した運動を行った。11回目で健康教室初日と同様の測定を行い、12回目に各指標の数値の説明を行い、教室全体の振り返りを行った。健康教室期間は３ヶ月間で、週１回の頻度で運動時間は90分とした。

C．１回の健康教室の流れ

健康教室は、２名の健康運動指導士が指導を行った。３～10回目の１回の健康教室の流れについては、表３に示した。参加者は、健康教室会場に到着後、安静を保ったのちに血圧・体重測定を行い、健康運動指導士が個別に体調チェックのための問診を行った。この時の血圧が収縮期血圧140mmHg 以上または拡張期血圧90mmHg 以上を示した者及び普段の血圧値より高値を示した者、寝不足や食事の未摂取などによる体調不良を訴えた者には、教室を休むかまたはストレッチングのみに参加するよう指示した。運動内容は、準備運動としてストレッチングを行い、メイン運動としてリズム体操またはイスを用いたエアロビクス、水中歩行、アクアビクスなどの有酸素運動を行った。最後に、補強運動として自重を用いた低強度の筋力トレーニングを行い、整理運動にストレッチングを行った。全ての運動は、集団運動プログラムで行った。2006年に発表された健康づくりのための運動指針―エクササイズガイド2006―[27]では、１週間に４エクササイズ以上の活発な運動をすることを目標としていることから、健康運動指導士はボルグスケール11～13の運動強度を目安に、１回の健康教室における運動量が４エクササイズ（200～300kcal のエネルギー消費）になるよう運動プログラムを作成した。健康教室は、１名の健康運動指導士が運動指導を行ない、もう１名の健康運動指導士が準備運動終了後に全員の参加者と個別に面談を行なった。

D．日常生活における指導

対象者には、在宅でも運動が行えるようウォーキングや自重を用いた筋力トレーニングの運動方法を示した教材（冊子「いきいき健幸生活」）を配布した（図１）。この教材は、厚生労働省が提示する「標準的な健診・保健指導プログラム（確定版）」の添付資料にある「保健指導に関する学習教材集」[28]で紹介されたものであり、健康教室の委託先の健康運動指導士らが作成したものである。教材は、生活習慣病の解説や食事に関するアドバイス、健康教室で行う測定数値の評価を解説し、日常生活がセルフモニタリングできるよう体重及び血圧、歩数、運動実施の有無を記入できる。健康運動指導士は、健康教室開催２回目に参加者と個

表２．健康教室の全体の流れ

<table>
<tr><td>１回目</td><td>・開校式
・測定
形態測定：身長、体重、体脂肪率、腹囲
体力測定：筋力、柔軟性、平衡性
メディカルチェック：血圧、脈波伝播速度（baPWV）
血液検査（総コレステロール、HDL コレステロール、中性脂肪、血糖）
・ストレッチング指導</td></tr>
<tr><td>２回目</td><td>・個別カウンセリング
・測定結果の解説
・運動（自重トレーニング、ストレッチング）</td></tr>
<tr><td>３回目</td><td rowspan="8">・体調チェック
・生活習慣病に関する講話
・準備運動：ストレッチング
・メイン運動
リズム体操、チェアビクス、水中歩行、アクアビクスなどの有酸素運動
・補強運動：自重を用いた低強度の筋力トレーニング
・整理運動：ストレッチング
＊教室中、対象者全員と個別に面談を行った</td></tr>
<tr><td>４回目</td></tr>
<tr><td>５回目</td></tr>
<tr><td>６回目</td></tr>
<tr><td>７回目</td></tr>
<tr><td>８回目</td></tr>
<tr><td>９回目</td></tr>
<tr><td>10回目</td></tr>
<tr><td>11回目</td><td>１回目と同様の測定</td></tr>
<tr><td>12回目</td><td>・個別カウンセリング（３ヶ月のまとめ、成果の説明）
・測定結果の解説
・終了式</td></tr>
</table>

表３．３～10回目の健康教室の流れ

<table>
<tr><th>時間（計90分）</th><th colspan="2">内　容</th></tr>
<tr><td>５分</td><td colspan="2">体調チェック　血圧測定</td></tr>
<tr><td>10分</td><td colspan="2">生活習慣病に関する講話</td></tr>
<tr><td>10分</td><td>準備運動：ストレッチング</td><td rowspan="3">・個別に対象者と面談
教材への記入内容と行動目標の達成度の確認。参加者の１週間の様子を聞き取り調査し、必要に応じてアドバイスや目標の修正を行った。</td></tr>
<tr><td>45分</td><td>メイン運動
リズム体操、チェアビクス、水中歩行、アクアビクスなどの有酸素運動</td></tr>
<tr><td>10分</td><td>自重を用いた低強度の筋力トレーニング</td></tr>
<tr><td>10分</td><td colspan="2">整理運動：ストレッチング</td></tr>
</table>

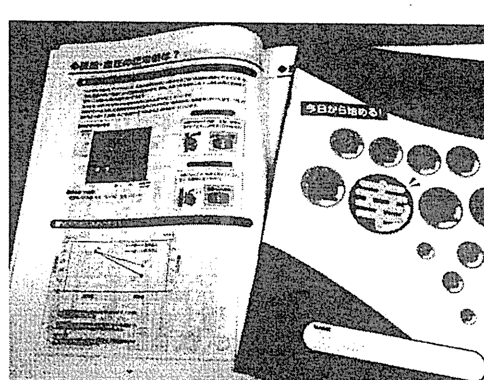

図１．教材「いきいき健幸生活」

別に面談を行い、健康教室初回に実施した各測定数値を説明した。さらに健康教室参加の目的を聞き目標設定（大目標）を行った。その目標を達成するために日々の生活の中で遂行可能な2～3つの行動目標（小目標）を、参加者自身が決定できるよう個々の参加者の日常生活行動を考慮してアドバイスした。参加者自身が小目標を決定した。

