A Comparison of Self-Reported Energy Intake With Total Energy Expenditure Estimated by Accelerometer and Basal Metabolic Rate in African-American Women With Type 2 Diabetes

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OBJECTIVE — This study assesses the validity of dietary data from African-American women with type 2 diabetes by comparing reported energy intake (EI) with total energy expenditure (TEE) estimated by an accelerometer and basal metabolic rate (BMR).

RESEARCH DESIGN AND METHODS — EI of 200 African-American women was assessed by three telephone-administered 24-h diet recalls using a multiple-pass approach. Physical activity was measured over a 7-day period by accelerometer, which also provided an estimate of TEE. Underreporting of EI was determined by using cutoffs for EI-to-TEE and EI-to-BMR ratios.

RESULTS — Participants, on average, were 59 years of age, with a BMI of 35.7, 10.5 years of diagnosed diabetes, and 10.7 years of education. Mean EI was 1,299 kcal/day; mean EI-to-TEE and EI-to-BMR ratios were 0.65 and 0.88, respectively. Among the 185 subjects with complete dietary data, 81% ($n = 150$) were classified as energy underreporters using the EI-to-TEE ratio cutoff; 58% ($n = 107$) were classified as energy underreporters using the EI-to-BMR ratio. Energy underreporters had significantly lower reported fat, higher protein, but similar carbohydrate intakes compared with non-underreporters. The EI-to-TEE ratio was not significantly associated with any demographic variables or following a diet for diabetes, but it was inversely associated with BMI ($r = -0.37$, $P < 0.0001$). In a multivariate model, demographic variables, BMI, and following a diet for diabetes explained 16% of the variance in the EI-to-TEE ratio, with the latter two variables being the only significant predictors (inversely associated).

CONCLUSIONS — Widespread energy underreporting among this group of overweight African-American women with type 2 diabetes severely compromised the validity of self-reported dietary data.

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Abbreviations: BMR, basal metabolic rate; DLW, doubly labeled water; EI, energy intake; IQR, interquartile range; MET, metabolic equivalent; PAL, physical activity level; RMR, resting metabolic rate; TEE, total energy expenditure.

Accurate estimates of dietary intake are important in interpreting the effects of dietary interventions on dietary behaviors and treatment outcomes. Because assessments of dietary intake are generally obtained by self-report, they are prone to a number of reporting biases, which may lead to misrepresentation of actual intake and compromise the validity of the data. There is ample evidence that underreporting energy intake (EI) is a common phenomenon associated with dietary assessments (1–3). However, the degree of underreporting varies greatly, from 10 to 91%, depending on several population characteristics and the method, definition, or cutoff value used to classify energy underreporters. The most commonly identified characteristics associated with energy underreporting are high BMI (4–6), female sex (7–9), increased age (10–12), and the desire to lower body weight (13–15). Only a few studies, however, focus specifically on African Americans (16) or individuals with type 2 diabetes (17).

The purpose of this research was to assess the validity of diet self-reports in a sample of older African-American women with type 2 diabetes by comparing reported EI with total energy expenditure (TEE) and basal metabolic rate (BMR). Because an objective measure of physical activity was collected, we were able to calculate EI-to-TEE ratios and did not have to rely on published age- and sex-specific cutoff levels of physical activity (18), which is an approach often used to define energy underreporting (based on EI-to-BMR ratios) (19,20). Estimates of energy underreporting based on the more commonly used EI-to-BMR cutoff equation are included to allow for comparisons with other published reports. In addition, we present data comparing the reported dietary composition of under- versus non-underreporters, and we also include a description of the relationship between energy underreporting, demographic factors, and behaviors of trying to lose weight and following a diet for diabetes.

RESEARCH DESIGN AND METHODS

— Study participants were recruited from seven primary care practices in central North Carolina to participate in a randomized controlled trial of a diet and physical activity intervention (21,22). To participate, patients had to be African-American women, ≥40 years of age, with type 2 diabetes (defined as diagnosis of diabetes at ≥20 years of age with no history of ketoacidosis). Exclusion criteria included diabetes secondary to another condition, pregnancy/lactation, and renal insufficiency. Eligible patients were referred to the study by their primary care clinicians. Written informed consent was obtained from each participant in accordance with study protocols approved by the institutional review board of the University of North Carolina at Chapel Hill. Participant data for this study represent baseline measures.

