式食事歴法質問票（diet history questionnaire: DHQ）を用いた．DHQと食事記録（Dietary records）との相関係数はエネルギー 0.48，GI 0.65－0.72，GL 0.66－0.71 であった(Sasaki S, et al. J Epidemiol. 1998, Murakami K, et al. Br J Nutr. 2008)．食事のGI・GLが将来の耐糖能にどの様な影響を与えるかを検討するため，食事質問票より算出したGI・GLと，HbA1c・空腹時血糖に関して検討した．また，GI・GLとメタボリックシンドロームの関連指標に関しても解析を行った．

C．D．E．研究結果．考察．結論

236名が研究に参加し、10名が研究を中断、最終的に226名の対象者で解析を行った。対象者の年齢は平均54歳で、半数が男性、平均BMI 30.6，平均HbA1c 6.3 %であった。ベースラインのGLとHbA1cとの間に正の関連を認め，先行研究（Schulze MB, et al. Am J Clin Nutr. 2004, Salmeron J, et al. Diabetes Care. 1997）を支持する結果であった．また，GIとHbA1c・空腹時血糖との間には関連を認めなかった．GIが炭水化物の総摂取量を反映しないとする報告や，腹部肥満者ではGIは2型糖尿病リスクと関連を認めなかったとする報告もあり，本研究の対象者は，腹部肥満者も多く含まれていたため，GIとHbA1c・空腹時血糖との関連を認めなかった可能性も考えられる．GI・GLとメタボリックシンドロームの関連指標とは関連を認めなかった．先行研究ではGL・GIとHDLとの負の関連やTGとの正の関連が報告されており（Liu S, et al. Am J Clin Nutr. 2001)，また肥満女性で，GI・GLとメタボリックシンドロームとの関連があると報告されている(Kim K, et al. Br J Nutr.)．本研究ではGI・GLとメタボリックシンドロームの関連指標には関連を認めず，対象者が肥満者に限られていることや，欧米人とアジア人の人種差をみている可能性も考えられた．

F．研究発表

1．論文発表

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G．知的財産権の取得状況

1. 特許取得

なし

2. 実用新案

なし

3. その他

なし

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分担研究報告書

簡易型自記式食事歴法質問票を用いた栄養素・食品群摂取量の推定

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研究要旨

各種の栄養素・食品群摂取量がさまざまな生活習慣病に関連していることは数多くの栄養疫学研究において示唆されている。しかし、日本人に対しては、この課題に関してじゅうぶんに科学的な方法を用いた研究はそれほど多いわけではない。そこで、本研究では、対象者の回答負担が比較的に少なく、その妥当性がすでに検証され、各種の栄養疫学研究で用いられ、その妥当性と有用性が明らかになっている簡易型自記式食事歴法質問票（BDHQ）を用いて、各種の栄養素・食品群摂取量の推定を試みた。ここでは、基礎データとして、性・年齢階級別の主要食行動、主要栄養素・食品群摂取量を報告する。BDHQ に回答が得られたのは 3077 人（男性 1832 人、女性 1245 人）であった。総エネルギー摂取量を調整した摂取量では、男性では多くの栄養素・食品群摂取量において年齢階級間で有意な差が認められ、総じて 70 歳以上がもっとも高く、30 歳未満が最も低い傾向であった。一方、アルコール摂取量は 50 歳代でもっとも多かった。女性でもほぼ同様の傾向を示したが、アルコール摂取量は 20 歳代でもっとも多かった。食品群摂取量については、男女ともに、穀類、肉類、油脂類（女性では菓子類も）の摂取量は年齢が高いほど有意に少なく、他の多くの食品群の摂取量は有意に多い傾向が認められた。以上、この集団では、主要栄養素ならびに食品群摂取量に年齢階級間で有意な差が認められ、その特徴が男女間でわずかだが異なるものと考えられた。その原因ならびにこのちがいが健康に及ぼす影響など、食習慣と健康状況との関連について今後、詳細な検討を加えていく。