日々の行動目標の達成度及び体重、歩数、血圧等は教材に記入するよう指示した。健康運動指導士は、個別に健康教室ごとに教材への記入内容の確認を行い、前回の健康教室からの行動目標の達成度及び日常生活内での食事や運動の状況を聞き取り調査し、行動目標の達成度が高い場合には賞賛をし、低い場合には個々の生活の様子に合わせて代替案を提示するなど目標達成に向けてアドバイスを行い、生活習慣病予防・改善の支援を行った。行動目標は達成度合いを評価し、少しずつ大目標に近づくよう変更した。

E．健康運動指導士の役割

健康運動指導士は、健康教室前に依頼を受けた自治体の担当者と打ち合わせを行い、参加者の様子やその自治体住民の特性を聞き取り調査した。打ち合わせの内容を踏まえ、健康教室の全体の流れと1回の健康教室の運動内容を計画立案した。健康づくりのための運動指針―エクササイズガイド2006―[27]や特定保健指導の実施を支援するe-ヘルスネット[29]などが紹介する科学的根拠に基づき、運動プログラムを作成した。健康教室中に運動強度が高すぎるもしくは低すぎる、欠席者が多い等の運動の計画に不具合が生じた場合には、健康運動指導士の判断のもと、適宜健康教室の全体の流れや運動内容の変更を行った。健康教室では参加者に、教室内で行う運動から予測される効果について説明を行い、一つ一つの動作についてどこの部位に意識をさせて運動を行うか意識性の原則に基づき説明した。健康運動指導士は参加者の個々の行動変容の準備度を把握し、行動科学理論に基づいた支援を行なった。さらに健康教室のプログラムに、グループワークを取り入れる等の仲間づくりに努め、健康運動指導士だけでなく、同じ健康教室の参加者からも運動継続及び定着に向けた社会的支援が得られるようにした。各参加者のそれぞれの生活状況や測定結果の内容を健康教室期間中を通して把握し、日常生活内に運動を取り入れ、さらに健康教室終了後も個人で継続して運動が実施できるよう個別に支援した。健康教室ごとに行う面談では、参加者との信頼関係の構築に努め、今までの生活習慣の振り返りを行ない、肥満や高血圧、高血糖の状態になった原因を、対象者自身が気づき行動できるよう支援した。参加者が行動目標を主体的に考え、短期的で実行可能な目標になるようアドバイスした。行動目標を継続できるように個別に支援した。

F．測定項目

健康教室の開始時及び終了時に、対象者に以下に示す測定を実施した。

1．形態測定

身長、体重、BMI（Body Mass Index）、体脂肪率、腹囲を測定した。体脂肪率はインピーダンス法を用いて評価し、腹囲は、立位の臍部で息を吐いた時の周囲径を測定した。

2．体力測定

筋力、柔軟性、平衡性を評価した。握力を測定し、筋力を評価した。立位体前屈を測定し、柔軟性を評価した。閉眼片脚立ちを測定し、平衡性を評価した。

3．歩数

歩数計は参加者が各自で用意するよう指示した。健康教室開始日から1週間の平均歩数と健康教室終了日前の1週間の平均歩数を比較した。

4．メディカルチェック

各測定は、自治体の健康教室の実施時間に合わせて、午前10時30分から11時30分の間、もしくは、午後13時30分から15時の間に行い、室内温度は冬期に20℃前後、夏期に28℃前後の快適温度内に保たれるよう設定した。

i．血圧、動脈スティフネス

動脈スティフネスは、上腕足首間脈波伝播速度（baPWV: brachial-ankle Pulse wave velocity）を指標として、血圧脈波検査装置を（formPWV/ABI: オムロンコーリン株式会社）を用いて、仰臥位安静時の両上腕及び足首の収縮期血圧（Systolic Blood pressure: SBP）、拡張期血圧（Diastolic Blood Pressure: DBP）と同時に測定した。baPWVは、左右の上腕と足首にセンサー付きカフを取り付けることで、非侵襲的に全身性の動脈スティフネスの指標として評価することができる[30]。カフ内の容積脈波から両上腕と両足首の脈波を獲得でき、これらの脈波から立ち上がり時間の差（ΔT）を測定し、身長から求めた大動脈弁口から足首までの長さ（La）、大動脈弁口から上腕までの長さ（Lb）を求め、以下に示すような式からbaPWVを算出した[31]。

$$baPWV = (La - Lb)/\Delta T$$

測定時には、仰臥位にてセンサー付きカフを両腕・両足首に装着し、安定した心拍応答を確認した後、測定を行った。本法によるbaPWV測定の再現性テストによる推定標準誤差は、±3％であった。

ii．血液検査

椅子座位で肘部皮静脈から採血し、総コレステロール及び中性脂肪、HDL コレステロール、血糖値の測定を行った。午前中の健康教室参加者には朝食を摂取しないよう指示し、午後の健康教室参加者には、朝食に脂質の多い食事摂取を控え、昼食を摂取しないよう指示した。

G．群分け方法

運動頻度と動脈スティフネスの関連性をみるために、参加者を健康教室の出席率から３群に分けた。2004年～2006年に特定健康診査・保健指導の先駆的・モデル的事業として国保ヘルスアップ事業を行った山形県鶴岡市の報告書[32]は、12週間の短期プログラムの参加率が８割を超えたことを報告した。この事実を踏まえて本研究では全健康教室に参加した100％の出席率だった者を参加率の高い群（n=48）、99～80％の者を普通群（n=38）、80％未満の者を低い群（n=16）とした。

H．統計処理

統計処理は、統計ソフトは、Macintosh 版 Statview-J 5.0を用いて行った。健康教室開始時及び終了時の比較には、対応ありのｔ検定を用いた。各群における健康教室開始時及び終了時の比較にも群ごとに対応ありのｔ検定を用いて有意差の検定を行った。各測定項目の参加動機による３群間の比較には、一元配置分散分析を行なった。結果は全て平均値±標準偏差にて表記し、統計学的な有意水準を危険率（p）５％未満とした。