Table 1—*Participant characteristics**

	Value
Age (years)	59.2 ± 10.0
Diabetes duration (years)	10.5 ± 10.0
Educational achievement (years)	10.7 ± 3.0
Total annual household income <$10,000 (%)†	52.2
Weight (kg)	94.2 ± 21.5
BMI (kg/m²)	35.7 ± 8.0
GHb (%)‡	11.1 ± 2.7
Diabetes treatment (%)	
Oral medication only	47.7
Insulin only	32.3
Combined insulin and oral medication	10.0
Diet only	10.0

Data are means ± SD. *n = 200; †data provided by 111 participants, option given to not provide income data; ‡normal range for assay is 5.5–7.8%.

Physical activity

Physical activity was assessed with a Caltrac accelerometer (Muscle Dynamics, Torrance, CA), a small electronic monitor worn on the waist that measures vertical accelerations that, when worn correctly, is considered to objectively measure physical activity energy expenditure (23,24). Participants were instructed to wear the accelerometer during waking hours for 1 week, exclusive of time spent bathing or when in water. At the end of 1 week, participants were called to obtain accelerometer results and to assess daily wearing time and number of days worn. If a participant wore the monitor for <4 h on a given day, it was not considered as a day worn. To be included in the physical activity analysis, a minimum of 4 days of wearing the monitor was required.

Each subject's height, weight, sex, and age were programmed into the monitor before wearing. The average daily value for TEE was calculated by dividing the accelerometer's reading for total kilocalories (in kcal) by the number of days worn. Daily energy expenditure attributed to physical activity (physical activity kcal/day) was calculated by subtracting both the estimated resting energy expenditure (derived from the Mifflin equation) (25) and the thermic effect of food (23) from TEE.

Dietary intake

A series of three 24-h dietary recalls of the previous day's food and drink intake were obtained via telephone using a multiple pass approach and Nutrition Data System software (NDS version 2.91/2.92, 1996/1997; Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN); nutrient calculations were performed using NDS Food Database version 2.92, Nutrient Database version 13A. Before data collection, participants were given a chart with 2-dimensional portion sizes (26) and were instructed on how to use it during the interview. Trained interviewers called participants unannounced to conduct the dietary recalls on 2 weekdays and 1 weekend day. No calls were made on major holidays, 2 days before or 3 days after Thanksgiving or Christmas, or 1 day after other major holidays.

If the total energy calculated for a recall was <600 kcal or >6,000 kcal, these extremes in dietary intake values were not included in the analysis. Such cutoffs, although arbitrary, are commonly used to exclude reporting errors (27). Participants with extremes in dietary intake on at least two of the recalls were excluded from the analysis. Reported dietary intake was calculated as the average of eligible recalls.

Energy underreporting

The concept of energy underreporting is based on the principle that in the presence of a stable weight, i.e., no weight loss or gain, reported EI should equal TEE, or the ratio of EI to TEE should be equal to 1. When EI < TEE, the EI-to-TEE ratio is <1, and there is some level of energy underreporting. To validate reported EI against TEE, we used the ratio of EI to TEE <0.79 as a cutoff value defining energy underreporters. This value represents the lower 95% confidence limit of the ratio of EI to TEE, where TEE is measured directly by doubly labeled water (DLW) (28,29)

When energy underreporting is defined in terms of the ratio of EI to BMR, the Goldberg equation (19,20) is generally used to establish the cutoff values. Because an individual's total energy requirement and BMR both vary with age, sex, and body size, TEE may be represented in general terms as multiples of BMR (30). This expression of energy requirement as the ratio of TEE to BMR is known as the physical activity level (PAL) or the average daily metabolic rate (19). If TEE is replaced by the term BMR × PAL, then energy underreporting can be defined as: EI < BMR × PAL or the ratio of EI to BMR < PAL.

