散分析を実施し，有意差が見られた項目についての多重比較はScheffe法を用いた．一方，膝痛・転倒・尿失禁の有症は年齢の影響を受けるので，歩容は年齢を調整した上で検討した．各徴候の程度による歩容変数の差を検定するために，それぞれの徴候を有しない健常群，軽症群，中程度以上群に分けて一元配置分散分析を行い，有意差を認めた項目については多重比較を施した．それぞれの徴候に関連する要因を抽出するために，軽度徴候と中程度以上の徴候を従属変数とし，歩容変数を独立変数とした多重ロジスティック回帰分析を実施した．解析は，統計パッケージSPSS 18.0 for Windowsで行い，統計学的有意水準はP<0.05に設定した．

表1　各徴候の有症率

症状	n	(%)
徴候無	231	(26.6)
膝痛	326	(37.5)
尿失禁	333	(38.3)
転倒	166	(19.1)
膝痛＋尿失禁	152	(17.5)
尿失禁＋転倒	68	(7.8)
転倒＋膝痛	85	(9.8)
膝痛＋尿失禁＋転倒	41	(4.7)

結　果

各徴候の有症率は，膝痛37.5%，尿失禁38.3%，転倒19.1%であった（表1）．一方，複数徴候保持者は，膝痛＋尿失禁17.5%，尿失禁＋転倒7.8%，転倒＋膝痛9.8%，膝痛＋尿失禁＋転倒4.7%であった．

各群間で測定項目を比較した（表2）．年齢は群間に有意差を認め，尿失禁80.1±4.2歳，転倒79.9±7.1歳，膝痛79.6±4.2歳と徴候を有しない健常群より高かった．歩行速度，ケイデンス，ストライド，歩幅，歩行角度で群間の有意差を認め，膝痛，尿失禁，転倒者は健常者より低い値を示した．一方，膝痛，尿失禁者の歩隔は健常者より増大を，転倒群で歩行角度の左右差は健常群より増大した．

それぞれの徴候において「健常群」,「軽症群」,「中程度以上群」の歩容を比較した（表3）．膝痛の軽症，中程度以上群では健常群より歩行速度の低下，ストライド，歩幅の減少，歩行角度の増大を認めた．歩隔は中程度以上群で，健常群より増大していた．次に，尿失禁の軽症群，中程度以上群は健常群に比べて歩行速度の低下，ケイデンス，ストライド，歩幅の減少，歩行角度の増大を認めた．歩行角度左右差は，中程度以上群で増大を認めた．転倒経験者は歩行速度，ケイデンス，ストライド，歩幅の減少，歩行角度の増大を認めた．複数回転倒者は健常群に比べて，歩隔，歩行角度の左右差の増大を認め

表2　体格及び歩容変数の群間比較

変数	膝痛群 (n＝326) M±SD	尿失禁群 (n＝333) M±SD	転倒群 (n＝166) M±SD	健常群 (n＝231) M±SD	P値*	多重比較**
年齢（歳）	79.6±4.2	80.1±4.2	79.9±7.1	78.2±3.7	<.001	健<膝，尿，転
身長（cm）	147.9±5.7	147.6±5.5	147.5±5.4	149.1±5.1	0.106	
体重（kg）	50.2±8.1	49.8±8.0	48.6±7.9	50.5±5.9	0.277	
歩行速度（cm/sec）	111.2±23.8	110.9±22.4	107.5±24.7	124.2±19.4	<.001	健>膝，尿，転
ケイデンス（step/min）	128.5±14.5	128.1±14.7	126.2±15.0	133.8±19.7	<.001	健>膝，尿，転
ストライド（身長%）	69.9±12.2	69.9±12.1	68.8±12.5	75.0±10.6	<.001	健>膝，尿，転
歩幅（身長%）	36.8±6.3	36.8±6.0	35.8±6.7	39.8±4.3	<.001	健>膝，尿，転
歩隔（身長%）	5.9±2.0	5.9±2.0	5.7±2.2	5.3±1.9	0.020	健<膝，尿
歩行角度（°）	9.9±5.7	9.7±4.8	10.0±6.9	7.7±3.0	<.001	健<膝，尿，転
つま先角度（°）	0.1±5.3	−0.3±5.9	0.1±5.9	0.2±5.5	0.764	
ストライド左右差（身長%）	4.1±4.4	4.0±4.9	3.5±4.4	4.7±5.1	0.180	
歩幅左右差（身長%）	1.6±1.6	1.6±1.8	1.8±2.6	1.6±1.7	0.714	
歩隔左右差（身長%）	0.9±0.7	0.9±0.7	1.0±0.8	0.9±0.7	0.699	
歩行角度左右差（°）	1.6±1.6	1.6±1.5	2.0±3.8	1.2±1.0	0.028	健<転
つま先角度左右差（°）	5.2±4.1	5.9±6.0	5.7±4.6	4.9±4.0	0.127	