Ⅲ．結　果

A．全参加者における健康教室開始時及び終了時の変化

全参加者における健康教室開始時及び終了時の各測定項目の変化を表４に示した。

１．形態測定

体重及び BMI は健康教室終了時に有意に減少していた（$p<0.05$）が、身長及び体脂肪率、腹囲は有意な差を示さなかった。

２．体力測定

握力及び立位体前屈は健康教室終了時に有意に増加していた（$p<0.05$）が、閉眼片脚立ちは有意な差を示さなかった。

３．メディカルチェック

baPWV 及び収縮期血圧、拡張期血圧は、有意に減少した（$p<0.05$）。血液検査では、総コレステロールが有意に減少した（$p<0.05$）が、HDL コレステロール及び中性脂肪、血糖値は有意な差を示さなかった。

表４．健康教室開始時と終了時の変化

項　目	開始時	終了時
身長(cm)	153.9±6.2	153.9±6.2
体重(kg)	56.8±9.0	56.1±8.6*
BMI(kg/m2)	24.0±3.2	23.7±3.1*
体脂肪率(%)	28.4±6.6	29.1±6.3
腹囲(cm)	80.8±11.6	80.3±11.0
収縮期血圧(mmHg)	130±18	124±16*
拡張期血圧(mmHg)	77±10	74±9*
baPWV(cm/s)	1501±307	1454±289*
総コレステロール(mg/dl)	233±34	227±32*
HDL コレステロール(mg/dl)	68±17	69±18
中性脂肪(mg/dl)	123±80	115±59
血糖値(mg/dl)	107±14	105±22
握力(kg)	24.3±6.9	25.7±6.8*
立位体前屈(cm)	12.4±7.2	13.7±7.2*
閉眼片脚立ち(秒)	13.4±18.9	16.1±15.1
歩数(歩／日)	8374±3609	8451±3346

平均値±標準偏差　*$p<0.05$

baPWV；上腕足首間脈波伝播速度

４．歩数

健康教室開始日から１週間及び健康教室終了前の１週間のそれぞれの平均歩数は、健康教室の開始時及び終了時で有意な差を示さなかった。

B．参加率からみた健康教室開始時及び終了時の変化

１．形態測定

参加率からみた形態測定の結果を表５に示した。健康教室開始時及び終了時の比較では、全ての参加率別の群において、体重と BMI が健康教室終了時に有意に減少した（$p<0.05$）。身長及び体脂肪率、腹囲は３群ともに健康教室開始時及び終了時に有意な差を示さなかった。各測定項目値の３群間の比較では、体脂肪率は健康教室開始時及び終了時ともに参加率が低い群が他の２群と比較して有意に高値を示した（$p<0.05$）。健康教室開始時の腹囲において、参加率の低い群は高い群より有意に高値を示した（$p<0.05$）。身長及び体重、BMI は３群間に有意な差を示さなかった。

２．体力測定

参加率からみた体力測定の結果を表６に示した。健康教室開始時及び終了時の比較では、参加率が高い群では、握力と立位体前屈が健康教室終了時に有意に増加した（$p<0.05$）。普通の群では、握力が有意に増加した（$p<0.05$）。その他の群では有意な差を示さなかった。各測定項目値の３群間の比較では、握力は健康教室開始時及び終了時ともに普通の群より低い群で有意に低値を示し（$p<0.05$）、立位体前屈は教室終了時において高い群より低い群で有意に低値を示した（p<

0.05)。閉眼片脚立ちは3群間に有意な差を示さなかった。

3．メディカルチェック

参加率からみたメディカルチェックの変化について、血圧とbaPWVの変化を図2、3に、血液指標の変化を表7に示した。健康教室開始時及び終了時の比較では、参加率が高い群と普通の群においてbaPWVと収縮期血圧、拡張期血圧は、有意に低下した（$p<0.05$）。低い群では、有意な差を示さなかった。総コレステロール及びHDLコレステロール、中性脂肪、血糖値は、全ての群で有意な差を示さなかった。各測定項目値の3群間の比較では、健康教室終了時の中性脂肪において低い群がその他の群と比較して有意に高値を示した（$p<0.05$）。その他の項目は3群間に有意な差を示さなかった。

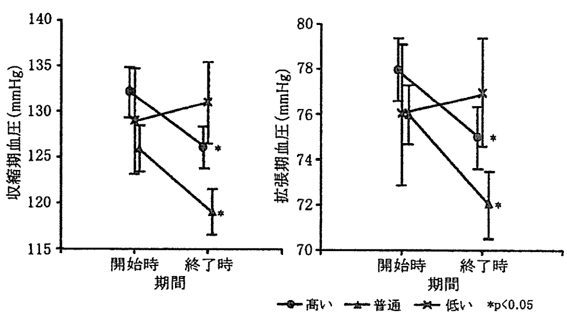

図2．参加率からみた血圧の変化

Ⅳ．考　　察

特定保健指導の該当者と健康運動指導士の有効な関連性を示す知見として、数ヶ月間の健康運動指導士が指導する健康教室の介入により動脈スティフネス及び血圧が改善し、体力が向上することが確認された。加えて、週1回実施する健康教室のような運動形態では、参加者の参加率がこれらの改善に影響を及ぼすことを示唆した。

本研究では、健康教室開始時に、健康運動指導士が形態・体力測定、メディカルチェックの結果を参加者に説明した。この時にbaPWVの結果からおおよその血管年齢を提示し、血管の硬さの模型を対象者に視覚

