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Validity of a self-administered food-frequency questionnaire in the estimation of amino acid intake

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The objective of the present study was to evaluate the validity of a FFQ in the estimation of dietary amino acid intake. Amino acid intake was calculated using a composition database developed based on the Standard Tables of Food Composition for amino acids in Japan. Subjects were subsampled from two populations of the Japan Public Health Center-based Prospective Study who volunteered to participate in the validation study of the FFQ. The first group was from the population the FFQ was developed for (internal population; *n* 215) and the second was a separate population to confirm external validity (external population; *n* 350). The validity of the FFQ was evaluated using 28 d weighed dietary records (DR) as a reference method. Spearman's rank correlation coefficients (CC) between amino acid intake from the FFQ and DR were calculated. The dietary intake of amino acids was slightly underestimated by the FFQ. Deattenuated CC of energy-adjusted amino acid intake according to the FFQ and corresponding amino acid intake according to the DR ranged from 0·15 to 0·52. The median CC for twenty amino acids were 0·33 for men and 0·25 for women in the internal population, and 0·40 for men and 0·30 for women in the external population. In conclusion, the validity of the FFQ in estimating amino acid intake was low to moderate.

Amino acids: Food-frequency questionnaires: Validity

In their basic biological role, amino acids, molecules containing both an amine and a carboxyl functional group, act as structural units in the construction of protein. Twenty standard amino acids are used in this role. However, recent biochemical research has identified functions beyond protein construction, such as the regulation of immunity by arginine[1] and the control of protein synthesis by leucine[2]. In terms of human research, specific amino acids have been indicated in preventing particular diseases. Arginine, for example, a precursor of NO, has a potential protective effect against CHD[3–5], while a number of studies have investigated the association between methionine and colorectal cancer or adenoma[6–9]. Results to date remain inconclusive, however, at least partly due to difficulties in assessing dietary intake.

Dietary intake in epidemiological studies is often assessed using FFQ. Before any evaluation of estimated intake can be done, however, the validity of the FFQ must be confirmed. The ability of an FFQ to estimate dietary intake is validated by comparing the estimated intake by the FFQ with that by other methods. Typical methods used for reference are multiple day dietary records (DR) or 24 h recall, which directly measure detailed intake in individuals[10]. Another reference method is the measurement of biochemical indicators, which represent the physiological status of individuals responding to the dietary intake of nutrients[10]. The relative validity is evaluated by different statistical approaches including correlation, cross-classification and comparison of intake estimates[10]. Because errors in dietary assessment are unavoidable, correlations of validity generally tend to be in the range of 0·5–0·7[10]. The lower the accuracy, the greater the attenuation of association with the disease.

The aim of the present study was to evaluate the validity of an FFQ for estimating amino acids using 28 d weighed DR as the reference method. To our knowledge, no study has comprehensively evaluated the validity of estimations of the twenty amino acids.

Subjects and methods

Study setting

The Japan Public Health Center-based Prospective (JPHC) Study is a population-based prospective cohort study that

Abbreviations: DR, dietary record; JPHC, Japan Public Health Center-based Prospective.

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consists of two cohorts. The first started in 1990 in Ninohe, Yokote, Saku and Chubu (formerly named Ishikawa) public health centre areas (cohort I); the second started in 1993 in Mito, Kashiwazaki, Chuo-higashi, Kamigoto, Miyako and Suita public health centre areas (cohort II). The aim of the JPHC was to investigate associations between chronic diseases and various lifestyle factors such as diet. The study design and participants in the overall cohort have been described previously[11]. The dietary intake of individuals in these populations was assessed using a semi-quantitative FFQ developed based on data from 3 d weighed DR in a random sample from cohort I[12].

Two FFQ validation studies were conducted in subsamples of cohort I and cohort II, the former to validate the FFQ within the population for which it was developed and the latter to validate it in a population for which it was not developed (external validity). The cohort I validation study was initiated in February 1994, and that in cohort II in May 1996. Approximately thirty married couples aged 45–75 years (to age 65 years for cohort I) were recruited through the respective public health centres[13,14]. Subjects from both cohorts were healthy volunteers of normal weight and without dietary restrictions. The majority were salaried workers. Oral or written informed consent from the participants was received before the study. The study did not undergo ethical approval since it was conducted before the advent of ethical guidelines for epidemiology research in Japan, which mandate such approval.