A. 研究の背景ならびに目的

各種の栄養素・食品群摂取量がさまざまな生活習慣病に関連していることは数多くの栄養疫学研究において示唆されている。しかし、日本人に対しては、この課題に関してじゅうぶんに科学的な方法を用いた研究はそれほど多いわけではない。これは、栄養素や食品の習慣的な摂取量を定量的に把握することが極めて難しく、日本人を対象としたその測定技術の確立の遅れが大きな原因と考えられる。

そこで、本研究では、対象者の回答負担が比較的に少なく、その妥当性がすでに検証され、各種の栄養疫学研究で用いられ、その有用性が明らかになっている簡易型自記式食事歴法質問票(brief self-administered diet history questionnaire: BDHQ) [1,2] を用いて、各種の栄養素・食品群摂取量の推定を試みた。今後、これらと各種疾患の罹患並びに発症状況との関連を検討していくが、ここでは、基礎データとして、性・年齢階級別の主要栄養素・食品群摂取量を報告することにする。

B. 研究方法

調査方法

対象者に BDHQ の質問票を送付し、自宅にて自分で回答し、健診受診時に持参するように依頼した。健診会場にて BDHQ 質問票を回収すると同時に、

BDHQ の構造に詳しい担当者が欠損ならびに明らかな非論理回答をチェックし、健診会場にて本人に確認し、可能な場合は再回答をお願いした。回収されたBDHQ質問票は分担研究者の研究室にて、BDHQの構造に詳しい担当者（管理栄養士）1人が欠損ならびに明らかな非論理回答を再度チェックし、非論理的な回答だがその回答内容から正しい回答を類推できる場合には類推した回答に変更した。その後、すべてのデータを入力し、BDHQ専用栄養価計算プログラムにて栄養価計算を行った。同時に、すべての対象者に対して、個人の栄養価計算結果をわかりやすくまとめた「個人結果帳票」を作成し、現場の調査担当者を通じて、対象者に返却していただくようにした。

解析方法

本研究の解析対象者は BDHQ への回答が得られた3077である。

エネルギー、主要栄養素、主要食品群の1日当たり摂取量について、平均値と標準偏差を算出した。主要栄養素は循環器疾患を中心とするいわゆる生活習慣病に関連する可能性が示唆されている栄養素を中心とし、具体的には、炭水化物、たんぱく質、総脂質、アルコール、ナトリウム、カリウム、カルシウム、マグネシウム、リン、鉄、亜鉛、銅、レチノール、カロテン、ビタミンB1、ビタミンB2、ナイアシン、葉酸、ビタミンC、総食物繊維、飽和脂肪酸、一価不飽和脂肪酸、多価不飽和脂肪酸、n-3系脂肪酸、n-6系脂肪酸、コレステロールとした。主要食品群は基本的には日本食品標準成分表にしたがって分類し、穀類、芋類、豆類、野菜類（緑黄色野菜（野菜類の中で100g当たりカロテン含有量が600μg以上のもの）、その他の野菜類）、果実類、肉類、魚介類、卵類、乳製品、菓子・砂糖類、非アルコール性飲料、アルコール性飲料、油脂類、調味料類とした。

摂取量の単位には、エネルギーはkcal/日、エネルギー産生栄養素はエネルギー摂取量にしめる割合（%エネルギー）、その他のすべての栄養素とすべての食品群には1000kcal当たりの摂取量重量（g/1000kcalなど）を用いた。

解析は、性（男・女）、年齢階級（30歳未満、40〜49歳、50〜59歳、60〜69歳、70歳以上）別に行い、カテゴリー変数についてはカイ2乗検定を用い、量的変数については男女差の検定では対のないt-検定を、年齢階級間の検定では一元配置分散分析（ANOVA）を用いた。$P<0.05$ をもって有意とした。

C．研究結果

表1に性・年齢階級別にみた体格ならびに食行動に関する結果を示す。女性に比べて男性で有意に「家庭の味付けは外食に比べて薄い」「食事摂取基準のときにしょうゆ・ソースを頻回に使う」「その量は多い」「外食の定食一人前に比べて自分が普段食べているおかずの量は多い」「外食の定食一人前に比べて自分が普段食べているごはんの量は多い」「食べる速さは速い」「肉の脂身を好んで食べていた」と回答していた。一方、男性に比べて女性で有意に「この1か月間に栄養補助食品を頻回に使った」と答えていた。

