栄養学雑誌 Vol. 66 No. 4 195～200 (2008)

研究ノート

ボディービルダーの基礎代謝量と身体活動レベルの検討

山本祥子*1,2，髙田和子*2，別所京子*2，谷本道哉*2，
宮地元彦*2，田中茂穂*2，戸谷誠之*1，田畑泉*2
*1 昭和女子大学，*2 独立行政法人国立健康・栄養研究所

Basal Metabolic Rate and Physical Activity Level in Bodybuilders

Sachiko Yamamoto *1,2, Kazuko Ishikawa-Takata *2, Kyoko Bessyo *2, Michiya Tanimoto *2,
Motohiko Miyachi *2, Shigeho Tanaka *2, Masayuki Totani *1 and Izumi Tabata *2
*1 Showa Women's University ; *2 National Institute of Health and Nutrition

We measured the basal metabolic rate (BMR), fat-free mass (FFM) and physical activity level (PAL) of well-trained bodybuilders as typical athletes with muscular development by resistance training in order to examine the standard BMR and PAL ranges for athletes. The subjects were 14 bodybuilders (mean ± SD age : 36.8 ± 9.1 y. ; height : 171.6 ± 6.2 cm ; weight : 77.1 ± 7.6 kg ; FFM : 67.6 ± 6.8 kg) who each trained for an average of 7.5 h per week. BMR was measured by using a Douglas bag, the oxygen and carbon dioxide concentrations were analyzed by mass spectrometry, and FFM was measured by dual X-ray energy absorptiometry. PAL was measured by the doubly labeled water method for 7 subjects selected from the 14 bodybuilders. BMR/FFM was 25.4 ± 2.1 kcal/kg of FFM/day. Total energy expenditure (TEE) was 3,432 ± 634 kcal, and PAL calculated as TEE divided by BMR was 2.00 ± 0.21. The FFM value needs to be considered when evaluating a standard BMR range, and both training and daily physical activity levels should be considered when evaluating a standard PAL range.

Jpn. J. Nutr. Diet., **66** (4) 195～200 (2008)

Key words : basal metabolic rate, bodybuilder, physical activity level , fat-free mass

緒言

「日本人の食事摂取基準（2005年版）」1) (Dietary Recommended Intake : DRI) では推定エネルギー必要量 (Estimated Energy Requirement : EER) を，基礎代謝量 (Basal Metabolic Rate : BMR) と身体活動レベル (Physical Activity Level : PAL) を用いて算定している。DRI は健康な個人または集団を対象としており，極端にエネルギー消費量の多いスポーツ選手や高い身体活動量を有する者，傷病者等を含んでいないため，スポーツ選手の EER 推定のためには，スポーツ選手の基礎代謝基準値及び PAL の値の設定が必要となる。そのため，国立スポーツ科学センター (Japan Institute of Sports Science : JISS) は，日本人スポーツ選手を対象とした基準値策定に関するプロジェクトを立ち上げ，スポーツ選手を対象とした BMR と PAL について報告した2,3)。

BMR については，JISS のプロジェクトでは DRI に示されている基礎代謝基準値と日本人の一般的な体格から除脂肪量 (Fat Free Mass : FFM) あたりの BMR (BMR/FFM) を 28.5 % kcal/kgFFM/day と設定した。これは，これまでの報告においてボート選手及びランナーと非運動群の間で FFM あたりの BMR に差が見られず，運動習慣や運動種目による差がなかったという研究報告4) を根拠としたものである。一方で，Weinsier, R. L.ら5) は BMR と FFM を測定した文献をレビューし，FFM の大きく異なる対象では BMR/FFM が小さくなることを報告している。FFM が異なる対象で FFM あたりの BMR が異なる理由として，FFM に含まれる組織中の代謝率の高い組織と低い組織の割合の影響があると言われている5～8)。JISS が設定した BMR/FFM の値は，一般人の値からの推定値であり，一定の BMR/FFM の値が各種スポーツ選手に適用可能かについては，各種のスポーツ選手について実測した BMR の値のデータを収集したうえで，検討する必要が

キーワード：基礎代謝量，ボディービルダー，身体活動レベル，除脂肪量

（連絡先：髙田和子　〒162-8636　新宿区戸山1-23-1　独立行政法人国立健康・栄養研究所健康増進プログラム　電話 03-3203-8061
FAX 03-3203-1731　E-mail kazu@nih.go.jp）

ある。そこで，本研究の第一の目的として，FFMの多い選手としてボディービルダーを対象にBMRの測定を行い，スポーツ選手における基礎代謝基準値について検討することとした。なお，BMRは，生命維持に必要な生理化学的反応を行うための覚醒安静時の最小エネルギーと定義され，実際には食後12時間以上経過した早朝空腹時に仰臥安静・覚醒状態で適正な室温において測定される[9,10]。しかし，食事摂取基準における基礎代謝基準値の算定根拠となったデータは，宿泊して起床後すぐに測定したデータと，測定当日に測定室に来室し30分程度の仰臥安静後，測定されたデータが混在している。そこで本研究においては，BMRを測定当日に測定場所へ来所した後移動し30分の仰臥安静後に空腹状態で測定した。また，引用する文献についても測定日の宿泊の有無を問わず，早朝空腹時に十分な安静後に測定した値をすべてBMRとして比較することとした。

PALについては，DRIでは二重標識水（Doubly Labeled Water：DLW）法を用いて測定したエネルギー消費量の測定値に基づいて，3段階に分類されている[1]。スポーツ選手のPALの設定にあたって，JISSのプロジェクトはスポーツ選手を対象とした先行研究におけるPALの値を基に，持久系，瞬発系，球技系，その他の種目カテゴリー別にオフトレーニング期と通常トレーニング期の期ごとにPALの値を示した[2,3]。瞬発系，球技系についてはスポーツ選手の値の平均値，持久系ではトレーニング時間が長いことと，体重が比較的軽い選手が多いことから既存研究のデータの上限値が採用されている。これまで測定されている選手のデータは，まだ限られた種目であり，特に日本人選手を対象としたものは少ない。そこで本研究の第二の目的として，レジスタンストレーニングを主として実施しているボディービルダーについてDLW法を使用してPALを測定し，スポーツ選手における身体活動レベルについて検討することとした。本研究で対象としたボディービルダーは，筋力の高度な発達を目的として，ほぼ毎日レジスタンストレーニングを実施している。トレーニング内容は他競技が筋力向上のために行っている内容とほぼ同じであるが，練習時間は他種目に比べ比較的短い対象である。

方　　法

1．対象

対象者は，22～55歳の健康な成人男性で，週3～5回のトレーニングを行い，定期的に大会に参加しているボディービルダー14名である。全員，日本ボディービルディング連盟において薬物の使用がないことが確認されている。トレーニング量は週に平均4.6 ± 0.9回，1回のトレーニング時間は平均99 ± 21分で，週あたりの平均トレーニング時間は7.5 ± 2.4時間であった。測定期間は冬季であり，通常のトレーニング期であった。調査期間中は，できるだけ体重変動のない生活をするように指示し，それ以外は，通常の食事，トレーニングをするように指示した。

本研究は，独立行政法人国立健康・栄養研究所「人間を対象とする生物医学的研究に関する倫理委員会」の承認を得て，ヘルシンキ宣言の精神を遵守して実施した。被検者にはあらかじめ実験の目的と内容を説明し，文書により同意を得た。

2．測定項目

(1) 身体組成

身長及び体重は早朝空腹時に測定した。体脂肪率及びFFMはDXA法（Dual Energy X-ray Absorptiometry）（QDR－4500, Hologic, USA）により測定した。

(2) 基礎代謝量（BMR）

被験者は測定前夜の午後9時までに通常通りの夕食を済ませ，測定当日に朝食をとらずに測定場所に到着した後，9時から23～25℃の快適な室温で30分以上仰臥させた。測定場所への移動はできるだけ静かに行うように指示したが，移動による活動量は把握しなかった。その後，仰臥位のまま10分間の呼気を1分の間隔を置いてダグラスバッグに2回採集した。呼気は直ちに質量分析計（ARCO－1000，アルコシステム，千葉）を用いて酸素及び二酸化炭素量の濃度を分析した。その後，乾式ガスメーター（DC－5，シナガワ，東京）にて呼気量を測定した。それらの測定値から酸素摂取量（VO_2）と二酸化炭素排出量（VCO_2）を算出し，Weir[11]の式により1分あたりのBMRを求めた。さらに1,440（分）に換算し，1日あたりのBMR（kcal/day）とした。BMRは体重（Body Weight：BW）あたり（kcal/kg BW/day）及びFFMあたり（kcal/kg FFM /day）でも算出した。

(3) 身体活動レベル（PAL）の測定

対象者のうち7名について，DLW法を用いて総エネルギー消費量（Total Energy Expenditure：TEE）を測定し，それをBMRで除してPALを算出した。DLW法は，現時点では自由生活下での身体活動量を最も精度が高く評価できる方法とされており，ヒューマンカロリーメータとの比較により検討した正確度は約±4％とされている[12]。

10％^{18}O（太陽日酸，東京）と99.9％^{2}H（Cambridge Isotope Laboratories, Inc., USA）を混合した液により，体重あたり0.14gの^{18}Oと0.06gの^{2}Hを投与した。投与前，投与後4及び5時間後，翌日（2回）と8日後（2

Table 1 Physical characteristics and basal metabolic rate among body builders

	N	Age (yr.)	Height (cm)	BW (kg)	FFM (kg)	BMR (kcal)	BMR/BW (kcal/kg)	BMR/FFM (kcal/kg)
20 − 29yrs	3	24.0 ± 3.5	172.3 ± 7.6	80.0 ± 11.5	70.7 ± 11.0	1,843 ± 264	23.0 ± 0.4	26.1 ± 1.2
30 − 39yrs	5	35.6 ± 2.6	174.8 ± 4.6	80.2 ± 6.3	69.4 ± 5.1	1,722 ± 198	21.5 ± 1.9	24.8 ± 2.1
40 − 49yrs	5	41.8 ± 2.5	169.5 ± 6.4	72.6 ± 6.4	65.0 ± 6.0	1,590 ± 171	21.9 ± 1.4	24.5 ± 1.7
50 − 59yrs	1	56	164.3	75.4	62.7	1,873	24.8	29.9
Total	14	36.8 ± 9.1	171.6 ± 6.2	77.1 ± 7.6	67.6 ± 6.8	1,712 ± 209	22.2 ± 1.6	25.4 ± 2.1

BW：body weight, FFM：fat free mass assessed by dual energy X-ray absorptiometry, BMR：basal metabolic rate per day

回）の同時刻に採尿した。サンプルは密閉した状態で，分析まで－30 ℃で保存した。^{2}H は Pt を触媒として H_2 ガスで，^{18}O は CO_2 ガスで平衡法により前処理を行った後，^{2}H，^{18}O の安定同位体比を質量比分析計（Finnigan Delta Plus，Thermo Fisher Scientific，USA）により分析した。分析の測定誤差は，^{2}H で 0.5 ‰，^{18}O で 0.03 ‰である。また，10 名のサンプルを 2 回分析した際の誤差は，1.6 ± 3.9 %であった。