Development of a database for amino acids

Energy and protein intake according to the FFQ and DR were calculated using the *Standardized Tables of Food Composition*, 4th ed.[15], which include 1622 food items. Because the database for amino acids, published as a follow-up to the *Standardized Tables of Food Composition*, 4th ed.[15], covered only 18 % of these items, however, a comprehensive database of the amino acid content of foods using four substitution methods was developed. Method A used food products derived from the same species of animal, different parts of the same species, cultivated food products for wild products (or vise versa), food products harvested in different countries, or processed food products for raw material (or vise versa); method B used food products of a similar species; method C used composition values from the US Department of Agriculture; method D used values computed with recipe data. These methodologies have been evaluated using a comparison of actual and substituted values for twenty-one arbitrarily selected foods using Pearson's correlation coefficients (r varied from 0·93 for method D to 0·99 for method A).

Data collection

Data collection has been described in detail elsewhere[13,14]. In brief, each subject completed a 7 d DR during each of the four seasons and two identical FFQ (FFQ_V and FFQ_R), conducted for different purposes. The FFQ_V was completed immediately or 3 months after the last DR was administered to obtain the data required for comparison with the DR. The other FFQ (FFQ_R) was administered to provide data to evaluate the reproducibility of the FFQ_V. For the present paper, we analysed the validity of the FFQ in the estimation of amino acids using data from 215 and 350 subjects in cohorts I and II, respectively, who had complete data for the total 28 d DR and the FFQ_V.

DR were collected over 7 consecutive days in each of the four seasons, except in Chubu (two seasons). Local dietitians instructed the subjects to weigh all foods and beverages with scales and measuring utensils provided, and to record the results in a specially designed booklet. The subjects in cohort I, however, were instructed to use standardised portion sizes for some foods that were difficult to weigh (semi-weighed DR). The subjects described each food, method of preparation, and the names of dishes in detail. They also reported all dietary supplements used, if any. At the end of each season, the DR were reviewed in a standardised manner, and each food was coded using the food item code in the *Standardized Tables of Food Composition*, 4th ed.[15] by local dietitians. Energy and nutrient intakes were calculated by summing the product of the intake of each food multiplied by the amino acid content of that food.

The self-administered semi-quantitative FFQ consisted of 138 food items and fourteen supplementary questions concerning the use of dietary supplements, dietary habits and others. The results were used to assess the usual dietary intake of the preceding year for each individual. The intake of each food item was calculated by multiplying the frequency of consumption (never, 1–3 times/month, 1–2 times/week, 3–4 times/week, 5–6 times/week, once/d, 1–2 times/d, 4–6 times/d, 7 times/d and more) by the relative portion size (small, medium, and large). The food item code in the *Standardized Tables of Food Composition*, 4th ed.[15] was also assigned to the respective food item in the FFQ[16], and the daily intakes of energy and nutrients according to the FFQ for each individual were calculated by summing the product of the intake of each food multiplied by the amino acid content of that food for the same nutrients as those calculated for the DR. Because a database for dietary supplements was not available, intake from dietary supplements was not included in calculations for either the DR or FFQ.

Statistical analysis

The mean intakes of total protein and amino acids according to both the 28 d DR (14 d for Okinawa) and FFQ were calculated by sex and cohort group. Percentage differences were calculated using the following formula: (intake according to the FFQ − intake according to the DR)/intake according to the DR. Spearman's rank correlation coefficients between intakes according to the DR and FFQ were calculated for crude value, energy-adjusted (residual model) value and deattenuated value, which was corrected for the attenuating effect of random intra-individual error (deattenuation). Deattenuation was done using the following formula: deattenuated correlation coefficients $= \sqrt{(1 + (\lambda_x / n_x))}$, where r is the observed correlation, λ_x is the ratio of intra- to inter-subject variation, and n_x is number of DR for each subject[17]. In addition, the number of subjects classified into the same, adjacent, and extreme categories by joint classification by quintile was computed using energy-adjusted values. Furthermore, Bland–Altman analysis, which assesses the agreement between two methods, was applied for protein intake.

This method is achieved by plotting the mean intake from two methods, (FFQ + DR)/2 on the *x* axis, and the difference between the methods, FFQ − DR on the *y* axis. Before plotting, protein intake was log-transformed, energy-adjusted by the residual method, and then residuals were added to the constant (predicted protein intake for the mean energy intake) so that the values appear similar to the actual intake values. Overall agreement is assessed by the mean of difference, width of limit of agreement (2 SD) and the dependence of difference on the magnitude of estimates[18,19]. All analyses were performed using SAS (version 9.1; SAS Institute Inc., Cary, NC, USA).