表2に男女別のエネルギー・栄養素摂取量を示す。粗摂取量ではカロテンとビタミンCのみ女性のほうが男性よりも有意に摂取量が多かったが、ほとんどの栄養素で男性のほうが女性よりも有意に摂取量が多かった。ところが、エネルギー密度で比較すると、ほとんどすべての栄養素で女性のほうが男性よりも有意に摂取量が多い傾向が認められた。例外はアルコールとレチノールであった。

表3に、男女別の食品群摂取量を示す。粗摂取量では多くの食品群で男性のほうが女性よりも有意に摂取量が多かったが、野菜類（緑黄色野菜、その他の野菜も、ともに）、果物類、菓子・砂糖類は例外的に女性のほうで摂取量が有意に多かった。ところが、エネルギー密度で比較すると、ほとんどすべての栄養素で女性のほうが男性よりも有意に摂取量が多い傾向が認められた。例外は穀類、アルコール飲料、調味料類で男性のほうが女

性よりも有意に摂取量が多かった。

表４に、男女別・年齢階級別の栄養素・食品群摂取量を示す。栄養素では、年齢階級が高い群で有意に摂取量が多かったのは男女ともに次のとおりである：たんぱく質、n-3 系脂肪酸、コレステロール、ナトリウム、カリウム、カルシウム、マグネシウム、リン、鉄、亜鉛、銅、レチノール、カロテン、ビタミンD、ビタミンB1、ビタミンB2、ナイアシン、葉酸、ビタミン C、総食物繊維。一方、年齢階級が低い群で有意に摂取量が多かったのは男女ともに次のとおりである：脂質、飽和脂肪酸、一価不飽和脂肪酸、n-6 系脂肪酸、アルコール（女性のみ）。食品群では、年齢階級が高い群で有意に摂取量が多かったのは男女ともに次のとおりである：芋類、豆類、野菜類、緑黄色野菜、その他の野菜、果物類、魚介類、乳製品、調味料類。一方、年齢階級が低い群で有意に摂取量が多かったのは男女ともに次のとおりである：穀類、肉類、菓子・砂糖類（女性のみ）、アルコール飲料、油脂類。

D．考察

本研究において収集したデータを用いて、主要栄養素ならびに食品群摂取量について、性・年齢階級間におけるちがいを検討した。年齢階級間で有意な差が認められ、その特徴が男女間でやや異なるものと考えられた。その原因ならびにこのちがいが健康に及ぼす影響など、食習慣と健康状況との関連について今後、詳細な検討を加えていく必要があると考えられた。

ところで、有意差は認められなかったものの、エネルギー摂取量は男女ともに年齢階級があがるほど高いように見受けられた。若年成人でエネルギー摂取量の過小申告がそれより上の年齢階級より大きい現象は世界的には珍しいものの、他の日本人集団でも認められている。[4] しかし、70 歳以上を含めて検討した例はいままでにあまり存在しない。今回の結果では 70 歳以上の平均エネルギー摂取量はその年齢階級における推定エネルギー必要量（身体活動レベルが「ふつう」の場合）である男性 2200kcal/日、女性 1700kcal/日をそれぞれ 277 kcal/日、376 kcal/日上回っており、平均として過大申告の傾向が認められた。この原因が対象者にあるのか、BDHQ の評価能力（の問題）にあるのかは未知であり、今後、詳細な検討ならびに基礎研究を要するものと考えられた。これら過小・過大申告の影響を可能な限り除去するために、今回はエネルギー調整を行い、結果を検討した。しかしながら、エネルギー調整でこの種の問題を完全に回避できるか否かはまだ明らかでなく、詳細な検討ならびに基礎研究を要するものと考えられた。