身体水分量（Total Body Water ： TBW）は投与後 4 及び 5 時間後の尿中の安定同位体濃度から，$N=[WA(\delta a-\delta t)]/[18.02a(\delta s-\delta b)]$ の式により求めた。ただし，N は ^{2}H 及び ^{18}O の希釈容積（mol），W は同位体比分析の際に DLW を希釈するのに用いた飲料水の量（g），A は投与した DLW の量（g），δa は希釈した DLW における同位体比，δt は DLW の希釈に用いた飲料水の同位体比，a は同位体比分析の際に飲料水で希釈された DLW の量（g），δs は尿中の同位体比，δb はベースラインでの尿の同位体比である。TBW は，^{2}H の N を 1.041 で除したものと，^{18}O の N を 1.007 で除したものの平均値とした。

測定期間中の安定同位体の減衰率を $k=[\ln(\delta f-\delta b)-\ln(\delta i-\delta b)]/t$ から求めた。δf は 8 日後の尿中の同位体比，δb はベースライン尿の同位体比，δi は投与翌日の同位体比，t は測定期間である。二酸化炭素の排出量は，rCO_2（mol/day）$=0.4554TBW(1.007ko-1.041kh)$ により求めた。ko は ^{18}O の減衰率，kh は ^{2}H の減衰率である。DLW 法においては，全期間を通じた呼吸商（Respiratory Quotient ： RQ）の直接測定が不可能なため，体重変動のないエネルギーバランスのとれた状態では食事調査より求めた食物商（Food Quotient ： FQ）[13] を使用して，TEE を求めることが最も適切とされている[14]。そこで，TEE は DLW 法による身体活動量の調査期間中の食事調査より求めた FQ を用いて，Weir[11] の式により求めた。

(4) 食事調査

PAL の測定を行った 7 名については，測定期間中に 3 日間の食事記録法により食事調査を行った。食事の記録内容は，調査終了後に管理栄養士が面接により確認した。摂取栄養素量は，エクセル栄養君 ver.4.0（建帛社，東京）により計算した。補助食品については，各メーカーの資料により栄養素量を求め，追加した。

(5) 統計処理

すべてのデータは，平均値と標準偏差（mean ± SD）で表した。本研究で得られた各指標の統計処理は，SPSS13.0 J for Windows (SPSS Inc., USA) にて行った。

結　　　果

1. 基礎代謝量（BMR）

14 名のボディービルダーの身体特性及び BMR を Table 1 に示した。全対象における 1 日あたりの BMR は，1 日あたりでは 1,712 ± 209kcal/day，BW 1 kg あたりでは 22.2 ± 1.6kcal/kg/day，FFM あたりでは 25.4 ± 2.1kcal/kgFFM/day であった。年代別に分けると，各年代の人数は少ないものの，身体特性，BMR とも一定した傾向は認められなかった。

2. 身体活動レベル（PAL）

ボディービルダー 7 名の身体特性，BMR，TEE，PAL，歩数及び 1 週間あたりのトレーニング時間（分）を Table 2 に示した。DLW 法で測定した 1 日の TEE は，3,432 ± 634kcal/day であった。 TEE と BMR から計算した PAL は，2.00 ± 0.21 であった。 また，総エネルギー摂取量（Total Energy Intake ： TEI）は 1 日あたりでは 3,268 ± 663kcal/day，体重あたりでは 43.3 ± 6.8kcal/kg/day であった。タンパク質，脂質，炭水化物の摂取量は，161 ± 55g，79 ± 25g，429 ± 130g，FQ は 0.923 であった。TEI と BMR から求めた TEI/BMR は 1.93 ± 0.24 であった。

考　　　察

本研究で，高度にトレーニングされたボディービルダー男性の BMR を測定したところ，BMR/FFM は 25.4 ± 2.1kcal/kgFFM/day であり，JISS が設定した値 (28.5kcal/kgFFM/day)[2,3] より低いことをみとめた。また，週に約 8 時間のトレーニングを行っているボデ

Table 2 Physical characteristics, basal metabolic rate, and physical activity level among body builders

ID	Age (yr.)	Height (cm)	BW-pre (kg)	BW-post (kg)	BW-change (kg)	FFM (kg)	BMR (kcal)	BMR/FFM (kcal/kg)	TEE (kcal)	PAL	Walk steps (steps/day)	Time (min)	TEI (kcal)
02	41	166.0	78.2	80.1	+1.8	69.9	1,845	26.4	4,191	2.20	10,870 ± 3,190	73	4,373
03	37	173.6	75.9	73.2	−1.7	63.8	1,741	27.3	3,884	2.23	13,903 ± 5,202	62	3,359
05	46	166.5	61.5	61.1	−0.3	55.2	1,385	25.1	2,421	1.81	12,759 ± 2,897	55	2,396
06	56	164.3	75.5	77.2	+1.7	62.7	1,873	29.9	3,228	1.78	5,374 ± 2,663	55	3,350
07	33	174.3	76.2	75.1	−1.1	65.5	1,555	23.7	2,965	1.81	–[a]	–[a]	2,533
09	42	163.4	73.7	72.6	−1.1	63.3	1,610	25.4	3,324	1.95	12,949 ± 3,016	46	3,280
11	39	181.6	90.0	89.1	−0.9	74.0	1,800	24.3	4,015	2.23	11,663 ± 2,655	34	3,587

BW : body weight, FFM : fat free mass assessed by dual energy X-ray absorptiometry, BMR : basal metabolic rate per day, TEE : total energy expenditure measured by doubly labeled water method, PAL : physical activity level calculated as TEE divided by BMR, Walk steps : mean value during TEE measurement assessed by accelerometer, Time : mean training time (minutes) per day during TEE measurement, TEI : total energy intake estimated by 3-day food records

[a] Values could not be assessed.

ィービルダーのPALは約2.0であった。

今回の結果では，FFM67.6kgのボディービルダーのBMR/FFMは25.4kcal/kgFFM/dayとなった。この値は，JISSが示した28.5kcal/kgFFM/day[2, 3]や，先行研究におけるウォーキングまたはローイングをしているスポーツ愛好者男性（FFM52kg）28.5kcal/kgFFM/day[15]，水泳選手（FFM69kg）29.5kcal/kgFFM/day[16]，柔道選手（FFM67.1kg）28.1kcal/kgFFM/day[16]，空手選手（FFM64.5kg）28.2kcal/kgFFM/day[16]よりも，小さい値であった。FFMが35～45kgの者を対象とした研究[4, 15, 17]のBMR/FFMは，30～31kcal/kgFFM/dayと高い値が報告されていた。しかしながら，これらの先行研究では，FFMの測定法がBOD POD（空気置換法）[4, 15]，DXA法[16, 17]，水中体重法[17]と異なっている。また，BMRの測定条件や方法も，前日より宿泊してダグラスバッグにより測定したもの[4, 15]，当日来所しフードを使用したもの[16]，当日あるいは前日に移動しフードを使用したもの[17]と様々であり，単純な比較は困難である。本研究と同じFFM，BMRの測定法による先行研究はなく，測定法による一定の傾向もみられなかった。

Weinsier, R. L. ら[5]のレビューによると，FFMが大きい対象においてBMR/FFMが小さくなることが指摘されている。その理由は，FFMが大きくなるとFFM中で安静時の代謝活性の低い筋組織の割合が安静時の代謝活性の高い内臓組織よりも大きくなるからであると指摘されている[5～8]。ボディービルディングでは，筋肉を高度にトレーニングしている。そのため，FFM中の筋肉の割合が非運動者や他の種目に比べて大きいことが推測され，FFMあたりの代謝率に影響する可能性は高い。一方で，Bosselares, I. ら[18]はヒューマンカロリーメータを使用して，ボディービルダーと非運動者の睡眠時代謝を比較し，年齢，FFM，体脂肪量（FM）で調整した睡眠時代謝には差がないとしている。また，Midorikawa ら[19]は水中体重法によりFFMを，MRIにより内臓の重量を測定し，肝臓と腎臓のFFMに占める割合は，運動群と非運動群でほぼ同じであり，FFMが大きくなってもその比率は減少しないという結果を得ている。脳・肝臓・心臓・腎臓の4器官は重量は体重の約6％しか占めないが，安静時の代謝量は約58％を占めており，そのうちでも肝臓と腎臓の代謝量は特に大きい[8]。しかし，FFMの量がBMRの違いに大きく影響していることは否定できず，選手の基礎代謝基準値としてBMR/BWよりもBMR/FFMを使用することは適切と考えられる。一方で，すべての選手に同一の値を使用できるかについては，今後，各種スポーツ選手について一定の方法でBMRとFFMを測定し，種目や体格などを考慮した基礎代謝基準値の設定が必要となるであろう。

TEEについては，齊藤らのレビュー[12]によると，スポーツ選手のPALは大学生女子水泳選手の1.71からツールドフランスのレース中の者の4.95となっている。日常的なトレーニングを行っていたスポーツ選手に限定すると，PALが2.2以内に75％の選手が分布する[20]。これまでに測定されたスポーツ選手のTEEに関する調査結果の平均値は2.03となったと報告されている[20]。本研究では7名のボディービルダーに対しDLW法による測定を行い，PALを算出したところ，2.00 ± 0.21となり，これらの報告とほぼ一致した。しかし，個人差は大きく1.78～2.23とばらついていた。この個人差の要因の1つは，個別のトレーニング内容には大きな差がないことから，1日あたりトレーニング時間が34～73分と倍以上の違いがあることによると推測される。しかしながら，Phillips, W. T. ら[21]の報告よりレジ

スタンストレーニング中の身体活動強度を3.9METs，運動時以外の平均を1.5METsとすると，30分のトレーニング時間の違いによるPALの差は（3.9－1.5）×30/1,440＝0.05となり，個人差を説明できるものではない。DLW法は自由生活下でのTEEを最も正確に評価できる方法とされているが，1～2週間の測定期間の1日の平均のTEEでしか評価できないという欠点がある。PALが2以上であった3名は，トレーニング指導員（2名）と技能職で仕事中も立位と歩行が多い作業であり，歩数も多い。一方で，最もPALの低い1名は歩数が少なく，仕事はほとんど座業でありトレーニング以外の身体活動量が極めて低かったことが推測される。ボディービルダーは特にトレーニング時間が短いが，それ以外のスポーツ選手でも合宿中などを除くと，トレーニング時間は限られている。トレーニング時間以外の生活における身体活動量による個人差を考慮しながら，どのように各種目のスポーツ選手の1日のPALを評価するか，今後，評価方法や基準となるPALの設定方法なども検討が必要であると考える。

以上より，スポーツ選手のBMRを測定した既存の資料では，FFM，BMRとも測定条件，方法などが異なり比較は困難であるが，今後，スポーツ選手の基礎代謝基準値の設定においては，種目や体格を考慮して示す必要があると考えられた。また，レジスタンストレーニングを主とするボディービルダーのPALは2.00±0.21であったが，個人差が大きく，スポーツ選手のPALの評価においては，トレーニング時間や内容の評価とそれ以外の時間の身体活動をどのように組み合わせて設定していくかが課題であると考えられた。

まとめ

22～55歳の高度にトレーニングを積んでいるボディービルダー14名を対象にBMR，FFM，PALを測定し，スポーツ選手のBMRとPALの基準値について検討した。

1）ボディービルダーの1日あたりのBMRは1,712±209kcal/dayであった。BMR/FFMは25.4±2.1kcal/kgFFM/dayであり，先行研究に比べると小さい傾向にあった。スポーツ選手の基礎代謝基準値の設定においては，その測定方法・条件を統一するとともに，種目や体格をどのように考慮するかを検討する必要があると考えられた。