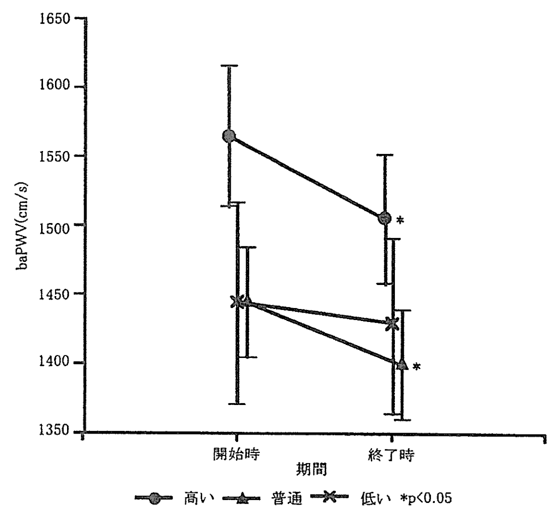

図3．参加率からみたbaPWVの変化

表5．参加率からみた形態指標の変化

参加動機	n	身　長（cm）		体　重（kg）		BMI（kg/m²）		体脂肪率（%）		腹囲（cm）	
		開始時	終了時	開始時	終了時	開始時	終了時	開始時	終了時	開始時	終了時
高い群（100%）	48	154.0±6.5	154.1±6.6	56.3±10.0	55.7±9.4*	23.7±3.5	23.4±3.3*	27.9±7.4	28.4±6.7	79.0±11.1	78.5±11.4
普通群（99～80%）	38	154.7±6.1	154.7±6.0	56.9±9.1	56.0±8.4*	23.8±3.0	23.4±2.8*	27.2±5.3	28.6±5.7	80.7±12.9	80.2±11.5
低い群（80%未満）	16	151.6±5.5	151.6±5.5	57.8±5.4	57.6±5.6*	25.2±2.4	25.1±2.5*	32.3±6.3∴ʃ	32.9±5.6∴ʃ	86.0±8.5ʃ	84.9±6.9

平均値±標準偏差　*p<0.05 開始時 vs 終了時、∴p<0.05 低い群 vs 普通群、ʃp<0.05　低い群 vs 高い群

表6．参加率からみた体力指標の変化

参加動機	n	握　力（kg）		立位体前屈（cm）		閉眼片脚立ち（秒）	
		開始時	終了時	開始時	終了時	開始時	終了時
高い群（100%）	48	24.7±6.7	26.1±6.8*	13.1±6.8	15.0±6.3*	13.3±18.1	17.3±16.7
普通群（99～80%）	38	25.3±7.3	27.0±5.8*	12.8±7.6	13.6±8.0	12.7±19.8	14.3±11.3
低い群（80%未満）	16	21.1±7.8∴	21.5±7.8∴	9.3±7.2	10.3±7.2ʃ	15.5±20.1	16.9±18.4

平均値±標準偏差　*p<0.05 開始時 vs 終了時、∴p<0.05 低い群 vs 普通群、ʃp<0.05　低い群 vs 高い群

表７．参加率からみた血液指標の変化

参加動機	n	総コレステロール (mg/dl)		HDL コレステロール (mg/dl)		中性脂肪 (mg/dl)		血糖値 (mg/dl)	
		開始時	終了時	開始時	終了時	開始時	終了時	開始時	終了時
高い群 (100%)	48	233±33	229±34	67±18	68±18	115±64	116±70	106±14	109±31
普通群 (99～80%)	38	229±28	226±27	69±16	72±19	131±99	112±49	105±13	98±6
低い群 (80%未満)	16	243±48	226±35	68±15	63±16	131±73	120±45∴′	114±17	108±12

平均値±標準偏差　∴$p<0.05$ 低い群 vs 普通群、′$p<0.05$　低い群 vs 高い群

的に示し、さらに実際に参加者自身の手で模型を触ることにより自身の血管の硬さの度合いを理解させた。参加率が高い群の健康教室開始時の baPWV の数値は、健診受診者で心血管疾患や動脈硬化危険因子がなく正常血圧の健常人から得た60代の baPWV 基準値[33]と比べて高い値を示した。さらに有意な差はないものの、参加率が普通の群及び低い群に比べても高かった。本研究の結果は、年代の基準値より高値を示す baPWV 値であったとしても運動の介入及び生活習慣の見直しにより改善を望めることを示唆する。健康運動指導士は、参加者に対し、メディカルチェックの結果及び各参加者の生活プロフィールを参考に健康教室が生活習慣病の予防・改善に貢献するよう運動プログラムを作成した。健康教室の中で実施した個別面談において、血圧及び動脈スティフネス、体重が高値を示す者及び生活習慣病リスクを重複して保有する者には、そうでない者と比べて、運動だけでなく栄養指導及びストレスコーピングの指導などを多面的に行ない、生活習慣改善に向けての支援及び行動の修正に関するアドバイスを多く行なった。健康運動指導士の関わりの度合いが参加者の高い参加動機に関係し、血圧及び動脈スティフネスの減少に結びついたことが示唆される。さらに本研究の参加者は、自治体の健康教室の募集告知に対して任意で集まった集団である。生活習慣病予防・改善を目的に健康教室が行なわれることを理解していて、今までの生活習慣に危機感を持っている、または健康教室に参加することが生活習慣病の予防・改善効果が生じることへの期待が、健康教室の高い参加動機に関与しているものと推察する。

健康教室時以外の身体活動を検討する指標として、歩数計の着用を促したが、健康教室開始時及び終了時で歩数に変化がみられなかった。本研究と同様に運動を行った保健指導モデルを検討した先行研究においても歩数は増加しなかったが、体重や血圧の減少を報告している[34,35]。本研究の結果は、先行研究の報告を支持する結果であった。

本研究の対象者の９割は女性であった。女性の動脈スティフネスを検討する場合、女性ホルモンの一つであるエストロゲンの影響を考慮しなくてはならない。先行研究は、エストロゲンが血管拡張作用および NO 産生に関与し、女性は男性より低い baPWV の値を示すが、60歳以上では閉経の影響から baPWV の男女差は無くなることを報告している[12]。さらに月経周期に伴い動脈コンプライアンスは変動するものの、大動脈 PWV[36]や脚の PWV[37]は明らかな変動を示さないことも報告されている。本研究の対象者はすでに閉経の平均年齢を超えている年代であることからエストロゲンの影響を考慮しなかった。

先行研究において、運動の動脈スティフネス改善効果の報告は、運動頻度を週２～５日で設定している場合が多い[9,18～20,22,24～26]。本研究と同様に日本人の中高齢者を対象とした先行研究では、閉経後の女性を対象に12週間、週３～５日の低強度もしくは中強度の有酸素運動トレーニングを実施した場合、どちらの強度でも動脈スティフネスが低下することを報告している[19]。大槻ら[26]は、12週間週５日の有酸素運動トレーニングにより動脈スティフネスが低下したことを報告した。本研究では３ヵ月間の週１回の集団運動プログラムで実施した健康教室の参加により動脈スティフネスが低下した。ACSM の運動処方の指針においては、週に３～５回の頻度での運動を推奨している[38]。一方、文部科学省では、成人の週１回以上のスポーツ実施率を目指しており、同省の「体力・運動能力調査報告書」では週１日以上の運動実施頻度の者は、しない者に比べて体力水準が高いと報告している[39]。健康づくりのための運動指針―エクササイズガイド2006―では、持久力と筋力が高いと生活習慣病の発症リスクが低くなると報告されている[27]。以上の科学的根拠に基づき、運動プログラムを作成したことが本研究の成果に結びついたと考える。