E．結論

本研究では、対象者の回答負担が比較的に少なく、その妥当性がすでに検証され、各種の栄養疫学研究で用いられ、その妥当性と有用性が明らかになっている簡易型自記式食事歴法質問票（BDHQ）を用いて、各種の栄養素・食品群摂取量の推定を試みた。ここでは、基礎データとして、性・年齢階級別の主要食行動、主要栄養素・食品群摂取量を報告した。BDHQ に回答が得られたのは 3077 人（男性 1832 人、女性 1245 人）であった。総エネルギー摂取量を調整した摂取量では、男性では多くの栄養素・食品群摂取量において年齢階級間で有意な差が認められ、総じて 70 歳以上がもっとも高く、30 歳未満が最も低い傾向であった。一方、アルコール摂取量は 50 歳代でもっとも多かった。女性でもほぼ同様の傾向を示したが、アルコール摂取量は 20 歳代でもっとも多かった。食品群摂取量については、男女ともに、穀類、肉類、油脂類（女性では菓子類も）の摂取量は年齢が高いほど有意に少なく、他の多くの食品群の摂取量は有意に多い傾向が認められた。以上、この集団では、主要栄養素ならびに食品群摂取量に年齢階級間で有意な差が認められ、その特徴が男女間でわずかだが異なるものと考えられた。その原因ならびにこのちがいが健康に及ぼす影響など、食習

慣と健康状況との関連について今後、詳細な検討を加えていく。

F．研究発表

1．論文発表

なし

2．学会発表

なし

G．知的所有権の取得状況

なし

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表1　性・年齢階級別にみた体格ならびにエネルギー・主要栄養素摂取量（平均±標準偏差）[1]

	50歳未満	50～69歳	70歳以上	ANOVA	合計
男性					
対象者数	28	898	169		1095
年齢（歳）	35.9±3.4	57.8±7.5	73.6±3.4	---	59.7±9.8
身長 (cm)	173.9±4.6	168.6±5.9	164.2±5.6	<0.0001	168.1±6.1
体重 (kg)	74.9±15.8	67.2±9.1	62.7±7.7	<0.0001	66.7±9.3
BMI (kg/m^2)	24.7±4.8	23.6±2.7	23.3±2.7	0.0395	23.6±2.8
エネルギー (kcal/日)	2286±588	2428±661	2477±678	0.3383	2432±662
総脂質 (%エネルギー)	26.5±5	24.8±4.8	27.0±5.5	<0.0001	25.2±5.0
アルコール (g/1000kcal)	8.6±9.4	9.8±10.2	6.9±9.1	0.0029	9.3±10.0
食塩 (g/1000kcal)	5.7±0.7	5.8±1.1	6.3±1.1	<0.0001	5.9±1.1
カリウム (mg/1000kcal)	1286±290	1376±316	1603±371	<0.0001	1409±335
カルシウム (mg/1000kcal)	257±84	283±82	347±85	<0.0001	292±86
マグネシウム (mg/1000kcal)	131±22	139±25	156±26	<0.0001	141±26
飽和脂肪酸 (g/1000kcal)	0.7±0.2	0.7±0.2	0.7±0.1	0.0034	0.7±0.2
一価不飽和脂肪酸 (g/1000kcal)	1.1±0.2	1.0±0.2	1.1±0.2	<0.0001	1.0±0.2
多価不飽和脂肪酸 (g/1000kcal)	0.8±0.1	0.8±0.2	0.8±0.2	<0.0001	0.8±0.2
n-3系脂肪酸 (g/1000kcal)	0.16±0.04	0.16±0.05	0.19±0.05	<0.0001	0.17±0.05
n-6系脂肪酸 (g/1000kcal)	0.63±0.11	0.60±0.13	0.65±0.14	<0.0001	0.61±0.13
コレステロール (mg/1000kcal)	189±64	189±63	213±69	<0.0001	193±65
食物繊維 (g/1000kcal)	6.0±1.8	6.6±1.7	7.9±2.0	<0.0001	6.7±1.9
女性					
対象者数	28	575	78		681
年齢（歳）	35.6±1.8	58.2±7.2	72.7±2.8	---	58.9±9.5
身長 (cm)	157.9±4.5	156.2±5.4	152.5±4.3	<0.0001	155.8±5.4
体重 (kg)	52.3±4.9	54.3±8.4	51.5±6.6	0.0092	53.9±8.1
BMI (kg/m^2)	21.0±1.9	22.3±3.2	22.2±2.7	0.0982	22.2±3.1
エネルギー (kcal/日)	1976±668	1980±489	2076±501	0.2770	1991±499
総脂質 (%エネルギー)	28.6±5.7	29.1±4.6	29.3±4.4	0.7665	29.1±4.6
アルコール (g/1000kcal)	4.4±7.7	1.8±4.8	0.8±2.1	0.0023	1.8±4.7
食塩 (g/1000kcal)	5.4±1.1	6.3±1.1	6.6±1.1	<0.0001	6.3±1.1
カリウム (mg/1000kcal)	1364±310	1701±358	1810±322	<0.0001	1700±360
カルシウム (mg/1000kcal)	279±89	348±88	383±92	<0.0001	350±90
マグネシウム (mg/1000kcal)	132±21	160±28	167±26	<0.0001	159±28
飽和脂肪酸 (g/1000kcal)	0.8±0.2	0.8±0.2	0.8±0.2	0.1978	0.8±0.2
一価不飽和脂肪酸 (g/1000kcal)	1.2±0.2	1.2±0.2	1.2±0.2	0.9983	1.2±0.2
多価不飽和脂肪酸 (g/1000kcal)	0.8±0.2	0.9±0.2	0.9±0.1	0.0144	0.9±0.2
n-3系脂肪酸 (g/1000kcal)	0.16±0.04	0.20±0.05	0.21±0.04	0.0002	0.20±0.05
n-6系脂肪酸 (g/1000kcal)	0.64±0.16	0.69±0.13	0.71±0.12	0.1134	0.69±0.13
コレステロール (mg/1000kcal)	200±53	213±66	220±69	0.3973	214±66
食物繊維 (g/1000kcal)	6.4±2.0	8.3±2.1	9.0±2.1	<0.0001	8.3±2.1

