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ABSTRACT

Background: A limited number of studies have evaluated self-reported dietary intakes against objective recovery biomarkers.

Objective: The aim was to compare dietary intakes of multiple Automated Self-Administered 24-h recalls (ASA24s), 4-d food records (4DFRs), and food-frequency questionnaires (FFQs) against recovery biomarkers and to estimate the prevalence of under- and overreporting.

Design: Over 12 mo, 530 men and 545 women, aged 50–74 y, were asked to complete 6 ASA24s (2011 version), 2 unweighed 4DFRs, 2 FFQs, two 24-h urine collections (biomarkers for protein, potassium, and sodium intakes), and 1 administration of doubly labeled water (biomarker for energy intake). Absolute and density-based energy-adjusted nutrient intakes were calculated. The prevalence of under- and overreporting of self-report against biomarkers was estimated.

Results: Ninety-two percent of men and 87% of women completed $\geq$3 ASA24s (mean ASA24s completed: 5.4 and 5.1 for men and women, respectively). Absolute intakes of energy, protein, potassium, and sodium assessed by all self-reported instruments were systematically lower than those from recovery biomarkers, with underreporting greater for energy than for other nutrients. On average, compared with the energy biomarker, intake was underestimated by 15–17% on ASA24s, 18–21% on 4DFRs, and 29–34% on FFQs. Underreporting was more prevalent on FFQs than on ASA24s and 4DFRs and among obese individuals. Mean protein and sodium densities on ASA24s, 4DFRs, and FFQs were similar to biomarker values, but potassium density on FFQs was 26–40% higher, leading to a substantial increase in the prevalence of overreporting compared with absolute potassium intake.

Conclusions: Although misreporting is present in all self-report dietary assessment tools, multiple ASA24s and a 4DFR provided the best estimates of absolute dietary intakes for these few nutrients and outperformed FFQs. Energy adjustment improved estimates from FFQs for protein and sodium but not for potassium. The ASA24, which now can be used to collect both recalls and records, is a feasible means to collect dietary data for nutrition research. *Am J Clin Nutr* 2018;107:80–93.

Keywords: 24-h recalls, dietary assessment, food-frequency questionnaire, recovery biomarker, 4-d food records, under-reporting, and overreporting

INTRODUCTION

Over the past decades, nutritional epidemiologic studies have made significant contributions to identifying diet-disease relations (e.g., folate and neural tube defects, alcohol and breast cancer). Yet the quality of evidence from observational studies has been criticized, in part due to methodologic limitations, one of which is measurement error inherent in all self-reported dietary intakes (1). Dietary assessment methods traditionally used in research are food records in which participants record food and beverage consumption in real time for several consecutive or nonconsecutive days; 24-h recalls for which, traditionally, trained interviewers ask participants to report all food and beverage intakes for the previous day from midnight to midnight; and food-frequency questionnaires (FFQs), which query frequency and portion size of food items consumed during a defined period such as the past year (2).

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Supplemental Figures 1 and Supplemental Tables 1–4 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/ajcn/.

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Abbreviations used: ASA24, Automated Self-Administered 24-h recall; DHQ, Diet History Questionnaire; DLW, doubly labeled water; FFQ, food-frequency questionnaire; IDATA, Interactive Diet and Activity Tracking in AARP; NCI, National Cancer Institute; OPEN, Observing Protein and Energy Nutrition; PABA, para-aminobenzoic acid; VSPP, Validation Studies Pooling Project; 4DFR, 4-d food record.

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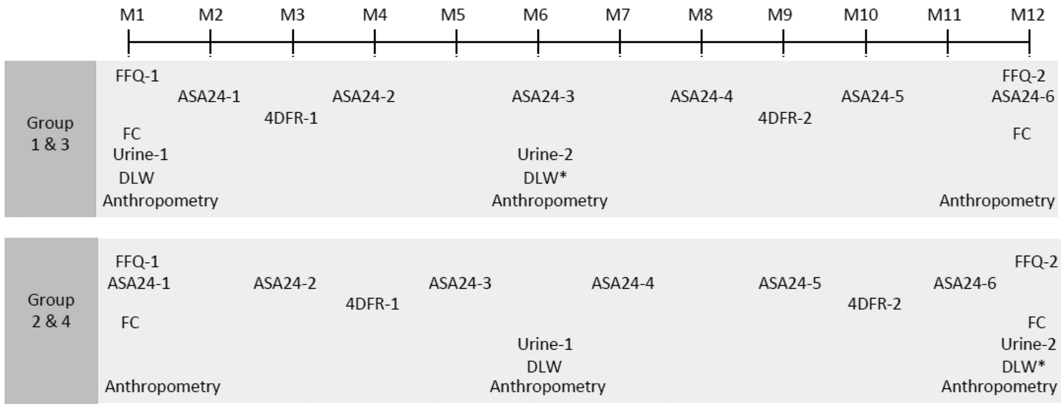

FIGURE 1 Timeline of dietary assessments and biomarker measurements in the IDATA study. Participants were recruited on a rolling basis until the quota for each group and total sample size were met. On average, groups 3 and 4 started their study activities ∼3 mo later than groups 1 and 2. *The second DLW was administered to a small subset of participants. ASA24, Automated Self-Administered 24-h recall; DLW, doubly labeled water; FC, 7-d food checklist; FFQ, food-frequency questionnaire; IDATA, Interactive Diet and Activity Tracking in AARP; M, month; 4DFR, 4-day food record.

Previous research indicates that, compared with FFQs which usually assess diet over a long period of time, short-term dietary assessment instruments such as records or recalls produce more accurate and less biased absolute nutrient intake estimates when evaluated against recovery biomarkers (3–11). For example, studies comparing multiple-day food records with FFQs found that records provided more accurate estimates and higher correlations for protein, potassium, and sodium intakes in comparison with recovery biomarkers (3, 4). Subsequently, the Observing Protein and Energy Nutrition (OPEN) Study found that two 24-h recalls also performed better than an FFQ when absolute energy and protein intakes were compared with recovery biomarkers (5, 6). Similar results were found for multiple 24-h recalls compared with FFQs in later recovery biomarker studies (7–11).

Despite this evidence, the use of traditional 24-h recall or food record methods in large observational studies was considered impractical because of feasibility issues and costs associated with scheduling, training interviewers or respondents, and coding data. Tackling this challenge, many investigators have developed new technologies that might mitigate these issues (12, 13). The National Cancer Institute (NCI) approached this issue by developing the Automated Self-Administered 24-h recall tool (ASA24), a freely available, web-based, automatically coded, self-administered recall or record instrument (14). The ASA24 was evaluated with respect to equivalence to traditional interviewer-administered 24-h recalls and in a feeding study in which true intakes were known (15–18). However, no study has yet evaluated the ASA24 against recovery biomarkers. In addition, few studies have used recovery biomarkers to assess traditional 24-h recalls, food records, or FFQs (3–7, 9–11).

Therefore, we conducted the Interactive Diet and Activity Tracking in AARP (IDATA) Study to evaluate the structure of measurement error for ASA24 as well as for 4-d food records (4DFRs) and FFQs. Another purpose of the IDATA study was to evaluate measurement error in self-reported physical activity instruments (to be reported elsewhere). In this article, we describe the IDATA study and report the initial findings on average accuracy of absolute and energy-adjusted nutrient intakes from all dietary assessment instruments in comparison to recovery biomarkers.