2）DLW法で求めたボディービルダーの1日のTEEは3,432±634kcalで，PALは2.00±0.21であった。PALには個人差が大きく，PALの設定においては，トレーニング内容や時間の考慮だけでなく，それ以外の時間の身体活動量をどのように評価するか検討する必要があると考えられた。

謝　辞

本研究の趣旨に賛同し，本研究に被験者としてご協力いただきました皆様に深い感謝の意を表します。また，研究の実施にあたりご協力いただきました独立行政法人国立健康・栄養研究所健康増進プログラムの田中祥子氏，坂田晶子氏に深く御礼申し上げます。

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（受付：平成19年7月25日，受理：平成20年2月16日）

Public Health Nutrition: 9(5), 651–657 DOI: 10.1079/PHN2005894

The influence of age and body mass index on relative accuracy of energy intake among Japanese adults

Hitomi Okubo[1], Satoshi Sasaki[1,*†], Naoko Hirota[2], Akiko Notsu[3], Hidemi Todoriki[4], Ayako Miura[5], Mitsuru Fukui[6] and Chigusa Date[7]‡

[1]Scientific Evaluation of Dietary Reference Intakes' Project, National Institute of Health and Nutrition, Tokyo, Japan: [2]Department of Living Sciences, Nagano Prefectural College, Nagano, Japan: [3]Tottori College, Tottori, Japan: [4]Department of Environmental and Preventive Medicine Faculty of Medicine, School of Medicine, University of Ryukyus, Okinawa, Japan: [5]Department of Nutritional Health, Kwassui Women's College, Nagasaki, Japan: [6]Department of Statistics, Osaka City University Medical School, Osaka, Japan: [7]Department of Food Sciences and Nutrition, School of Human Environmental Sciences, Mukogawa Women's University, Hyogo, Japan

Submitted 4 April 2005: Accepted 20 October 2005

Abstract

Objective: To examine relationships between the ratio of energy intake to basal metabolic rate (EI/BMR) and age and body mass index (BMI) among Japanese adults.
Design: Energy intake was assessed by 4-day semi-weighed diet records in each of four seasons (16 days in total). The EI/BMR ratio was calculated from reported energy intake and estimated basal metabolic rate as an indicator of reporting accuracy.
Setting: Residents in three areas in Japan, namely Osaka (urban), Nagano (rural inland) and Tottori (rural coastal).
Subjects: One hundred and eighty-three healthy Japanese men and women aged ≥ 30 years.
Results: The oldest age group (≥ 60 years) had higher EI/BMR values than the youngest age group (30–39 years) in both sexes (1.74 vs. 1.37 for men; 1.65 vs. 1.43 for women). In multiple regression analyses, age correlated positively (partial correlation coefficient, $\beta = 0.012$, $P < 0.001$ for men; $\beta = 0.011$, $P < 0.001$ for women) and BMI correlated negatively ($\beta = -0.031$, $P < 0.001$ for men; $\beta = -0.025$, $P < 0.01$ for women) with EI/BMR.
Conclusion: Age and BMI may influence the relative accuracy of energy intake among Japanese adults.

Keywords
Energy intake
Underreporting
Age
Body mass index
Japanese adults

Reliable dietary information plays a critical role in many aspects of human nutrition. Investigators have often relied on self-reported dietary data assessed by diet records, 24-hour dietary recalls and food-frequency questionnaires to interpret the associations between diet and disease. However, the results of various studies applying different assessment methods and investigating different populations have shown common problems such as reporting bias[1,2]. In particular, underreporting of energy intake is a serious threat to the validity of self-reported dietary assessment data. Studies using the doubly labelled water technique as an external biomarker of energy intake not only reveal underreporting of energy intake, but also identify the subject characteristics and factors associated with underreporting[3,4]. Moreover, other studies using the ratio of energy intake to basal metabolic rate (EI/BMR) as an alternative approach to identify the low energy reporters have shown similar results[5,6].

Most studies found a higher proportion of underreporting among women and older subjects[7,8]. Moreover, underreporting of energy intake was common among obese subjects[9–11], but was also observed in non-obese subjects[12,13]. Other factors such as body image, health consciousness, social desirability, educational level and smoking status also affected reporting accuracy[2,14,15]. However, all of these studies were conducted in Western countries. The only study conducted in Japan showed a significantly negative correlation between BMI and EI/BMR among women aged 18–20 years[16]. Thus the purpose of the present study was to examine the relative accuracy of self-reported energy intake among various age ranges in the Japanese population.

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†Correspondence address: 1-23-1 Toyama, Shinjuku-ku, Tokyo 162-8636, Japan.

‡Present address: Department of Food Science and Nutrition, Faculty of Human Life and Environment, Nara Women's University, Nara, Japan.

*Corresponding author: Email stssasak@nih.go.jp

Subjects and methods

Subjects

We selected three areas which have different geographical conditions in Japan: Osaka (urban), Nagano (rural inland) and Tottori (rural coastal). We invited 32 healthy married women aged 30–69 years from each of the three areas to distribute eight women equally in each age class of 30–39, 40–49, 50–59 and 60–69 years. The total number of women recruited was 96. Their husbands (aged 31–76 years) were also invited to participate in the study. None of the subjects was currently receiving or had recently received diet counselling from a doctor or dietitian, nor had a history of educational hospitalisation for diabetes. The subjects were not randomly sampled but asked by local study staff to participate in the study. Here, subject recruitment was continued until a sufficient number of subjects was obtained. Prior to the study, we held group orientations for the subjects where we explained the study purposes and protocol. All subjects giving written informed consent were finally considered eligible for the study.

Dietary assessment

The subjects completed 4-day semi-weighed diet records four times at 3-month intervals from November 2002 to August 2003. Dietary intake was assessed from four randomly assigned days, including one weekend day and three weekdays. A digital scale (Tanita KD-173; ± 2 g precision for 0–250 g and ± 4 g precision for 250–1000 g) was given to each couple to weigh all the foods eaten. When measurement was difficult, e.g. when eating out, we instructed them to record in as much detail as possible the size and quantity of foods they ate. For each recording day, the subjects were asked to fax the completed forms to the local staff (dietitians). The study staff checked the submitted forms and asked the subjects to add and/or modify the records as necessary by telephone or fax. In some cases, the responses were handed directly to the study staff rather than faxed.

All the collected diet records were checked by trained dietitians in each local centre and then in the study centre. The diet records were analysed for nutrient intake by trained dietitians using the food composition table of Japanese foods, 5th edition[17].

Physical activity level and anthropometric measurements

Physical activity level was obtained from a questionnaire which queried information about each subject's occupation and leisure-time activity. One answer was chosen from four categories, i.e. 'low', 'relatively low', 'moderate' and 'heavy' physical activity level. This classification was referenced to the recommended dietary allowance for Japanese, 6th edition[18]. The gross energy expenditure of each category was considered to require 1.3, 1.5, 1.7 and 1.9 times the BMR, respectively[18]. Therefore, we converted the categorical classification of physical activity level to the ratio of BMR based on above values, and expressed as it as a score for easy interpretation.

Body weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively, with subjects wearing light clothing and no shoes. BMI was calculated as body weight (kg) divided by the square of body height (m^2). We classified BMI into four categories: $<18.5\,kg\,m^{-2}$, 18.5–$24.9\,kg\,m^{-2}$, 25.0–$27.9\,kg\,m^{-2}$ and $\geq 28\,kg\,m^{-2}$. Because the proportion of obese subjects ($BMI \geq 30\,kg\,m^{-2}$) was very low ($n = 1$ for men aged 40–49 years; $n = 0$ for women), BMI $\geq 28\,kg\,m^{-2}$ was used as the highest category instead of $\geq 30\,kg\,m^{-2}$ in the present analysis.

BMR was estimated for each subject using formulas based on body weight given by the Food and Agriculture Organization/World Health Organization/United Nations University (FAO/WHO/UNU)[19] as follows.

- Men aged 30–60 years:
  $BMR = 0.0485 \times bodyweight(kg) + 3.67.$
- Men aged >60 years:
  $BMR = 0.0565 \times bodyweight(kg) + 2.04.$
- Women aged 30–60 years:
  $BMR = 0.0364 \times bodyweight\ (kg) + 3.47.$
- Women aged >60 years:
  $BMR = 0.0439 \times bodyweight\ (kg) + 2.49.$

Statistical analysis

We included 183 subjects (91 women and 92 men) with complete 16-day diet records living in the Osaka (29 women and 30 men), Nagano (31 women and 31 men) and Tottori (31 women and 31 men) areas in the present analysis.

We calculated the ratio EI/BMR to evaluate the relative accuracy of the reported energy intake. Subjects were allocated into quintiles of EI/BMR to compare 'low energy reporters' with 'high energy reporters'. Low ratios describe subjects reporting comparatively low energy intake relative to their energy requirement. To compare the relative degree of under- and overreporting, we temporarily used the values defined by FAO/WHO/UNU: the minimum survival level of 1.27, the sedentary level for men of 1.55 and women of 1.56, and the maximum sustainable lifestyle level of 2.0–2.4.

Results are given as mean ± standard deviation. Student's *t*-test and one-way analysis of variance (ANOVA) were used to test for differences between the groups. When ANOVA indicated a difference among the groups, Dunnett's *t*-test was applied to compare to the first group as a control. The chi-square test was used to test for proportionate differences between categories. Multivariate evaluation of the simultaneous effects of age, BMI, physical activity level and living area on EI/BMR was performed by a stepwise multiple regression analysis.

We also computed the partial correlation coefficients between each independent variable and EI/BMR adjusting for other independent variables.

All statistical analyses were performed using version 8.2 of the SAS software package (SAS Institute, Inc., Cary, NC, USA). A P-value of <0.05 was considered significant.

Results

Table 1 presents a summary of the physical characteristics of the subjects. Mean age was 52.8 ± 12.1 (range 31–76) years in men and 49.5 ± 11.4 (range 31–69) years in women. Mean values of EI/BMR were not different between sexes (1.55 for men vs. 1.48 for women, $P = 0.12$). Men had a higher BMI (23.3 vs. 22.1 $\mathrm{kg\,m^{-2}}$, $P < 0.01$) and a higher proportion of overweight (21% vs. 11% for BMI of 25.0–27.9 $\mathrm{kg\,m^{-2}}$ and 10% vs. 2% for BMI $\geq 28\,\mathrm{kg\,m^{-2}}$, $P = 0.03$) than women. Men had a higher physical activity level than women (1.48 vs. 1.43, $P = 0.02$), and 38% and 59% of women were classified into low and relatively low physical activity levels, respectively.