[1]エネルギー・主要栄養素摂取量は自記式食事歴法質問票による。

表2 性・年齢階級別にみた食品群摂取量(平均±標準偏差)[1]

	50歳未満	50～69歳	70歳以上	ANOVA	合計
男性					
対象者数	28	898	169		1095
穀類 (g/1000kcal)	235±51	234±62	205±62	<0.0001	230±62
いも類 (g/1000kcal)	28±15	32±22	45±29	<0.0001	34±24
砂糖・甘味料類 (g/1000kcal)	3±3	2±2	2±1	0.0023	2±2
豆類 (g/1000kcal)	36±15	36±18	46±20	<0.0001	38±18
緑黄色野菜 (g/1000kcal)	51±30	52±29	62±33	0.0005	54±30
その他の野菜 (g/1000kcal)	87±47	90±41	113±50	<0.0001	94±44
果実類 (g/1000kcal)	23±22	38±29	60±39	<0.0001	41±32
魚介類 (g/1000kcal)	45±19	50±25	61±27	<0.0001	52±25
肉類 (g/1000kcal)	40±15	29±14	27±14	<0.0001	29±14
卵類 (g/1000kcal)	18±10	19±11	20±11	0.4581	19±11
乳類 (g/1000kcal)	50±41	60±43	73±41	0.0009	62±43
油脂類 (g/1000kcal)	12±3	12±4	12±4	0.0668	12±4
菓子類 (g/1000kcal)	15±9	17±13	20±16	0.0150	17±14
嗜好飲料類 (g/1000kcal)	407±178	435±177	360±168	<0.0001	423±177
女性					
対象者数	28	575	78		681
穀類 (g/1000kcal)	216±61	202±56	193±51	0.1330	202±55
いも類 (g/1000kcal)	22±12	41±26	49±28	<0.0001	41±26
砂糖・甘味料類 (g/1000kcal)	2±2	2±1	3±1	0.0271	2±1
豆類 (g/1000kcal)	33±18	43±19	46±22	0.0156	43±20
緑黄色野菜 (g/1000kcal)	63±44	73±38	79±36	0.1404	73±38
その他の野菜 (g/1000kcal)	97±56	133±54	138±54	0.0014	132±55
果実類 (g/1000kcal)	37±28	62±39	76±48	<0.0001	63±40
魚介類 (g/1000kcal)	39±18	60±29	64±31	0.0004	60±29
肉類 (g/1000kcal)	41±14	31±16	28±16	0.0012	31±16
卵類 (g/1000kcal)	20±13	20±11	20±12	0.9379	20±11
乳類 (g/1000kcal)	66±47	71±41	81±48	0.1399	72±42
油脂類 (g/1000kcal)	13±5	14±4	14±4	0.1860	14±4
菓子類 (g/1000kcal)	27±23	25±16	24±15	0.6644	25±16
嗜好飲料類 (g/1000kcal)	377±193	393±166	361±169	0.2712	388±168

