Table 1. Continued

References	Study	Subjects	Dietary assessment	Depressive symptom assessment[a)]	Adjustment for potential confounders	Main findings
						and French (β: −0.14; 95% CI: −2.73, −1.17) samples
Liu *et al.* [24]	Survey conducted in seven cities of China, 2003–2004, cross-sectional design	2579 college students	FFQ, number of items not shown, not validated	Three items derived from the 20-item CES-D	Gender, grade, city, perceived weight, smoking level, alcohol use	Descriptive information on food consumption and depression score not available. Significant inverse relation of consumption frequency of fruit with the depression score ($p<0.0001$). Significant positive relation of consumption frequency of ready-to-eat food[c)] and fast food[d)] with the depression score ($p<0.05$). No relation of consumption frequency of snack food[e)] with the depression score
Merete *et al.* [25]	Massachusetts Hispanic Elderly Study, USA, 1993–1997, cross-sectional design	Representative sample of Hispanic elders ($n=618$) and a comparison group of non-Hispanic white elders ($n=251$)	FFQ, 118 items, previously validated against a 24-h dietary recall	CES-D, 20 items, potential score of 0–60	Age, sex, ethnicity, total energy intake, folate intake, education	Mean value (SE) of vitamin B-6 intake (crude) and CES-D score: 1.96 (0.04) mg/day and 15.4 (0.5) for Hispanics and 2.05 (0.06) mg/day and 10.0 (0.6) for non-Hispanic whites, respectively. Prevalence of depressive symptoms (CES-D ≥16): 41% for Hispanics; 23% for non-Hispanic whites. Significant inverse relation of vitamin B-6 intake (crude) with CES-D score (β: −0.30; SE: 0.14; $p<0.05$), but no relation with the prevalence of depressive symptoms
Murakami *et al.* [26]	Survey of municipal employees of two offices, Japan, 2006, cross-sectional design	301 men and 208 women aged 21–67 years	BDHQ, 56 items, previously validated against DRs and serum biomarkers	CES-D, 20 items, potential score of 0–60	Age, BMI, work place, marital status, occupational physical activity, leisure-time physical activity, current smoking, current alcohol drinking, job stress score	Mean dietary intake (SD) in men and women (energy-adjusted): 174 (55) and 224 (78) μg/1000 kcal for folate, 0.66 (0.17) and 0.77 (0.20) mg/1000 kcal for riboflavin, 0.62 (0.14) and 0.73 (0.16) mg/1000 kcal for vitamin B-6, 4.8 (2.3) and 4.8 (2.5) μg/1000 kcal for vitamin B-12, 1.31 (0.36) and 1.48 (0.38) % energy for total n-3 PUFA, 0.85 (0.23) and 1.00 (0.24) % energy for ALA, 0.14 (0.08) and 0.14 (0.08) % energy for EPA, and 0.23 (0.12) and 0.24 (0.12) %

Table 1. Continued

References	Study	Subjects	Dietary assessment	Depressive symptom assessment[a)]	Adjustment for potential confounders	Main findings
						energy for DHA, respectively. Prevalence of depressive symptoms (CES-D ≥ 16): 36% for men and 37% for women. Significant inverse relation of folate intake (energy-adjusted) with the prevalence of depressive symptoms in men (OR (95% CI) for the highest quartile compared with the lowest: 0.50 (0.23, 1.06); p for trend = 0.045) but not in women. No relation of riboflavin, vitamin B-6, vitamin B-12, total n-3 PUFA, ALA, EPA, or DHA intake (energy-adjusted) with depressive symptoms in either sex
Sontrop *et al.* [27]	Prenatal Health Project, Canada, 2002–2005, cross-sectional design	2061 pregnant women between 10 and 22 wk' gestation	FFQ, 106 items, previously validated against DRs	CES-D, 20 items, potential score of 0–60	Age, marital status, education, income, occupational stress, smoking status, physical activity, meeting Canada Food Guide to Healthy Living guidelines, energy intake	68% reported fish consumption ≥ once/wk. Median intake of EPA+DHA: 85.1 mg/day. Mean score (SD) of CES-D: 9.9 (8.0). No relation of intake (crude) of fish or EPA+DHA with CES-D score
Jacka *et al.* [28]	Hordaland Health Study, Norway, 1997–1999, cross-sectional design	5708 community residents (1220 men and 1726 women aged 46–49 years and 1241 men and 1521 women aged 70–74 years)	FFQ, 169 items, previously validated against DRs and serum and adipose tissue biomarkers	HAD depression scale, seven items, potential score of 0–21	Gender, age, waist-hip ratio, BMI, systolic blood pressure, education, income, smoking, alcohol consumption, physical activity	Mean value (SD) of magnesium intake (crude) and HADS depression scale: 391 (97) mg/day and 3.5 (2.9) for men aged 46–49 years, 321 (87) mg/day and 3.0 (2.9) for women aged 46–49 years, 334 (89) mg/day and 3.6 (2.9) for men aged 70–74 years, and 275 (83) mg/day and 3.5 (2.9) for women aged 70–74 years, respectively. Prevalence of depressive symptoms (HADS depression scale ≥ 8): 9.1%. Significant inverse relation of magnesium intake (energy-adjusted) with the depression score (β: −0.11; 95% CI: −0.16, −0.05), but no relation with the

Table 1. Continued

References	Study	Subjects	Dietary assessment	Depressive symptom assessment[a)]	Adjustment for potential confounders	Main findings
						prevalence of depressive symptoms
Jeffery *et al.* [29]	Telephone survey, USA, cross-sectional design	4655 women aged 40–65 years enrolled in the Group Health Cooperative	FFQ, 30 items, not validated (developed based on a validated 60-item FFQ)	Brief PHQ, nine items, potential score of 0–27	Energy intake, BMI	Mean (SD) frequency of consumption: 1.77 (1.33) times/day for high-calorie sweets[f)]; 7.11 (2.78) times/day for high-calorie nonsweets[g)]; 2.81 (1.25) times/day for low-calorie foods[h)]. Mean score (SD) of brief PHQ: 5.1 (4.7). Significant positive relation of high-calorie sweets with brief PHQ score (β: 0.012; $p<0.01$). Significant inverse relation of high-calorie nonsweets (β: −0.018; $p<0.01$) and low-calorie foods (β: −0.027; $p<0.001$) with brief PHQ score
Case-control design						
Browne *et al.* [30]	Survey, New Zealand, case-control design	80 first-time mothers (41 with postnatal depression[b)] and 39 without postnatal depression), no mention for matching strategy	FFQ, number of items not shown, not validated. Dietary assessment conducted during pregnancy	EPDS, 10 items, potential score of 0–30. BDI, 21-items, potential score of 0–63	Household income, current breastfeeding	85% reported consumption of fish. No relation of consumption frequency of fish with the risk of postnatal depression
Prospective cohort design						
Hakkarainen *et al.* [31]	Alpha-Tocopherol, Beta-Carotene Cancer Prevention Study, Finland, 1985–1994, prospective cohort design (6-year follow-up)	27 111 male smokers aged 50–69 years (at baseline) participating in an intervention trial	DHQ, 276 items, baseline only, previously validated against DRs	Self-report of depressed mood (one item). Hospital treatment due to depressive disorder derived from the National Hospital Discharge Register	Baseline age, BMI, energy intake, serum total and high-density lipoprotein cholesterol levels, consumption of alcohol, education, marriage, self-reported anxiety, self-reported depression, smoking	Mean (SD) dietary intake (energy-adjusted): 39 g/day for fish; 0.5 g/day for n-3 PUFA from fish; 1.7 g/day for n-3 PUFA from vegetables; 2.1 g/day for total n-3 PUFA. Incidence of depression: 32% defined by self-report and 0.9% defined by discharge register. No relation of intake (energy-adjusted) of fish, n-3 PUFA from fish, n-3 PUFA from vegetables, or total n-3 PUFA with the risk of depression defined by self-report or discharge register
Jacka *et al.* [32]	Geelong Osteoporosis Study, Australia, 1994–2001,	Randomly selected community sample of women ($n=755$; aged 23–97 years)	FFQ, number of items not shown, not validated. Assessment	Self-report of depression based on DSM-IV criteria	Age, weight, smoking status	Mean (interquartile range) intake of n-3 PUFA (crude): 0.11 (0.05–0.22) g/d. 12.9% identified as depressed. No difference in