Table 2 presents a summary of the physical characteristics of men and women in the four age groups (30–39, 40–49, 50–59 and ≥60 years). Body height decreased with increasing age in both sexes. Body weight and BMR increased as age increased to 40–49 years, and then decreased with increasing age group in both sexes. Although BMI was lowest among the youngest age group in both sexes, a statistically significant difference between age groups was observed only for women ($P < 0.01$). Energy intake was not different between age groups in either sex. On the other hand, mean EI/BMR became significantly higher with increase in age for men

Table 1 Characteristics of study subjects* ($n = 183$)

	Men ($n = 92$)	Women ($n = 91$)	P-value†
Age (years)	52.8 ± 12.1	49.5 ± 11.4	0.06
Body height (cm)	168.0 ± 6.7	155.6 ± 5.9	<0.001
Body weight (kg)	66.2 ± 11.2	53.4 ± 7.2	<0.001
Reported EI ($\mathrm{MJ\,day^{-1}}$)	9.9 ± 1.8	7.8 ± 1.2	<0.001
BMR ($\mathrm{MJ\,day^{-1}}$)‡	6.5 ± 0.9	5.3 ± 0.4	<0.001
EI/BMR	1.55 ± 0.31	1.48 ± 0.24	0.12
BMI ($\mathrm{kg\,m^{-2}}$)	23.3 ± 3.1	22.1 ± 2.6	<0.01
<18.5	4 (4)	6 (7)	0.03§
18.5–24.9	60 (65)	73 (80)	
25.0–27.9	19 (21)	10 (11)	
≥28.0	9 (10)	2 (2)	
Physical activity level	1.48 ± 0.19	1.43 ± 0.11	0.02
Low	37 (40)	35 (38)	<0.001§
Relatively low	36 (39)	54 (59)	
Moderate	11 (12)	2 (2)	
Heavy	8 (9)	0 (0)	

EI – energy intake; BMR – basal metabolic rate; BMI – body mass index.

* Values are expressed as mean ± standard deviation or n (%).

† Significant difference between sexes (t-test).

‡ BMR was calculated using formulas given by the Food and Agriculture Organization/World Health Organization/United Nations University (1985)[19].

§ Significant difference between sexes in all categories (chi-square test).

Table 2 Characteristics of study subjects according to age group in 92 men and 91 women†

	Men					Women				
	30–39 years‡ ($n = 16$)	40–49 years ($n = 24$)	50–59 years ($n = 20$)	≥ 60 years ($n = 32$)	P-value§	30–39 years‡ ($n = 23$)	40–49 years ($n = 22$)	50–59 years ($n = 23$)	≥ 60 years ($n = 23$)	P-value§
Age (years)	36.1 ± 2.2	44.0 ± 3.2	54.8 ± 2.3	66.4 ± 4.6	<0.001	35.7 ± 2.7	43.1 ± 3.2	54.1 ± 2.6	64.7 ± 3.0	<0.001
Body height (cm)	171.8 ± 5.7	171.0 ± 5.8	168.5 ± 7.0	163.7 ± 5.1***	<0.001	158.6 ± 5.7	156.1 ± 5.9	155.6 ± 6.0	152.0 ± 4.0***	<0.01
Body weight (kg)	64.7 ± 11.3	70.1 ± 12.7	69.3 ± 10.7	62.0 ± 9.0	0.02	51.2 ± 6.1	55.3 ± 7.0	55.0 ± 7.8	52.3 ± 7.2	0.14
Reported EI ($\mathrm{MJ\,day^{-1}}$)	9.3 ± 1.2	10.2 ± 2.5	10.5 ± 1.7	9.6 ± 1.3	0.15	7.7 ± 1.3	7.6 ± 1.3	7.9 ± 0.8	7.9 ± 1.2	0.76
BMR ($\mathrm{MJ\,day^{-1}}$)¶	6.8 ± 0.6	7.1 ± 0.6	7.0 ± 0.5	5.5 ± 0.5***	<0.001	5.3 ± 0.2	5.5 ± 0.3	5.5 ± 0.3	4.8 ± 0.3***	<0.001
EI/BMR	1.37 ± 0.21	1.44 ± 0.33	1.50 ± 0.28	1.74 ± 0.25***	<0.001	1.43 ± 0.23	1.39 ± 0.22	1.45 ± 0.14	1.65 ± 0.26***	<0.001
Physical activity level	1.50 ± 0.21	1.51 ± 0.23	1.48 ± 0.17	1.44 ± 0.15	0.59	1.44 ± 0.11	1.44 ± 0.10	1.42 ± 0.10	1.41 ± 0.12	0.82
BMI ($\mathrm{kg\,m^{-2}}$)	21.8 ± 3.0	23.9 ± 3.5	24.3 ± 2.8*	23.1 ± 2.7	0.07	20.3 ± 2.0	22.7 ± 2.9**	22.7 ± 2.2**	22.6 ± 2.7**	<0.01
< 18.5	1 (6)	1 (4)	1 (5)	1 (3)	0.27‖	5 (22)	1 (5)	0 (0)	0 (0)	0.03‖
18.5–24.9	13 (81)	14 (58)	9 (45)	24 (75)		18 (78)	16 (73)	20 (87)	19 (83)	
25.0–27.9	1 (6)	5 (21)	8 (40)	5 (16)		0 (0)	4 (18)	3 (13)	3 (13)	
≥ 28.0	1 (6)	4 (17)	2 (10)	2 (6)		0 (0)	1 (5)	0 (0)	1 (4)	

EI – energy intake; BMR – basal metabolic rate; BMI – body mass index.

† Values are expressed as mean ± standard deviation or n (%).

‡ Significant difference compared with 30–39 year category between age groups within sex (Dunnett's t-test): *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

§ Significant difference between age groups within sexes (analysis of variance).

¶ BMR was calculated using formulas given by the Food and Agriculture Organization/World Health Organization/United Nations University (1985)[19].

‖ Significant difference between age groups within sexes in all categories (chi-square test).

Table 3 Anthropometric characteristics and lifestyle variables by quartile of EI/BMR ratio†

	Men					Women				
	First quartile ($n = 23$)‡	Second quartile ($n = 18$)	Third quartile ($n = 22$)	Fourth quartile ($n = 29$)	P-value§	First quartile ($n = 22$)‡	Second quartile ($n = 28$)	Third quartile ($n = 24$)	Fourth quartile ($n = 17$)	P-value§
EI/BMR	1.17 ± 0.12	1.41 ± 0.05	1.57 ± 0.05	1.90 ± 0.17		1.19 ± 0.09	1.42 ± 0.05	1.58 ± 0.05	1.83 ± 0.14	
Age (years)	44.8 ± 8.8	51.8 ± 10.3	54.6 ± 15.0*	58.3 ± 9.8***	<0.001	44.5 ± 9.8	47.2 ± 9.9	53.1 ± 118*	54.5 ± 12.5*	0.01
Body height (cm)	171.2 ± 4.8	168.8 ± 5.7	168.4 ± 6.7	164.7 ± 7.3**	<0.01	154.0 ± 5.4	156.9 ± 5.7	155.1 ± 5.8	156.0 ± 6.7	0.36
Body weight (kg)	72.0 ± 10.4	68.1 ± 7.4	64.5 ± 12.5	61.6 ± 11.0**	<0.01	53.7 ± 7.4	54.6 ± 6.5	54.1 ± 8.4	50.4 ± 5.5	0.27
EI (MJ day^{-1})	8.3 ± 1.0	9.5 ± 0.6*	9.9 ± 1.6***	11.4 ± 1.7***	<0.001	6.4 ± 0.7	7.6 ± 0.6***	8.3 ± 0.7***	9.1 ± 0.8***	<0.001
BMR (MJ day^{-1})¶	7.1 ± 0.6	6.7 ± 0.6	6.3 ± 0.9**	6.0 ± 0.9***	<0.001	5.4 ± 0.3	5.4 ± 0.3	5.3 ± 0.4	5.0 ± 0.4**	<0.01
Physical activity level	1.47 ± 0.19	1.41 ± 0.12	1.47 ± 0.18	1.53 ± 0.21	0.16	1.41 ± 0.10	1.43 ± 0.11	1.45 ± 0.09	1.42 ± 0.12	0.60
BMI (kg m^{-2})	24.5 ± 3.0	24.0 ± 2.8	22.6 ± 3.2	22.6 ± 3.0	0.06	22.6 ± 2.9	22.2 ± 2.4	22.5 ± 3.0	20.7 ± 1.7	0.11
< 18.5	0 (0)	0 (0)	1 (5)	3 (10)	0.34§	1 (5)	2 (7)	2 (8)	1 (6)	0.82§
18.5–24.9	13 (57)	11 (61)	14 (63)	22 (76)		17 (77)	22 (79)	18 (75)	16 (94)	
25.0–27.9	7 (30)	5 (28)	5 (23)	2 (7)		3 (14)	4 (14)	3 (13)	0 (0)	
≥ 28.0	3 (13)	2 (11)	2 (9)	2 (7)		1 (5)	0 (0)	1 (4)	0 (0)	

EI – energy intake; BMR – basal metabolic rate; BMI – body mass index.

† Values are expressed as mean ± standard deviation or *n* (%).

‡ Significant difference compared with the first quartile of EI/BMR (Dunnett's *t*-test): *, $P < 0.05$, **, $P < 0.01$; ***, $P < 0.001$.

§ Significant difference between quartile within sexes (analysis of variance).

¶ BMR was calculated using formulas given by the Food and Agriculture Organization/World Health Organization/United Nations University (1985)[19].

($P < 0.001$). Although women aged 40–49 years had the lowest EI/BMR among the women, the trend of the relationship between mean EI/BMR and age was almost the same as that of men ($P < 0.001$).

Table 3 presents the mean values of anthropometric characteristics by quartile of EI/BMR. Age and reported energy intake increased significantly with the increase in EI/BMR in both sexes (all $P < 0.001$ except for age in women, where $P < 0.01$). However, with increasing EI/BMR quartile, body height and body weight decreased significantly in men (both $P < 0.01$), as did BMR in both sexes ($P < 0.001$ for men, $P < 0.01$ for women). BMI was slightly lower in the lowest category of EI/BMR than in the other categories in men, although it was not significant.

Table 4 shows the results of multiple regression analyses with EI/BMR as the dependent variable to examine the prediction for relative accuracy of reporting. For men, age and physical activity level correlated positively (partial regression coefficient, $\beta = 0.012$, $P < 0.001$ and $\beta = 0.377$, $P = 0.01$, respectively), and BMI and living area (urban) correlated negatively ($\beta = -0.031$, $P < 0.001$ and $\beta = -0.114$, $P = 0.045$, respectively), with EI/BMR. On the other hand, age and body height correlated positively ($\beta = 0.011$, $P < 0.001$ and $\beta = 0.011$, $P = 0.01$, respectively) and BMI correlated negatively ($\beta = -0.025$, $P < 0.01$) with EI/BMR for women. All the independent variables explained 35.7% and 25.7% of the variation in EI/BMR for men and women, respectively.

Figures 1a and 1b show the joint effect of age and BMI on EI/BMR values by cross-classifying subjects by both variables. Compared with subjects classified into the lowest BMI and oldest age group, subjects in the highest

Table 4 Results of stepwise multiple regression analyses with EI/BMR ratio as dependent variable*

Independent variable	β†	SE‡	P-value	Partial R^2 (%)§
Men ($n = 92$)				
Age (years)	0.012	0.002	<0.001	17.9
BMI (kg m^{-2})	−0.031	0.009	<0.001	9.9
Physical activity level	0.377	0.145	0.01	4.8
Living area (rural coastal area as reference)				
Urban	−0.114	0.056	0.05	3.1
Women ($n = 91$)				
Age (years)	0.011	0.002	<0.001	12.1
BMI (kg m^{-2})	−0.025	0.009	0.005	7.0
Body height (cm)	0.011	0.004	0.01	6.6

EI – energy intake; BMR – basal metabolic rate; BMI – body mass index.