M＝平均値，SD＝標準偏差
*一元配置分散分析
**膝＝膝痛，尿＝尿失禁，転＝転倒，健＝健常群
ストライド，歩幅，歩隔，歩行角度，つま先角度は左右のうち支持足の左を代表値とした

表3　各徴候の程度と歩容変数の比較

徴候	程度	n	歩行速度 (cm/sec) M SD	*	ケイデンス (step/min) M SD	*	ストライド (身長%) M SD	*	歩幅 (身長%) M SD	*	歩隔 (身長%) M SD	*	歩行角度 (°) M SD	*	つま先角度 (°) M SD
膝痛	なし（健常群）	214	124.2±19.4		133.8±19.7		75.0±10.6		39.8±4.3		5.3±1.9		7.7±3.0		0.2±5.5
	軽度	179	113.1±24.1		128.5±14.3		71.0±12.5		37.3±6.5		5.8±1.9		9.7±6.8		0.4±5.3
	中程度以上	147	110.1±24.3		129.7±14.4		69.1±11.9		36.4±6.2		6.1±2.0		10.0±4.2		−0.2±5.7
尿失禁	なし（健常群）	214	124.2±19.4		133.8±19.7		75.0±10.6		39.8±4.3		5.3±1.9		7.7±3.0		0.2±5.5
	軽度	175	113.0±21.1		129.3±14.3		70.5±10.0		37.3±5.0		5.5±2.0		8.8±3.7		−0.1±6.0
	中程度以上	158	108.2±23.0		126.9±14.6		69.1±14.1		36.2±6.9		6.3±2.0		10.6±5.6		−0.5±5.8
転倒	なし（健常群）	214	124.2±19.4		133.8±19.7		75.0±10.6		39.8±4.3		5.3±1.9		7.7±3.0		0.2±5.5
	1回転倒	124	108.4±24.6		126.2±14.3		69.5±12.9		36.0±6.9		5.6±2.3		9.7±7.0		0.0±6.0
	複数回転倒	42	103.8±24.6		125.8±17.0		66.3±11.7		34.9±6.3		6.3±2.1		11.3±6.6		0.6±5.8

徴候	程度	n	ストライド左右差 (身長%) M SD	歩幅左右差 (身長%) M SD	歩隔左右差 (身長%) M SD	歩行角度左右差 (°) M SD	*	つま先角度左右差 (°) M SD
膝痛	なし（健常群）	214	4.7±5.1	1.6±1.7	0.9±0.7	1.2±1.0		4.9±4.0
	軽度	179	3.9±4.0	1.6±1.7	0.9±0.7	1.7±1.8		5.0±4.1
	中程度以上	147	4.5±5.0	1.6±1.3	1.0±0.8	1.6±1.2		5.4±4.0
尿失禁	なし（健常群）	214	4.7±5.1	1.6±1.7	0.9±0.7	1.2±1.0		4.9±4.0
	軽度	175	4.0±4.4	1.5±1.3	0.9±0.7	1.3±1.0		5.6±4.3
	中程度以上	158	3.9±5.2	1.7±2.2	1.0±0.8	1.9±1.9		6.3±7.1
転倒	なし（健常群）	214	4.7±5.1	1.6±1.7	0.9±0.7	1.2±1.0		4.9±4.0
	1回転倒	124	3.3±4.6	1.9±2.9	1.0±0.7	2.0±4.3		5.5±4.5
	複数回転倒	42	4.0±3.7	1.3±1.1	1.0±0.9	2.1±2.1		6.1±4.8

M＝平均値，SD＝標準偏差
＊多重比較：Scheffe 法
ストライド，歩幅，歩隔，歩行角度，つま先角度は左右のうち支持足の左を代表値とした

た．

次に，それぞれの徴候を従属変数，歩容変数を独立変数としたロジスティック回帰分析を施した（表4）．歩行速度は，軽症膝痛（Odds Ratio（以下：OR）＝0.97，95% Confidence Intervals（以下：CI）0.96〜0.99），軽症尿失禁（OR＝0.97，95% CI 0.96〜0.98），1回転倒（OR＝