METHODS

Study population and design

The IDATA study mailed an invitation letter to AARP (formerly known as the American Association of Retired Persons) members living in the Pittsburgh, Pennsylvania, area between January and September 2012. Individuals who preregistered on the study website or by phone ($n = 4967$) were interviewed via telephone ($n = 3515$) to determine eligibility, which included being able to read and speak English, not following a weight-loss diet, being reasonably mobile, being free of health conditions affecting metabolism, and having access to high-speed Internet. Only 1 AARP member/household was eligible to participate in the study. Eligible individuals visited the study center, and for those whose eligibility was confirmed provided informed consent ($n = 1130$; **Supplemental Figure 1**). After excluding 20 individuals who did not provide any data, a total of 1110 men and women aged 50–74 y were included in the IDATA analytic cohort. The study was approved by the NCI Special Studies Institutional Review Board.

Participants were randomly assigned to 1 of 4 study groups (groups 1–4: n = 183, 192, 240, and 460, respectively; **Figure 1**). Data collection and activities were identical for each group, but the timing of the various data collection activities varied to account for seasonal variations in diet and for practical reasons related to study center load. The first wave of participants started their 12-mo study protocol in March 2012, and the last wave completed their protocol in October 2013. All of the participants came to the study center for anthropometric measurements at months 1, 6, and 12. The doubly labeled water (DLW) protocol, to measure total energy expenditure, was completed at the study center at month 1 in groups 1 and 3 and at month 6 in groups 2 and 4. A subset of participants ($n = 38$) repeated the DLW 6 mo after the first measurement. Participants were asked to complete self-reported dietary assessments and 24-h urine collections at home. Participants' heights and weights were measured by trained staff during study center visits at month 1, 6, and 12.

Each participant was provided an account for the IDATA study website, which was used to manage all study activities. Although hard-copy instructions were provided to participants during study center visits for various diet and physical activity tools as well as for 24-h urine collections and DLW spot urine samples, the website provided another resource for finding instructions and answers to frequently asked questions. Furthermore, staff at the study center and a telephone call-in center answered participants' questions throughout the study period.

A study management system supported all operational activities, including managing participants' study accounts, scheduling study center visits and at-home activities, e-mailing reminders, managing biospecimen collections, shipping biospecimens to laboratories or a biorepository, tracking study activities, generating reports to track study progress, and capturing, backing up, and storing data. Participants were remunerated for their participation in the study after each study center visit (total = $400: $150 at the DLW visit and at study end and $100 at an interim visit).

Self-reported dietary assessment tools

The ASA24 (19) is a web-based dietary assessment instrument that was modeled on the USDA's Automated Multiple-Pass Method for 24-h dietary recalls. IDATA used ASA24-2011, which asked participants to recall and record all foods and drinks they consumed the previous day from midnight to midnight; it included a module that queried dietary supplement intakes. More information on the ASA24 can be found on the NCI website (19). Briefly, the tool first asks participants to list foods consumed at each meal. This is followed by detailed questions with regard to food type, preparation, additions, and portion size with the use of images depicting incremental portions or sizes.

Over a 12-mo period, participants were asked by e-mail to complete 6 ASA24s, each unannounced and on a randomly assigned day approximately every other month. If a participant did not complete the requested ASA24 within 24 h of the e-mail notification, a reminder e-mail was sent on a new randomly selected day. Participants were provided 3 attempts to complete each of 6 recalls. Nutrient and food group intakes in the ASA24-2011 were estimated by using the USDA's Food and Nutrient Database for Dietary Studies, version 4.1; MyPyramid Equivalents Database, version 2.0; and the NHANES Dietary Supplement Database 2007–2008.

FFQs were administered at months 1 (FFQ-1) and 12 (FFQ-2). Participants could start the web-based FFQ in the study center and complete it there or at home within 14 d. The FFQ used was the web-based Diet History Questionnaire (DHQ) II, developed by the NCI (20). It consists of 134 food items and 8 dietary supplement questions and asks about frequencies and the portion sizes of foods consumed over the past 12 mo. The DHQ II queried frequency of intake by using 10 predefined categories ranging from "never" to "≥6 times per day" for beverages and from "never" to "≥2 times per day" for foods. Three portion-size categories were available. The DHQ II also asks about frequency and dose of multivitamins, calcium, iron, vitamins C and E, and antacids. In addition, the use of several other vitamins, minerals, and herbal supplements was queried with yes or no response categories only. Frequencies reported on the DHQ II were converted into daily frequencies and then multiplied by nutrient and food group contents per portion size. Nutrient intakes were estimated by using data from the NHANES 2001–2002, 2003–2004, and 2005–2006, which included the Food and Nutrient Database for Dietary Studies, versions 1.0, 2.0, and 3.0, respectively, and MyPyramid Equivalents Database, version 2.0. More information about the construction of the DHQ II database can be found on the NCI website (20).

Participants were also asked to complete 2 paper-and-pencil, unweighed 4DFRs in which meals, meal location, and foods and beverages consumed were recorded for 4 consecutive days. Instructions on how to complete the record along with a serving-size booklet were provided. Dietary supplement intakes were not reported. The 4DFRs were administered twice, 6 mo apart. The handwritten 4DFRs were coded by trained coders with the use of the USDA's Survey Net. The nutrient and food group databases underlying the 4DFRs and ASA24-2011 were identical.

A 7-d food checklist consisting of 32 food items (21, 22) was administered at months 1 and 12. Participants were asked to check a box next to a food item each time they consumed the food for 7 consecutive days. This paper-based, machine-readable form was scanned to assess frequency of intake. Analyses of the 7-d food checklist are not included here.

Recovery biomarkers: DLW and urinary nitrogen, potassium, and sodium

DLW is water that contains nonradioactive, naturally occurring heavy isotopes of hydrogen and oxygen. It provides a measure

TABLE 1
Characteristics of study participants: IDATA study[1]

	Men (n = 530)	Women (n = 545)
Mean age, %	64	62
50–59 y	24	35
60–69 y	56	51
≥70 y	20	13
White race/ethnicity, %	95	89
BMI, kg/m^2, %		
18.5 to <25	22	34
25 to <30	50	34
30 to <40	29	32
Weight change during the study,[2] %		
Stable	88.0	82.3
Gain	4.7	8.4
Loss	7.4	9.3
Dietary supplement use[3]		
ASA24	80	87
FFQ-1	71	88
FFQ-2	74	86
Participants who completed, % (n)		
≥3 ASA24s	92 (485)	87 (472)
≥5 ASA24s	81 (428)	74 (405)
FFQ-1	81 (427)	85 (465)
FFQ-2	73 (389)	70 (382)
4DFR-1	79 (419)	76 (414)
4DFR-2	69 (366)	64 (350)

[1]ASA24, Automated Self-Administered 24-h recall; FFQ, food-frequency questionnaire; IDATA, Interactive Diet and Activity Tracking in AARP; 4DFR, 4-d food record.

[2]Stable: weight change from month 1 to month 12 was within 5% of body weight at month 1; gain/loss: ≥5% of body weight gain or loss from month 1 to month 12; number of people with no BMI at month 12 = 174.

[3]Any dietary supplement use in ASA24; vitamin and mineral supplements in FFQ.