Results

Subject characteristics are presented in Table 1. Mean age was slightly higher for men than women, and higher for participants in cohort II than cohort I, since cohort II included older subjects.

Mean intakes of total protein and amino acids according to DR and FFQ are presented in Table 2. Amino acid intake according to the FFQ was lower than intake by the DR. The difference was greater for men than women, and for the cohort II than cohort I population (median percentage differences of twenty amino acids were −14 % for cohort I men, −4 % for cohort I women, −18 % for cohort II men and −9 % for cohort II women).

Deattenuated Spearman's correlation coefficients of energy-adjusted intakes of protein and amino acids according to the FFQ and corresponding intake according to the DR ranged from 0·15 to 0·52. Median correlation coefficients for twenty amino acids were 0·33 and 0·25 for cohort I men and women, and 0·40 and 0·30 for cohort II men and women, respectively.

A comparison of FFQ and DR for amino acid intake based on joint classification by quintile is presented in Table 3. The median percentage of subjects whose amino acid intake according to the DR and FFQ were categorised into the same quintile was 25–32 %, and was higher among men than women, and in cohort I than cohort II. However, fewer subjects had their amino acid intake categorised into the extreme quintile in cohort II than cohort I.

Agreement between the two methods examined by the Bland–Altman plot in Fig. 1 showed that the mean difference for men was greater for cohort II, indicating that the degree of relative bias was greater for the external population. Further, the larger width of limit of agreement indicated greater random error in the external population.

Discussion

Here, we evaluated the validity of an FFQ using DR as a reference method. Levels of intake were underestimated by the FFQ, and its validity for ranking individuals varied from low to moderate.

Although associations between the intake of specific amino acids and diseases have been examined in several studies, the validity of FFQ in estimating dietary intake has not been evaluated[6,9]. Because the collection of information on the amino acid components of all foods is both expensive and time-consuming, obtaining intake data from a DR, which requires the composition data of a variety of foods, is not trivial. Here, we used a composition table for amino acids developed by substitution methods. To our knowledge, the present study is the first to comprehensively evaluate the validity of an FFQ in the estimation of dietary amino acid intake.

Underestimation was observed with amino acid intake, particularly among men. In analyses among our validation study subjects, energy intake estimated using the FFQ was closely similar to that using DR among men, and somewhat overestimated among women. Among macronutrients, total fat intake was overestimated by the FFQ among men and women, whereas protein was underestimated, as indicated in the present study[14,20], most likely because of missing food items or inadequate portion size estimation by the FFQ. In fact, the results from our previous study showed that fish, meat and eggs, which contribute to protein intake, were more strongly underestimated in the external population (cohort II)[14]. We cannot deny the possibility that the reference method (DR) underestimated the true intake of individuals such that the underestimation by the FFQ was exacerbated, since we did not use a more objective method such as doubly labelled water[21,22]. However, we assume that the underestimation was not particularly severe since energy intake seemed appropriate for the sex and age of

Table 1. Basic characteristic of the study participants
(Mean values and standard deviations)

	Cohort I				Cohort II			
	Male (*n* 102)		Female (*n* 113)		Male (*n* 174)		Female (*n* 176)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	55·6	5·2	53·3	5·3	58·9	7·6	55·9	7·1
Height (cm)	164·5	4·9	151·1	5·5	164·9	5·5	152·7	5·1
Weight (kg)	65·8	9·3	54·6	8·0	64·6	8·1	55·2	7·7
BMI (kg/m^2)	24·3	3·0	23·9	3·1	23·7	2·6	23·7	3·2
Energy intake, estimated using DR (kJ)	9983	1824	7757	1347	9493	1477	7381	1075
Energy intake, estimated using DR (kcal)	2386	436	1854	322	2269	353	1764	257
Energy intake, estimated using FFQ (kJ)	9678	2782	8234	3297	9188	2711	7703	2736
Energy intake, estimated using FFQ (kcal)	2313	665	1968	788	2196	648	1841	654

DR, dietary records.