表4　膝痛，尿失禁，転倒に関与する歩容変数

徴候の程度	従属変数	独立変数	オッズ比	95% 信頼区間	P 値
軽度					
	膝痛	歩行速度（cm/sec）（1単位毎に）	0.979	0.968 ～ 0.991	0.001
	尿失禁	歩行速度（cm/sec）（1単位毎に）	0.975	0.964 ～ 0.986	<0.001
	転倒	歩行速度（cm/sec）（1単位毎に）	0.976	0.954 ～ 0.997	0.029
中程度以上					
	膝痛	歩隔（%）（1単位毎に）	0.588	0.409 ～ 0.845	0.004
		歩行角度（°）（1単位毎に）	1.620	1.302 ～ 2.015	<0.001
	尿失禁	歩行速度（cm/sec）（1単位毎に）	0.978	0.962 ～ 0.995	0.011
		歩行角度（°）（1単位毎に）	1.140	1.029 ～ 1.263	0.012
		歩行角度左右差（°）（1単位毎に）	1.430	1.097 ～ 1.865	0.008
	転倒	歩幅（%）（1単位毎に）	0.858	0.790 ～ 0.931	<0.001
		歩行角度左右差（°）（1単位毎に）	1.362	1.001 ～ 1.854	0.049

従属変数：軽度＝1，健常群＝0；中程度以上＝1，健常群＝0

0.97，95% CI 0.95～0.99）で有意に関連していた．

一方，中程度以上膝痛では歩隔（OR＝0.58，95% CI 0.40～0.84），歩行角度（OR＝1.62，95% CI 1.30～2.01）が，中程度以上尿失禁では歩行速度（OR＝0.97，95% CI 0.96～0.99），歩行角度（OR＝1.14，95% CI 1.02～1.26），歩行角度左右差（OR＝1.43，95% CI 1.09～1.86）が，複数回転倒では歩幅（OR＝0.85，95% CI 0.79～0.93），歩行角度左右差（OR＝1.36，95% CI 1.01～1.85）が有意であった．

考　察

本研究では，70歳以上の女性の膝痛，尿失禁，転倒と歩行要因を比較した結果，いずれの軽症徴候には歩行速度の低下が，中程度以上徴候には徴候特異的歩容の変化が特徴付けられた．

歩行速度や歩幅，歩隔などの歩容は加齢により変化することはこれまでの多くの研究から報告されている[18][19]．一般的に高齢者は加齢に伴う筋肉量減少や筋力の低下，バランス機能の衰え，関節の変形，疼痛などで歩行障害が起きやすく，したがって高齢者の歩行は若年者と比べて歩行速度が遅く，歩幅・ストライドが短く，股関節の屈曲・伸展が減少し，踵・つま先の挙上が減少するなどの特徴が現れてくる[20][21]．こうした加齢による歩行変化は同年代の高齢者間においても膝痛，尿失禁，転倒を有する群で差がみられた．

さらに，それぞれの徴候の中程度以上化にしたがって歩行速度の低下が明らかとなった．同様に歩容についても徴候の中程度以上化にしたがって，歩幅やケイデンスが減少していることから，歩容の変化が歩行速度の低下に影響していることを表している．

これまでの研究から転倒経験者や尿失禁有症者は，健康な高齢者と比べて歩行速度の遅いことが報告されているが[11][14][22][23]，歩容について検討した報告は少なく，これらの徴候と歩容との関連性についてのより詳細な検討が課題といえる．

さらに，徴候出現に関わる歩容変数を明らかにするためにロジスティック回帰分析を実施した結果，それぞれの徴候において軽度の発現には歩行速度の低下のみが関与しているのに対し，中程度以上徴候の出現には歩行速度のみではなく，歩容がより強く関与していることが明らかとなった．すなわち徴候の中程度以上化への進行あるいは慢性状態は歩容にも変化が生じていることが示唆された．徴候のために歩容が変化するのか，歩容の変化が徴候を重篤にするのかを判断することは困難であるが，これらの徴候の軽症段階では歩容には差を認めないために，徴候初期に現れる歩行速度の低下と中程度以上化の進行に従い現れる歩容変化の注意深い観察が必要であることが示唆された．

膝の痛みは移動機能の制限と密接に関わっていると指摘されているが[24]，本研究で検証した中程度以上の膝痛には「歩行角度」と「歩隔」が有意に関連している可能性が示唆された．このことは歩行角度の大きさにも関わらず歩隔の小さいことから，前方向への歩幅の減少が予想された．膝痛では，痛みによる関節可動域の減少や筋肉の不使用，別の部位への過度の負担により歩き方に変化の現れている可能性が考えられる．さらに膝痛の改善には膝関節周辺を取り囲む大腿四頭筋の強化が重要なことからも，これらの筋肉が衰えているために足を前方向に大きく出すことができなくなっている可能性が考えられる．尿失禁者は正常群に比べて，歩行速度の低下を認めたことから，歩行機能の向上は尿失禁の改善に寄与する可能性を指摘している[25]．しかし，本研究で中程度以