TABLE 2
Geometric means of nutrient intakes and mean differences between biomarker and self-reported intake[1]

	Men				Women			
Nutrient	*n*	Mean	25th–75th percentile	Difference,[2] %	*n*	Mean	25th–75th percentile	Difference,[2] %
Energy, kcal/d								
Biomarker	347	2748	2439–3045	Ref	356	2136	1892–2382	Ref
3 ASA24s[3]	485	2274	1956–2749	−17	472	1807	1528–2218	−15
All ASA24s[4]	510	2276	1950–2750	−17	511	1821	1529–2177	−15
4DFR-1	419	2244	1891–2741	−18	414	1725	1433–2084	−19
4DFR-2	366	2177	1826–2671	−21	350	1727	1476–2098	−19
FFQ-1	427	1932	1556–2407	−29	465	1516	1204–1950	−29
FFQ-2	389	1809	1422–2329	−34	382	1404	1119–1800	−34
Protein, g/d								
Biomarker 1	431	103.2	86.2–131.1	Ref	439	76.0	61.0–96.4	Ref
Biomarker 2	427	103.7	83.5–133.6	—	433	76.8	63.1–94.7	—
3 ASA24s[3]	485	93.1	76.7–113.9	−10	472	73.3	60.7–90.4	−5
All ASA24s[4]	510	93.3	77.9–112.5	−10	511	74.1	61.7–89.6	−4
4DFR-1	419	86.9	72.6–105.4	−16	414	66.8	55.8–79.5	−15
4DFR-2	366	85.3	70.8–103.5	−19	350	67.5	57.4–80.4	−14
FFQ-1	427	73.4	55.8–99.8	−31	465	58.4	45.3–77.8	−25
FFQ-2	389	69.3	52.2–92.1	−34	382	53.6	41.7–70.5	−32
Potassium, mg/d								
Biomarker 1	431	3650	2891–4789	Ref	439	2716	2063–3613	Ref
Biomarker 2	427	3670	2861–4892	—	433	2840	2185–3871	—
3 ASA24s[3]	485	3099	2602–3832	−16	472	2638	2217–3589	−6
All ASA24s[4]	510	3106	2638–3758	−16	511	2665	2193–3255	−5
4DFR-1	419	2989	2503–3681	−19	414	2480	2055–3044	−13
4DFR-2	366	2962	2452–3616	−21	350	2492	2070–3049	−14
FFQ-1	427	3338	2624–3430	−11	465	2880	2240–3764	1
FFQ-2	389	3173	2390–4018	−15	382	2680	2133–3337	−7
Potassium including supplements,[5] mg/d								
3 ASA24s[3]	485	3132	2626–3852	—	472	2661	2210–3323	—
All ASA24s[4]	510	3138	2667–3804	—	511	2688	2223–3277	—
FFQ-1	427	3378	2688–4302	—	465	2921	2360–3764	—
FFQ-2	389	3217	2540–4090	—	382	2721	2266–3418	—
Sodium, mg/d								
Biomarker 1	431	4593	3263–6664	Ref	439	3226	2364–4605	Ref
Biomarker 2	427	4386	3308–6055	—	433	3366	2609–4654	—
3 ASA24s[3]	485	3989	3308–4849	−13	472	3065	2535–3758	−9
All ASA24s[4]	510	3993	3379–4826	−13	511	3109	2639–3755	−8
4DFR-1	419	3771	3194–4610	−18	414	2887	2398–3445	−16
4DFR-2	366	3711	3113–4450	−20	350	2877	2435–3492	−18
FFQ-1	427	2917	2211–3851	−36	465	2240	1750–2872	−34
FFQ-2	389	2774	2034–3667	−40	382	2081	1627–2705	−39

[1]ASA24, Automated Self-Administered 24-h recall; FFQ, food-frequency questionnaire; Ref, reference; 4DFR, 4-d food record.
[2]Difference = 100 × exponential (mean of log self-reported – mean log biomarker value) – 100; negative values indicate underestimation in self-reports; positive values indicate overestimation in self-reports.
[3]Three ASA24s completed among participants who completed ≥3 ASA24s: first, third, and fifth ASA24s were selected if participants completed ≥5 ASA24s, and first, second, and third or fourth ASA24s if participants completed 3-4 ASA24s.
[4]Includes all ASA24s completed (mean number of ASA24s completed = 5.4 in men and 5.1 in women).
[5]Includes intakes from dietary supplements.

of total energy expenditure over a 2-wk period. The administration method used in the IDATA study was essentially the same as described in the OPEN study (5). Briefly, at a morning study center visit for which participants had fasted for ≥8 h, a baseline urine sample was collected and participants were dosed with DLW on the basis of body weight. After administration of the dose, they provided urine samples every hour for the next 4 h. One hour after dosing, an 8-ounce (240 mL) can of meal-replacement beverage was provided. Participants could drink an additional 7 ounces (210 mL) of liquid over the next 4 h; all liquid intakes were recorded. To test for postvoid urinary retention, saliva was collected 3 h after dosing. After the collection of all urine samples, participants were instructed on how to collect 2 spot urine samples 10 d later, and left the study center with an at-home spot urine collection kit and written instructions. During the DLW protocol period of ∼2 wk, participants were asked not to travel far from

TABLE 3
Geometric means of nutrient density and mean differences between biomarker and self-reported intake[1]

	Men				Women			
Nutrient	*n*	Mean	25th–75th percentile	Difference,[2] %	*n*	Mean	25th– 75th percentile	Difference,[2] %
Protein density, % of energy intake								
Biomarker 1[3]	331	15.3	12.7–18.7	Ref	335	14.4	12.0–17.7	Ref
Biomarker 2	316	15.1	12.2–19.1	—	324	14.5	11.7–17.8	—
3 ASA24s[4]	485	16.4	14.4–18.7	6	472	16.2	14.2–18.7	10
All ASA24s[5]	510	16.4	14.6–18.4	6	511	16.3	14.5–18.6	10
4DFR-1	419	15.5	13.7–17.6	0.1	414	15.5	13.8–17.4	4.0
4DFR-2	366	15.7	13.8–17.7	0.4	350	15.6	13.7–17.9	3.9
FFQ-1	427	15.2	13.5–17.3	−3	465	15.4	13.9–17.6	4
FFQ-2	389	15.3	13.7–17.2	−3	382	15.3	13.7–17.4	2
Potassium density, mg/1000 kcal								
Biomarker 1	331	1326	1045–1727	Ref	335	1279	977–1700	Ref
Biomarker 2	316	1344	1070–1770	—	324	1355	1052–1876	—
3 ASA24s[4]	485	1363	1190–1579	0.4	472	1460	1274–1699	8
All ASA24s[5]	510	1365	1196–1582	0.6	511	1464	1269–1702	8
4DFR-1	419	1332	1163–1525	−2.1	414	1437	1242–1662	5.0
4DFR-2	366	1361	1187–1557	−0.8	350	1443	1242–1676	4.4
FFQ-1	427	1727	1531–1977	26	465	1900	1617–2215	40
FFQ-2	389	1754	1556–2028	27	382	1909	1662–2232	38
Sodium density, mg/1000 kcal								
Biomarker 1	331	1659	1243–2367	Ref	335	1548	1153–2134	Ref
Biomarker 2	316	1588	1247–2156	—	324	1608	1248–2198	—
3 ASA24s[4]	485	1754	1530–2018	4	472	1696	1504–1969	3
All ASA24s[5]	510	1755	1563–1973	4	511	1707	1514–1942	3
4DFR-1	419	1681	1477–1914	−1.4	414	1673	1468–1910	0.4
4DFR-2	366	1705	1508–1938	0.6	350	1666	1472–1910	−1.2
FFQ-1	427	1509	1358–1724	−11	465	1478	1335–1674	−10
FFQ-2	389	1534	1351–1749	−11	382	1482	1323–1701	−10

[1]ASA24, Automated Self-Administered 24-h recall; FFQ, food-frequency questionnaire; Ref, reference; 4DFR, 4-d food record.
[2]Difference = 100 × exponential (mean of log self-reported – mean log biomarker value) – 100; negative values indicate underestimation in self-reports; positive values indicate overestimation in self-reports.
[3]Adjusted for doubly labeled water energy.
[4]Three ASA24s completed among participants who completed ≥3 ASA24s: first, third, and fifth ASA24s were selected if participants completed ≥5 ASA24s, and first, second, and third or fourth ASA24s if participants completed 3-4 ASA24s.
[5]Includes all ASA24 completed (mean number of ASA24s completed = 5.4 in men and 5.1 in women).

their residential area. All of the urine samples were analyzed at the University of Wisconsin's Isotope Ratio Mass Spectrometry Core by using the isotope measurement method described in the OPEN study (5). A total of 1082 participants completed the DLW protocol, but only 756 participants' DLW samples, including all repeated DLW samples, were analyzed due to limited funding. Of these, 52 were excluded due to invalid estimates (e.g., failure to confirm equilibration of DLW into urine).