Age- and sex-specific average values for PAL have been established using data from DLW studies (18,30). Using these PAL values, the Goldberg formula is applied to calculate the cutoff below which it is unlikely that the reported intake represents either usual intake during the measurement period or a randomly low intake. Because the published mean values for PAL were generated from healthy adult men and women living in Europe, North America, and Australia, we used

Table 2—*Dietary intake, energy expenditure, and energy ratios**

	Value
Dietary intake	
Total EI	1,298.9 ± 368.8
Energy distribution (% of total [g])	
Carbohydrates	47.0 ± 9.1 (151.5 ± 48.4)
Protein	19.5 ± 5.0 (62.3 ± 20.0)
Fat	34.3 ± 7.5 (51.0 ± 20.5)
Saturated fat	10.8 ± 2.8 (15.9 ± 6.8)
Monounsaturated fat	13.7 ± 3.6 (20.2 ± 8.8)
Polyunsaturated fat	6.7 ± 1.9 (9.9 ± 4.6)
Cholesterol (mg/day)	281.3 ± 136.3
Estimated energy expenditure (kcal/day)†	
TEE	2,053.7 ± 355.0
Physical activity	325.5 ± 169.7
Difference between EI and TEE	−754.7 ± 457.2
Estimated BMR	1,503.6 ± 243.8
EI:TEE ratio	0.65 ± 0.19
EI:BMR ratio	0.88 ± 0.27
PAL‡	1.32 ± 0.11

Data are means ± SD *n = 185; †measured by accelerometer, n = 199; ‡PAL = ratio of TEE to BMR, n = 199.

instead subject-specific PAL values obtained in our sample from accelerometer data.

Statistical analysis

Analysis of data included Pearson product moment correlation for bivariate associations, general linear model regression for multivariate associations, and nonparametric one-way ANOVA test for the comparison of differences between continuous variables. For all analyses, a P value of <0.05 was considered significant. Data were analyzed using SAS-PC version 8.0 (SAS Institute, Cary, NC).

RESULTS — Participant characteristics are summarized in Table 1. This sample of 200 African-American women ranging from 41 to 83 years of age was primarily of lower socioeconomic status and characterized by high levels of obesity (73.5% had a BMI >30 and only 6% had a BMI <25).

Reported dietary intake and estimated energy expenditure are presented in Table 2. The data for reported EI excludes 15 observations whose reported EI was <600 kcal/day for at least two of the three 24-h recalls. These excluded observations represent women who were not significantly different from others in the sample by age, BMI, or years with diagnosed diabetes; they had, however, lower educational achievement (8.6 vs. 10.9 years, $P < 0.01$). EI data were collected over a period of 5–181 days (median = 28 days; interquartile range [IQR] = 18–54 days), with 28% of dietary recalls started while the accelerometer was being worn. In most cases, energy expenditure data were collected before dietary recalls, with a median of 7 days (IQR = −1 to 26 days) between the end of wearing the accelerometer and the first dietary recall. The time elapsed between measures of EI and TEE was, however, not significantly correlated with EI ($r = 0.05$, $P = 0.48$), TEE ($r = 0.11$, $P = 0.11$), or the EI-to-TEE ratio ($r = 0.02$, $P = 0.79$).

The reported dietary pattern presented in Table 2 closely resembles that currently recommended by the American Diabetes Association (31) for protein (15–20%), polyunsaturated fats (∼10%), cholesterol (<300 mg), and energy from monounsaturated fats and carbohydrates combined (60–70%). The reported intake of saturated fats is slightly higher than the currently recommended level of <10% of total EI. The average reported EI represented 88% of BMR and 65% of estimated energy expenditure. Physical activity expenditure findings (based on accelerometers worn for an average of 6.7 ± 0.6 days) indicate this group of women was, on average, rather sedentary.

The percent of dietary reports classified as energy underreporting varied by the cutoff value used. Using the ratio of EI to BMR cutoff based on the Goldberg equation, 58% ($n = 107$) were classified as energy underreporters. Applying the ratio of EI to TEE <0.79 as a cutoff resulted in 81% ($n = 150$) of the sample as energy underreporters. If the commonly used "survival minimum" PAL of 1.27 for women (30) was applied, the percent energy underreporting in this sample would have been 92% ($n = 170$). It should be noted that these latter two estimates of energy underreporting are based on cutoffs derived from TEE data measured by DLW.

In comparing energy underreporters to non-underreporters based on both EI-to-TEE and EI-to-BMR ratio cutoffs (Table 3), underreporters were found to have significantly higher TEE and BMR (both related to higher BMI). PAL was significantly higher in energy underreporters classified by EI-to-BMR ratio cutoff only. Irrespective of the cutoff used, reported intake of protein was significantly higher, and intakes of all fats were significantly lower in energy underreporters. There was no significant difference in reported carbohydrate intake.

