All authors have no conflicts to declare.

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Data availability

Data described in the manuscript, code book, and analytic code will be made available upon request pending application and approval.

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