Participants were asked to collect two 24-h urine samples, 6 mo apart, to measure the concentrations of nitrogen, sodium, and potassium, which are recovery biomarkers (i.e., true intakes) for protein, sodium, and potassium intakes, respectively. At the end of study center visits at months 1, 6, or 12, depending on study group, 24-h urine collection kits that included containers, instructions, and a cooler were provided to participants to take home. On urine collection days, which occurred 7–10 d after a study center visit, participants discarded the first void of the morning and began collecting urine for the next 24 h, including the first void of the next morning. They were also asked to take a 100-mg para-aminobenzoic acid (PABA) tablet, a marker for completeness of 24-h urine collection, at breakfast and dinner. Participants were given a urine collection log to report any missed voids and time at which the PABA tablet was taken. Because the OPEN study reported that the determination of completeness of 24-h urine collections by either PABA or self-reported missing voids had little effect on results (23), the PABA analyses were not conducted.

The 24-h urine collections were delivered to the study center by a courier. The urine was weighed, separated into aliquots in 5-mL cryovials, and stored at −70°C until it was sent to the Food Components and Health Laboratory of the USDA's Agricultural Research Service. Urinary nitrogen was measured by the Dumas procedure (CN 2000; Leco Corporation), and urinary potassium and sodium were measured by ion-selective electrode potentiometry (Vitros 5,1 FS chemistry system; Ortho-Clinical Diagnostics). Given that 81% of consumed nitrogen, 80% of consumed potassium, and 86% of consumed sodium are excreted in urine (24–26), we converted the urinary values into dietary intakes by

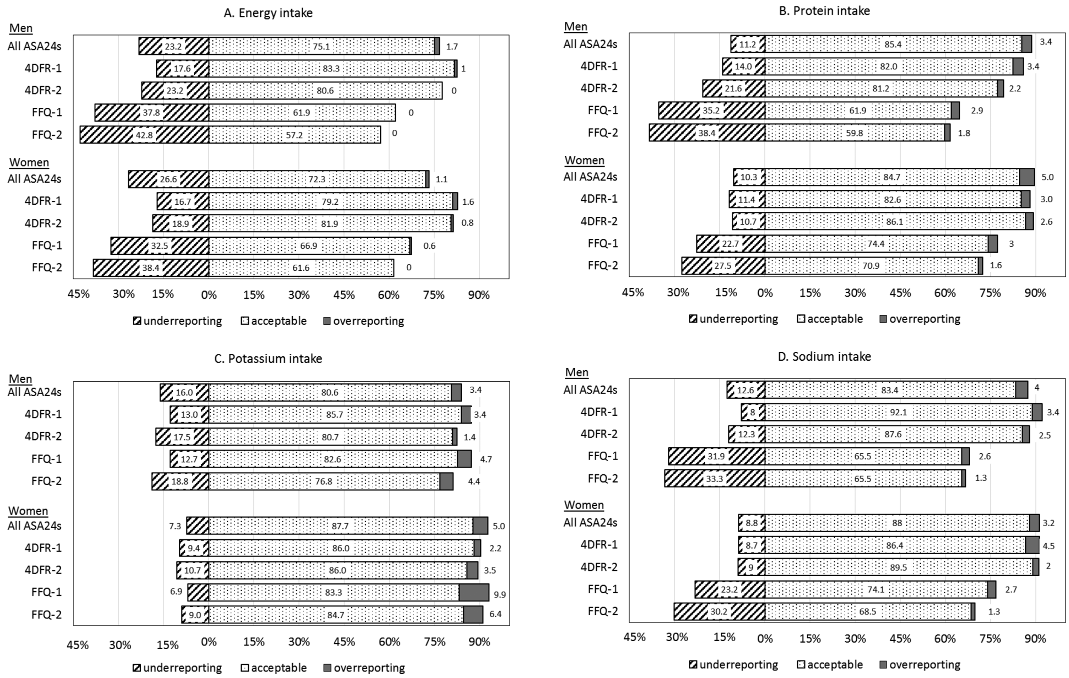

FIGURE 2 (A–D) Prevalence of under- and overreporting of nutrient intakes in self-reported dietary assessment tools. For energy intake analysis, $n = 345$, 307, 272, 294, and 290 in men and 350, 305, 260, 320, and 284 in women for all ASA24s, 4DFR-1, 4DFR-2, FFQ-1, and FFQ-2, respectively. For protein, potassium, and sodium analyses, $n = 470$, 414, 365, 386, and 388 in men and 464, 404, 346, 406, and 378 in women for all ASA24s, 4DFR-1, 4DFR-2, FFQ-1, and FFQ-2, respectively. ASA24, Automated Self-Administered 24-h recall; FFQ, food-frequency questionnaire; 4DFR, 4-d food record.

dividing by the respective conversion factors. Dietary protein was calculated as nitrogen × 6.25 (16% of protein is nitrogen). A total of 949 participants provided at least one 24-h urine sample.

Statistical analysis

We excluded participants who did not complete ≥1 ASA24 and 1 FFQ ($n = 25$), leaving a final analytic sample of 1075 participants (530 men and 545 women). Nearly all (99%) ASA24s administered in the study ($n = 5307$) included data for both the food and beverage and the supplement sections. For those recalls for which food and beverage data were complete and supplement data were not ($n = 59$, or 1%), dietary data were included. A 4DFR was determined to be complete when all 4 d were reported. Ninety-eight percent of all 4DFRs collected included 4 full days of data ($n = 1549$). Incomplete 4DFRs ($n = 25$) were excluded.

Per-person daily nutrient intakes from ASA24s and 4DFRs were estimated by averaging all completed ASA24s (mean = 5.3 ASA24s) and across 4 d of each 4DFR. To assess the effect of having data on fewer compared with more recalls, we also estimated nutrient intakes by using 3 ASA24s among participants who completed ≥3 ASA24s: first, third, and fifth ASA24s were selected if participants completed ≥5 ASA24s (82% of participants); and first, second, and third or fourth ASA24s if participants completed 3–4 ASA24s. Because energy intakes on any given day can be highly variable, we did not exclude any ASA24 or 4DFR days. However, because FFQs are intended to measure usual intakes, we excluded those with unusually high or low energy estimates on the basis of cutoffs commonly applied in epidemiologic studies (2) [men: <800 or >4200 kcal ($n = 28$, FFQ-1; $n = 23$, FFQ-2); women: <600 or >3500 kcal ($n = 21$, FFQ-1; $n = 22$, FFQ-2)].

To satisfy the requirement for unbiasedness of recovery biomarkers, values for biomarkers and daily self-reported intakes of energy, protein, potassium, and sodium were log-transformed and used to calculate geometric means and IQRs, and then back-transformed to the original scale. Mean percentage differences between self-reported and biomarker intakes were estimated as 100 × exponential (mean of log self-reported – mean log biomarker value) – 100 (27, 28). In addition, nutrient intakes were energy-adjusted by using a density method: percentage of energy for protein and intake per 1000 kcal for potassium and sodium. For this latter analysis, urinary protein, potassium, and sodium values were also adjusted for DLW energy (e.g., urinary potassium per 1000 kcal measured by DLW). For all other self-reported nutrients, geometric means for absolute intake and nutrient density were computed.

Under- and overreporters were defined by using the statistical methods from the OPEN study (5). Briefly, we first log-transformed all biomarkers and self-reported dietary intakes and estimated the log ratio of self-reported dietary intakes to biomarker intakes. For an unbiased estimate, the log ratio would have a mean of zero and a variance equal to the sum of within-person variation in self-reported dietary intake and the biomarker. Thus, values smaller than the lower limit of the 95% CI of the log ratio indicate underreporting, whereas values greater than the upper limit of the 95% CI of the log ratio indicate overreporting. All of the analyses were conducted by using SAS, version 9.4 (SAS Institute, Inc.).