Table 1. Continued

References	Study	Subjects	Dietary assessment	Depressive symptom assessment[a)]	Adjustment for potential confounders	Main findings
	prospective cohort design (6-year follow-up)		conducted at baseline, 2-, 4-, and 6-year follow-up and the average value used			n-3 PUFA intake (crude) between depressed and non-depressed women
Tolmunen *et al.* [33]	Kuopio Ischemic Heart Disease Study, Finland, 1984–2000, prospective cohort design (13-year follow-up)	2313 men aged 42–60 years	4-d DRs, baseline only	Discharge diagnosis of depressive disorder during the follow-up period obtained by computer linkage to the national hospital discharge resister	Age, examination center, current SES, baseline HPLDS score, intake (energy-adjusted) of fiber, vitamin C, total fat	Mean (SD) dietary intake (energy-adjusted): 256 (76) μg/day for folate and 9.5 (9.5) μg/day for vitamin B-12. Incidence of depression: 2%. Significantly higher risk of depression among those below the median of folate intake (energy-adjusted) than those above the median (OR (95% CI): 2.53 (1.17, 5.48)). No relation of vitamin B-12 intake (energy-adjusted) with the risk of depression
Miyake *et al.* [34]; Miyake *et al.* [35]; Murakami *et al.* [36]	Osaka Maternal and Child Health Study, Japan, 2001–2003, prospective cohort study (diet during pregnancy and postpartum depression)	865 women during pregnancy at baseline	DHQ, 150 items, previously validated against DRs and urine and serum biomarkers	EPDS, ten items, potential score of 0–30	Age, gestation, parity, cigarette smoking, family structure, occupation, family income, education, changes in diet in the previous one month, season in which baseline data were collected, BMI, time of delivery before the second survey, medical problems in pregnancy, baby's sex, baby's birth weight. For dietary glycemic index and glycemic load, intake of n-3 PUFA and riboflavin (energy-adjusted)	Mean (SD) dietary intake (energy-adjusted): 48 (28) g/day for fish; 2.3 (0.8) g/day for n-3 PUFA; 0.2 (0.2) g/day for EPA; 0.3 (0.2) g/day for DHA; 11.0 (2.9) g/day for n-6 PUFA; 286 μg/day for folate; 5.7 μg/day for vitamin B-12; 1.0 mg/day for vitamin B-6; 1.4 mg/day for riboflavin; 63.9 (3.9) for dietary glycemic index (crude); 80.1 (12.1)/1000 kcal for dietary glycemic load. 14% classified as having postpartum depression (EPDS ≥9). No relation of dietary intake (energy-adjusted) of fish, n-3 PUFA, EPA, DHA, n-6 PUFA, ratio of n-3 to n-6 PUFA, total fat, SFA, MUFA, cholesterol, LA, ALA, arachidonic acid, meat, egg, dairy products, folate, vitamin B-12, vitamin B-6, riboflavin, dietary glycemic index, or glycemic load with postpartum depression
Sanchez-Villegas *et al.* [37]	SUN (Seguimiento Universidad de Navarr[a)] cohort study, Spain,	7903 university graduates without physician-	FFQ, 136 items, baseline only, previously	Self-reported physician diagnosis of	Age, gender, incapacitating disease at baseline, energy intake, physical	Median (10th–90th percentiles) dietary intake (energy-adjusted): 0.87 (0.39–1.89) g/day for long

Table 1. Continued

References	Study	Subjects	Dietary assessment	Depressive symptom assessment[a)]	Adjustment for potential confounders	Main findings
	1999–2006, prospective cohort design (2-year follow-up)	diagnosed depression at baseline	validated against DRs	depression, anxiety, or stress or use of antidepressant medication or tranquilizers during follow-up	activity during leisure time, change in physical activity since baseline	chain n-3 PUFA and 83 (36–162) g/day for fish. Incidence of mental disorders of 6.5%. No relation of long chain n-3 PUFA or fish intake (energy-adjusted) with mental disorders
Bots *et al.* [38]	Finland, Italy and the Netherlands Elderly Study, 1989–1995, prospective cohort design (5-year follow-up)	526 non-demented and non-depressed European men aged 70–89 years at baseline	DHI, baseline only	ZSDS, 20 items, potential score of 20–80	Age	Mean baseline dietary intake (SD) in non-depressed and depressed men (crude): 9739 (2445) and 10023 (2689) kJ/day for energy, 90.9 (29.1) and 90.9 (35.1) g/day for total fat, 14.3 (8.5) and 12.1 (6.5) g/day for PUFA, 36.5 (18.0) and 38.1 (24.8) g/day for SFA, and 282 (152) and 309 (203) mg/day for cholesterol, respectively. Incidence of depressive symptoms (ZSDS $\geq$48) of 11%. No relation of intake of energy, fat, SFA, PUFA, or cholesterol (crude) with depressive symptoms
Astorg *et al.* [39]; Astorg *et al.* [40]	SU.VI.MAX Study, France, 1994–2002, prospective cohort design (8-year follow-up)	1864 adults participating in an intervention trial (809 men aged 45–60 years and 1055 women aged 35–60 years at baseline)	6 × 24-h DRs collected during the first 2 years of follow-up	Self-report of antidepressant or lithium prescription during follow-up	Age, intervention group, family status, education level. For fatty acids and fish, also tobacco use. For folate, also socio-professional category, total energy intake	Mean intake (SD) of fish and seafood (crude), EPA+DPA+DHA (energy-adjusted), and folate (crude): 49 (35) g/day, 0.20 (0.15) % energy, and 342 (94) μg/day for men without any depressive episode, 49 (35) g/day, 0.18 (0.13) % energy, and 350 (109) μg/day for men with a single depressive episode, 34 (30) g/day, 0.18 (0.16) % energy, and 282 (87) μg/day for men with recurrent depressive episodes, 39 (29) g/day, 0.21 (0.16) % energy, and 289 (85) μg/day for women without any depressive episode, 37 (30) g/day, 0.21 (0.17) % energy, and 286 (93) μg/day for women with a single depressive episode, and 39 (34) g/day, 0.22 (0.21) % energy, and 297 (114) μg/day for women with recurrent depressive episodes, respectively. Occurrence of a single and

Table 1. Continued

References	Study	Subjects	Dietary assessment	Depressive symptom assessment[a)]	Adjustment for potential confounders	Main findings
						recurrent depressive episodes: 6 and 4% for men and 12 and 9% for women, respectively. Significant inverse relation of fish and seafood intake (crude) with the risk of recurrent depressive episodes (OR (95% CI) for the highest tertile compared with the lowest: 0.39 (0.16, 0.97); p for trend = 0.03), but not with the risk of any depressive episodes or a single depressive episode, in men. No relation of fish and seafood with depressive episodes in women. No relation of EPA+DPA+DHA intake (energy-adjusted) with depressive episodes in either sex. Significant inverse relation of folate intake (crude) with the risk of recurrent depressive episodes (OR (95% CI) for the highest tertile compared with the lowest: 0.25 (0.06, 0.98); p for trend = 0.046), but not with the risk of any depressive episodes or a single depressive episode, in men. No relation of folate with depressive episodes in women

ALA, alpha-linolenic acid; β, regression coefficient; BDHQ, brief diet history questionnaire; BDI, Beck Depression Inventory; CES-D, Center for Epidemiologic Studies Depression Scale; CI, confidence interval; DASS-21, Depression, Anxiety and Stress Scales (21-item version); DHA, docosahexaenoic acid; DHI, diet history interview; DHQ, diet history questionnaire; DPA, docosapentaenoic acid; DR, dietary record; DSM, diagnostic and statistical manual; EPA, eicosapentaenoic acid; EPDS, Edinburgh Postnatal Depression Scale; ETA, eicosatetraenoic acid; FFQ, food frequency questionnaire; GDS, Geriatric Depression Scale; HAD, hospital anxiety and depression; HPLDS, Human Population Laboratory Depression Scale; HSCL, Hopkins symptom checklist; LA, linoleic acid; OR, odds ratio; OTA, octadecatetraenic acid; PHQ, Patient Health Questionnaire; SE, standard error; SES, socioeconomic status; SF-36, Short Form Health Survey 36; SFA, saturated fatty acid; YAQ, Youth and Adolescent food frequency Questionnaire; ZSDS, Zung Self-rating Depression Scale

a) A higher score indicated a more depressed mood, unless otherwise indicated.

b) Mothers with a score of ≥ 9 on EPDS or a score of ≥ 10 on BDI classified as depressed.

c) Including instant noodles and frozen, canned, or microwave foods.

d) Including anything from a fast food restaurant.

e) Including potato chips, corn chips, and tortilla chips.

f) Including cake, chocolate, cornbread, sweetened soda, and sweetened fruit drinks.

g) Including French fries, potato salad, spaghetti, buttered bread, chips, mayonnaise, hamburger, steak, beef stew, fried chicken, fried fish, pork, eggs, margarine, lunch meat, bacon, butter, cheese, and whole milk.

h) Including orange juice, green salad, roast chicken, baked fish, low-fat milk, and cold cereal.