To determine which characteristics were associated with the EI-to-TEE ratio, bivariate and multivariate analyses were conducted. EI was significantly correlated with TEE ($r = 0.20$, $P = 0.006$), and the EI-to-TEE ratio was inversely associated with BMI (r = −0.37, $P < 0.0001$). No significant relationships were found for the EI-to-TEE ratio with age, education, income, or years with diagnosed diabetes. Participants who reported they were "trying to lose weight" had significantly higher BMI than participants who were not (mean 37.5 vs. 32.0, $P < 0.0001$), but there was no significant difference in reported EI. There was, however, significantly lower reported EI among women who said they were following a diet for diabetes (mean 1,206.9 vs. 1,418.8 kcal/day, $P < 0.0001$). Unlike the findings with participants who reported that they were trying to lose weight, there was no significant mean difference in BMI comparing participants who said they were following a diet for diabetes with those who were not.

Regressing the EI-to-TEE ratio on BMI, age, education, years with diagnosed diabetes, and following a diet for diabetes resulted in 16% of the variance in the ratio

Table 3—*Comparison of underreporters with non-underreporters of energy intake using two cutoffs**

	TEE			BMR		
	Underreporters (EI-to-TEE ratio <0.79)	Non-underreporters (EI-to-TEE ratio ≥0.79)	*P*	Underreporters (EI-to-BMR ratio < Goldberg cutoff)	Non-underreporters (EI-to-BMR ratio ≥ Goldberg cutoff)	*P*
n	150	35		107	78	
EI-to-TEE ratio	0.57 ± 0.12	0.95 ± 0.14	<0.0001	0.53 ± 0.09	0.85 ± 0.16	<0.0001
TEE (kcal/day)	2,099.1 ± 348.2	1,859.0 ± 320.3	0.0003	2,151.7 ± 340.6	1,919.2 ± 331.4	<0.0001
EI (kcal/day)	1,189.7 ± 274.2	1,767.2 ± 358.2	<0.0001	1,098.4 ± 224.2	1,574.1 ± 351.1	<0.0001
EI-to-BMR ratio	0.79 ± 0.17	1.28 ± 0.21	<0.0001	0.71 ± 0.14	1.11 ± 0.23	<0.0001
BMR (kcal/day)	1,532.3 ± 241.3	1,381.0 ± 217.8	0.0008	1557.5 ± 234.9	1,429.8 ± 237.8	0.0004
PAL	1.33 ± 0.11	1.30 ± 0.08	0.162	1.34 ± 0.11	1.30 ± 0.10	0.012
Energy distribution (% of total)						
Carbohydrate	47.4 ± 9.6	45.6 ± 6.6	0.30	47.6 ± 10.0	46.3 ± 7.9	0.36
Protein	20.0 ± 5.3	17.2 ± 2.8	0.003	20.3 ± 5.7	18.3 ± 3.7	0.006
Fat	33.4 ± 7.7	37.9 ± 5.5	0.001	32.9 ± 7.5	36.2 ± 7.1	0.002
SFA	10.6 ± 3.0	12.0 ± 2.1	0.009	10.4 ± 2.9	11.4 ± 2.8	0.017
MFA	13.2 ± 3.6	15.4 ± 2.8	0.0008	13.0 ± 3.6	14.6 ± 3.4	0.005
PFA	6.6 ± 1.9	7.3 ± 2.0	0.039	6.4 ± 1.8	7.1 ± 2.0	0.009

Data are means ± SD. *n* = 185. *EI-to-TEE ratio cutoff based on the lower limit of the 95% CI, with TEE measured by DLW (28). EI-to-BMR ratio cutoff is based on the Goldberg equation using subject-specific PAL (19). MFA, monounsaturated fatty acids; PFA, polyunsaturated fatty acids; SFA, saturated fatty acids.

of EI to TEE explained ($F = 6.73$, $P < 0.0001$), with BMI ($\beta = -0.009$, 95% CI −0.012 to −0.005, $P < 0.001$) and following a diet for diabetes ($\beta = -0.067$, 95% CI −0.123 to −0.012, $P < 0.02$) as the only significant predictors. BMI alone explained 13% of the variance in the EI-to-TEE ratio. "Trying to lose weight" did not emerge as an independent predictor of EI-to-TEE ratio because of its significant correlation with BMI.