健康教室の参加率から動脈スティフネスの改善を評価した場合、高い群だけでなく、普通の群においても動脈スティフネスが低下した。参加率が99～80%は、健康教室開催数からみると教室を１回もしくは２回休んだことに相当する。山形県での国保ヘルスアップ事業[32]においても参加者のプログラムの参加率が約８割で生活習慣病リスクが改善していることから、健康教室を１回もしくは２回休んだとしても生活習慣病予防・

改善効果は期待されるものと推察する。

本研究は、特定保健指導における運動実施において、健康運動指導士の指導が有効であるかどうかに着目した。健康運動指導士は、昭和63年に地域保健法に基づく厚生省令「健康づくりのための運動指導者の知識および技能の審査・証明事業の認定に関する規定」（本省令は平成17年に廃止）により発足し、現在は財団法人健康・体力づくり事業財団独自の事業として継続している[40]。保健医療関係者と連携しつつ安全で効果的な運動を実施するための運動プログラム作成及び実践指導計画の調整等を行なう役割を担っている[41]。しかしながら、筆者が調べた中高齢者を対象とした運動健康教室における生活習慣病リスクの改善効果に関する先行研究において、健康運動指導士が運動指導したと明記されている論文は3報であった[7~9]。韓ら[7]は、60歳以上の女性を対象に26週間週1回の健康運動指導士が指導する「健康づくり運動」により、等尺性膝伸展力や歩行機能が改善したと報告している。このことは6.5ヵ月の継続であれば週1回の頻度でも改善することを示唆する。河村ら[8]は、高齢者を対象に12週間週2回の健康運動指導士が指導する介護予防筋力トレーニング事業の実施により、運動機能の向上及び腹腔内脂肪やアディポカインの分泌活性に好影響を及ぼすことを報告している。このことは3ヵ月の継続であれば週2回の頻度で改善することを示唆する。本研究と同様に動脈スティフネスに着目した研究では、柿山ら[9]が、6ヵ月間週2回の頻度で健康運動指導士が中高年を対象に、個別に低強度の運動トレーニングをエアロバイクや筋力トレーニングマシンを用いて実施し、動脈硬化性疾患の無い健常者の動脈スティフネス及び血圧が減少することを報告している。本研究は、3ヵ月間週1回の集団運動プログラムの実施により、baPWV及び血圧が低下したことを示した。トレーニングマシンを用いない方法論であっても、地域の実情に合わせた個々の健康運動指導士からの運動指導が、baPWV及び血圧値を改善させる可能性を示唆する。

2005年に山下ら[42]が市町村保健センターを対象に行なったアンケート調査では、73%の保健センターで運動を通した健康づくり事業を実施していることを報告している。事業に携わっているスタッフは保健師、栄養士についで健康運動指導士・実践指導者の順に多く、実際に運動指導を行なっているスタッフの資格は健康運動指導士・実践指導者、保健師、体育系指導員・インストラクターの順に多いことも報告されている。しかしながら、地域住民を対象とした健康づくり事業の報告は多くあるが、実際にその指導を行なった者の資格と指導内容の関連を明記してあるものは少ない。2008年度から、特定健康診査・保健指導は40～74歳の国民に義務化された[3]。医療保険者は、メタボリックシンドロームに着目し、生活習慣病の予防を重視した特定健康診査とその結果により生活習慣の改善が必要な人への特定保健指導を実施しなければならず、その構成する項目に運動が含まれる。特定保健指導の基本的な考え方は、対象者の自己選択と行動変容に着目し、個々人の検診結果を読み解くとともにライフスタイルを考慮した方法で、さらに科学的根拠に基づく指導をすることである。現行の健康運動指導士の養成プログラムはこの内容を網羅しており、特定保健指導において健康運動指導士は、特定保健指導を統括する医師、保健師、管理栄養士等と協力して事業に貢献できるものと考える。特定健康診査・保健指導は登録された保健事業者へアウトソーシングが可能である。集団運動プログラムとして積極的支援を行う場合、保健指導を請け負うもしくは実施する側が、参加率が動脈スティフネスや血圧に影響を与える事実も把握して保健指導プログラムを作成する、もしくはコーディネイトすることが成果に結びつくものと予測する。

本研究から、週1回の健康教室への参加で動脈スティフネスと血圧が改善する可能性が示唆された。血清脂質の面からみると明らかな改善は認められなかった。血清脂質の運動効果に関する統一した見解を示す報告は今のところない[34,35,43,44]。今後、運動強度や運動内容の面からの検討が必要であると考える。しかしながら、本研究のような地域住民を対象とした集団運動プログラムであったとしても、健康運動指導士が指導し実施することで、メタボリックシンドロームの診断基準項目の一つである血圧が改善するという事実は、今後のメタボリックシンドローム対策に貢献するものと考える。

本研究の対象者は、任意で健康教室に参加しており、運動を肯定的にとらえている者が多かったと推察する。健康運動指導士による運動介入の効果だけでなく、健康増進に対する関心の高さが本研究の結果に付加されている可能性は否定できない。今後は、生活習慣是正の糸口をみつけられない者や運動習慣獲得に興味を示さないような者を対象に健康運動指導士と健康づくり事業に携わるその他の職種を加えた介入の有効性を検討し、地域住民に対し、特定保健指導を活用した健康づくり制度の構築が望まれる。

V. まとめ

地域住民を対象とした週1回3ヵ月間の健康運動指導士が指導する有酸素運動を主体とする健康教室の実施が、動脈スティフネス及び血圧を改善させる可能性が示唆された。参加率が高く、健康運動指導士からの介入を多く受けることが、動脈スティフネスや血圧の