Table 2. Distribution of studies on the relation between dietary intake and depressive symptoms by type of finding[a)]

	Men						Women						Men and women not separated					
	Studies showing significant positive associations		Studies showing null associations		Studies showing significant inverse associations		Studies showing significant inverse associations		Studies showing significant inverse associations		Studies showing null associations		Studies showing null associations		Studies showing significant positive associations		Studies showing significant positive associations	
	n	Reference[b)]	*n*	References[b)]	*n*	References[b)]	*n*	Reference[b)]	n	Reference[b)]	n	Reference[b)]	n	Reference[b)]	n	Reference[b)]	n	Reference[b)]
Energy	0		0		2	[11, 38]	0		0		1	[11]	0		0		0	
Fat	0		0		2	[11, 38]	0		0		2	[11, 34]	0		0		1	[21]
SFA	0		0		1	[38]	0		0		1	[34]	0		0		1	[21]
MUFA	0		0		0		0		0		1	[34]	0		0		1	[21]
PUFA	0		0		1	[38]	0		0		0		0		0		1	[21]
n-3 PUFA	0		0		3	[20, 26, 31]	0		0		4	[20, 26, 32, 34]	0		1	[12]	0	
ALA	0		0		1	[26]	0		0		2	[26, 34]	0		1	[12]	0	
OTA	0		0		0		0		0		0		0		0		1	[12]
ETA	0		0		0		0		0		0		0		0		1	[12]
EPA	0		0		1	[26]	0		0		2	[26, 34]	0		0		1	[12]
DPA	0		0		0		0		0		0		0		0		1	[12]
DHA	0		0		1	[26]	0		0		2	[26, 34]	0		0		1	[12]
EPA+DHA	0		1	[18]	0		0		0		1	[27]	0		0		1	[12]
EPA+DPA+DHA	0		0		1	[39]	0		0		1	[39]	0		0		0	
n-3 PUFA from fish	0		0		1	[31]	0		0		0		0		0		2	[22, 37]
n-3 PUFA from vegetables	0		0		1	[31]	0		0		0		0		0		0	
n-6 PUFA	0		0		0		0		0		1	[34]	0		0		0	
LA	0		0		0		0		0		1	[34]	0		0		0	
arachidonic acid	0		0		0		0		0		1	[34]	0		0		0	
Ratio of n-3 to n-6 PUFA	0		0		0		0		0		1	[34]	0		0		0	
Cholesterol	0		0		1	[38]	0		0		1	[34]	0		0		1	[21]
Carbohydrate	0		0		0		0		0		0		0		0		1	[21]
Sucrose	0		0		1	[11]	0		0		1	[11]	0		0		0	
Dietary fiber	0		0		0		0		0		0		0		1	[21]	0	
Dietary glycemic index	0		0		0		0		0		1	[36]	0		0		0	
Dietary glycemic load	0		0		0		0		0		1	[36]	0		0		0	
Thiamin	0		0		0		0		0		0		0		0		1	[21]
Riboflavin	0		0		2	[10, 26]	0		0		2	[26, 35]	0		1	[21]	0	
Niacin	0		0		0		0		0		0		0		0		1	[21]
Vitamin B-6	0		0		5	[10, 11, 19, 20, 26]	0		0		4	[11, 20, 26, 35]	0		1	[25]	0	
Vitamin B-12	0		0		6	[10, 11, 19, 20, 26, 33]	0		0		4	[11, 20, 26, 35]	0		0		0	
Folate	0		4	[10, 26, 33, 40]	3	[11, 19, 20]	0		0		5	[11, 20, 26, 35, 40]	0		0		0	
Vitamin C	0		0		0		0		0		0		0		0		1	[21]
Vitamin A	0		0		0		0		0		0		0		1	[21]	0	
Vitamin D	0		0		1	[11]	0		0		1	[11]	0		0		0	
Calcium	0		0		1	[11]	0		0		1	[11]	0		0		0	
Magnesium	0		0		0		0		0		0		0		1	[28]	0	
Iron	0		0		1	[11]	0		0		1	[11]	0		0		1	[21]
Iodine	0		0		0		0		0		0		0		0		1	[21]

Table 2. Continued

	Men						Women						Men and women not separated					
	Studies showing significant positive associations		Studies showing null associations		Studies showing significant inverse associations		Studies showing significant inverse associations		Studies showing significant inverse associations		Studies showing null associations		Studies showing null associations		Studies showing significant positive associations		Studies showing significant positive associations	
	n	Reference[b]	*n*	References[b]	*n*	References[b]	*n*	Reference[b]	n	Reference[b]	n	Reference[b]	n	Reference[b]	n	Reference[b]	n	Reference[b]
Isoflavone	0		0		0		0		0		0		0		0		1	[21]
Fish	0		2	[23, 39]	2	[13, 31]	0		1	[13]	4	[27, 30, 34, 39]	0		4	[7, 8, 9, 14]	3	[17, 21, 37]
Meat	0		0		0		0		0		1	[34]	0		0		0	
Egg	0		0		0		0		0		1	[34]	0		0		0	
Dairy products	0		0		0		0		0		1	[34]	0		0		0	
Fruit	0		0		1	[11]	0		0		1	[11]	0		1	[24]	2	[17, 21]
Vegetables	0		0		1	[11]	0		0		1	[11]	0		1	[21]	1	[17]
High-calorie sweets[c]	0		0		0		1	[29]	0		0		0		0		0	
High-calorie nonsweets[d]	0		0		0		0		1	[29]	0		0		0		0	
Low-calorie foods[e]	0		0		0		0		1	[29]	0		0		0		0	
Ready-to-eat food[f]	0		0		0		0		0		0		1	[24]	0		0	
Snack food[g]	0		0		0		0		0		0		0		0		1	[24]
Fast food[h]	0		0		0		0		0		0		1	[24]	0		0	
Tea	0		0		0		0		0		0		0		1	[17]	0	
Coffee	0		0		0		0		0		0		0		0		1	[17]
Soft drinks	1	[11]	0		0		0		0		1	[11]	0		0		0	

ALA, alpha-linolenic acid; DHA, docosahexaenoic acid; DPA, docosapentaenoic acid; EPA, eicosapentaenoic acid; ETA, eicosatetraenoic acid; LA, linoleic acid, OTA, octadecatetraenic acid; SFA, saturated fatty acid

a) Studies investigating dietary patterns [15, 16] not included.

b) References in square brackets: prospective cohort design; references in parentheses: case-control design; others: cross-sectional design.

c) Including cake, chocolate, cornbread, sweetened soda, and sweetened fruit drinks.

d) Including French fries, potato salad, spaghetti, buttered bread, chips, mayonnaise, hamburger, steak, beef stew, fried chicken, fried fish, pork, eggs, margarine, lunch meat, bacon, butter, cheese, and whole milk.

e) Including orange juice, green salad, roast chicken, baked fish, low-fat milk, and cold cereal.

f) Including instant noodles and frozen, canned, or microwave foods.

g) Including anything from a fast food restaurant.

h) Including potato chips, corn chips, and tortilla chips.

on n-3 long-chain PUFAs, almost all studies showed no association. Several papers ($n = 1$–7) investigated other nutrients such as vitamins, minerals, and isoflavones, with particular focus on folate and other B vitamins, but again almost all studies showed no association, with the exception for folate in men. Four articles reported a significant inverse relation between folate intake and depressive symptoms, while no association was observed in three. Several studies ($n = 1$–7) investigated a wide range of foods, but again almost all studies showed no association, with the exception of fish: seven articles (two in men, one in women, and four in men and women combined) reported a significant inverse relation of fish intake with depressive symptoms, while nine (two in men, four in women, and three in men and women combined) observed no association.

4 Discussion

In the present review, we systematically reviewed observational studies investigating the association between dietary intake and depressive symptoms in free-living humans (23 cross-sectional, 10 prospective cohort, and 1 case-control studies). The studies varied in the number and age of subjects, dietary assessment method used, and depressive symptom assessment applied. The most frequently investigated dietary variables included long-chain n-3 PUFAs, fish, folate, and other B vitamins. Most studies showed no association between dietary variables and depressive symptoms. However, most studies included at least one important methodological limitation, such as no inference for causality (*i.e.* in a cross-sectional study, since the exposure (*e.g.* diet) and outcome (*e.g.* depression) are measured at the same time, it is not possible to say which is cause and which is effect), unreliable or rough assessment of diet or depressive symptoms, inadequate treatment of potential confounding factors, and ignorance of the possible mediating or confounding influence of other dietary variables. Thus, firm conclusions regarding the association between dietary intake and depressive symptoms cannot be drawn at present. The present review, to our knowledge the first systematic review of observational studies on diet and depressive symptoms, may nevertheless be useful for future research on this important topic.

Although a meta-analysis of these studies would have been interesting, our review showed that the number of observational studies is relatively limited, with only one to seven studies for each dietary variable. Additionally, the reliability of meta-analyses depends the homogeneity of the subjects examined and methods used, which the existing research does not necessarily provide. We therefore consider that it is too early to conduct a meta-analysis of observational studies on dietary intake and depressive symptoms.