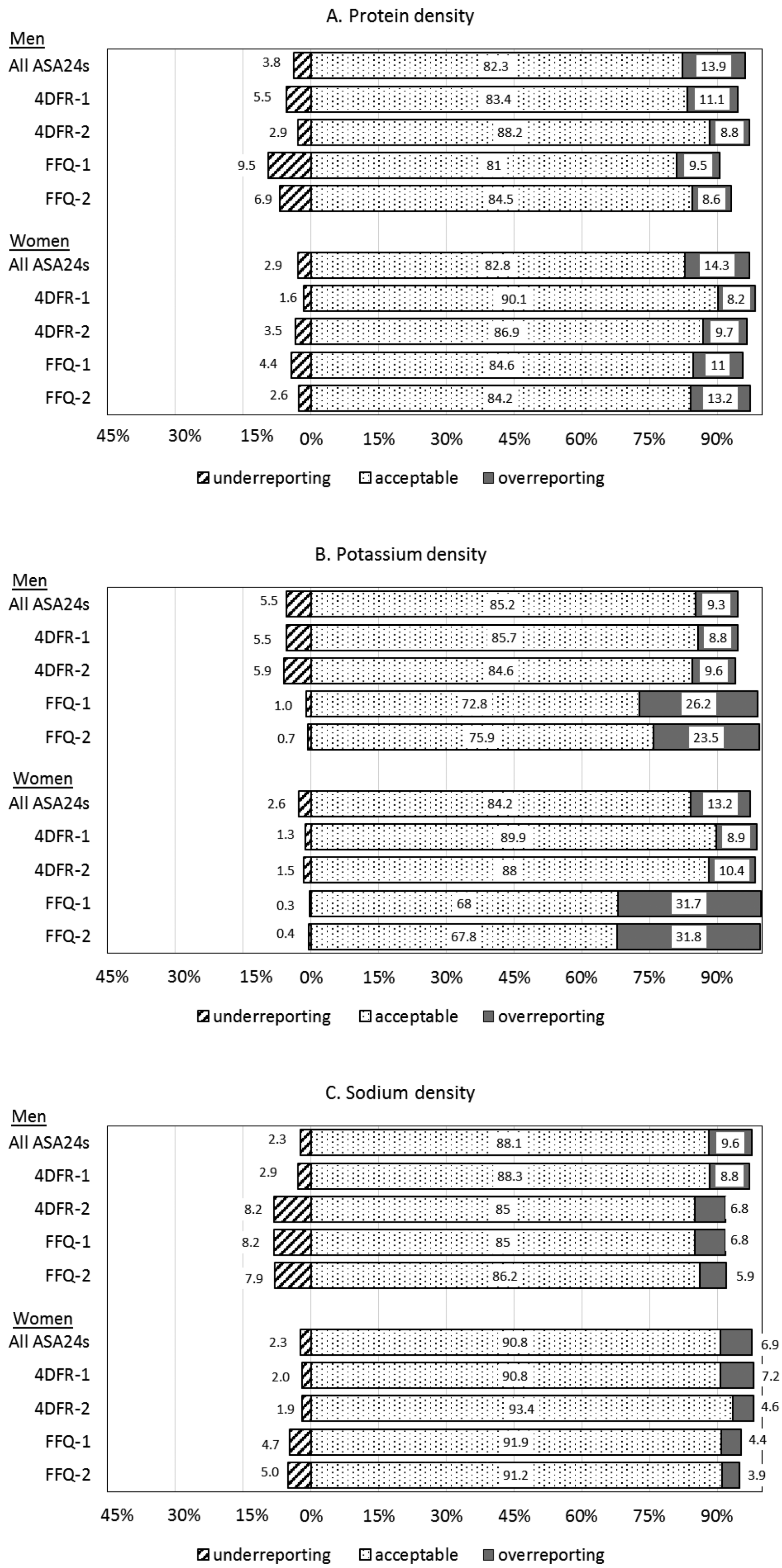

FIGURE 3 (A–C) Prevalence of under- and overreporting of energy-adjusted nutrient intakes by using a density method in self-reported dietary assessment tools. For protein, potassium, and sodium density analyses, $n = 345$, 307, 272, 294, and 290 in men and 350, 305, 260, 320, and 284 in women for all ASA24s, 4DFR-1, 4DFR-2, FFQ-1, and FFQ-2, respectively. ASA24, Automated Self-Administered 24-h recall; FFQ, food-frequency questionnaire; 4DFR, 4-d food record.

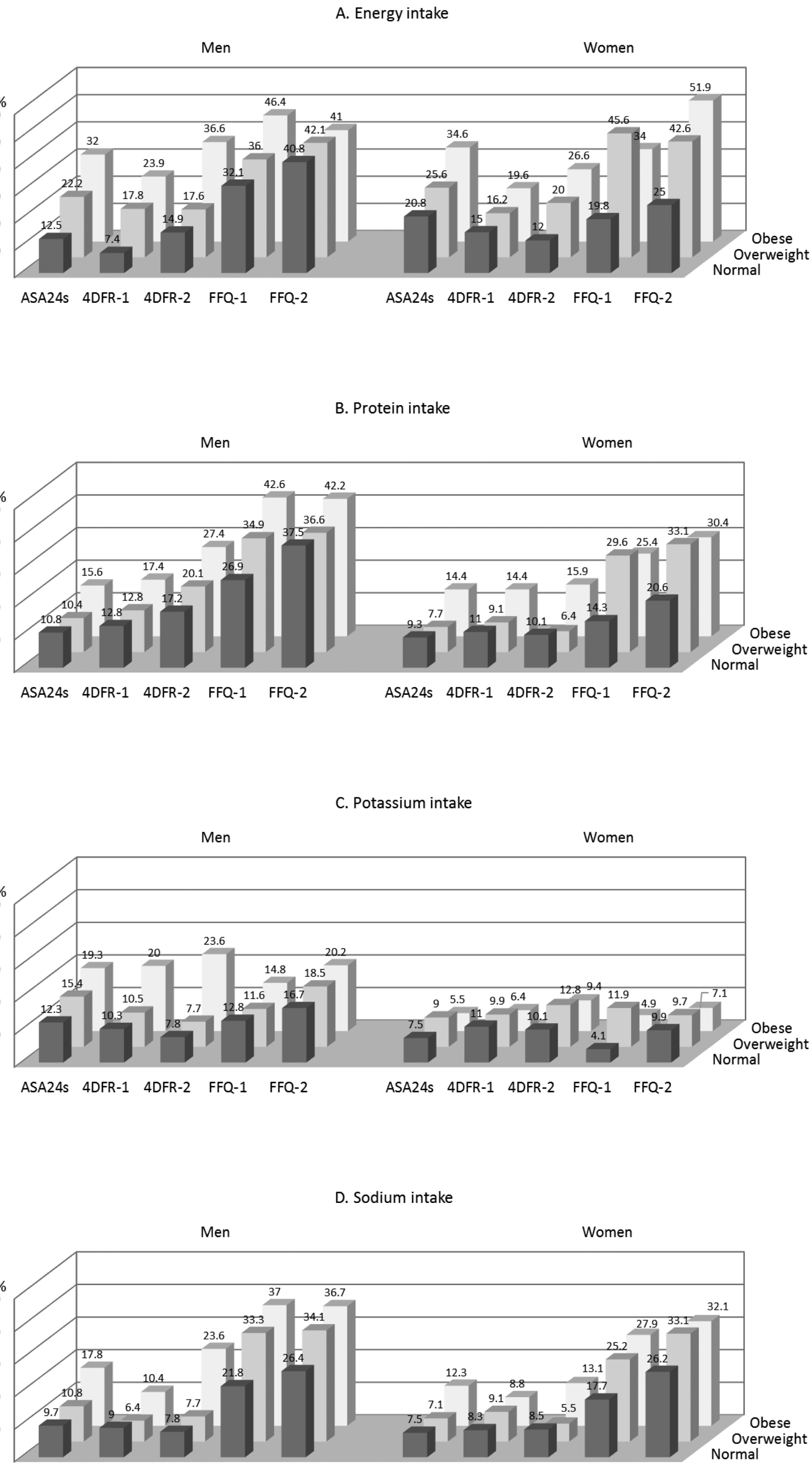

FIGURE 4 (A–D) Prevalence of underreporting of nutrient intakes by BMI in men and women. ASA24, Automated Self-Administered 24-h recall; FFQ, food-frequency questionnaire; 4DFR, 4-d food record.