改善に有効である可能性も示唆された。

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Long-term Detraining Increases the Risk of Metabolic Syndrome in Japanese Men

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Objective: The aim of the present study was to examine the effect of long-term detraining on metabolic syndrome (MetS).
Methods: 1109 Japanese men were categorized by their exercise habits. Clinical data, number of MetS risk factors, and differences in lifestyle-related behaviors of the non-training group (n = 233) and the detraining group (n = 483) were compared with those of the training group (n = 87).
Results: Waist circumference and body mass index were significantly higher in the non-training group and the detraining group than in the training group, and also higher in the detraining group than in the non-training group. High-density lipoprotein cholesterol (HDL-C) was lower and low-density lipoprotein cholesterol (LDL-C) was higher in the non-training group and the detraining group than in the training group. Both the non-training group and the detraining group had more MetS risk factors than the training group. The odds ratio for smoking was higher in the detraining group than in the training group.
Conclusions: Detraining results in similar degrees of obesity, low HDL-C, high LDL-C, and high MetS risk as non-training. To prevent lifestyle-related diseases, it is particularly important not only to encourage adults to become physically active, but also discourage active young people from discontinuing physical exercise.

Key words: metabolic health, exercise, health behavior, older adults, youth

INTRODUCTION

It is well known that habitual exercise has beneficial effects on health. In addition to amelioration of obesity [1-5], there is ample evidence to show that exercise can prevent or ameliorate risk factors for cardiovascular disease (CVD) such as type 2 diabetes [6-9], hypertension [10, 11], and dyslipidemia [12-16]. Metabolic syndrome (MetS) is characterized by increased insulin resistance associated with central obesity and clustering of metabolic risk factors, including impaired glucose tolerance, hypertension, and dyslipidemia. In order to prevent or ameliorate MetS, it is important to remain physically active [17, 18].

Some people discontinue habitual exercise even though they had exercised regularly during their student days. However, little is known about the effects of long-term detraining on health. It has been reported that short-term detraining (several days to weeks) has negative effects on lipid metabolism, such as increased triglyceride (TG) [19] and decreased high-density lipoprotein cholesterol (HDL-C) [20-23]. Moreover, relatively longer-term detraining (several years) has been reported to increase body mass index (BMI) and adiposity [24, 25], exacerbate lipid metabolism, and decrease bone mineral density [26, 27]. As to the effects of long-term detraining, or detraining for several decades since youth, there has been only one report on the risk of fractures in men [28] but no report focusing on MetS risk factors.

In the present study, in order to examine the effect of long-term detraining on MetS, 1109 Japanese men were categorized into four groups according to their exercise habits (training group, non-training group, detraining group, and others), and the clinical data and numbers of MetS risk factors of the non-training group or the detraining group were compared with those of the training group.

METHODS

Subjects

Of 1467 men who underwent annual health checks at the Health Planning Center at Makita General Hospital between February and March 2007, 1109 men aged 40-74 years, excluding those who were already treated for hypertension, dyslipidemia, or diabetes, were selected. Medical history was surveyed using a self-administered questionnaire. Habitual exercise dur-

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ing the student days (from primary school to college) was defined as maintaining physical activity ≥ 2 hours a day more than three times a week. Present habitual exercise was defined as maintaining physical activity ≥ 30 min a day more than once a week. Information about exercise habits was obtained through an interview. The subjects were categorized into four groups according to their exercise habits. The training group consisted of individuals who were continuing habitual exercise from youth to the present. The non-training group consisted of those who never had a habit of exercise, while the detraining group consisted of subjects who had exercised regularly during their student days but not at present. Finally, the others group consisted of individuals with other exercise habits. In this study, the clinical characteristics of the detraining group were compared with those of the training group or the non-training group. This study was designed in compliance with the ethics regulations outlined in the Declaration of Helsinki. Anonymized health records were used for analysis, and the privacy of participants was completely protected by unlinkable anonymization.

Measurements and definition of MetS

Anthropometric measurements were performed, and blood samples were obtained after overnight fasting. All measurements were included in the routine health check examinations. BMI was calculated by dividing weight (kg) by height squared (m^2). Waist circumference (WC) was accurately assessed by a trained staff member at the end of expiration in the standing position, measuring the minimum circumference at the level of the umbilicus to the nearest 0.5 cm. Blood pressure was measured at the right upper arm in a sitting position. Glycosylated hemoglobin (HbA1c) was measured by a high performance liquid chromatography (HPLC) method. The value for HbA1c (%) was estimated as a National Glycohemoglobin Standardization Program (NGSP) equivalent value (%) calculated by the formula HbA1c (%) ≈ HbA1c (Japan Diabetes Society, JDS) (%) + 0.4%, considering the relational expression of HbA1c (JDS) (%) measured by the previous Japanese standard substance and measurement methods and HbA1c (NGSP) [29]. Serum lipid levels were measured enzymatically. The following cut-off values were used according to the Japanese definition of MetS [30]: WC ≥ 85 cm, hypertension (systolic blood pressure (BP) ≥ 130 mmHg and/or diastolic BP ≥ 85 mmHg), FPG ≥ 110 mg/dl, triglyceride (TG) ≥ 150 mg/dl, and/or high-density lipoprotein cholesterol (HDL-C) < 40 mg/dl. The presence of WC ≥ 85 cm and two or more of the other risk factors constitutes a diagnosis of MetS. Information about lifestyle-related behaviors, including smoking, snacking, and drinking alcohol (≥ 50 g/day), was obtained using a questionnaire.

Statistics

Data are expressed as means ± SD. StatView-J 5.0 (Statistical Analysis System Inc, Cary, NC, USA) was used for the statistical analyses. Significant differences in age and clinical data among the three groups were evaluated using Scheffe's multiple comparison test. Odds ratios (*OR*) and 95% confidence intervals (CI) were calculated for WC ≥ 85 cm, BMI ≥ 25 cm/m^2, the presence of MetS, and the differences in lifestyle-related behaviors, using the training group as the reference. The numbers of MetS risk factors (hypertension, dyslipidemia, and hyperglycemia) were compared by ridit analysis [31] using the training group as the standard. All p values were two-tailed, and $p < 0.05$ was considered significant.