When comparing or summarizing the results of several studies, consideration should be given to differences among study subjects and in the methods used. Because depressive symptoms are difficult to define, the studies reviewed here defined them using a variety of methods, including discharge diagnosis, established scale, and self-reported information. More importantly, several articles relied on self-reported information without any validity investigation. These differences in the assessment of depressive symptoms may have influenced the results on these studies. Additionally, because most of the established scales were validated with clinical depressed patients, these may not be suitable for measuring mood in non-depressed participants. Further, some of the scales were designed for measuring anxiety as well as depressed mood. Efforts for developing scales on depressive symptoms suitable for epidemiologic research on healthy persons may be needed.

Dietary assessment methods also varied among studies. Most of the articles examined used relatively accurate methods such as dietary records, diet history interviews, and validated dietary questionnaires. Several articles used less accurate methods, however, such as non-validated dietary questionnaire. These differences in dietary assessment method may also have impacted the results of the association between dietary intake and depressive symptoms.

The misreporting of dietary intake, particularly by overweight subjects, is a serious problem in self-report dietary assessment [41]. Nevertheless, evidence suggests that error by misreporting can be cancelled by energy adjustment, at least in part [42, 43]. About 60% of the present studies used non-energy adjusted values, however, and further research using energy-adjusted dietary intake values is needed.

Although many studies controlled for well-known confounding factors, few took account of potential confounding or mediating dietary intake variables. More importantly, while there appear to be sex differences in the association between dietary intake and depressive symptoms (*i.e.* folate), analyses in the 60% (12 out of 20) of studies, which included both men and women were conducted with both sexes combined. Further research on this area should be conducted in men and women separately.

Although most of the studies reviewed were cross-sectional in nature (70%), the lack of association between dietary variables and depressive symptoms in most of both the cross-sectional and prospective cohort studies suggested that the overall results of this review were not materially affected by study design. Nevertheless, because a cross-sectional design hampers the drawing of conclusions on causal inferences between diet and depressive symptoms, further research with prospective cohort designs are needed.

In the present review, because the literature search was limited to only one database (PubMed), with a manual check of the reference lists of the included papers, articles appearing in journals not included in PubMed or in languages other than English were not identified. Additionally, research with negative results may likely remain unpublished (publication bias).

In conclusion, our systematic review identified only a limited number of observational studies investigating the

association between dietary intake and depressive symptoms (23 cross-sectional, 10 prospective cohort, and 1 case-control studies). The number and age of subjects, and the dietary and depressive symptom assessment methods used varied among studies. Dietary variables most frequently investigated included long-chain n-3 PUFAs, fish, folate, and other B vitamins. Most studies showed no association between dietary variables and depressive symptoms. However, most studies included at least one of important methodological limitation, such as no inference for causality, unreliable or rough assessment of diet or depressive symptoms, inadequate treatment of potential confounding factors, and ignorance of the possible mediating or confounding influence of other dietary variables. Given that the relationship between eating and mood is quite complex, and that food intake pattern reflects complex interrelations and interactions among the individual, the culture, and the society in which people live [2], firm conclusions regarding the association between dietary intake and depressive symptoms cannot be drawn at present. Because intervention trials are usually conducted in depressive patients rather than healthy persons, these inevitably provide information for treatment but not for prevention. Conversely, observational studies among healthy people provide information for prevention. Thus, further evidence from well-designed observational studies is required to confirm or refute the association between dietary intake and depressive symptoms in free-living settings.

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Relation of body composition to daily physical activity in free-living Japanese adult women

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Abstract

The objective of the present study was to investigate the relationship between the indices of body size such as BMI, fat-free mass index (FFMI, FFM/height^2), fat mass index (FMI, FM/height^2), and body fat percentage (%BF), and physical activities assessed by the doubly-labelled water (DLW) method and an accelerometer in free-living Japanese adult women. We conducted a cross-sectional study in 100 female subjects ranging in age from 31 to 69 years. Subjects were classified in quartiles of BMI, FFMI, FMI and %BF. Daily walking steps and the duration of light to vigorous physical activity were simultaneously assessed by an accelerometer for the same period as the DLW experiment. Only physical activity-related energy expenditure (PAEE)/FFM and PAEE/body weight (BW) decreased in the highest quartile of BMI. Physical activity level, PAEE/FFM and PAEE/BW decreased in the highest quartile of FMI and %BF, whereas they were not different among quartiles of FFMI. Daily walking steps and the duration of moderate- and vigorous-intensity physical activities decreased or tended to decrease in the highest quartile of FMI and %BF, but did not differ among quartiles of FFMI and BMI. These results clearly showed that Japanese adult women with higher fat deposition obviously had a low level of physical activities assessed by both the DLW method and accelerometry, but those with larger BMI had lower PAEE/FFM and PAEE/BW only. Our data suggest that the relationship between obesity and daily physical activities should be discussed using not only BMI but also FMI or %BF.

Key words: Body composition: Physical activity: Doubly-labelled water: Accelerometry: Japanese adult women

Obesity is caused by an imbalance between energy intake and energy expenditure. Obese individuals are often considered to be physically less active than normal-weight individuals. However, most cross-sectional studies using the doubly-labelled water (DLW) method, which is known to be the most accurate method of measuring energy expenditure in free-living conditions[1,2], have reported that physical activity level (PAL; the ratio of total energy expenditure(TEE):BMR) did not differ among BMI categories[3–6]. The reason for the lack of this association may be partly explained by differences in the distribution of fat-free mass (FFM) and fat mass (FM). PAL appears to be negatively associated with FM[7,8], but not correlated with FFM[5]. However, these studies have only reported information on the association between PAL and either FM or FFM, which are not adjusted for body size, such as body height. To our knowledge, no information is available from thoroughly examining the relationship between BMI or body composition, i.e. FFM index (FFMI, FFM divided by height squared), FM index (FMI, FM divided by height squared) or body fat percentage (%BF) and physical activity in adult women, particularly in Asian populations.

Recently, many cross-sectional studies on adult women in Western countries and Japan reported that BMI and %BF were inversely associated with daily walking steps[9,10]. Furthermore, %BF was negatively associated with the duration of vigorous-intensity physical activity assessed by accelerometry[11]. Therefore, not only physical activity-related energy expenditure (PAEE) but also the intensity of the physical activity or walking steps should be lower among adult women with higher body mass or fat deposition.

In the present study, we investigated the relationship between various indices of body size such as BMI, FFMI,

Abbreviations: %BF, body fat percentage; BW, body weight; DHQ, diet history questionnaire; DMW, doubly-labelled water; FFM, fat-free mass; FFMI, fat-free mass index; FM, fat mass; FMI, fat mass index; METs, metabolic equivalents; PAEE, physical activity-related energy expenditure; PAL, physical activity level; SCOP, Saku Control Obesity Program; TEE, total energy expenditure.

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FMI and %BF, and daily physical activities assessed by the DLW method and accelerometry in free-living Japanese adult women.

Methods

Subjects

Study participants were recruited through healthcare centres or at workplaces from various prefectures of the Kanto area (central Japan) and the Kyushu area (Western Japan), and from the Saku Control Obesity Program (SCOP). The details of SCOP are described elsewhere[12]. In each location, subjects were included according to the following criteria: (a) in good health; (b) not pregnant or breast-feeding; (c) BMI higher than 18·5 kg/m^2; (d) living in their home prefecture 2 weeks before and during the study; (e) not on a weight-loss or treatment diet; and (f) alcohol consumption less than 40 g/d. As a result, 100 female subjects aged 31 to 69 years participated in the present study. Daily physical activity was estimated over the 14 d study period in free-living conditions using the DLW method and accelerometry. Over the entire assessment period, subjects were carefully instructed to maintain their normal daily activities and eating patterns and to make no conscious effort to lose or gain weight.

Procedures

The experimental design is shown in Fig. 1. Participants completed two visits to study sites on day 0 and day 15. On the day before the start of measuring physical activity (day 0), urine samples were collected early in the morning, 12 h or longer after the last meal (baseline urine sample), and body weight (BW) and height were measured. BMR was measured in the supine position and then the participants received a dose of DLW. On the day after the physical activity measurement (day 15), BW was measured and we then received back the urine samples, accelerometer and a self-administered diet history questionnaire (DHQ). The present study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the Ethical Committee of the National Institute of Health and Nutrition in Japan. All subjects gave their written informed consent before the commencement of the investigations.

Anthropometric measures

Anthropometric measures were obtained in the fasting state on the day before (day 0) and after the 14 d study period (day 15). BW was measured to the nearest 0·1 kg and height to the nearest 0·1 cm, in individuals wearing the lightest clothing, with underwear and no shoes. BMI was calculated as BW (kg) divided by the square of body height (m^2).