* Age (as a continuous variable), BMI (as a continuous variable), height (as a continuous variable), physical activity level (as a continuous variable) and area of living (rural coastal, rural inland, urban) were entered into the model as independent variables.

† Partial regression coefficient; change in the dependent variable related to a one-unit change in the independent variable.

‡ Standard error of the regression coefficient.

§ Explained variance; adjusted R^2 and P-values are for independent variables in multiple regression analysis. R^2 value for EI/BMR was 35.7% and 25.7% for men and women, respectively, when all variables were included in the model.

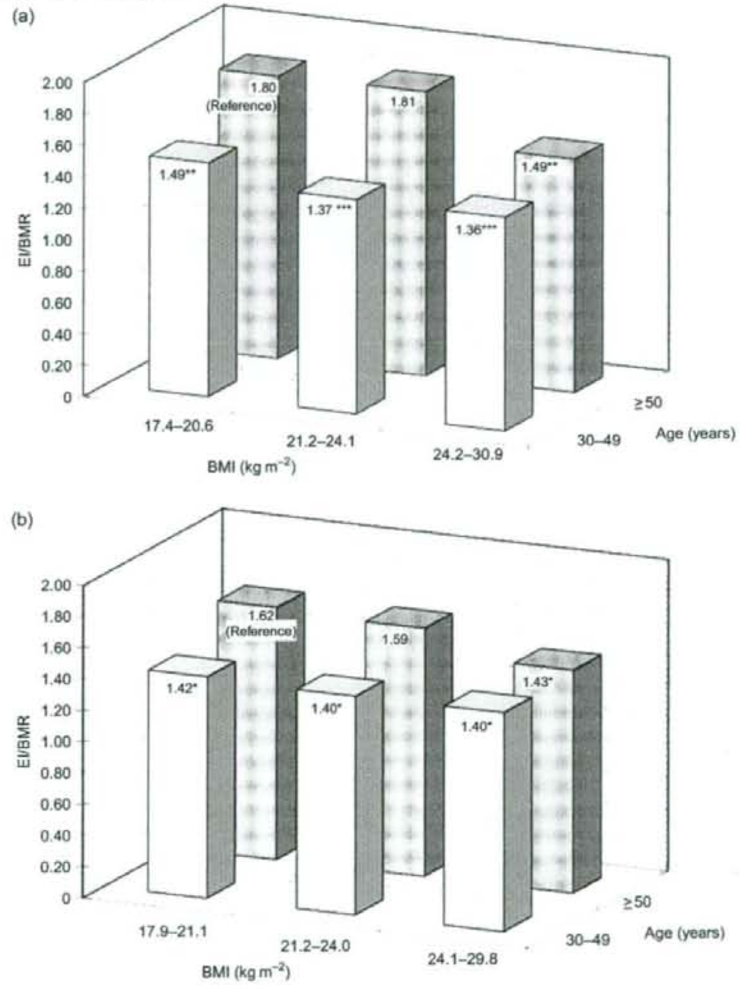

Fig. 1 The interaction of age and body mass index (BMI) in relationships with the ratio of reported energy intake to estimated basal metabolic rate (EI/BMR). Mean value of EI/BMR by tertile of BMI and age group (30–49, ≥50 years) in (a) Japanese men aged 32–76 years ($n = 92$) and (b) Japanese women aged 31–69 years ($n = 91$). EI/BMR values were adjusted for physical activity level and living area. Significance of difference compared with the oldest age and lowest BMI group (Dunnett's *t*-test of one-way analysis of variance): *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

BMI and youngest age group had EI/BMR that was 24% and 14% lower in men and women, respectively.

Discussion

To our knowledge, this is the first report to evaluate EI/BMR values over a wide age range of Japanese men and women. We conducted semi-weighed diet records for 4 days in four seasons, which is often considered to be the most accurate and precise method for determining energy intake. Furthermore, fax delivery was used so that we could check the diet records immediately on each survey day. Therefore, we believe that the data have higher precision than in any other such survey conducted in Japan. The EI/BMR in our study was 1.55 among men and 1.48 among women. Although we refrained from using a specific cut-off value to identify underreporters, 20% and 23% of men and women, respectively, showed EI/BMR below 1.27, the minimum survival level reported by FAO/WHO/UNU[19]. Moreover, the proportion of subjects with EI/BMR < 1.27 decreased with increasing age in both sexes, except in the 40–49 year age group in women. However, 10% and 4% of men and women, respectively, showed EI/BMR exceeding 2.0 as the maximum level. Even when physical activity level was considered, the proportion of subjects with EI/BMR > 2.0 increased with increasing age, and was especially more pronounced in the age group ≥60 years for both sexes. This indicates that older Japanese men and women tend to relatively overestimate energy intake rather than underreport.

The main finding of this study was that age and BMI independently affect EI/BMR as a positive and a negative factor, respectively. The statistical power of these findings became stronger after adjustment for potentially confounding factors such as physical activity level and living area (urban or rural) for both sexes (Figs 1a and 1b). According to previous studies, physiological and psychological factors are also related to reporting accuracy; for example, smoking habits, education level, socio-economic status and obesity-related behaviours[14,15,20–22]. However, we did not examine the effect of these factors on reporting accuracy because of a lack of information.

Most studies conducted in Western countries revealed that underreporting of energy intake was more prevalent among older subjects than among younger counterparts[7,23,24]. The tendency was completely opposite in this Japanese population. To our knowledge, no previous study has found underreporting to be more prevalent among younger compared with older subjects, either in Western or Asian countries. Possible factors affecting reporting accuracy may include dietary consciousness and knowledge of foods and diet. According to the National Nutrition Survey in Japan[25], the percentage of subjects who paid high attention to diet and nutrition was 12.1%, 17.5%, 24.4% and 27.2% among 30–39-, 40–49-, 50–59- and ≥60-year-old men, respectively, and 27.5%, 35.7% 42.9%, and 48.6%, respectively, among women. The capability to recognise foods and diet may be related to recording as correctly as possible. Some previous studies reported that cultural, behavioural and psychological factors affect reporting accuracy[14,15,20–22]. The results were, however, inconsistent and differed among the populations examined. Further research focusing on dietary consciousness and behaviours connected with food and the process of dietary assessment is needed.

Our study has several limitations. First, the subjects may not be representative because they were not randomly sampled from the general Japanese population. Moreover, the participants might be highly health-conscious because almost all of them completed the study despite the strict study design. Second, the sample size was relatively small. Therefore, the results may arise by chance. Third, we cannot exclude the possibility that the subjects changed their dietary behaviour or food choices during the recording periods. However, the relationships between EI/BMR and age and body weight did not change materially when the dietary record data of the first four days were used in the analysis (data not shown). Fourth, we used body height to take into consideration body size although body height is not an ideal marker of body size. Fifth, the reliability of the BMR prediction from the FAO/WHO/UNU formulas may be inappropriate when applied to the Japanese population[26]. The validity of the self-reported physical activity levels from the 6th Japanese recommended dietary allowance is questionable because of the lack of a validation study[18].

In summary, the results of the present study suggest that age and BMI may influence the relative accuracy of reported energy intake among Japanese adults. The positive correlation found between age and EI/BMR was especially interesting because almost all previous studies conducted in Western populations showed a negative correlation. This indicates that the factors related to reporting accuracy of energy intake may depend on population characteristics. Further studies are needed to examine whether or not this is a consistent tendency in Asian or Japanese populations.

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European Journal of Clinical Nutrition (2007), 1–8
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www.nature.com/ejcn

ORIGINAL ARTICLE

Misreporting of dietary energy, protein, potassium and sodium in relation to body mass index in young Japanese women

K Murakami[1], S Sasaki[1], Y Takahashi[1], K Uenishi[2], M Yamasaki[3], H Hayabuchi[4], T Goda[5], J Oka[6], K Baba[7], K Ohki[8], T Kohri[9], R Watanabe[10] and Y Sugiyama[11]

[1]Nutritional Epidemiology Program, National Institute of Health and Nutrition, Tokyo, Japan; [2]Laboratory of Physiological Nutrition, Kagawa Nutrition University, Saitama, Japan; [3]Department of Health and Nutrition Science, Faculty of Health and Social Welfare Science, Nishikyushu University, Saga, Japan; [4]Department of Human Environmental Science, Fukuoka Women's University, Fukuoka, Japan; [5]Department of Nutrition, School of Food and Nutritional Sciences and COE21, University of Shizuoka, Shizuoka, Japan; [6]Department of Food and Nutrition, Faculty of Home Economics, Tokyo Kasei University, Tokyo, Japan; [7]Department of Nutrition, Mie Chukyo University Junior College, Matsusaka, Japan; [8]Graduate School of Science for Living System, Showa Women's University, Tokyo, Japan; [9]Department of Nutritional Sciences, Otemae College of Nutrition, Osaka, Japan; [10]Course of Food and Nutrition, Department of Human Life Environments, Niigata Women's College, Niigata, Japan and [11]Department of Nutrition Management, Faculty of Health and Nutrition, Minamikyushu University, Miyazaki, Japan

Objective: Although under-reporting of dietary intake is more common in persons with a high body mass index (BMI), it is not well known whether or not misreporting is selective for different foods (and hence energy and nutrients), particularly in non-Western populations. We examined misreporting of dietary intake against biomarkers and its relation with BMI in young Japanese women.

Design: Cross-sectional study.

Subjects: A total of 353 female Japanese dietetic students aged 18–22 years (mean BMI: 21.4 kg/m^2, mean fat intake: 29.8% of energy).

Methods: Misreporting of dietary energy, protein, potassium and sodium (assessed by a self-administered diet history questionnaire) was examined against respective biomarkers (estimated energy expenditure and 24-h urinary excretion). Reporting accuracy was calculated as the ratio of reported intake to that estimated from corresponding biomarkers (complete accuracy: 1.00).

Results: Mean reporting accuracy of absolute intake (amount per day) varied considerably (0.86–1.14). Reporting accuracy of absolute intake decreased with increasing BMI (P for trend <0.001). However, no association was observed between reporting accuracy of energy-adjusted values and BMI (P for trend >0.15), indicating that BMI-dependent misreporting was canceled by energy adjustment. This was owing to positive correlation between the reporting accuracy of energy intake and that of absolute intake of the three nutrients (Pearson correlation coefficient: 0.49–0.67, $P<0.0001$).

Conclusions: Although differential misreporting of absolute intake was associated with BMI, differential misreporting of energy-adjusted value was not. These findings support the use of energy-adjusted values in the investigation of diet–disease relationships among lean populations with a low-fat intake.

European Journal of Clinical Nutrition advance online publication, 14 February 2007; doi:10.1038/sj.ejcn.1602683

Keywords: energy; protein; potassium; sodium; misreporting; body mass index

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Correspondence: Dr S Sasaki, Nutritional Epidemiology Program, National Institute of Health and Nutrition, Toyama 1-23-1, Shinjuku-ku, Tokyo 162-8636, Japan.
E-mail: stssasak@nih.go.jp

Guarantor: S Sasaki.