TABLE 4
Daily nutrient intakes from food only and from food and dietary supplements assessed by self-reported dietary assessment tools in men[1]

Nutrients	3 ASA24s[2]	All ASA24s[3]	4DFR-1	4DFR-2	FFQ-1	FFQ-2
Dietary intake (food only)						
Carbohydrate						
g	253	255	255	252.0	230	214
% energy	44.9	45.4	45.8	46.6	47.6	47.3
Total fat						
g	86.8	87.2	89.1	84.4	71.4	67.6
% energy	34.1	34.1	35.3	34.5	33.3	33.6
Saturated fat, % energy	11.3	11.3	11.4	11.2	10.4	10.5
Monounsaturated fat, % energy	12.3	12.3	12.6	12.3	12.4	12.5
Polyunsaturated fat, % energy	7.1	7.2	7.6	7.5	6.7	6.7
Cholesterol, mg	303	306	271	260	208	193
Oleic acid, g	29.2	29.3	29.9	28.2	24.7	23.5
Linoleic acid, g	15.7	16.0	16.9	16.2	12.6	11.8
Linolenic acid, g	1.6	1.7	1.7	1.6	1.2	1.2
Arachidonic acid, g	0.1	0.1	0.1	0.1	0.1	0.1
EPA+DHA, g	0.07	0.08	0.07	0.1	0.1	0.1
Dietary fiber, g	19.3	19.4	19.4	19.2	17.5	16.6
Total sugar, g	101	103	97.1	97.9	101	94
Vitamin A, μg RAE	741	763	748	729	733	682
Thiamin, mg	1.9	1.9	1.9	1.9	1.7	1.6
Riboflavin, mg	2.4	2.5	2.3	2.3	2.6	2.5
Niacin, mg	27.3	27.6	27.3	27.5	23.9	22.5
Vitamin B-6, mg	2.3	2.3	2.2	2.2	2.1	2.0
Folate, μg	469	472	479	478	461	440
Vitamin B-12, μg	5.7	5.8	5.3	5.4	5.4	5.0
Vitamin C, mg	83.5	85.6	70.1	74.4	100.2	94.9
Vitamin D, μg	4.2	4.3	4.7	4.7	4.4	4.1
Vitamin E, mg α-TE	8.5	8.6	8.9	8.7	8.2	7.8
Vitamin K, μg	113	121	95.7	97.0	121	114
α-Carotene, μg	214	268	245	200	347	324
β-Carotene, μg	2146	2418	2002	1807	2603	2422
Lycopene, μg	3850	4701	2793	2577	5021	4791
Lutein-zeaxanthin, μg	1472	1622	1317	1280	1936	1812
β-Cryptoxanthin, μg	56.5	64.2	48.9	57.0	117.7	109.7
Calcium, mg	968	979	1002	989	931	888
Magnesium, mg	336	337	323	320	347	328
Iron, mg	17.3	17.4	17.4	17.4	15.9	15.1
Zinc, mg	14.0	14.0	12.8	12.8	12.2	11.5
Phosphorus, mg	1518	1518	1479	1461	1290	1228
Selenium, mg	127	128	121	119	94.0	88.4
Copper, mg	1.5	1.5	1.3	1.3	1.5	1.4
Choline, mg	368	370	356	347	318	299
Total intake (food + dietary supplements)						
Vitamin A, μg RAE	1139	1163	—	—	1184	1166
Thiamin, mg	3.4	3.5	—	—	2.4	2.4
Riboflavin, mg	4.0	4.1	—	—	3.5	3.5
Niacin, mg	38.4	38.9	—	—	33.4	33.0
Vitamin B-6, mg	4.4	4.5	—	—	3.2	3.2
Folate, μg	659	663	—	—	649	641
Vitamin B-12, μg	17.8	18.1	—	—	10.7	10.4
Vitamin C, mg	158	160	—	—	169	166
Vitamin D, μg	10.4	10.7	—	—	9.1	9.2
Vitamin E, mg α-TE	22.3	22.7	—	—	18.0	18.7
Vitamin K, μg	124	132	—	—	136	129
α-Carotene, μg	215	269	—	—	—	—
β-Carotene, μg	2142	2411	—	—	2657	2439
Lycopene, μg	4160	4981	—	—	5222	4989
Lutein-zeaxanthin, μg	1610	1771	—	—	2115	2006
β-Cryptoxanthin, μg	56.7	64.2	—	—	—	—

(*Continued*)

TABLE 4
(*Continued*)

Nutrients	3 ASA24s[2]	All ASA24s[3]	4DFR-1	4DFR-2	FFQ-1	FFQ-2
Calcium, mg	1135	1142	—	—	1083	1052
Magnesium, mg	380	379	—	—	421	403
Iron, mg	18.8	18.9	—	—	23.9	23.6
Zinc, mg	20.3	20.3	—	—	19.1	19.0
Phosphorus, mg	1546	1547	—	—	1343	1286
Selenium, mg	152	154	—	—	105	99.6
Copper, mg	2.1	2.1	—	—	12.8	12.6
Choline, mg	368	370	—	—	—	—

[1]Values are geometric means. ASA24, Automated Self-Administered 24-h recall; FFQ, food-frequency questionnaire; RAE, retinol activity equivalents; α-TE, α-tocopherol equivalents; 4DFR, 4-d food record.

[2]Three ASA24s completed among participants who completed ≥3 ASA24s: first, third, and fifth ASA24s were selected if participants completed ≥5 ASA24s, and first, second, and third or fourth ASA24s if participants completed 3-4 ASA24s.

[3]Includes all ASA24s completed (mean number of ASA24s completed = 5.4 in men and 5.1 in women).

RESULTS

The mean age of participants was 64 y for men and 62 y for women (Table 1). Most participants were non-Hispanic whites, and 29% of men and 32% of women were obese [BMI (in kg/m^2) ≥30]. Most men (88%) and women (82%) maintained their body weight (±5% weight change) during the 12-mo study period. The average ± SD weight change was −0.3% ± 3.7% in men and 0.1% ± 4.4% in women. More than 70% of participants reported using a dietary supplement on either an ASA24 or an FFQ. The mean ± SD number of ASA24s completed per person was 5.4 ± 1.2 for men and 5.1 ± 1.4 for women. Most (92% of men and 87% of women) completed ≥3 ASA24s. Response rates for the second administration of an FFQ or a 4DFR were lower than those of the first administration.