Diet history questionnaire

The DHQ is a validated sixteen-page structured questionnaire that assesses dietary habits in the preceding 1-month period[13]. Well-trained dietitians checked the DHQ to find omissions or errors and corrected them by asking questions of each participant. Details of the DHQ, methods of calculating nutrients and validity are given elsewhere[13]. We calculated the food quotient using the data from the DHQ to evaluate TEE.

Doubly-labelled water

After providing a baseline urine sample, a single dose of approximately 0·06 g ^2H_2O/kg BW (99·8 atom%; Cambridge Isotope Laboratories, Andover, MA, USA) and 1·4 g $H_2{}^{18}O$/kg BW (10·0 atom%; Taiyo Nippon Sanso, Tokyo, Japan) was given orally to each subject on day 0. After dose administration, participants were asked to collect urine samples on day 1 (the day after the DLW dose) and on eight additional times during the study period at the same time of the day (Fig. 1). All urine samples except for the baseline one were collected by the participant either at home or their place of work, and the time of sampling was recorded. All samples were first stored by freezing at −30°C in airtight parafilm-wrapped containers, and then analysed in our laboratory.

Gas analysis

Gas samples for the isotope ratio mass spectrometer were prepared by equilibration of urine samples with a gas. The gas for equilibration of ^{18}O was CO_2 and that for ^2H was H_2. Pt catalyst was used for equilibration of ^2H. The urine was analysed by a DELTA Plus isotope ratio mass spectrometer (Thermo Electron Corporation, Bremen, Germany). Each sample and the corresponding reference were analysed in duplicate.

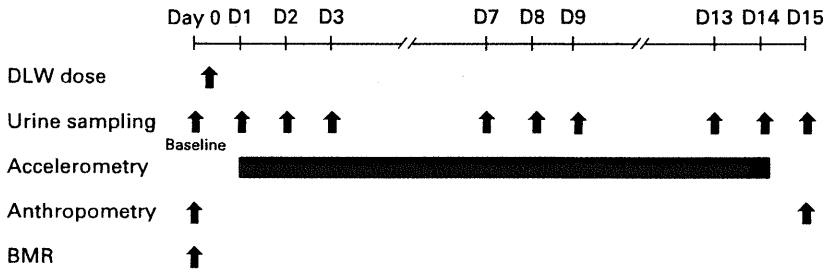

Fig. 1. Schematic representation of the experimental design. On day 0, the $^2H_2{}^{18}O$ (doubly-labelled water; DLW) dose was given orally to each subject after collecting a baseline urine sample and performing the BMR and anthropometric measurements.

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The average standard deviations through the analyses were 0·5‰ for ^{2}H and 0·03‰ for ^{18}O.

Calculations of total energy expenditure and body composition

The ^{2}H and ^{18}O zero-time intercepts and elimination rates (k_H and k_O) were calculated by using a least-squares linear regression on the natural logarithm of the isotope concentration as a function of the elapsed time from dose administration. The zero-time intercepts were used to determine the isotope pool sizes. Total body water (TBW) was calculated from the mean value of the isotope pool size of ^{2}H divided by 1·041 and that of ^{18}O divided by 1·007. FFM was calculated assuming a FFM hydration of 0·732[14]. FM was calculated as BW minus FFM and %BF was then computed from BW and FFM. The TEE (kJ/d) calculation was performed using a modification of Weir's formula[15] based on the CO_2 production rate (rCO_2) and respiratory quotient. rCO_2 was calculated as follows: $rCO_2 = 0{\cdot}4554 \times TBW \times (1{\cdot}007ko - 1{\cdot}041k_H)$. The food quotient calculated from DHQ was used instead of the respiratory quotient. This assumes that under conditions of perfect nutrient balance the food quotient must equal the respiratory quotient[16,17]. PAL was estimated by dividing TEE by BMR. PAEE was calculated as $0{\cdot}9 \times TEE - BMR$, assuming the thermic effect of food was 10% of TEE[18].

BMR

BMR was measured in the supine position in the early morning 12 h or longer after the last meal, as described previously[19]. The measurement was performed using a Douglas bag for 10 min × 2 with 1 min of intermission. After the expired air was sampled, the O_2 and CO_2 concentrations were measured using a gas analyser (Arco System, AR-1, Kashiwa, Japan for the participants from the SCOP study, or Arco System, ARCO-1000, Kashiwa, Japan, for the rest of the participants) and the volume of expired air was measured with a certified dry gas meter (DC-5; Shinagawa, Tokyo, Japan). BMR was estimated from O_2 consumption and CO_2 production using Weir's equation[15].

Accelerometry

The Lifecorder EX (Suzuken Co., Ltd, Nagoya, Japan) is a uniaxial accelerometer widely used in many countries due to its reasonable cost and reliable validity for measuring metabolic equivalents (METs) and step counts[20–22]. In the present study, the Lifecorder EX was attached on the left side of the waist at the midline of the left thigh. The movement data are categorised into eleven activity levels (0, 0·5, and 1 to 9). We applied METs for each activity level according to the study of Kumahara *et al.*, and the intensity of activity was divided into light (<3 METs), moderate (≥3 and < 6 METs) and vigorous (≥6 METs)[20].

Statistics

All values are presented as mean values and standard deviations. BMI was calculated as BW (measured before DLW dose) divided by height squared. FFMI and FMI were calculated as FFM and FM divided by height squared, respectively. Subjects were classified by quartiles of BMI, FFMI, FMI and %BF. Homoscedasticity or homogeneity of variances was examined using Levene's test. Because some variables in physical characteristics did not follow a normal distribution, the non-parametric test of Kruskal–Wallis analysis was used to compare the variables in physical characteristics among quartiles, and the Mann–Whitney *U* test was used for multiple comparisons. In variables that were normally distributed, one-way ANOVA was used to compare the variables among quartiles and Fisher's least square difference was used as a *post hoc* test for multiple comparisons. The associations between physical activities and body size or composition were examined by linear regression analysis. In one-way ANOVA, *post hoc* tests and Kruskal–Wallis tests, differences were considered to be statistically significant if the *P* value was less than 0·05; using the Mann–Whitney *U* test, differences were deemed significant at $P<0{\cdot}0125$ (modification using Bonferroni's inequality). All statistical treatments were done using SPSS for Windows (version 16.0J; SPSS Inc., Chicago, IL, USA).

Results

Of the total 100 women studied, the proportion of normal-weight (BMI ≥ 18·5 to < 25 kg/m^2) and overweight participants (BMI ≥ 25 kg/m^2) was 76 and 24%, respectively. The mean age of the subjects was 51·8 (SD 11·2; range 31–69) years. The mean BW and BMI were 57·4 (SD 12·2; range 41·7–109·7) kg and 23·5 (SD 4·4; range 18·8–40·0) kg/m^2, respectively. BW did not change during the study (change of BW 0·02 (SD 0·7) kg; $P=0{\cdot}987$). The range of PAL was 1·36–2·52, with a mean value of 1·88.

Physical characteristics and physical activity variables among quartiles of BMI, FFMI, FMI and %BF are shown in Tables 1–4, respectively. Among the physical characteristics, age and height were not significantly different among quartiles. BMI increased linearly with FMI (r 0·943) and %BF (r 0·749), whereas FFM increased in the 4th quartiles of FMI and %BF (Tables 3 and 4).

Of energy expenditure components, TEE/BW decreased linearly with BMI, FMI and %BF. On the other hand, TEE/BW decreased only in the 4th quartile of FFMI (Table 2). PAEE/FFM and PAEE/BW decreased in the 4th quartile of BMI, but PAL did not differ among quartiles (Table 1). Among FFMI quartiles, there were no significant differences among PAL, PAEE/FFM and PAEE/BW. However, among FMI quartiles, all PAL, PAEE/FFM and PAEE/BW decreased in the 4th quartile. Among %BF quartiles, PAL and PAEE/FFM were significantly lower in the 3rd and 4th quartiles than in the 2nd quartile, whereas PAEE/BW decreased from the 3rd quartile. Fig. 2 shows that PAL was negatively associated with FMI, but not with BMI and FFMI (Fig. 2). PAEE/FFM and PAEE/BW were

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Table 1. Participant characteristics, energy expenditure components and physical activity variables by BMI grouping
(Mean values and standard deviations)