Contributors: KM contributed to the concept and design of the study, the study protocol, data collection and management; and coordinated the field work, formulated the hypothesis, analyzed and interpreted the data, and wrote the manuscript. SS was responsible for the concept and design of the study, the study protocol, data collection and management; and interpreted the results and contributed to the writing and editing of the manuscript. YT contributed to the writing and editing of the manuscript. KU contributed to the concept and design of the study, the study protocol, and data collection. MY, HH, TG, JO, KB, KO, TK, RW, and YS contributed to data collection. All authors contributed to the final version of the manuscript.

Received 3 July 2006; revised 9 January 2007; accepted 9 January 2007

Introduction

Although accurate assessment of habitual dietary intake is a prerequisite in studies of diet and health, the difficulty of obtaining dietary data that accurately represents what people usually eat is now generally recognized (Livingstone and Black, 2003). In particular, obese people tend to underreport dietary intake to a greater extent than lean people (Livingstone and Black, 2003; Rosell *et al.*, 2003; Subar *et al.*, 2003; Tooze *et al.*, 2004; Mattisson *et al.*, 2005; Mahabir *et al.*, 2006). Whether this is a consequence of selective misreporting of certain foods, proportional misreporting of all foods, or both is not well established. This is an important issue: errors in dietary reporting do not necessarily invalidate dietary data if the misreporting is not selective, but may do so if the misreporting is selective.

Unfortunately, investigation of possible differential misreporting of dietary intake in free-living situations has been hampered, largely by a lack of suitable methods for quantifying absolute true intake for all dietary variables except energy (Black *et al.*, 1996), protein (Bingham and Cummings, 1985; Kipnis *et al.*, 2001), potassium (Holbrook *et al.*, 1984; Tasevska *et al.*, 2006) and sodium (Holbrook *et al.*, 1984; Willett, 1998). As a result, only a limited number of studies have examined this issue (Hulten *et al.*, 1990; Bingham *et al.*, 1995; Heitmann and Lissner, 1995, 2005; Black *et al.*, 1997, 2000; Heerstrass *et al.*, 1998; Heitmann *et al.*, 2000; Larsson and Johansson, 2002; Rosell *et al.*, 2003; Subar *et al.*, 2003; Freedman *et al.*, 2004), none of which were conducted in Asian countries, including Japan. A characteristic of Japanese people is their relatively low BMI and relatively low-fat consumption (Ministry of Health, Labour and Welfare, 2006), which differs somewhat from Western people. This difference hampers the extrapolation of findings in Western countries to Japanese.

Here, we examined misreporting of energy, protein, potassium and sodium intake assessed against estimated energy expenditure and 24-h urinary excretion of urea nitrogen, potassium and sodium, respectively, and its relation with BMI in a group of young Japanese women.

Methods

Subjects

The present study was based on a multi-centered nutritional survey conducted from February to March 2006 among female dietetic students from 10 institutions in Japan. All measurements at each institution were conducted according to the survey protocol. Staff at each institution briefly explained the survey to potential subjects. Subjects who responded positively were then provided detailed written and oral explanations of the general purpose and procedure of the survey. A total of 474 women took part in the survey. The protocol of the study was approved by the Ethics Committee of the National Institute of Health and Nutrition, and written informed consent was obtained from each subject, and also from a parent for subjects aged less than 20 years.

In total, 424 of 474 women undertook 24-h urine collection. For the present analysis, we selected 417 women aged 18–22 years without missing information on the variables used. We then excluded women whose 24-h urine collection was considered incomplete. Because the *p*-aminobenzoic acid (PABA) check method to verify the completeness of 24-h urine collection (Bingham and Cummings, 1983) was not available in the present study, we used the strict INTERMAP criteria for completeness of urine sampling (Stamler *et al.*, 2003) (a collection time outside the 22–26-h range ($n = 10$), subject response that collection was not complete ($n = 47$) and total volume <250 ml ($n = 1$)) as well as a widely used criteria determined by creatinine excretion in relation to body weight (creatinine (mg) divided by body weight (kg) of <10.8 or >25.2 (WHO Regional Office for Europe, 1984), $n = 13$). As some women were in more than one exclusion category, the final analysis sample comprised 353 women.

Diet history questionnaire

Dietary habits during the preceding month were assessed using a validated previously, self-administered diet history questionnaire (DHQ) (Sasaki *et al.*, 1998a, b 2000). All answered DHQs, as well as a lifestyle questionnaire, were checked at least twice for completeness. When necessary, forms were reviewed with the subject to ensure the clarity of answers. The DHQ is a 16-page structured questionnaire that consists of the following seven sections: general dietary behavior; major cooking methods; consumption frequency and amount of six alcoholic beverages; consumption frequency and semi-quantitative portion size of 122 selected food and nonalcoholic beverage items; dietary supplements; consumption frequency and semi-quantitative portion size of 19 cereals usually consumed as staple foods (rice, bread and noodles) and miso (fermented soybean paste) soup; and open-ended items for foods consumed regularly (≥once/week) but not appearing in the DHQ. Items and portion sizes were derived primarily from data in the National Nutrition Survey of Japan and several recipe books for Japanese dishes (Sasaki *et al.*, 1998a).

Estimates of dietary intake for 148 food and beverage items, energy and nutrients were calculated using an *ad hoc* computer algorithm for the DHQ based on the standard tables of food composition in Japan (Science and Technology Agency, 2000). Discretionary salt (table salt and other seasonings with salty flavor) and seasonings used during cooking were taken into consideration for estimating sodium intake. Information on dietary supplements and data from the open-ended questionnaire items were not used in the calculation. Detailed descriptions of the methods used to calculate dietary intake and the validity of the DHQ have been published elsewhere (Sasaki *et al.*, 1998a, b 2000).

Pearson correlation coefficients between the DHQ and 3-day estimated dietary records were 0.48 for energy, 0.48 for protein, 0.68 for potassium and 0.32 for sodium among 47 women (Sasaki *et al*., 1998a). In addition, Pearson correlation coefficients between the DHQ and 24-h urinary excretion were 0.40 for potassium and 0.23 for sodium among 69 women (Sasaki *et al*., 1998b).

Estimated energy expenditure

Body height and weight were measured to the nearest 0.1 cm and 0.1 kg, respectively, while wearing light clothes and no shoes. Basal metabolic rate (BMR) was estimated according to the FAO/WHO/UNU equation for women aged 18–30 years, as follows: BMR (kcal/day) = 14.7 × body weight (kg) + 496 (FAO/WHO/UNU, 1985). BMR calculated from the FAO/WHO/UNU equations was relatively comparable with measured BMR in Japanese people at the group level (arithmetic mean = 1182 and 1107 kcal/day, respectively) (Yamamura and Kashiwazaki, 2002). Energy expenditure can be estimated as BMR multiplied by an appropriate physical activity level value (Black *et al*., 1996). In the present study, subjects self-reported in a lifestyle questionnaire the frequency and duration of high-intensity activities (e.g., carrying heavy loads; bicycling, moderate effort; jogging; singles tennis), moderate-intensity activities (e.g., carrying light loads; bicycling, light effort; doubles tennis) and walking during the preceding month. On average, less than half an hour per day was spent on these activities (arithmetic mean = 0.07, 0.30, and 0.50 h/day, respectively), indicating a predominantly sedentary lifestyle in our sample. We therefore estimated energy expenditure as BMR multiplied by physical activity level value for light activity (1.56) (FAO/WHO/UNU, 1985), and used this value as a biological marker for energy intake.

24-h urine

A single 24-h urine sample was collected for biological markers of intake of protein, potassium and sodium. Subjects were instructed both in writing and orally on the method of urine collection and the necessity of obtaining a complete 24-h urine collection. We requested the subjects to eat and drink normally during the collection and to follow their usual pattern of activity. Subjects were then provided with a bag, three or four 1-l plastic bottles (containing no additives) and 10 400-ml cups. A recording sheet was also provided. In the morning, subjects were asked to discard the first specimen and to record the time (usually 0600–0900 h) on the sheet (the start of the collection period). Subjects were asked to collect all specimens by the time of the start of the collection period in the next morning. When some specimens were missed, subjects were asked to record the estimated volume of missing urine and the time. In the next morning, subjects were asked to collect the last specimen at the time when the specimen was discarded last morning and to record the time on the sheet (the end of the collection period). The sheet was reviewed by staff when the collection bottles were handed in, and any missing information was obtained from subjects. The height of urine in each bottle was measured and later converted into volume with an empiric formula based on repeated measurements of volume in identical bottles (Stamler *et al*., 2003). All urine from the 24-h collection period was then combined and mixed thoroughly by vigorous stirring, and several urinary aliquots were taken and sent by car or airplane to a laboratory in Tokyo. Urea nitrogen concentration was measured by urease ultraviolet spectorophotometry, potassium and sodium by electrode method and creatinine (for the assessment for completeness of urine collection) by enzymatic assay method. Total 24-h excretion was calculated by multiplying the measured concentration with the total volume of urine collected.

The urea nitrogen content in 24-h urine was multiplied by 9.08, assuming that urea nitrogen is in constant proportion (85%) to total urinary nitrogen (Bingham and Cummings, 1985), 81% of ingested nitrogen is excreted through the urine (Bingham and Cummings, 1985; Kipnis *et al*., 2001) and nitrogen constitutes 16% of protein. The value obtained was used as a biological marker for protein intake. Potassium content in 24-h urine was divided by 0.77, assuming that 77% of ingested potassium is excreted through the urine (Holbrook *et al*., 1984; Tasevska *et al*., 2006), and used as a biological marker for potassium intake. Sodium content in 24-h urine was divided by 0.86, assuming that 86% of ingested sodium is excreted through the urine (Holbrook *et al*., 1984; Willett, 1998), and used as a biological marker for sodium intake.

Reporting accuracy

Reporting accuracy was calculated as the ratio of reported dietary intake (energy, protein, potassium and sodium) obtained from DHQ to estimated dietary intake obtained from respective biological markers (estimated energy expenditure and 24-h urinary excretion) (Zhang *et al*., 2000), in terms of both absolute (amount/day) and energy-adjusted (% energy for protein and mg/1000 kcal for potassium and sodium) values. At the group level, reporting accuracy of <1 was considered underestimation, >1 overestimation and 1 accurate estimation (Zhang *et al*., 2000).

Other variables

BMI was calculated as body weight (kg) divided by the square of body height (m). Current smoking status was self-reported in the lifestyle questionnaire, whereas current dietary supplement use was assessed in the DHQ.

Statistical analysis

All statistical analyses were performed using SAS statistical software, version 8.2 (SAS Institute Inc., Cary, NC, USA).

Dietary intake (derived from both DHQ and biological markers) and reporting accuracy of energy, protein, potassium and sodium were natural-log transformed to meet the assumption of normal distribution. The formula $\log(X+1)$ was used for reporting accuracy. Geometric mean and 95% confidence intervals of these variables were calculated using back transformation. Differences between self-reported values and biological marker-based values were evaluated using the paired *t*-test. Reporting accuracy was compared with a value of 1 using the one-sample *t*-test. Mean values of dietary intake (derived from both DHQ and biological markers) and reporting accuracy were calculated by quintile categories of BMI. Linear trends with increasing levels of BMI were tested by assigning to each participant the median value for the category and modeling this value as a continuous variable. All reported *P*-values are two-tailed and were considered statistically significant at the <0.05 level.