CONCLUSIONS — In this sample of African-American women with type 2 diabetes, the validity of self-reported EI was severely compromised by energy underreporting. Energy underreporting increased with increasing degrees of overweight, whereas the reported macronutrient intakes were generally consistent with the currently recommended diet for diabetes, particularly among the energy underreporters. The observed differences in dietary composition of energy underreporters compared with those who were not are consistent with prior reports that show obese individuals specifically underreport foods high in fat and/or carbohydrates rather than total dietary intake (32–33). No differences in the reporting of carbohydrates, however, were observed in this sample of women with diabetes. Because energy underreporters were not only more likely to report that they were following a diet for diabetes, but actually reported diets closely matching the currently recommended diet for diabetes, it seems plausible that these study participants were more than likely reporting what they should be eating rather than actual intake.

Comparing the findings of this research with the only other report in the literature of energy underreporting among patients with type 2 diabetes, we find similar overall results, where "at least 50% of EIs were statistically likely to be underreported," and obese women were likely to report intakes similar to the diabetes dietary recommendations (17). Adams (17) found that among women, 42% (≥75 years) to 73% (40–64 years) were energy underreporters (defined by EI-to-BMR ratio < published PAL values); reported fat intake was significantly lower, with protein and carbohydrate intakes significantly higher among energy underreporters. Our findings, based on the Goldberg cutoff for EI-to-BMR ratio < PAL (Table 3), were similar with respect to reported fat and protein intakes, but no significant differences were found for carbohydrate intake.

As with all studies that seek to classify energy underreporters, estimates from this study vary with the cutoff values used. These cutoff values are generally based on the lower limit of the 95% confidence interval around the mean EI-to-BMR or EI-to-TEE ratio. The variances associated with measures of EI, BMR, and TEE are a function of the measurement method and determine these cutoff values. When applied to our study data, cutoffs based on data from TEE or BMR measured directly yield higher proportions of energy underreporters (81 and 93%, respectively) than cutoffs based on methods using estimation where the variances are larger (58% in this study where BMR is estimated).

The findings in this report are based on self-report of EI and estimates of energy expenditure (BMR and physical activity) from standard equations and accelerometer measurements. With very limited data available on the dietary intake and physical activity of African-American women with diabetes, comparisons are limited to findings from studies with African-American samples (16,34). In the study by Yanek et al. (16), where only 11% of the sample (mean age of 55 years) had diagnosed diabetes, and 60% had a BMI >30 kg/m^2, the average EI obtained by telephone-administered dietary recall was 1,587 ± 690 kcal/day (288 kcal/day greater than our findings). Kumanyika et al. (34), in their sample of African-American women (mean age 42 years and 50% with BMI ≥27 kg/m^2) who completed three telephone-administered

24-h recalls, reported EIs of 1,510 ± 436 kcal/day. Compared with these reports, our mean reported EI for this group of African-American women with diabetes was lower but, given the prevalence of obesity, not unexpected. The prevalence of overweight/obesity in this sample (73.5% with BMI >30 kg/m^2 and only 6% with a BMI <25 kg/m^2) is higher than the rates reported from a representative sample of African-American adults with type 2 diabetes, where 47% of African-American women had a BMI >30 kg/m^2 and 18% had a BMI <25 kg/m^2 (35).

Because our dietary data were collected by multiple 24-h recalls administered by telephone, one might speculate that our collection methods could possibly explain the low reported EI. In comparing telephone versus in-person 24-h recall methods among African-American women (16), no significant differences were found between methods for any nutrients. When different dietary assessment methods are compared relative to energy underreporting, one finds similar rates (36), and what seems to be emerging as a more plausible explanation is that energy underreporting appears to be a function of individual characteristics rather than dietary methods (29).