BMI (kg/m^2) quartiles‖...	1st (18·6–20·4)		2nd (20·5–22·1)		3rd (22·3–24·7)		4th (24·7–40·0)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* (ANOVA)	*r*
Physical characteristics										
Age (years)	49·7	11·9	51·4	11·8	53·9	11·9	52·4	9·4	0·630	0·038
Height (m)	1·55	0·04	1·56	0·06	1·56	0·04	1·56	0·06	0·890	0·133
Weight (kg)¶	47·1	3·1	52·1††	4·2	57·2†††‡‡	3·3	73·0†††‡‡§§	13·4	<0·001	0·948***
BMI (kg/m^2)¶	19·5	0·6	21·3††	0·5	23·5†††‡‡	0·9	29·8†††‡‡§§	3·9	<0·001	1
%BF¶	28·9	5·1	32·3	4·3	36·0†††‡‡	5·0	42·0†††‡‡§§	4·6	<0·001	0·747***
FFM (kg)¶	33·5	2·5	35·7	3·6	36·3††	3·8	42·2†††‡‡§§	6·7	<0·001	0·743***
FM (kg)¶	13·7	2·8	16·9††	2·7	20·6†††‡‡	3·3	30·5†††‡‡§§	7·7	<0·001	0·930***
Energy expenditure										
TEE (kJ/d)	8441	1149	8534	883	9333†‡	1244	9939†††‡‡	1523	<0·001	0·527***
TEE/BW (kJ/d per kg)	179·8	27·1	164·7†	21·2	163·5†	23·0	138·1†††§§	20·4	<0·001	−0·588***
BMR (kJ/d)	4492	351	4604	462	4777	588	5558†††‡‡§§	892	<0·001	0·725***
PAL	1·88	0·23	1·85	0·22	1·97	0·27	1·80	0·18	0·065	−0·187
PAEE (kJ/d)	3105	913	3077	747	3623	1069	3387	886	0·099	0·120
PAEE/FFM (kJ/d per kg)	92·4	24·8	86·8	21·8	100·7‡	30·6	81·3§	20·3	0·040	−0·207*
PAEE/BW (kJ/d per kg)	66·2	20·6	59·7	16·0	63·8	19·7	47·5†††§§	13·1	0·001	−0·403***
Accelerometer										
Step counts (per d)	8994	2151	8872	2619	8624	2729	7808	3402	0·427	−0·286**
Light (<3 METs) (min/d)	57·0	15·8	58·4	23·0	62·0	24·8	55·0	20·3	0·691	−0·107
Moderate (≥ 3 and < 6 METs) (min/d)	28·8	12·0	27·1	13·8	23·3	10·2	21·0	13·8	0·122	−0·316**
Vigorous (≥ 6 METs) (min/d)	3·7	3·4	3·0	2·9	2·7	2·7	2·0	2·7	0·246	−0·239*

%BF, body fat percentage; FFM, fat-free mass; FM, fat mass; TEE, total energy expenditure; BW, body weight; PAL, physical activity level (= TEE/BMR); PAEE, physical activity energy expenditure (= 0·9TEE − BMR); METs, metabolic equivalents.

* Significant correlation with BMI: * $P<0·05$, ** $P<0·01$, *** $P<0·001$.

Mean value was significantly different from that for the 1st quartile: † $P<0·05$, †† $P<0·01$.

Mean value was significantly different from that for the 2nd quartile: ‡ $P<0·05$, ‡‡ $P<0·01$.

Mean value was significantly different from that for the 3rd quartile: § $P<0·05$, §§ $P<0·01$.

‖ Subjects were categorised by quartile. There are twenty-five subjects in each quartile.

¶ Because some variables in physical characteristics did not follow a normal distribution, Kruskal–Wallis analysis was used to compare the variables among quartiles, and the Mann–Whitney *U* test was used for multiple comparisons.

Table 2. Participant characteristics, energy expenditure components and physical activity variables by fat-free mass index (FFMI) grouping (Mean values and standard deviations)

FFMI quartiles‖...	1st (12·2–13·8)		2nd (13·8–14·6)		3rd (14·7–15·6)		4th (15·7–21·6)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* (ANOVA)	*r*
Physical characteristics										
Age (years)	48·5	12·9	55·6	10·5	54·0	10·9	49·1	9·1	0·054	−0·026
Height (m)	1·56	0·05	1·56	0·05	1·55	0·06	1·57	0·05	0·587	0·093
Weight (kg)¶	50·1	4·4	52·0	4·5	56·2††	7·7	71·1††‡‡§§	15·1	<0·001	0·753***
BMI (kg/m^2)¶	20·6	1·4	21·6	2·1	23·3††	2·6	28·7††‡‡§§	5·2	<0·001	0·794***
%BF¶	34·9	4·0	32·8	6·2	33·9	7·4	37·6	8·3	0·045	0·247*
FFM (kg)¶	32·2	2·0	34·6††	2·2	36·8†‡‡	2·8	44·0††‡‡§§	4·9	<0·001	0·890***
FM (kg)¶	17·6	3·2	17·2	4·5	19·5	6·4	27·3††‡‡§§	10·5	<0·001	0·581***
FFMI (kg/m^2)	13·3	0·4	14·3	0·3	15·2	0·3	17·8	1·5	<0·001	1
Energy expenditure										
TEE (kJ/d)	8017	891	8676	932	9306††	1100	10248†‡‡§§	1358	<0·001	0·626***
TEE/BW (kJ/d per kg)	160·9	20·2	167·6	20·2	169·3	35·2	148·4‡§	26·8	0·025	−0·262**
BMR (kJ/d)	4391	444	4582	423	4871†‡‡	533	5587†‡‡§§	826	<0·001	0·708***
PAL	1·83	0·18	1·91	0·24	1·92	0·29	1·85	0·20	0·484	−0·064
PAEE (kJ/d)	2824	659	3226	841	3505†	1090	3636††	890	0·011	0·263**
PAEE/FFM (kJ/d per kg)	88·0	21·9	93·4	24·5	96·3	31·0	83·6	22·6	0·368	−0·151
PAEE/BW (kJ/d per kg)	56·6	13·1	62·4	17·1	64·5	24·7	53·6	17·3	0·182	−0·157
Accelerometer										
Step counts (per d)	8589	2592	8914	2437	8267	2635	8528	3403	0·878	−0·159
Light (<3 METs) (min/d)	53·6	20·4	59·1	17·2	55·7	18·9	64·1	26·5	0·320	0·040
Moderate (≥ 3 and < 6 METs) (min/d)	28·0	15·2	27·3	10·4	23·9	12·0	21·1	12·3	0·187	−0·300**
Vigorous (≥ 6 METs) (min/d)	3·4	3·0	2·6	2·8	3·1	3·6	2·3	2·3	0·513	−0·108

%BF, body fat percentage; FFM, fat-free mass; FM, fat mass; TEE, total energy expenditure; BW, body weight; PAL, physical activity level (= TEE/BMR); PAEE, physical activity energy expenditure (= 0·9TEE − BMR); METs, metabolic equivalents.

* Significant correlation with FFMI: * $P<0·05$, ** $P<0·01$, *** $P<0·001$.

Mean value was significantly different from that for the 1st quartile: † $P<0·05$, †† $P<0·01$.

Mean value was significantly different from that for the 2nd quartile: ‡ $P<0·05$, ‡‡ $P<0·01$.

Mean value was significantly different from that for the 3rd quartile: § $P<0·05$, §§ $P<0·01$.

‖ Subjects were categorised by quartile. There are twenty-five subjects in each quartile.

¶ Because some variables in physical characteristics did not follow a normal distribution, Kruskal–Wallis analysis was used to compare the variables among quartiles, and the Mann–Whitney *U* test was used for multiple comparisons.

Table 3. Participant characteristics, energy expenditure components and physical activity variables by fat mass index (FMI) grouping (Mean values and standard deviations)

FMI quartiles‖...	1st (2·94–6·39)		2nd (6·49–7·52)		3rd (7·55–9·73)		4th (9·82–19·49)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* (ANOVA)	*r*
Physical characteristics										
Age (years)	49·9	10·9	52·4	12·2	51·4	11·6	53·5	10·3	0·713	0·085
Height (m)	1·56	0·05	1·56	0·05	1·56	0·05	1·56	0·06	0·921	0·138
Weight (kg)¶	48·3	4·5	51·7	4·5	56·7††‡‡	4·4	72·8††‡‡§§	13·5	<0·001	0·897***
BMI (kg/m^2)¶	19·9	1·2	21·3††	1·2	23·2††‡‡	1·7	29·6††‡‡§§	4·2	<0·001	0·943***
%BF¶	26·4	4·2	32·9††	1·5	37·1††‡‡	1·7	42·9††‡‡§§	3·9	<0·001	0·916***
FFM (kg)¶	35·6	3·9	34·9	4·0	35·7	3·3	41·5††‡‡§§	7·1	0·001	0·565***
FM (kg)¶	12·8	2·4	17·0††	1·3	21·0††‡‡	1·7	30·9††‡‡§§	7·2	<0·001	0·982***
FMI (range) (kg/m^2)	5·3	0·9	7·0	0·3	8·6	0·7	12·6	2·3	<0·001	1
Energy expenditure										
TEE (kJ/d)	8810	1097	8782	1258	9049	1346	9607	1576	0·110	0·352***
TEE/BW (kJ/d per kg)	183·4	25·4	170·0†	20·7	159·4††	17·2	133·3††‡‡§§	16·7	<0·001	−0·696***
BMR (kJ/d)	4586	375	4584	457	4760	559	5503††‡‡§§	971	<0·001	0·610***
PAL	1·91	0·22	1·93	0·28	1·91	0·21	1·76††§	0·19	0·036	−0·254*
PAEE (kJ/d)	3343	847	3320	1082	3384	914	3143	876	0·827	−0·017
PAEE/FFM (kJ/d per kg)	94·3	23·6	95·9	31·3	94·3	21·1	76·8††‡‡§	20·4	0·024	−0·258**
PAEE/BW (kJ/d per kg)	69·6	19·0	64·2	19·5	59·4†	14·0	43·9††‡‡§§	11·7	<0·001	−0·502***
Accelerometer										
Step counts (per d)	8508	2034	9724	2154	8866	3387	7200‡‡§	2777	0·011	−0·293**
Light (<3 METs) (min/d)	56·5	17·0	63·0	21·2	61·3	26·5	51·7	17·8	0·224	−0·156
Moderate (≥ 3 and < 6 METs) (min/d)	24·9	9·7	30·3	13·2	25·7	14·6	19·3‡‡	11·0	0·021	−0·265**
Vigorous (≥ 6 METs) (min/d)	3·8	3·5	3·5	3·0	2·3	2·1	1·8†‡	2·7	0·042	−0·282**