Mean energy intakes reported on ASA24s, 4DFRs, and FFQs were all lower than DLW-measured total energy expenditure in both men and women (**Table 2**). Energy intakes from ASA24s were comparable to those based on 4DFRs. Group mean differences between biomarker energy and self-reported energy intakes (negative and positive values indicate average under- and overestimation by self-reports, respectively) ranged from −17% to −15% for ASA24s, −21% to −18% for 4DFRs, and −34% to −29% for FFQs. Mean and IQR estimates of protein, potassium, and sodium intakes on 3 completed ASA24s were nearly the same as those based on all available ASA24s. Nutrient intakes on the FFQ-2 were lower than those on the FFQ-1. Means of absolute intakes of protein, potassium, and sodium on ASA24s, 4DFRs, and FFQs were lower than their respective recovery biomarkers. The mean differences between biomarkers and intakes of protein, potassium, or sodium ranged from −16% to −4% for ASA24s, −21% to −13% for 4DFRs, and −40% to +1% for FFQs. When potassium from dietary supplements was added to total dietary intakes for ASA24s and FFQs, mean total potassium intakes increased by 23–32 mg/d and 40–41 mg/d, respectively.

When dietary intakes were energy-adjusted (i.e., percentage of energy or intake per 1000 kcal), protein and sodium densities on all 3 dietary instruments were similar to energy-adjusted biomarker values (**Table 3**). However, on average, potassium density on FFQs (e.g., 1727 mg/1000 kcal on FFQ-1 in men) was higher than potassium density on ASA24s (1365 mg/1000 kcal) or on 4DFRs (1332 mg/1000 kcal on 4DFR-1). Similar results were observed for women. Mean differences between energy-adjusted biomarkers and potassium intakes on FFQs ranged from +26% to +40% in men and women. For both absolute and energy-adjusted intake estimates, results were similar to those found in analyses restricted to participants who completed two 24-h urine collections and 2 FFQs or 2 4DFRs (**Supplemental Table 1**).

Overall, for absolute intake estimates, the prevalence of underreporting (8–43%) was substantially higher than for overreporting (mostly <5%) on all dietary assessment tools; however, the proportion of underreporting was greater on FFQs than on ASA24s or 4DFRs (Figure 2). For energy, protein, and sodium intakes, the prevalence of underreporting for FFQs was almost 2 times higher than that for ASA24s or 4DFRs. For potassium, however, underreporting was similar across all 3 tools. The results were unchanged when the analyses were restricted to participants who had stable body weight throughout the study (**Supplemental Table 2**).

Patterns of misreporting changed markedly for energy-adjusted nutrients (Figure 3). Underreporting on ASA24s, 4DFRs, and FFQs declined to 2–10% for protein density, 0.3–6% for potassium density, and 2–8% for sodium density, whereas overreporting increased substantially (4–32%), especially for potassium density for FFQs in which ∼25% of men and 32% of women were classified as overreporters. The prevalence of overreporting of potassium density was 9–13% on ASA24s and 4DFRs. The prevalence of underreporting was highest in obese individuals, followed by overweight and normal-weight individuals for all dietary assessment instruments (Figure 4).

Daily intakes of other nutrients, excluding supplements for ASA24s, were similar to those for 4DFRs in both men (Table 4) and women (**Table 5**). FFQ intakes, except for vitamin C and individual carotenoids, were similar to or slightly lower than those from ASA24s and 4DFRs. A similar pattern was observed for total intakes including dietary supplements. When adjusted for energy, FFQ intakes of total sugar, folate, individual carotenoids, calcium, magnesium, and vitamins C, E, and K were higher than those on ASA24s or 4DFRs (**Supplemental Tables 3 and 4**).

DISCUSSION

Misreporting, particularly underreporting, of absolute intakes of energy, protein, potassium, or sodium on 24-h recalls or FFQs

TABLE 5
Daily nutrient intakes from food only and from food and supplements assessed by self-reported dietary assessment tools in women[1]

Nutrients	3 ASA24s[2]	All ASA24s[3]	4DFR-1	4DFR-2	FFQ-1	FFQ-2
Dietary intake (food only)						
Carbohydrate						
g	207.4	207.7	198.5	197.7	185.0	168.9
% energy	46.2	46.0	46.3	46.1	48.8	48.1
Total fat						
g	70.1	71.6	70.0	70.2	58.3	54.6
% energy	34.5	34.9	36.0	36.1	34.6	35.0
Saturated fat, % energy	11.2	11.4	11.5	11.4	10.3	10.4
Monounsaturated fat, % energy	12.3	12.4	12.8	12.9	13.0	13.3
Polyunsaturated fat, % energy	7.6	7.7	8.0	8.0	7.2	7.3
Cholesterol, mg	227	235	206	211	163	148
Oleic acid, g	23.4	23.8	23.4	23.6	20.5	19.5
Linoleic acid, g	13.4	13.7	13.6	13.6	10.7	10.0
Linolenic acid, g	1.4	1.5	1.5	1.5	1.1	1.0
Arachidonic acid, g	0.1	0.1	0.1	0.1	0.1	0.1
EPA+DHA, g	0.06	0.07	0.06	0.09	0.1	0.09
Dietary fiber, g	17.5	17.6	17.0	17.1	16.0	14.9
Total sugar, g	89.1	89.7	80.3	81.0	87.0	77.8
Vitamin A, μg RAE	699	698	658	643	726	670
Thiamin, mg	1.4	1.4	1.4	1.4	1.3	1.2
Riboflavin, mg	2.0	2.0	1.8	1.8	2.0	1.9
Niacin, mg	20.7	20.9	19.7	19.9	17.8	16.6
Vitamin B-6, mg	1.8	1.8	1.7	1.6	1.6	1.5
Folate, μg	378	381	364	369	385	363
Vitamin B-12, μg	4.3	4.4	3.9	3.8	3.8	3.3
Vitamin C, mg	77.7	79.1	64.6	71.4	98.0	93.4
Vitamin D, μg	3.4	3.4	3.5	3.6	3.5	3.0
Vitamin E, mg α-TE	7.9	8.0	7.7	7.9	7.7	7.1
Vitamin K, μg	126	133	103	115	157	150
α-Carotene, μg	266	308	276	270	429	391
β-Carotene, μg	2710	2832	2272	2485	3517	3297
Lycopene, μg	2762	3494	2446	2321	4181	3849
Lutein-zeaxanthin, μg	1807	1931	1481	1664	2694	2585
β-Cryptoxanthin, μg	56.7	63.0	47.8	54.4	117.5	110.3
Calcium, mg	825	830	789	765	821	737
Magnesium, mg	295	298	265	268	304	284
Iron, mg	13.5	13.7	13.0	13.1	12.2	11.5
Zinc, mg	10.5	10.8	9.4	9.5	9.3	8.6
Phosphorus, mg	1225	1238	1164	1157	1059	964
Selenium, mg	99.1	100.4	91.6	92.6	77.3	71.8
Copper, mg	1.3	1.3	1.2	1.2	1.3	1.2
Choline, mg	289	293	275	282	254	232
Total intake (food + dietary supplements)						
Vitamin A, μg RAE	1055	1050	—	—	1170	1114
Thiamin, mg	3.0	3.0	—	—	2.1	2.0
Riboflavin, mg	3.6	3.7	—	—	3.1	2.9
Niacin, mg	30.7	30.7	—	—	27.7	26.7
Vitamin B-6, mg	4.0	4.2	—	—	2.9	2.7
Folate, μg	544	543	—	—	576	551
Vitamin B-12, μg	14.3	14.9	—	—	10.0	8.7
Vitamin C, mg	145	144	—	—	163	159
Vitamin D, μg	12.9	12.6	—	—	9.9	9.2
Vitamin E, mg α-TE	20.2	20.3	—	—	17.8	16.9
Vitamin K, μg	138	145	—	—	172	166
α-Carotene, μg	266	309	—	—	—	—
β-Carotene, μg	2718	2842	—	—	3550	3326
Lycopene, μg	2975	3677	—	—	4371	4038
Lutein-zeaxanthin, μg	2065	2187	—	—	2910	2830
β-Cryptoxanthin, μg	56.7	63.0	—	—	—	—

(*Continued*)

TABLE 5
(*Continued*)

Nutrients	3 ASA24s[2]	All ASA24s[3]	4DFR-1	4DFR-2	FFQ-1	FFQ-2
Calcium, mg	1227	1205	—	—	1136	1048
Magnesium, mg	350	354	—	—	453	411
Iron, mg	16.2	16.3	—	—	20.2	19.0
Zinc, mg	15.9	16.0	—	—	17.4	16.4
Phosphorus, mg	1247	1259	—	—	1112	1017
Selenium, mg	115	117	—	—	88.3	83.2
Copper, mg	1.9	1.9	—	—	10.8	9.5
Choline, mg	290	294	—	—	—	—

[1]Values are geometric means. ASA24, Automated Self-Administered 24-h recall; FFQ, food-frequency questionnaire; RAE, retinol activity equivalents; α-TE, α-tocopherol equivalents; 4DFR, 4-d food record.