[1]エネルギー・主要栄養素摂取量は自記式食事歴法質問票による。

III. 研究成果の刊行に関する一覧表

研究成果の刊行

書籍

著者氏名	論文タイトル名	書籍全体の編集者名	書籍名	出版社名	出版地	出版年	ページ
丸藤祐子、宮地元彦、門脇孝、真田弘美	運動療法、2)運動療法の実際と指導方法	門脇孝、真田弘美	すべてがわかる最新糖尿病 治療 ケア教育	照林社	東京	2011	125-128
Nakade M、Aiba N、Morita A、Watanabe S	Determinants of successful body weight reduction	Camilo Gouveia and Diego Melo.	Weight Change: Patterns, Risks and Psychosocial Effects.	Nova Science Publishers	New York	2012	127-136

雑誌

発表者氏名	論文タイトル名	発表誌名	巻号	ページ	出版年
松本希, 宮地元彦, 髙橋康輝, 安藤裕美, 小堀浩志, 小野寺昇	週1回の有酸素運動を主体とした特定保健指導の実施が動脈スティフネスに及ぼす影響.	日本生理人類学会誌.	16(3)	123-132	2011
Tanaka T, Morita A, Kato M, Hirai T, Mizoue T, Terauchi Y, Watanabe S, Noda M	SCOP Study Group. Congener-specific polychlorinated biphenyls and the prevalence of diabetes in the Saku Control Obesity Program (SCOP).	Endocr J.	58(7)	589-96	2011
Park J, Ishikawa-Takata K, Tanaka S,, Watanabe S, Miyachi M, Morita A, Aiba N.	Relation of body composition to daily physical activity in free-living Japanese adult women.	Br J Nutr.	106(7)	1117-27.	2011
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Noto H, Tsujimoto T, Sasazuki T, Noda M	Significantly increased risk of cancer in patients with diabetes mellitus: a systematic review and meta-analysis.	Endocrine Practice.	17	616-28	2011
村上 晴香, 川上 諒子, 大森 由実, 宮武 伸行, 森田 明美, 宮地 元彦	健康づくりのための運動基準2006における身体活動量の基準値週23メッツ・時と1 日あたりの歩数との関連.	体力科学	61(2)	183-191	2012
Nakade M, Aiba N, Suda N, Morita A, Miyachi M, Sasaki S, Watanabe S	Behavioral change during weight loss program and one-year follow-up: Saku Control Obesity Program (SCOP) in Japan.	Asia Pacific J Clin Nutr;	21(1)	22-34	2012
Abdul Jalil Rohana, Naomi Aiba, Nobuo Yoshiike, Miki Miyoshi.	Japan for Sustainability in Health through a New Movement of Food and Nutrition Education 'Shokuiku'.	International Medical Journal	18(1)	21 - 28	2011
田中憲子, 笠原靖弘, 森田明美, 宮地元彦	生体電気インピーダンス法による皮下脂肪厚の推定	肥満研究			2011 in print
Nakade M, Aiba N, Morita A, Miyachi M, Sasaki S, Watanabe S	What behaviors are important for successful weight maintenance?	Journal of Obesity			2012 in print

Ⅳ．研究成果の刊行物・別刷

British Journal of Nutrition (2011), **106**, 1117–1127
doi:10.1017/S0007114511001358
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Relation of body composition to daily physical activity in free-living Japanese adult women

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(Received 16 June 2010 – Revised 4 January 2011 – Accepted 14 February 2011 – First published online 17 May 2011)

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.