%BF, body fat percentage; FFM, fat-free mass; FM, fat mass; TEE, total energy expenditure; BW, body weight; PAL, physical activity level (= TEE/BMR); PAEE, physical activity energy expenditure (= 0·9TEE − BMR); METs, metabolic equivalents.

* Significant correlation with FMI: * $P<0·05$, ** $P<0·01$, *** $P<0·001$.

Mean value was significantly different from that for the 1st quartile: † $P<0·05$, †† $P<0·01$.

Mean value was significantly different from that for the 2nd quartile: ‡ $P<0·05$, ‡‡ $P<0·01$.

Mean value was significantly different from that for the 3rd quartile: § $P<0·05$, §§ $P<0·01$.

‖ Subjects were categorised by quartile. There are twenty-five subjects in each quartile.

¶ Because some variables in physical characteristics did not follow a normal distribution, Kruskal–Wallis analysis was used to compare the variables among quartiles, and the Mann–Whitney *U* test was used for multiple comparisons.

Table 4. Participant characteristics, energy expenditure components and physical activity variables by body fat percentage (%BF) grouping
(Mean values and standard deviations)

%BF quartiles‖...	1st (15·9–31·0)		2nd (31·4–34·5)		3rd (34·6–38·8)		4th (39·1–54·3)			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* (ANOVA)	*r*
Physical characteristics										
Age (years)	48·7	10·6	53·8	12·3	50·3	11·3	53·8	10·2	0·596	0·138
Height (m)	1·56	0·06	1·55	0·04	1·56	0·05	1·57	0·06	0·839	0·112
Weight (kg)¶	49·0	5·4	53·4†	6·5	54·8††	4·3	72·3††‡‡§§	13·9	<0·001	0·710***
BMI (kg/m^2)¶	20·1	1·3	22·1††	2·2	22·6††	2·0	29·3††‡‡§§	4·5	<0·001	0·749***
%BF¶	26·2	4·1	32·7††	0·9	37·0†††‡‡	1·2	43·2†††‡‡§§	3·4	<0·001	1
FFM (kg)¶	36·1	4·2	36·0	4·5	34·5	2·6	41·0‡§§	7·2	0·005	0·278**
FM (kg)¶	12·9	2·7	17·5††	2·4	20·3†††‡‡	1·8	30·9†††‡‡§§	7·2	<0·001	0·889***
Energy expenditure										
TEE (kJ/d)	8845	1091	9326	1375	8600	1090	9477	1657	0·074	0·122
TEE/BW (kJ/d per kg)	182·1	26·9	175·0	19·4	156·6†††‡‡	13·1	132·4†††‡‡§§	15·5	<0·001	−0·725***
BMR (kJ/d)	4640	372	4727	530	4680	556	5385†††‡§§	1041	<0·001	0·368***
PAL	1·90	0·22	1·98	0·26	1·85‡	0·22	1·78‡‡	0·19	0·013	−0·243*
PAEE (kJ/d)	3321	861	3666	1072	3059	806	3144	872	0·099	−0·124
PAEE/FFM (kJ/d per kg)	92·5	24·5	102·6	29·6	88·2‡	20·6	77·9‡‡	20·6	0·006	−0·244*
PAEE/BW (kJ/d per kg)	68·5	19·8	68·7	18·1	55·5†††‡‡	12·8	44·4†††‡§	12·0	<0·001	−0·515***
Accelerometer										
Step counts (per d)	8675	2082	9449	2173	9067	3288	7107†‡‡§	2869	0·013	−0·293**
Light (<3 METs) (min/d)	58·0	16·2	64·9	23·1	59·2	24·6	50·4	18·1	0·113	−0·168*
Moderate (≥ 3 and < 6 METs) (min/d)	25·7	10·2	26·4	11·2	28·7	15·7	19·4	11·8	0·057	−0·154
Vigorous (≥ 6 METs) (min/d)	3·4	3·4	3·9	3·0	2·3	2·3	1·8	2·7	0·052	−0·287**

FFM, fat-free mass; FM, fat mass; TEE, total energy expenditure; BW, body weight; PAL, physical activity level (= TEE/BMR); PAEE, physical activity energy expenditure (= 0·9TEE − BMR); METs, metabolic equivalents.
* Significant correlation with %BF: * $P<0·05$, ** $P<0·01$, *** $P<0·001$.
Mean value was significantly different from that for the 1st quartile: † $P<0·05$, †† $P<0·01$.
Mean value was significantly different from that for the 2nd quartile: ‡ $P<0·05$, ‡‡ $P<0·01$.
Mean value was significantly different from that for the 3rd quartile: § $P<0·05$, §§ $P<0·01$.
‖ Subjects were categorised by quartile. There are twenty-five subjects in each quartile.
¶ Because some variables in physical characteristics did not follow a normal distribution, Kruskal–Wallis analysis was used to compare the variables among quartiles, and the Mann–Whitney *U* test was used for multiple comparisons.