Results

Subject backgrounds are shown in Table 1. Subjects were characterized by a relatively low BMI (arithmetic mean $= 21.4\,\mathrm{kg/m^2}$), relatively low-fat intake (arithmetic mean = 29.8% of energy) and low smoking rate (3%). Although 39% of subjects consumed alcoholic beverages, their contribution to dietary intake was negligible (arithmetic mean = 0.4% of energy). Dietary supplements were used by 20% of subjects, but none consumed dietary supplements predominantly containing protein, potassium, or sodium. Table 2 shows the contribution of each food group to energy, protein, potassium and sodium intake, based on DHQ. Most food groups were important sources of at least one of them.

Table 1 Selected characteristics of subjects ($n = 353$)[a]

Variable	*Value*
Age (years)	19.4 ± 1.0
Body height (cm)	158.0 ± 5.8
Body weight (kg)	53.4 ± 7.7
Body mass index ($\mathrm{kg/m^2}$)	21.4 ± 2.7
Current smoker	10 (3)
Alcohol drinker[b]	139 (39)
Dietary supplement user[c]	69 (20)
Reported dietary intake[d]	
Energy (kcal/day)	1723 ± 398
Protein (% of energy)	13.8 ± 1.8
Fat (% of energy)	29.8 ± 5.0
Carbohydrate (% of energy)	54.8 ± 5.7
Alcohol (% of energy)	0.4 ± 1.0

[a] Values are arithmetic mean ± s.d. or number of subjects (%).
[b] Subjects who consumed more than 0 g of any of alcohol beverage during the previous month.
[c] Subjects who used any dietary supplement at least once during the previous month.
[d] Assessed by a self-administered diet history questionnaire.

Dietary intake (estimated by DHQ and biological markers) and reporting accuracy for energy, protein, potassium and sodium are shown in Table 3. Misreporting of dietary intake was differential rather than proportional. In terms of absolute values, energy was significantly ($P<0.0001$) underestimated (geometric mean reporting accuracy = 0.86) and sodium overestimated (geometric mean reporting accuracy = 1.14), whereas estimation of protein and potassium was relatively accurate (geometric mean reporting accuracy is equal to 0.97 and 1.03, respectively). Mainly owing to underestimation of energy, energy-adjusted values of all three nutrients were significantly ($P<0.0001$) overestimated (geometric mean reporting accuracy is equal to 1.14 for protein, 1.20 for potassium and 1.32 for sodium).

The association of dietary intake (estimated by DHQ and biological markers) and reporting accuracy with BMI is also shown in Table 3. Reporting accuracy of absolute intake of energy and the three nutrients significantly decreased with increasing BMI (*P* for trend <0.001), as result of increasing intake derived from biological markers but no increase in dietary intake derived from DHQ with increasing BMI. However, no association between reporting accuracy and BMI was observed when energy-adjusted values were used, indicating that the BMI-dependent misreporting of dietary intake was canceled by energy adjustment. This was owing to a significant correlation between the reporting accuracy of energy and that of the absolute value of the three nutrients (Pearson correlation coefficient is equal to 0.67 for protein, 0.56 for potassium and 0.49 for sodium, $P<0.0001$).

Table 2 Contribution of each food group to dietary intake of energy, protein, potassium and sodium as assessed by a self-administered diet history questionnaire ($n = 353$)[a]

	Energy	*Protein*	*Potassium*	*Sodium*
Cereals	38.8 (1)	23.9 (1)	8.4 (5)	9.6 (2)
Potatoes	2.4 (11)	1.0 (10)	7.6 (7)	0.2 (12)
Confectioneries[b]	14.7 (2)	7.0 (7)	5.0 (10)	3.5 (7)
Fat and oil	8.7 (3)	0.2 (13)	0.1 (14)	2.5 (8)
Pulses[c]	3.9 (7)	7.6 (5)	7.0 (8)	7.9 (3)
Fish and shellfish	4.3 (6)	15.9 (3)	7.8 (6)	4.9 (4)
Meats	7.5 (5)	17.2 (2)	8.8 (4)	2.3 (9)
Eggs	3.1 (8)	7.4 (6)	2.4 (11)	1.4 (10)
Dairy products	8.2 (4)	11.7 (4)	12.9 (2)	4.2 (6)
Vegetables[d]	2.9 (9)	4.4 (8)	22.3 (1)	4.7 (5)
Fruits	2.5 (10)	0.9 (12)	6.8 (9)	0.03 (14)
Seasonings[e]	0.6 (13)	0.9 (11)	1.8 (12)	58.2 (1)
Other foods[f]	0.2 (15)	0.1 (14)	0.1 (15)	0.1 (13)
Alcoholic beverages	0.5 (14)	0.04 (15)	0.2 (13)	0.01 (15)
Nonalcoholic beverages	1.6 (12)	1.7 (9)	8.9 (3)	0.5 (11)

[a] Values are the arithmetic mean percentage of total intake (ranking).
[b] Including sugar and sweeteners.
[c] Including nuts and miso (fermented soybean paste).
[d] Including mushrooms and sea vegatables.
[e] Including soups.
[f] Artificial sweeteners and nutrient supplement bars.

Table 3 Dietary intake (estimated by a self-administered diet history questionnaire (DHQ) and biological markers) and reporting accuracy of energy, protein, potassium and sodium and its relation with body mass index[a]

	Total (n = 353)[b,c]	Quintile category of body mass index					
		1 (n = 70)	*2 (n = 71)*	*3 (n = 71)*	*4 (n = 71)*	*5 (n = 70)*	*P for trend*[d]
Body mass index (kg/m^2)	21.1 (14.8–34.2)	18.4 (14.8–19.2)	19.9 (19.3–20.4)	21.1 (20.4–21.6)	22.2 (21.6–23.1)	24.7 (23.1–34.2)	
Absolute dietary intake							
Energy							
DHQ (kcal/day)	1678 (1638–1719)	1715 (1629–1805)	1637 (1546–1734)	1729 (1641–1821)	1644 (1561–1731)	1667 (1575–1764)	0.57
Biological marker (kcal/day)[e]	1992 (1975–2010)	1832 (1815–1850)	1918 (1898–1937)	1979 (1959–1999)	2029 (2009–2048)	2225 (2181–2271)	<0.0001
Reporting accuracy[f]	0.86 (0.83–0.88)	0.95 (0.9–0.99)	0.87 (0.82–0.92)	0.88 (0.84–0.93)	0.82 (0.78–0.86)	0.76 (0.72–0.81)	<0.0001
Protein							
DHQ (g/day)	57.6 (55.9–59.3)	59.0 (55.4–62.8)	58.1 (53.8–62.7)	60.1 (56.5–63.8)	55.3 (51.8–58.9)	55.5 (51.9–59.5)	0.12
Biological marker (g/day)[g]	60.9 (59.3–62.6)	54.6 (51.2–58.2)	61.1 (57.5–65.0)	61.9 (58.5–65.6)	60.6 (57.4–64.0)	66.9 (63.4–70.6)	<0.0001
Reporting accuracy[f]	0.97 (0.94–1.01)	1.11 (1.02–1.21)	0.98 (0.90–1.06)	1.00 (0.93–1.08)	0.93 (0.87–1.00)	0.85 (0.79–0.91)	<0.0001
Potassium							
DHQ (mg/day)	1902 (1833–1973)	2000 (1851–2162)	1957 (1796–2132)	2012 (1874–2159)	1747 (1613–1892)	1808 (1649–1982)	0.03
Biomarker (mg/day)[h]	1930 (1862–2001)	1793 (1677–1917)	1871 (1713–2044)	1993 (1843–2155)	1890 (1732–2061)	2121 (1969–2285)	0.005
Reporting accuracy[f]	1.03 (0.98–1.08)	1.15 (1.05–1.26)	1.10 (0.98–1.23)	1.06 (0.96–1.17)	0.96 (0.88–1.04)	0.89 (0.80–0.98)	<0.0001
Sodium							
DHQ (mg/day)	3442 (3321–3568)	3578 (3318–3859)	3477 (3182–3798)	3558 (3297–3839)	3275 (3030–3540)	3336 (3073–3620)	0.15
Biological marker (mg/day)[i]	3235 (3094–3384)	2830 (2535–3158)	3102 (2818–3415)	3495 (3228–3784)	3081 (2759–3440)	3753 (3426–4110)	0.0002
Reporting accuracy[f]	1.14 (1.07–1.21)	1.34 (1.17–1.52)	1.21 (1.05–1.38)	1.09 (0.96–1.21)	1.14 (0.98–1.30)	0.94 (0.84–1.05)	0.0002
Energy-adjusted dietary intake							
Protein							
DHQ (% energy)	13.7 (13.5–13.9)	13.8 (13.4–14.2)	14.2 (13.7–14.7)	13.9 (13.5–14.3)	13.4 (13.1–13.8)	13.3 (12.9–13.8)	0.02
Biological marker (% energy)[j]	12.2 (11.9–12.5)	11.9 (11.2–12.7)	12.8 (12.0–13.6)	12.5 (11.8–13.2)	11.9 (11.3–12.6)	12.0 (11.4–12.7)	0.61
Reporting accuracy[f]	1.14 (1.11–1.17)	1.17 (1.10–1.25)	1.13 (1.06–1.20)	1.13 (1.06–1.20)	1.14 (1.08–1.2)	1.12 (1.06–1.19)	0.42
Potassium							
DHQ (mg/1000 kcal)	1133 (1106–1161)	1167 (1106–1230)	1195 (1130–1264)	1164 (1104–1226)	1063 (1011–1117)	1085 (1027–1145)	0.005
Biological marker (mg/1000 kcal)[j]	969 (935–1003)	979 (915–1047)	976 (895–1064)	1007 (932–1088)	931 (855–1014)	953 (885–1026)	0.47
Reporting accuracy[f]	1.20 (1.16–1.25)	1.22 (1.13–1.31)	1.26 (1.15–1.38)	1.20 (1.09–1.31)	1.17 (1.08–1.27)	1.17 (1.08–1.27)	0.29
Sodium							
DHQ (mg/1000 kcal)	2052 (2000–2105)	2086 (1980–2199)	2124 (2013–2240)	2058 (1944–2178)	1992 (1874–2118)	2001 (1884–2126)	0.13
Biological marker (mg/1000 kcal)[j]	1624 (1555–1696)	1544 (1383–1724)	1617 (1470–1779)	1766 (1631–1913)	1518 (1363–1692)	1686 (1543–1842)	0.40
Reporting accuracy[f]	1.32 (1.26–1.39)	1.41 (1.26–1.57)	1.38 (1.22–1.54)	1.22 (1.10–1.34)	1.38 (1.20–1.58)	1.24 (1.11–1.37)	0.15

[a] Values are geometric mean (95% confidence intervals) except for body mass index (median (range)).
[b] Dietary intake values derived from DHQ were significantly different from the corresponding values derived from biological markers except for absolute potassium intakes ($P = 0.002$ for absolute protein intake, $P = 0.03$ for absolute sodium intake, and $P < 0.0001$ for other values; paired *t*-test).
[c] Reporting accuracy was significantly different from a value of 1 except for absolute protein and potassium intake ($P < 0.0001$; one sample *t*-test).
[d] Test for linear trend used the median value in each quintile as a continuous variable in linear regression.
[e] Calculated as estimated basal metabolic rate (14.7 × body weight (kg) + 496) (FAO/WHO/UNU, 1985) multiplied by 1.56 (physical activity level for light activity) (FAO/WHO/UNU, 1985) assuming that lifestyle of the subjects was predominantly sedentary.
[f] Calculated as the ratio of value derived from DHQ to that derived from biological marker.
[g] Calculated as 24-h urinary urea nitrogen multiplied by 9.08 assuming that urea nitrogen is a constant proportion (85%) of total urinary nitrogen (Bingham and Cummings, 1985), that 81% of the ingested nitrogen is excreted through the urine (Bingham and Cummings, 1985; Kipnis *et al.*, 2001), and that nitrogen constitutes 16% of protein.
[h] Calculated as 24-h urinary potassium divided by 0.77 assuming that 77% of the ingested potassium is excreted through the urine (Holbrook *et al.*, 1984; Tasevska *et al.*, 2006).
[i] Calculated as 24-h urinary sodium divided by 0.86 assuming that 86% of the ingested sodium is excreted through the urine (Holbrook *et al.*, 1984; Willett, 1998).
[j] Calculated using dietary intake values estimated by biological markers.