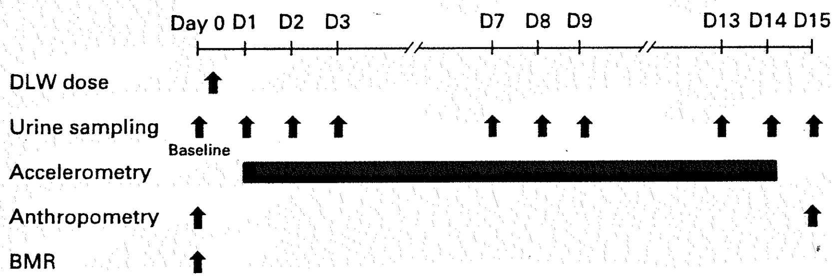

Fig. 1. Schematic representation of the experimental design. On day 0, the $^2H_2{}^{18}O$ (doubly-labelled water; DLW) dose was given orally to each subject after collecting a baseline urine sample and performing the BMR and anthropometric measurements.

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

Calculations of total energy expenditure and body composition

The ^2H 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 ^2H 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 0·9 × 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/m²) 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/m²)¶	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	10 248††‡‡§§	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/m²)¶	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/m²)	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.

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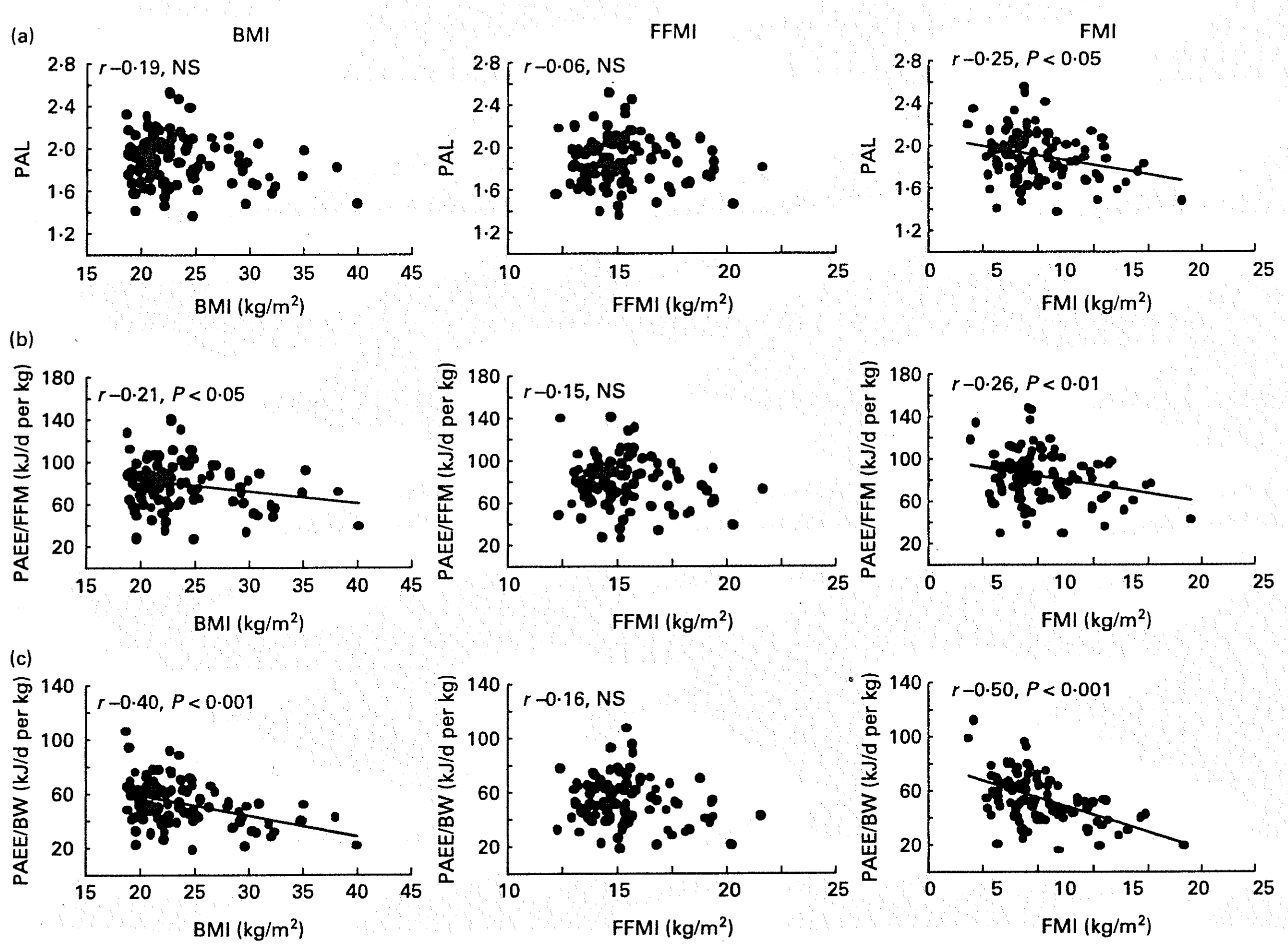