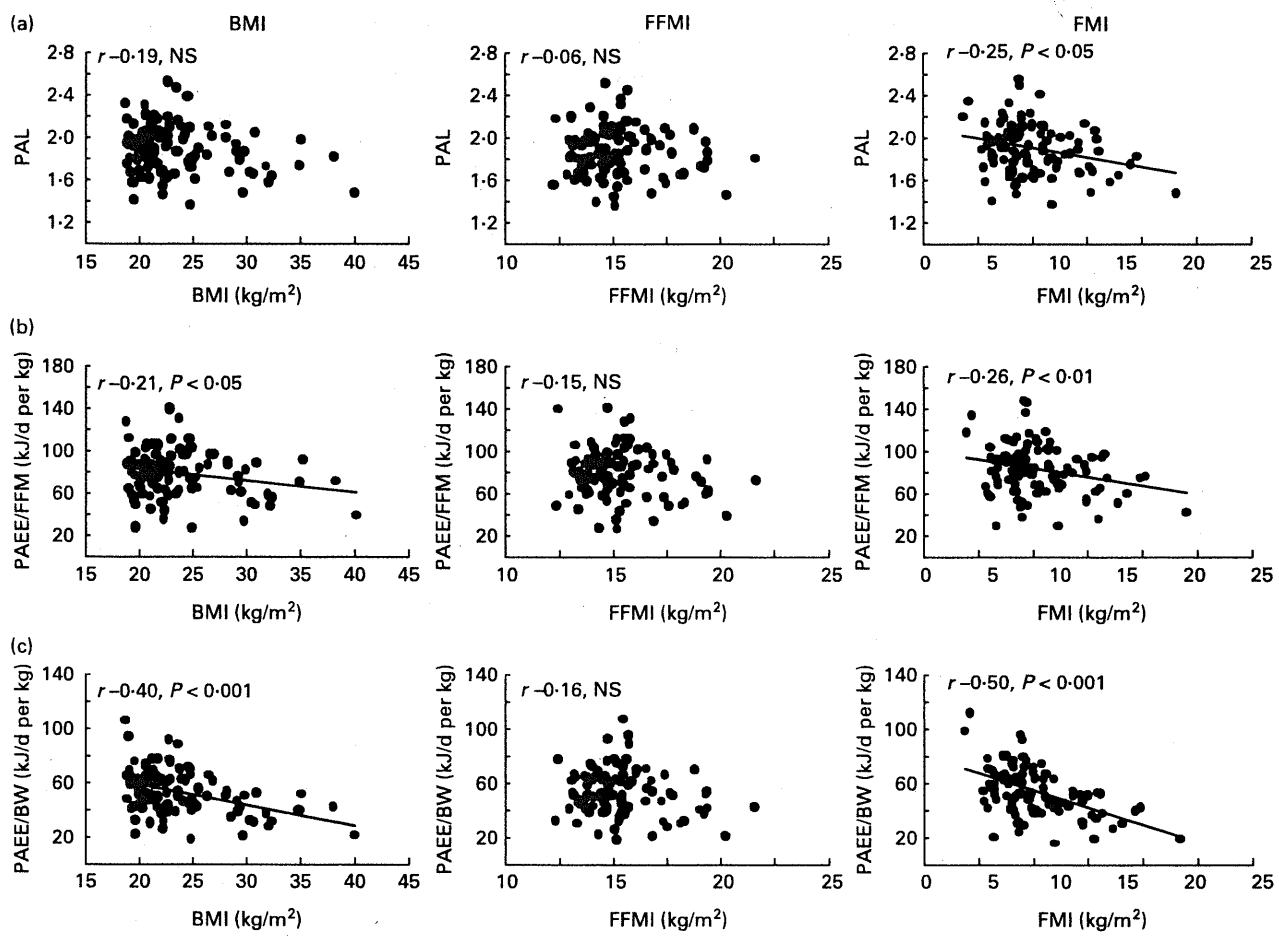

Fig. 2. Relationships between BMI, fat-free mass index (FFMI) or fat mass index (FMI) and physical activity level (PAL) (a), physical activity-related energy expenditure/fat-free mass (PAEE/FFM) (b) or PAEE/body weight (BW) (c). PAL = TEE/BMR, where TEE is total energy expenditure; PAEE = 0·9TEE − BMR; FMI was negatively associated with all physical activity variables obtained by the doubly-labelled water method.

negatively associated with BMI and FMI, but not with FFMI (Fig. 2).

In the accelerometry data, the step counts decreased in the 4th quartile of FMI (Table 3) and %BF (Table 4), whereas there was no difference among quartiles of BMI (Table 1) and FFMI (Table 2). Time spent on moderate- or vigorous-intensity activity decreased in the 4th quartile of FMI, whereas it did not differ among quartiles of BMI, FFMI and %BF. Time spent on light-intensity activity did not differ among quartiles of BMI, FFMI, FMI and %BF.

Discussion

The principal finding in the present study was that only PAEE/FFM and PAEE/BW assessed by the DLW method decreased among women in the highest quartile of BMI. On the other hand, women in the highest quartiles of FMI and %BF obviously had a low level of physical activities assessed by both the DLW method and accelerometer. Particularly, women in the 3rd quartile of FMI or %BF had lower PAEE/BW even though their BMI was below 25 kg/m^2.

The average PAL of 1·88 in the participants of the present study was a little higher than that of 1·75 in the general population of Eastern or Western countries[7,16,23,24]. The average BMR in the present data was 88·3 kJ/d per kg BW for normal-weight women (BMI < 25 kg/m^2) and 76·2 kJ/d per kg BW for overweight women (BMI ≥ 25 kg/m^2). These values were close to the average BMR of 88·8 kJ/d per kg BW for Japanese normal-weight adult women[25] and 74·9 kJ/d per kg BW in Japanese overweight adult women[19]. Moreover, the range of PAL in the present study was 1·36–2·52, which is within the PAL of the general population[26]. The average daily steps of about 8500 for participants in the present study were also comparatively higher than the daily steps for Japanese adults women, who generally walk an average of 7215 steps/d[27].

The lack of a significant difference in PAL among BMI quartiles in the present study is consistent with most previous studies[4–6]. In contrast, Tooze *et al.*[28] demonstrated that PAL was lower in obese women (BMI ≥ 30 kg/m^2) than in normal-weight women (BMI < 25 kg/m^2). However, they used an estimated RMR, but not a measured rate, so some errors in estimating PAL may be induced by the

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Table 5. Concordance of classification between BMI and fat mass index (FMI) or percentage body fat (%BF) (Percentages and number of subjects)

	FMI								%BF							
Quartile*...	1st		2nd		3rd		4th		1st		2nd		3rd		4th	
BMI quartile	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*
1st (lowest)	68	17	32	8	0	0	0	0	60	15	28	7	12	3	0	0
2nd	28	7	44	11	28	7	0	0	36	9	32	8	32	8	0	0
3rd	4	1	24	6	56	14	16	4	4	1	32	8	40	10	24	6
4th (highest)	0	0	0	0	16	4	84	21	0	0	8	2	16	4	76	19

* There are twenty-five subjects in each quartile.

different accuracy of estimated RMR between lean and obese participants[19].

Only PAEE/FFM and PAEE/BW decreased among women in the highest quartiles of BMI, whereas not only PAEE/FFM and PAEE/BW but also PAL apparently decreased in the highest quartile of FMI and %BF. Based on the results of the concordance of classification between BMI and FMI or %BF, most participants with a higher BMI have higher FM as well (Table 5). Thus, women in the highest quartile of BMI might be less active on the basis of PAEE when adjusting for body size. Contrary to the results of the present study, Snodgrass *et al.*[29] reported that PAEE/BW was not different between lean and overweight women. However, lean and normal-weight women in their study had much lower PAL (1·43 (SD 0·21)) and two of the seven women were underweight (BMI $< 18{\cdot}5\,kg/m^2$).

In contrast to the results of the decrease in PAEE/FFM and PAEE/BW among women in the highest quartile of BMI, there were no differences in PAEE/FFM and PAEE/BW among normal-weight women in the 1st to 3rd quartiles of BMI. Among participants in the 3rd quartile of BMI, the proportion of participants who are included in the 3rd quartile of FMI was only about half and the remaining spread to the other quartiles of FMI (Table 5). This phenomenon was similar to that of participants in the 2nd quartile of BMI. Thus, there appears to be a considerably large interindividual variability, especially for PAEE/FFM in normal-weight women who have a different distribution of FFM and FM at the same BMI.

The present study showed that TEE/BW was correlated with BMI, FMI or % BF. However, the overcorrection of TEE when adjusted by BW should be cautiously interpreted, because BMR accounts for approximately 60% of TEE in an individual with a PAL of 1·75. On the other hand, in PAEE, which is not influenced by BMR, someone with a larger body mass needs more energy for an activity than someone with a smaller body mass. Thus, PAEE/BW may well reflect lower physical activity among women in the highest quartile of BMI. However, we could not exclude the possibility that PAEE/BW might be also adjusted excessively because there was a great difference in BW and FM between the 3rd and 4th quartile of BMI in the present study. However, among quartiles of FMI and %BF, PAEE/BW was lower in the 3rd quartile than in the 1st or 2nd quartile, although it was not a great difference in BW between the 3rd quartile and the 1st or 2nd quartile. Therefore, lower PAEE/BW could well reflect the status of lower physical activity in women with higher BMI, especially with higher fat deposition, when FMI or %BF was effectively used.

Schulz *et al.*[7] reported a high correlation between PAEE/BW and %BF in healthy adult women, thereby providing support for our data that PAEE/BW decreased from the 3rd quartiles of FMI and %BF. Thus, PAEE/BW could be useful to understand daily physical activity, especially in normal-weight women with higher fat deposition.

Step counts and the duration of physical activity of moderate or vigorous intensity assessed by accelerometry apparently decreased in the highest quartile of FMI, but not among quartiles of BMI and FFMI. Contrary to the present results of no difference in step counts and moderate or vigorous intensity among BMI quartiles, Levine *et al.*[30] reported that the allocation of standing and ambulating during the day was lower in obese subjects than in lean subjects when using BMI cut-points. This discrepancy may be due to the different range of PAL among populations. Levine *et al.*[30] recruited both lean and obese individuals from among 'couch potato' subjects, all of whom were sedentary. The populations of the present study were free-living Japanese adult women with a wide PAL range from sedentary to active.

In a longitudinal study using the DLW method in adult women, Schoeller *et al.*[31] demonstrated that increases in weight were lower in active women with a PAL above 1·75. The present study did not attempt to determine a threshold of daily physical activity that is required to have a normal FMI, %BF or BMI due to the limited number of study subjects and the proportion of obese individuals in the present dataset. Another reason was that there were no definite cut-offs for FMI and %BF. Because the present study apparently showed a good relationship between FM (FMI or %BF) and various physical activities, further study is warranted to examine the threshold of daily physical activity that is required to suppress fat accumulation.

The BMI cut-off point is used as the standard for a classification of obesity. On the other hand, Bigaard *et al.* suggested that FMI was also an independent predictor of all-cause mortality in their epidemiological study[32]. They revealed that an excess of approximately $10\,kg/m^2$ of FMI value was associated with considerably increased mortality. The present study showed that Japanese adult women with an average FMI of $12{\cdot}6\,kg/m^2$ were less active than those with a below-average FMI of $8{\cdot}6\,kg/m^2$. Therefore, we consider that an increase in