Discussion

To date, no information has appeared on possible differential misreporting of dietary intake and its relation with BMI in Japanese populations, who are relatively lean and whose proportion of energy intake derived from fat is relatively low. In this study of young Japanese women, misreporting of dietary intake of energy, protein, potassium and sodium was differential rather than proportional. Additionally, differential misreporting of absolute intake of energy, protein, potassium and sodium was associated with BMI. Conversely, differential misreporting of energy-adjusted values for protein, potassium and sodium was not associated with BMI owing to a positive correlation between reporting accuracy of energy and that of the absolute values of the three nutrients. This finding supports the use of energy-adjusted values in the investigation of diet–disease relationships.

Mean values for the reporting accuracy of absolute intake of energy and three nutrients ranged from 0.86 to 1.14, indicating the differential misreporting of dietary intake. This is generally consistent with a limited number of previous Western studies, in which at least two kinds of quantitative biological markers were used. Although several UK studies showed a similar degree of under-reporting of energy and protein (potassium and sodium were not examined) (Black *et al.*, 1997, 2000), a study in US adults found that energy and protein were underestimated whereas potassium was estimated reasonably well (Freedman *et al.*, 2004). In contrast, a study of elderly Swedish men showed that underestimation of energy was greater than that of protein, potassium and sodium (Rosell *et al.*, 2003). Among Swedish adolescents, energy and potassium were underestimated but protein and sodium intakes agreed with the respective biological markers (Larsson and Johansson, 2002), whereas Danish adults underestimated energy to a greater extent than protein (Heitmann and Lissner, 1995, 2005; Heitmann *et al.*, 2000). Thus, although the degree and direction of misreporting seemed to be unpredictable, and several (Conway *et al.*, 2003, 2004; Ard *et al.*, 2006) but not all (Poppitt *et al.*, 1998; Paul *et al.*, 2005) observational validation studies of *ad libitum* intake under controlled conditions have shown proportional rather than differential reporting of dietary intake, accumulating evidence indicates that misreporting of dietary intake is differential rather than proportional in many free-living situations. Differential misreporting is a challenging issue that should be addressed in future studies, because the biases from this type of error cannot be eliminated by correction for energy intake (Lissner, 2002), as was shown in the present as well as several previous studies (Freedman *et al.*, 2004; Heitmann and Lissner, 2005).

A few Western studies have examined misreporting of absolute dietary intake against biological markers in relation to the degree of obesity. Under-reporting of energy intake generally increased with increasing BMI (Livingstone and Black, 2003; Tooze *et al.*, 2004). Protein under-reporting was positively associated with BMI in a Swedish study (Hulten *et al.*, 1990). Under-reporting of both energy and protein increased with increasing percentage of body fat in Danish adults (Heitmann and Lissner, 1995, 2005; Heitmann *et al.*, 2000). In a UK study, there was a positive relation of under-reporting of protein and potassium with BMI (Bingham *et al.*, 1995). Over-reporting of protein decreased and under-reporting of potassium increased with increasing BMI in Dutch adults (Heerstrass *et al.*, 1998). In the present Japanese study, under-reporting of energy, protein and potassium increased and over-reporting of sodium decreased with increasing BMI. Thus, in many free-living situations, the magnitude of misreporting of dietary intake generally appears to be associated with the degree of obesity, which is a major determinant of dietary misreporting (Livingstone and Black, 2003; Rosell *et al.*, 2003; Tooze *et al.*, 2004; Mattisson *et al.*, 2005; Mahabir *et al.*, 2006).

To our knowledge, only one group has investigated misreporting of energy-adjusted (rather than absolute) intake in relation to the degree of obesity. In a Danish study, with increasing degree of obesity measured as percentage body fat, the magnitude of energy under-reporting increased to a greater extent than that of protein under-reporting, and as a result, over-reporting of energy-adjusted protein intake increased with the increase in percentage body fat (Heitmann and Lissner, 1995, 2005; Heitmann *et al.*, 2000). Conversely, in the present study, the degree of over-reporting of energy-adjusted intake of protein, potassium and sodium, mainly as a result of energy under-reporting, was not associated with BMI. This was owing to a positive association between the reporting accuracy of energy and that of protein, potassium and sodium, which is consistent with the positive association between reporting accuracy of energy and protein observed in several previous studies (Black *et al.*, 1997, 2000; Subar *et al.*, 2003). The present finding suggests that energy-adjusted values of protein, potassium and sodium can be used when investigating relationships between diet and health outcome, although energy-adjusted values *per se* may be unreliable estimates of true dietary intake. Moreover, given the low overlap in the food sources of these nutrients (as shown in Table 2), our results based on protein, potassium and sodium might likely extend to other nutrients.

In the present study, reported dietary intake was obtained from a self-administered dietary assessment questionnaire (Sasaki *et al.*, 1998a, b, 2000). Mean values of reported energy and fat intake (1723 kcal/day and 29.8% of energy, respectively) were relatively comparable with those in a representative sample of Japanese women aged 18–29 years (1692 kcal/day and 29.0% of energy, respectively; not available for protein, carbohydrate and alcohol) (Ministry of Health, Labour and Welfare, 2006). This might give some indication of the validity of the questionnaire.

A number of methodological limitations of this study should be mentioned. First, given that we estimated energy expenditure as BMR multiplied by physical activity level value for light activity (1.56) (FAO/WHO/UNU, 1985), assuming a predominantly sedentary lifestyle of our subjects based on self-reported physical activity, energy expenditure of some subjects may have been underestimated. However, time spent on high- and moderate-intensity activities and walking was quite short, as indicated above. Additionally, there was no significant difference in time spent on each activity among quintile category of BMI (data not shown). Furthermore, a repeated analysis of 294 women after excluding subjects whose lifestyle were considered relatively active (those spending >30 min/day on high-intensity activities, >60 min/day on moderate-intensity activities, or >120 min/day on walking) provided similar results (data not shown). Thus, it is unlikely that the use of a physical activity level of 1.56 for all subjects had any major impact on the present findings, although the magnitude of under-reporting of energy intake might be underestimated. When a physical activity level value for moderate activity (1.64) (FAO/WHO/UNU, 1985) was used, the magnitude of under-reporting of energy intake increased (mean reporting accuracy: 0.81) while the magnitude of over-reporting of energy-adjusted value of three nutrients increased (mean reporting accuracy: 1.20 for protein, 1.26 for potassium and 1.39 for sodium), compared with reporting accuracy observed when a physical activity level of 1.56 was used. However, future research using more accurate assessment of energy expenditure is needed to confirm the present findings.

Second, obtaining a valid dietary intake derived from urine excretion requires that 24-h urine collection be complete. Although the use of PABA is undoubtedly a most appropriate strategy to verify the completeness (Bingham and Cummings, 1983), we did not use this method to maximize the response rate (to our knowledge, no previous studies conducted among Japanese people have used the PABA method). Instead, the present analysis was limited in only women who met the strict INTERMAP criteria (Stamler *et al.*, 2003) and a widely used criteria determined by creatinine (WHO Regional Office for Europe, 1984) for the assessment of completeness of urine sampling. We consider this strategy the best method available in the absence of the PABA method. However, as the reliability of present findings is largely dependent on the completeness of urine collection, our findings should be confirmed in future studies using the PABA method.

A second problem with regard to urine collection was that only a single 24-h urine sample was used, which is not optimal for characterizing individual habitual dietary intake and introduces random errors (Bingham, 2003). However, this kind of error would tend to result in bias toward attenuating rather than enhancing the relation, and multiple 24-h urine collections would have only provided more precise results.

Additionally, there have been concerns regarding the precision of the correction factors used for estimating dietary intake from 24-h urine. Many factors may influence the percentage of dietary protein (nitrogen), potassium and sodium excreted in the urine, for instance, the absolute level of dietary intake, the seasons during which balance studies are conducted, race and cooking methods (Zhang *et al.*, 2000). We used the factors observed in previous carefully designed balance studies (Holbrook *et al.*, 1984; Bingham and Cummings, 1985; Willett, 1998; Kipnis *et al.*, 2001; Tasevska *et al.*, 2006). However, use of other correction factors should have little influence on the association between misreporting and BMI observed in the present study, although the magnitude of misreporting should be interpreted with caution, which largely depends on the correction factor used.

We could not include nutrient intake from dietary supplements in the analysis because of the lack of a reliable composition table of dietary supplements in Japan. However, the one-fifth of subjects who consumed any dietary supplements during the preceding month equally distributed among quintile category of BMI (data not shown), and none consumed dietary supplements predominantly containing protein, potassium, or sodium. Additionally, a repeated analysis of 284 women after excluding dietary supplement users provided similar results (data not shown). Thus, it is unlikely that dietary supplement use had a major impact on the present findings. Finally, because our subjects were selected female dietetic students who may have been highly health conscious, our results may not be extrapolatable to the general Japanese population.

In summary, misreporting of dietary intake of energy, protein, potassium and sodium was not proportional but differential among a group of lean young Japanese women with a low-fat intake. Differential misreporting of absolute intake of energy, protein, potassium and sodium was associated with BMI. Nevertheless, differential misreporting of energy-adjusted values of protein, potassium and sodium was not associated with BMI because of a positive correlation between the reporting accuracy of energy and that of the absolute values of the three nutrients. These findings support the use of energy-adjusted values in the investigation of diet–disease relationships among lean populations with a low-fat intake. The results of the present study should be confirmed using a more accurate and precise evaluation of true dietary intake in a more representative sample of the Japanese population.

Acknowledgements

We thank Yuko Hisatomi, Junko Soezima and Kazumi Takedomi (Nishikyushu University), Yoko Umeki (Fukuoka Women's University), Yoko Ichikawa (University of Shizuoka), Tomoko Ide (Tokyo Kasei University), Maiko Suzuki (Mie Chukyo University Junior College), Etsuko Uneoka (Otemae College of Nutrition), Kanako Muramatsu (Niigata Women's College) and Mika Furuki (Minamikyushu University) for data collection.

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