Table 2. Amino acid intake assessed with dietary records (DR) for 28 d (or 14 d for Okinawa) and FFQ and their correlations

	Cohort I									Cohort II								
	DR			FFQ			Spearman's correlation coefficients			DR			FFQ				Spearman's correlation coefficients		
	Mean	SD	Median	Mean	SD	% Difference*	Crude	Energy-adjusted	Deattenuated	Mean	SD	Median	Mean	SD	Median	% Difference*	Crude	Energy-adjusted	Deattenuated
Male																			
Protein (g)	91	15	90	81	32	−10	0·50	0·33	0·35	88	15	87	76	29	71	−14	0·25	0·22	0·23
Isoleucine (mg)	4221	753	4174	3615	1447	−14	0·49	0·31	0·32	4101	727	4027	3360	1304	3164	−18	0·29	0·38	0·39
Leucine (mg)	7312	1297	7241	6368	2500	−13	0·50	0·31	0·32	7096	1230	6969	5933	2264	5574	−16	0·28	0·38	0·40
Lysine (mg)	6110	1138	6156	5070	2315	−17	0·46	0·32	0·34	6012	1189	5903	4709	2050	4299	−22	0·30	0·31	0·33
Methionine (mg)	2248	393	2258	1942	802	−14	0·48	0·29	0·30	2178	403	2148	1813	731	1729	−17	0·29	0·29	0·31
Cystine (mg)	1504	264	1506	1282	449	−15	0·54	0·35	0·37	1490	252	1474	1196	403	1155	−20	0·28	0·47	0·48
SAA (mg)	3756	647	3725	3222	1242	−14	0·51	0·31	0·32	3671	636	3624	3007	1124	2856	−18	0·28	0·36	0·37
Phenylalanine (mg)	4239	761	4223	3668	1390	−13	0·53	0·31	0·33	4130	701	4060	3414	1242	3236	−17	0·28	0·44	0·45
Tyrosine (mg)	3209	570	3195	2838	1104	−12	0·53	0·32	0·33	3253	625	3200	2631	986	2479	−19	0·31	0·34	0·36
AAA (mg)	7434	1329	7420	6502	2495	−13	0·53	0·32	0·33	7375	1309	7195	6036	2225	5681	−18	0·29	0·39	0·41
Threonine (mg)	3776	670	3760	3218	1328	−15	0·48	0·32	0·33	3685	667	3619	2984	1193	2827	−19	0·28	0·35	0·37
Tryptophan (mg)	1143	199	1134	990	379	−13	0·53	0·37	0·39	1127	197	1111	926	345	866	−18	0·28	0·41	0·43
Valine (mg)	5059	895	5004	4390	1695	−13	0·53	0·33	0·35	4911	856	4821	4080	1536	3821	−17	0·30	0·39	0·40
Histidine (mg)	3197	573	3245	2754	1182	−14	0·36	0·31	0·34	3117	666	3065	2558	1094	2355	−18	0·30	0·31	0·34
Arginine (mg)	6135	1094	6122	4960	1928	−19	0·53	0·33	0·35	5927	1064	5810	4551	1694	4352	−23	0·28	0·38	0·40
Alanine (mg)	4925	870	4884	4126	1672	−16	0·51	0·34	0·35	4797	882	4700	3788	1495	3576	−21	0·30	0·31	0·32
Aspartic acid (mg)	9185	1695	9105	7726	3135	−16	0·52	0·38	0·40	8935	1647	8816	7097	2770	6690	−21	0·30	0·40	0·42
Glutamic acid (mg)	16 662	2936	16 724	14 120	5288	−15	0·47	0·32	0·33	16 440	2659	16 293	13 378	4837	12 480	−19	0·24	0·41	0·43
Glycine (mg)	4215	738	4272	3440	1396	−18	0·48	0·30	0·32	4114	748	4045	3151	1229	2945	−23	0·27	0·31	0·33