Fig. 2. Relationships between BMI, fat-free mass index (FFMI) or fat mass index (FMI) and physical activity level (PAL) (a), physical activity-related energy expenditure/fat-free mass (PAEE/FFM) (b) or PAEE/body weight (BW) (c). PAL = TEE/BMR, where TEE is total energy expenditure; PAEE = 0·9TEE − BMR; 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

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 < 18·5 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 12·6 kg/m^2 were less active than those with a below-average FMI of 8·6 kg/m^2. Therefore, we consider that an increase in

PAL may decrease FMI, leading to a decrease in risk of all-cause mortality.

The present study has the following limitations: first, the FFM hydration was assumed as 0·732 for all participants equally[14], so some errors in estimating FFM may be induced by the different levels of obesity. Second, the present results were drawn from a cross-sectional design. Therefore, we were not able to infer a cause–effect relationship between an inactive lifestyle and obesity. Observational or intervention studies with longitudinal design are needed to evaluate the effect of inactivity on the development of obesity for adult women. However, the main purpose of the present study was to investigate the relationship between daily physical activity and body size or body composition. Moreover, the present study provided the results only for Japanese adult women, but not for men or children.

In conclusion, Japanese adult women with larger BMI had lower PAEE adjusted by FFM or BW. Especially, Japanese adult women with higher fat deposition were apparently less active, on the basis of not only PAEE but also the physical activity of moderate or vigorous intensity. The present data suggest that the relationship between obesity and daily physical activities should be discussed using not only BMI but also FMI or %BF.

Acknowledgements

The present study was performed as part of the Health and Labor Sciences Research Grants (Comprehensive Research on Cardiovascular and Life-style Related Diseases) from the Ministry of Health, Labour and Welfare of Japan. We thank the staff of the National Institute of Health and Nutrition for their kind cooperation.

The authors' responsibilities were as follows: interpretation of the data and writing the manuscript, J. P., K. I-T. and S. T.; DLW analysis, J. P., K. I-T. and Y. H.; conception, design, and conducting of DLW studies and obtaining funding, K. I-T., S. T. and I. T.; aiding in designing the manuscript and providing critical revision, Y. H. and K. O.; designing and conducting the Saku Control Obesity Program, K. I-T., S. T., S. W., M. M., A. M. and N. A.; obtaining funding for Saku Control Obesity Program, S. W.

The authors have no relevant financial interest in this article.

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