[2]Three ASA24s completed among participants who completed ≥3 ASA24s: first, third, and fifth ASA24s were selected if participants completed ≥5 ASA24s, and first, second, and third or fourth ASA24s if participants completed 3-4 ASA24s.

[3]Includes all ASA24s completed (mean number of ASA24s completed = 5.4 in men and 5.1 in women).

has consistently been found in previous studies (5, 7, 9, 10, 27–31). Likewise, our study found that underreporting was more common than overreporting, but that the prevalence of underreporting differed by nutrient and dietary assessment tool. Average underreporting of absolute energy, protein, and sodium intakes on FFQs ranged from 25% to 40%, 1.5–3 times higher than underreporting on ASA24s or 4DFRs. On the other hand, the prevalence of potassium underreporting on FFQs was comparable to that found on ASA24s and 4DFRs. The Validation Studies Pooling Project (VSPP), a pooled analysis of 5 recovery biomarker–based diet validation studies (27, 28) showed similar results: average underreporting on 24-h recalls (0% for potassium to 18% for energy) was more modest than that from FFQs (6% for potassium to 39% for sodium). Unlike recalls and food records that collect detailed information on consumption by using open-ended methods, FFQs use closed-ended methods that include a limited number of food and beverage items, frequency of intake categories (e.g., 3–4 times/wk, ≥2 times/d), and portion-size categories (e.g., <0.5 cup, 0.5–1 cup, >1 cup). The restricted list of items queried as well as the restricted response categories on an FFQ likely contribute to measurement error.

Compared with absolute intakes, energy-adjusted intakes resulted in less underestimation for protein and sodium on FFQs, but not for potassium. This is comparable to findings from the VSPP (27, 28). Because, on FFQs, potassium was less underreported than protein or sodium, and energy was substantially underreported, the resulting FFQ potassium density was substantially overreported (25–40%). Another FFQ validation study in Japanese women also found that energy-adjusted protein, potassium, and sodium intakes were overestimated by 14–32% compared with energy-adjusted recovery biomarkers (32). Consistent with this, nutrient densities, especially for vitamins C and K and individual carotenoids, were notably higher on FFQs than on ASA24s and 4DFRs as a result of lower absolute intakes of energy and higher absolute intakes of these nutrients (excluding supplements) on FFQs. Under the assumption that the short-term measurements are more accurate on average, the findings of potential overestimation of energy-adjusted intakes of potassium, vitamins C and K, and individual carotenoids on FFQs compared with ASA24s or 4DFRs suggest a bias in FFQ reporting in the direction of a diet healthier than truth. Because energy-adjusted nutrient intakes are often used in evaluating diet adequacy (e.g., Dietary Reference Intakes given energy intake) and diet quality (e.g., Healthy Eating Index), the tendency toward overestimation in energy-adjusted intakes could lead to erroneous assessments of relations between energy-adjusted dietary constituents and disease. ASA24s and 4DFRs, however, both showed underreporting of these nutrients. This is likely partially due to issues related to memory on recalls, reactivity to records, and poor portion-size estimation, in addition to day-to-day variations in intakes.

The difference in assessing intakes from dietary supplements between ASA24s and FFQs in our study is noteworthy. Although the prevalence of dietary supplement use was similar on both tools, supplemental intakes assessed on the basis of ASA24s compared with FFQs were higher. The ASA24 asks participants to report all dietary supplements taken on the reporting day, including antacid and herbal supplements; the FFQ, however, queries a limited number of generic, common dietary supplements with limited information on dose. For purposes of assessing total nutrient intakes, accounting for dietary supplements is critical because their use is common (33) and they often contain high doses of nutrients that can easily meet or exceed daily intakes from foods.

Consistent with our findings, previous studies have also found that higher BMI is related to greater underreporting of absolute energy, protein, potassium, and sodium intakes for all self-reported dietary assessment tools (5, 7, 27–29, 34, 35). Other personal characteristics, such as age, sex, race/ethnicity, education, and socioeconomic status, have also been shown to be associated with underreporting, but findings are inconsistent for characteristics other than BMI across studies and types of dietary instruments (27–29, 36). The homogeneity of our study sample—mostly white, older adults—limits the generalizability of our findings to other populations. Nonetheless, our results are consistent with VSPP analyses that included a wide range of age groups and racial/ethnic minorities (23, 24).

Multiple-day food records and recalls have both been used as reference instruments in FFQ validation studies because they provide more detailed and less biased data than FFQs. To date, however, the evidence for the accuracy of food records against recovery biomarkers has been limited to energy. Studies found that energy intake on multiple-day food records, on average, was underestimated by 20–25% compared with DLW (37–40). More recently, the Nutrition and Physical Activity Assessment Study (NPAAS) evaluated a 4DFR against recovery biomarkers in women and found that mean energy intakes were underestimated by 20%, whereas absolute intakes of protein and sodium were underestimated by 2–4% and the absolute intake of potassium was overestimated by 20% (7, 11). In contrast, on 4DFRs in our study, mean absolute intakes of protein, potassium, and sodium were underestimated by 15–20% compared with a 20% underestimation of energy. The NPAAS participants were older and completed their 4DFRs during a 2-wk interval between study visits, as opposed to our study in which they were collected over a 6-mo period. The close proximity of record completion to a study center visit may have increased self-monitoring and reactivity.

The utility of self-administered web-based recalls or records is supported by our study as well as by other studies. The IDATA study found that multiple administrations of ASA24s performed about the same as food records, and fairly well relative to objective recovery biomarkers. Furthermore, the feasibility and usability of the ASA24 have been shown previously (15–18). The Energetics study also showed that multiple administration of the web-based DietDay 24-h recall performed better than a paper-based FFQ (8). The NutriNet-Sante study reported that energy, protein, potassium, and sodium intakes assessed by a web-based, nonconsecutive 3-d food record were comparable to those assessed by biomarkers (41). Taken together, and given that self-administered web-based tools are cost-effective from a data collection and management perspective, the ASA24, the latest version of which can be used to collect both recalls and single- or multiday food records, is a promising dietary assessment tool for dietary data collection in large-scale nutrition research.

In conclusion, our study clearly showed that multiple administrations of the ASA24 and a 4DFR provide reasonable estimates of absolute dietary intakes, outperforming an FFQ. FFQs, however, provide important information about episodically consumed foods that can be missed in short-term instruments (42). Future nutrition studies should consider collecting multiple ASA24 records or recalls over time as the primary dietary assessment instrument in conjunction with an FFQ in epidemiologic and clinical research.

The authors' responsibilities were as follows—YP, KWD, VK, FET, NP, DM, RPT, HB, and AFS: designed the study; YP and HB: conducted the study and collected the data; DAS and DJB: conducted laboratory analyses; YP, KWD, VK, and DM: analyzed the data; YP and AFS: drafted the manuscript; YP: had primary responsibility for the final content; and all authors: participated in data interpretation, provided critical review and commentary on the draft of the manuscript, and read and approved the final manuscript. None of the authors reported a conflict of interest related to the study.

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