Proline (mg)	4890	876	4913	4337	1652	−11	0·47	0·31	0·32	4852	818	4811	4200	1612	3806	−13	0·30	0·50	0·52
Serine (mg)	4179	750	4127	3586	1365	−14	0·54	0·33	0·34	4077	699	4032	3345	1230	3131	−18	0·29	0·45	0·46
Median						−14	0·51	0·32	0·33							−18	0·29	0·38	0·40
Female																			
Protein (g)	75	13	75	76	39	1	0·42	0·22	0·22	72	11	72	70	31	65	−2	0·22	0·16	0·16
Isoleucine (mg)	3515	634	3538	3383	1741	−4	0·39	0·23	0·24	3421	573	3445	3135	1402	2869	−8	0·31	0·29	0·30
Leucine (mg)	6072	1079	6103	5943	2999	−2	0·40	0·23	0·24	5912	980	5931	5521	2426	5077	−7	0·31	0·29	0·31
Lysine (mg)	5132	973	5116	4822	2805	−6	0·34	0·24	0·25	4980	854	4951	4460	2220	4028	−10	0·31	0·27	0·28
Methionine (mg)	1840	323	1841	1794	953	−3	0·38	0·19	0·20	1771	293	1749	1661	769	1549	−6	0·31	0·26	0·28
Cystine (mg)	1246	214	1255	1193	547	−4	0·43	0·28	0·29	1259	261	1244	1102	433	1036	−12	0·22	0·26	0·27
SAA (mg)	3088	532	3082	2985	1495	−3	0·41	0·22	0·22	3032	531	3018	2761	1194	2560	−9	0·27	0·28	0·30
Phenylalanine (mg)	3525	632	3548	3430	1698	−3	0·42	0·26	0·27	3469	608	3474	3179	1338	2980	−8	0·28	0·31	0·32
Tyrosine (mg)	2645	469	2675	2635	1320	0	0·41	0·24	0·25	2724	501	2702	2439	1050	2239	−10	0·29	0·22	0·23
AAA (mg)	6160	1099	6243	6062	3014	−2	0·42	0·26	0·27	6190	1097	6182	5612	2382	5213	−9	0·29	0·28	0·29
Threonine (mg)	3138	564	3163	3007	1612	−4	0·39	0·23	0·24	3069	526	3068	2776	1272	2553	−10	0·28	0·28	0·29
Tryptophan (mg)	949	166	957	927	456	−2	0·40	0·25	0·26	948	175	941	864	373	795	−9	0·27	0·30	0·31
Valine (mg)	4200	740	4215	4093	2025	−3	0·40	0·24	0·25	4110	711	4124	3794	1645	3478	−8	0·31	0·29	0·30
Histidine (mg)	2601	476	2605	2526	1416	−3	0·25	0·14	0·15	2495	422	2468	2358	1257	2143	−5	0·29	0·31	0·33
Arginine (mg)	5004	923	4984	4561	2399	−9	0·42	0·30	0·32	4874	853	4825	4170	1785	3760	−14	0·27	0·27	0·28
Alanine (mg)	4022	726	4001	3814	2050	−5	0·41	0·25	0·26	3924	644	3950	3479	1565	3140	−11	0·29	0·24	0·25
Aspartic acid (mg)	7647	1448	7566	7273	3965	−5	0·42	0·31	0·32	7501	1308	7432	6650	2956	6036	−11	0·29	0·31	0·33
Glutamic acid (mg)	14 061	2419	14 257	13 398	6586	−5	0·39	0·29	0·30	13 924	2372	13 821	12 575	5299	11 922	−10	0·27	0·33	0·34
Glycine (mg)	3434	617	3443	3175	1743	−8	0·40	0·22	0·23	3354	577	3344	2894	1298	2655	−14	0·25	0·24	0·25
Proline (mg)	4241	730	4286	4204	1977	−1	0·36	0·27	0·28	4221	797	4114	4039	1800	3720	−4	0·31	0·44	0·46
Serine (mg)	3494	627	3514	3364	1661	−4	0·42	0·24	0·25	3442	598	3446	3116	1321	2915	−9	0·30	0·33	0·35
Median						−4	0·40	0·24	0·25							−9	0·29	0·29	0·30