RESULTS

Table 1 shows the categorization of the groups by exercise habits. The 1109 Japanese men were categorized as follows: training group ($n = 87$), detraining group ($n = 483$), non-training group ($n = 233$), and others ($n = 306$). Those who had not exercised during their student days but started exercise thereafter were included in the others ($n = 72$). The ages ($M \pm SD$) of those in the training, non-training, and detraining groups were 50.8 ± 7.7, 51.4 ± 7.2, and 49.2 ± 7.1 years, respectively. Overall, 93% of the subjects in the detraining group had exercised regularly until they were college students, which indicates that most of them discontinued exercise after they started working. The frequency of present physical activity in the training group was as follows: once a week (36%), twice a week (13%), 3 times a week (19%), 4 times a week (2%), and ≥ 5 times a week (30%).

Since part of their BMI data when they were 20 years of age were available, we have analyzed the data as below.

training group ($n = 56$; 64% of total, $M = 20.9$, $SD = 1.6$)

detraining group ($n = 360$; 75% of total, $M = 21.3$, $SD = 2.6$)

non-training group ($n = 144$; 62% of total, $M = 21.1$, $SD = 2.6$)

There were no statistical differences among all the groups by Scheffe's multiple comparison tests.

The clinical characteristics according to exercise habits are shown in Table 2. WC and BMI were significantly higher in the non-training and the detraining groups than in the training group. Moreover, the detraining group had a significantly higher WC and BMI than the non-training group. HDL-C was significantly lower and low-density lipoprotein cholesterol (LDL-C) was significantly higher in the non-training and the detraining groups than in the training group. TG and total cholesterol (TC) tended to be higher in the non-training and the detraining groups than in the training group. Table 2 illustrates the numbers of MetS risk factors present according to exercise habits. On ridit analysis, the values of the mean ridit for the non-training group (0.616, $p < 0.01$) and the detraining group (0.596, $p < 0.01$) were significantly higher using the training group as the standard (mean ridit: 0.5). The result of ridit analysis demonstrated that both the non-training and the detraining group had significantly more MetS risk factors than the training group. However, there was no difference between the non-training group and the detraining group on ridit analysis.

The *OR*s and 95% CIs for the presence of obesity and MetS, and differences in lifestyle-related behaviors are shown in Table 3. The *OR*s for WC ≥ 85 cm, BMI

Table 1 Categorization of the groups according to exercise habits

	Exercise habits		Subjects	
Category	Student days	Present	*n*	(%)
Training	≥ 2 hours/day and ≥ 3 times/week	≥ 30 mins/day and ≥ once/week	87	(7.8)
Non-training	none	none	233	(21.0)
Detraining	≥ 2 hours/day and ≥ 3 times/week	none	483	(43.6)
Others	any other patterns of exercise habits		306	(27.6)
Total			1109	(100)

Table 2 Comparison of clinical characteristics by exercise habits

	Training	Non-training	Detraining
WC (cm)	81.1 ± 5.7	86.8 ± 9.9**	88.8 ± 8.4**,#
BMI (kg/m^2)	22.8 ± 2.2	24.0 ± 3.7*	24.9 ± 3.3**,##
SBP (mmHg)	125.8 ± 16.9	130.1 ± 18.0	128.8 ± 17.2
DBP (mmHg)	74.8 ± 11.1	78.0 ± 11.3	77.3 ± 12.3
FPG (mg/dl)	104.4 ± 17.0	109.7 ± 23.7	109.0 ± 24.0
HbA1c (%)	5.6 ± 0.5	5.8 ± 1.0	5.8 ± 0.9
TG (mg/dl)	122.9 ± 134.3	137.0 ± 86.3	145.5 ± 108.2
HDL-C (mg/dl)	64.6 ± 16.5	59.1 ± 16.6*	58.1 ± 14.5*
LDL-C (mg/dl)	134.7 ± 33.2	147.6 ± 36.7*	147.8 ± 37.8*
TC (mg/dl)	202.1 ± 33.4	209.2 ± 33.1	209.4 ± 35.2
No. of MetS risk factors			
0	35 (40%)	61 (26%)	137 (28%)
1	35 (40%)	84 (36%)	176 (36%)
2	14 (16%)	61 (26%)	133 (28%)
3	3 (3%)	27 (12%)	37 (8%)
Mean ridit	0.500	0.616**	0.596**

Data are M ± *SD* or *n* (%). BMI, body mass index; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol
*: $p < 0.05$, **: $p < 0.01$ relative to training group, #: $p < 0.05$, ##: $p < 0.01$ relative to non-training group (Scheffe's multiple comparison test)

Table 3 Odds ratios and 95% confidence intervals for WC ≥ 85 cm, BMI ≥ 25 kg/m^2, the presence of metabolic syndrome (MetS) and the differences in lifestyle-related behaviors

	Non-training	Detraining
WC ≥ 85 cm	5.98 (3.34 – 10.70)	10.30 (5.91 – 17.96)
BMI ≥ 25 kg/m^2	6.94 (3.06 – 15.70)	9.02 (4.08 – 19.93)
MetS	3.82 (1.75 – 8.35)	4.28 (2.02 – 9.08)
Smoking	1.32 (0.78 – 2.25)	2.01 (1.23 – 3.29)
Snacking	1.33 (0.68 – 2.60)	1.88 (0.93 – 3.78)
Drinking (≥ 50 g/day)	1.64 (0.78 – 9.43)	1.88 (0.93 – 3.78)

The training group was used as the reference

≥ 25 kg/m^2, and the presence of MetS were significantly higher in both the non-training and the detraining group in contrast to the training group (referent group). Compared with the training group, the *OR* for smoking was significantly higher in the detraining group. Although the detraining group showed higher *OR*s compared with the non-training group, there were no significant differences in *OR*s for snacking and drinking alcohol (≥ 50 g/day).