We used estimates of TEE (BMR and physical activity) to assess the quality of dietary self-report in this study. Although there are some data on PALs among African-American women with type 2 diabetes (37), most are collected by self-report measures. Our mean total physical activity expenditure collected by accelerometer was 325.5 kcal/day (or 312 metabolic equivalent [MET]-minutes/day), which is similar to the 287 MET-minutes/day reported for moderate-to-vigorous physical activity in older African-American women (38). The average estimated BMR of 1,504 kcal/day in our sample is very comparable to reports of resting metabolic rate (RMR) measured by indirect calorimetry in obese African-American women. In a sample of postmenopausal obese African-American women, Nicklas et al. (39) reported a mean RMR of 1,490 ± 26 kcal/day (adjusted for lean body mass); Foster et al. (40) reported a mean value of 1616.5 ± 242.2 kcal/day adjusted for fat-free mass in obese African-American women (only 10% of the sample was postmenopausal). Moreover, our estimate of BMR was derived with the Mifflin equation (25), which has been shown to provide accurate estimates of RMR (compared with indirect calorimetry) in obese and nonobese individuals (41). These data suggest that our estimates of energy expenditure are probably valid at the group level.

In this study to assess the validity of self-reported dietary intake, we found a 35% difference between reported EI and energy expenditure as measured by accelerometer. When EI is compared with energy expenditure measured by DLW, underreporting of EI by 25% in older women (42) and by 34% among obese women (43) has been reported. Although our findings are consistent with other research showing the strong relationship between obesity and energy underreporting, we find it particularly interesting that patients' perceptions of whether they were following a diet for diabetes significantly predicted energy underreporting, whereas "trying to lose weight" did not. This distortion of EI may be related to social desirability bias (27) or prior dietary instruction (44).

There are some limitations to the findings of this study that relate to our measurement of EI, energy expenditure, and energy underreporting. One limitation relates to our inability to distinguish between underreporting and restricting EI for the purpose of weight management or diabetes control. Because we do not have a measure of weight change during the time the dietary intake information was obtained, and we observed that there was a significant difference in reported EI by whether participants felt they were following a diet for diabetes, there is no way to completely rule out energy restriction as a contributing factor in the difference between reported EI and expenditure. It should, however, be noted that no significant weight loss was observed in this group 6 months after these data were collected (22).

Another potential limitation is that the use of uniaxial accelerometers to measure physical activity expenditure may underestimate expenditure for activities with limited vertical accelerations (e.g., bicycling) and do not measure activities such as swimming. Moreover, accelerometers are likely to underestimate physical activity expenditure if not worn during the entire period that the subject is awake. Although we excluded days when the device was worn for <4 h, we may have included days when it was not worn during periods of activity. If, in fact, our measure of physical activity is underestimated, our findings relative to energy underreporting (defined by the EI-to-TEE ratio) would also be underestimated.

The time elapsed between physical activity measures and EI data collection may also represent a limitation to these findings if either is not representative of usual or habitual levels during the data collection time period. Because we found no significant association between the time elapsed and either EI, TEE, or the EI-to-TEE ratio, the effect on these findings are likely minimal.

Additionally, our estimates of underreporting are conservative because 7.5% of the sample (15 participants) was excluded from the analysis because of reported EIs <600 kcal/day on at least two of the dietary recalls. Finally, the homogeneity of the sample population relative to BMI limits generalizations to the larger population of African-American women with type 2 diabetes.

In summary, the findings of this study suggest that in this group of African-American patients with type 2 diabetes and a high prevalence of obesity, dietary self-reports may be of questionable validity because of widespread underreporting. With the reported dietary composition so similar to the current diet prescription for diabetes, especially among energy underreporters, the effectiveness of a dietary intervention would be very difficult to determine by dietary self-report. If diet self-reports are explained more by individual biases than actual intake, then measurements over time will likely be similarly biased (29) and will produce invalid estimates of dietary change. Cognitive research methods (45–46) may help us in understanding why underreporting is inversely associated with BMI and how individuals retrieve information from memory and respond to questions about dietary intake. These methods focus on understanding how information is organized in memory, which may inform the selection of appropriate cues and question formats to facilitate retrieval. Because information retrieval is only part of the total response process, cognitive research can also help to identify whether factors, such as social desirability, social approval, etc., influence the final response to questions about diet.

The major implication of our findings is that dietary assessments by self-report should be independently validated, particularly in study populations of patients with diabetes, where overweight/obesity is prevalent and energy restriction is a general treatment prescription. Future research is needed to identify more accurate approaches to dietary assessment for this population, including methods of validating diet self-reports that rely on biological markers of dietary intake (47).

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