SAA, sulfur-containing amino acids (methionine and cystine); AAA, aromatic amino acids (phenylalanine and tyrosine).
* (Intake according to the FFQ − intake according to the DR)/intake according to the DR.

Table 3. Comparison of FFQ with dietary records (DR) for amino acid intake based on joint classification by quintile (%)*

	Cohort I			Cohort II		
	Same category†	Adjacent category‡	Extreme category§	Same category†	Adjacent category‡	Extreme category§
Male						
Protein	34	63	1	24	60	3
Isoleucine	35	63	2	26	65	2
Leucine	36	61	2	24	64	1
Lysine	33	65	3	26	64	2
Methionine	28	65	3	24	64	2
Cystine	31	70	4	33	71	1
SAA	27	65	3	26	66	1
Phenylalanine	25	63	2	29	68	1
Tyrosine	33	61	1	28	64	1
AAA	32	65	1	29	68	1
Threonine	36	59	3	30	66	2
Tryptophan	31	65	1	32	67	1
Valine	27	62	4	29	66	1
Histidine	34	61	1	28	63	3
Arginine	36	66	1	26	66	1
Alanine	33	64	3	26	66	2
Aspartic acid	36	64	2	30	67	1
Glutamic acid	29	67	4	28	71	2
Glycine	30	66	2	26	58	1
Proline	26	60	2	34	72	2
Serine	32	65	2	29	72	1
Median of twenty amino acids	32	64	2	28	66	1
Female						
Protein	28	61	4	21	60	2
Isoleucine	31	60	2	23	61	2
Leucine	27	61	2	20	60	2
Lysine	35	59	3	23	63	3
Methionine	28	59	3	23	63	1
Cystine	32	64	4	28	62	2
SAA	32	57	3	28	62	2
Phenylalanine	30	64	4	26	63	1
Tyrosine	30	64	3	24	60	3
AAA	31	65	3	22	63	2
Threonine	34	59	2	24	64	3
Tryptophan	28	65	3	24	61	2
Valine	27	61	2	25	59	2
Histidine	25	60	4	27	64	2
Arginine	32	69	4	28	64	3
Alanine	30	62	4	30	61	3
Aspartic acid	34	64	3	28	61	2
Glutamic acid	29	66	3	33	64	1
Glycine	27	61	4	22	64	3
Proline	29	62	2	30	68	1
Serine	33	60	4	30	61	1
Median of twenty amino acids	30	62	3	25	62	2

SAA, sulfur-containing amino acids (methionine and cystine); AAA, aromatic amino acids (phenylalanine and tyrosine).
* Energy-adjusted intakes of amino acids according to DR and FFQ for each individual classified into quintiles.
† Percentage of subjects whose FFQ and DR were classified into the same quintile.
‡ Percentage of subjects whose FFQ and DR were classified into the same or adjacent quintile.
§ Percentage of subjects whose FFQ and DR were classified into the extreme quintile (lowest or highest).

those participants of normal weight. In addition, protein intake was higher than the intake level in Japanese populations of the same age as the participants. According to the 2004 National Health and Nutrition Survey, the average protein intake for men and women aged 50–59 years is 82·0 and 70·5 g, respectively[23].

The validity of our FFQ for ranking individuals by amino acid intake was lower than that by the general level of other nutrients in similar studies, particularly among women. Results from previous validation studies of a number of FFQ among Japanese[24–26], including ours[20,27], tend to show lower validity than those from Western populations, possibly because of the complexity of the Japanese diet, for example, in the variety of mixed dishes, seasonal variation, and others. It is also possible that relatively poor agreement between the FFQ and the DR might be due to the heavy burden of 28 d weighed dietary recording. Lower validity due to instrument measurement error would