DISCUSSION

In subjects undergoing regular health check-ups, the influence of long-term habitual exercise on MetS was evaluated. While other studies examining the effects of detraining on MetS risk factors have been limited to a few years of detraining, the present study is the first to examine the effects of detraining over several decades, starting from student days. The prevalence of obesity and MetS was significantly increased in the detraining group (discontinued exercise), compared to the training group (continued exercise). In other words, detraining led to obesity to the same extent as in the non-training group, and the risk of MetS was clearly increased.

Since this study was a cross-sectional study, all of the subject s data from their school days were not available. However, the analysis of more than 60% of subject s BMI data when they were 20 years old indicated that there were no statistical differences among all the groups by Scheffe s multiple comparison tests. These results suggested that although their BMI were almost same when they are 20, BMI has changed afterward probably due to their different excise habits.

MetS risk factors include obesity, impaired glucose tolerance, hypertension, and dyslipidemia (high TG and low HDL-C). In the present study, changes in obesity and HDL-C were noted. WC and BMI, indicators of central and overall obesity, respectively, were both increased with detraining in comparison to the training as well as the non-training groups. WC measurements can vary greatly depending on the examiner, but in the present study, a single pre-trained examiner took all measurements, thus ensuring highly reliable data. With detraining, obesity progressed due to a decrease in energy expenditure, but a questionnaire was used to confirm whether there were also other changes in lifestyle habits. The results showed no differences in frequency of snacking or drinking alcohol.

The effects of aerobic exercise on lipid metabolism (TG, HDL-C, TC, and LDL-C) have been reported in several subject populations. For example, in healthy males aerobic exercise decreased TC and TG and increased HDL-C [12], in obese subjects it decreased TG [14], in elderly subjects (age ≥ 50 years) it decreased TC and LDL-C and increased HDL-C [15], and in CVD patients aerobic activity decreased TG and increased HDL-C [16]. On the other hand, increases in TG [19] and decreases in HDL-C [21–23] have been observed within a short period of a few days to few weeks of detraining. The reason for this is thought to be a loss in the enhanced activity of lipoprotein lipase provided by exercise [20, 21]. In our study, HDL-C significantly decreased, and LDL-C significantly increased in the non-training and the detraining groups compared to the training group.

In the present study, habitual exercise during student days was defined as physical activity ≥ 2 hours a day at least 3 days a week, and present habitual exercise was defined as physical activity ≥ 30 minutes a day at least once a week. This was done because, among respondents who regularly exercised during school days, exercise frequency was ≥ 3 days a week in 99%, and exercise time during each bout was ≥ 2 hours in 93%. On the other hand, approximately half of respondents who presently exercised did so at a frequency of 1 to 2 days per week. In addition, to eliminate variations due to different interviewers, the survey on habitual exercise was conducted using an interview format by a single investigator. In our study, the training group had less obesity, higher HDL-C, and lower LDL-C than the detraining group. Thus, it is clear that continuing exercise even once per week is important in preventing lifestyle diseases, and discontinuing exercise is just like having never exercised. Since the present study specifically focused on the effect of long-term detraining on MetS, whether beneficial effects of exercise are observed in subjects who had not exercised during their student days but started exercise thereafter was analyzed separately.

With respect to lifestyle habits, snacking and drinking alcohol did not differ among the three groups, but smoking was more common in the detraining group than in the training group. This suggests that discontinuing exercise may have an adverse impact on other lifestyle habits. Detraining might also cause unhealthy dietary habits leading to obesity. However, our survey was limited to snacking, which may not be enough to demonstrate the dietary causes of detraining-induced obesity. In order to clarify this question, we have already started another study to examine the impact of dietary habits on detraining-induced obesity using different subjects.

The limitations of this study include its cross-sectional design and the fact that test values were compared only during the survey period. Baseline (student days) and interim clinical data were not obtained. Moreover, although the type of habitual exercise during the student days was surveyed in detail, due to the wide variety of exercise types, this variable was excluded from our analysis. Indeed, since exercise type (e.g., aerobic, endurance, resistance) and intensity may have different effects on each parameter, this is an issue for future investigation. Furthermore, although the importance of continuing exercise was demonstrated, frequency was not evaluated. Thus, when conducting a longitudinal study on the influence of detraining on MetS, a study designed to clarify the above points is necessary.

In conclusion, detraining (discontinuing exercise) led to obesity and lower HDL-C, to the same extent as in the non-training group, MetS risk factors were increased, and LDL-C was increased. Therefore, guidance to adults to continue present physical exercise, and guidance to youth not to discontinue physical exercise, must be provided to prevent future lifestyle-related diseases.

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The authors declare no conflicts of interest.

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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.

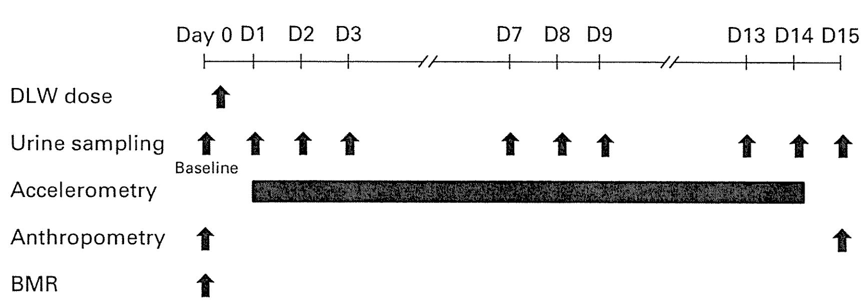

Fig. 1. Schematic representation of the experimental design. On day 0, the $^2H_2{}^{18}O$ (doubly-labelled water; DLW) dose was given orally to each subject after collecting a baseline urine sample and performing the BMR and anthropometric measurements.

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: $rCO_2 = 0{\cdot}4554 \times TBW \times (1{\cdot}007k_O - 1{\cdot}041k_H)$. 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 16.0 J; SPSS Inc., Chicago, IL, USA).

Results

Of the total 100 women studied, the proportion of normal-weight ($BMI \geq 18{\cdot}5$ to $< 25\,kg/m^2$) and overweight participants ($BMI \geq 25\,kg/m^2$) 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/m²)¶	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/m²)	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/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.