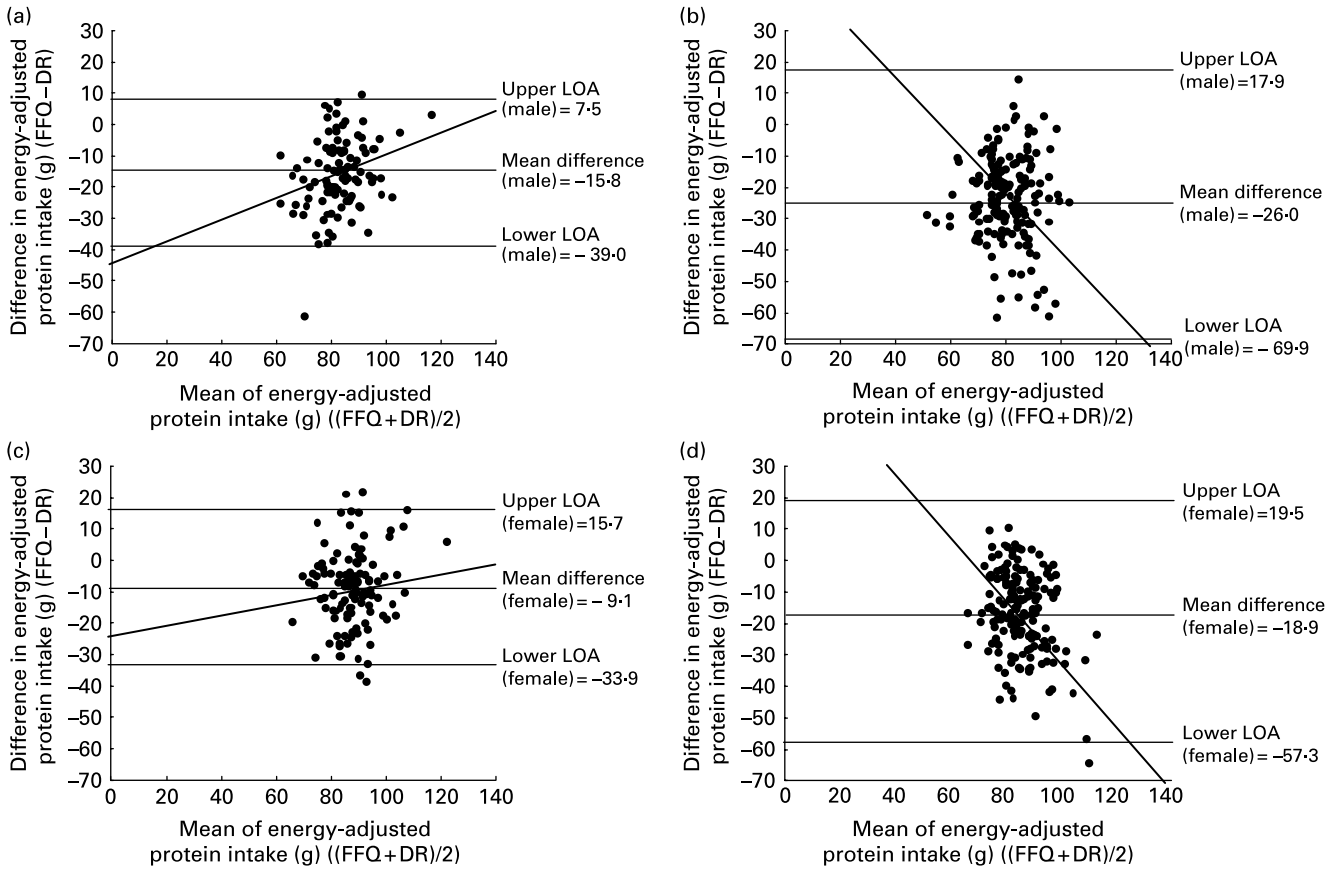

Fig. 1. Bland–Altman method of assessing agreement between the FFQ and dietary records (DR) for energy-adjusted protein intake in (a) cohort I males ($y = 0{\cdot}36x - 45{\cdot}7$; $P<0{\cdot}01$), (b) cohort II males ($y = -1{\cdot}03x + 58{\cdot}1$; $P<0{\cdot}01$), (c) cohort I females ($y = 0{\cdot}18x - 24{\cdot}6$; $P=0{\cdot}19$) and (d) cohort II females ($y = -1{\cdot}11x + 76{\cdot}7$; $P<0{\cdot}01$). LOA, limit of agreement.

of course attenuate the association between intake and disease, in turn indicating the need for awareness of the difficulty in distinguishing between a true null *v.* an attenuated association.

Correlation coefficients for amino acids were similar to that for protein within the same group. Although protein consists of amino acids, the amino acid content of individual foods and individual intake varies. Nevertheless, the present results suggest the possibility of surrogating the validity of protein determination for that of amino acids. Protein is one of the few nutrients whose intake is directly reflected by an available recovery biomarker, i.e. 24 h urine N[28]. The fact that the validity of amino acid intake could be surrogated by that of protein may suggest the possibility of using this biomarker to assess amino acid intake, a valuable notion if confirmed, as no single ideal biochemical indicator of dietary intake of amino acids is known[10]. One weakness of the present study is that we did not measure urinary N, which would have greatly strengthened the results. If feasible, a future study of this in our frozen 24 h urine samples would be of interest.

A limitation of the present study was that amino acid intake from supplements was not included in the estimations of intake. However, given that very few subjects (less than 2 %) consumed supplements that included amino acids, intake from this source is probably negligible.

Compared with 28 d DR, the FFQ is a valid tool to rank participants according to high and low intakes of amino acids in this population of Japanese men and women. In conclusion, the validity of this FFQ in estimating amino acid intake was low to moderate. However, because the degree of validity in estimating protein and amino acids was similar, the use of protein intake as a surrogate for that of amino acids in investigations of the association between specific amino acids and diseases may be possible.

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