上の尿失禁には歩行速度のみならず歩行角度や歩行角度の左右差が関与していることを検証した．歩行角度が大きくなると前方向への距離に対して横方向の距離が増大していることを表している．このことは歩行中に足がまっすぐに前に出るように導く役割を担っている大腿筋膜張筋，縫工筋，内転筋，大腿四頭筋の衰えによる下肢機能の脆弱に強く関連していると推測できる．一方，前頭葉は歩行速度を制御する中枢であり[25]，尿意中枢でもある[27]．歩行速度は歩幅とケイデンスに依存することから[28]，ケイデンスの低下が尿失禁と有意差を認めた本研究の結果は興味深く（表3），発展的な研究につなげていきたい．

歩行速度と転倒との関連性については，様々な角度から検討されている．多くの研究で，歩行速度の低下と歩幅の短縮は転倒と密接に関連すると指摘し[29][30]，地域在宅高齢者の複数回転倒発生率について調べた5年間の追跡調査によれば，通常歩行速度は複数回の転倒発生の予知因子であることを報告している[14]．本研究では，歩幅の短縮による歩行速度の低下が複数回転倒と関連する可能性が示唆された．

ほかに，重程度以上の尿失禁，複数回転倒には歩容の左右差が徴候の特徴として現れた．歩行は身体を前進させるために左右の下肢が交互に支点となるため重心が上下，左右に動揺する．左右方向の揺れは歩行角度に影響する可能性が高く，歩行角度左右差は支持足でない方の足の筋力低下や関節可動域の低下，痛みや変形などで支持性が低下することから足を前方に振り出せずに，どちらか一方で左右差の生じる可能性が考えられる．したがって，歩行角度左右差に特徴の現れた尿失禁，転倒の歩容は下肢の筋力低下の影響の大きいことが示唆された．しかし，歩容に影響する要因は様々であり，とくに不眠による睡眠剤服用者，心不全や呼吸不全患者は歩行速度が遅く，通常痛みはあっても，鎮痛剤を服用すれば痛みは緩和され，歩容が良い結果となってしまう可能性が考えられるが，これらの有無の検討がなされなかったのは本研究の制限点である．

老年症候群はADLを低下させ，健康寿命の短縮に寄与していることからも早期発見，早期予防のための対策の確立が望まれる．これまで歩行速度が高齢者のADL低下の予測因子として知られているが，歩行速度に歩容を加えることで老年症候群の早期発見に寄与できる可能性が示唆された．本研究で得た結果を一般化するためには，歩容の変化と老年症候群の新規発生との関連性を究明するための縦断研究が必要といえる．

まとめ

都市部在住75歳以上の高齢女性870名の歩容を分析した結果，膝痛，尿失禁，転倒経験を有する高齢者は，歩行速度が遅く，ケイデンス，ストライド，歩幅が低下し，歩隔，歩行角度，歩行角度左右差の増大がみられた．また，軽症の膝痛，尿失禁，転倒には歩行速度が強く関連していた．一方，中程度以上の膝痛で歩隔，歩行角度，中程度以上の尿失禁で歩行速度，歩行角度，歩行角度左右差，複数回の転倒では歩幅，歩行角度左右差が強く関連した．以上の結果から膝痛，尿失禁，転倒では歩行速度の低下だけでなく，歩容の変化に着目することで徴候の早期発見に活かせる可能性が示唆された．

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Are gait parameters related to knee pain, urinary incontinence and a history of falls in community-dwelling elderly women?

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Abstract

Aim: To examine the association between gait parameters and knee pain, urinary incontinence, and a history of falls.

Methods: Comprehensive health examinations were conducted in 2009 among 971 elderly women over 70 years of age, in which the questionnaire and gait parameter results of 870 participants were analyzed. Knee pain, urinary incontinence and a history of falls were assessed through face-to-face interview surveys. Gait parameters were measured using a walk-way to assess walking speed, cadence, stride, stride length, step width, walking angle, toe angle and the differences in each parameter between the right and left foot. Multiple logistic regression analyses were performed to examine the associations between the gait parameters and knee pain, urinary incontinence and a history of falls.

Results: The elderly women with knee pain, urinary incontinence and a history of falls had slower walking speeds, smaller strides and strides length, and wider step width and walking angles. The multiple logistic regression analysis showed the walking speed to be significantly associated with mild knee pain and urinary incontinence and single a history of fall; moderate/severe knee pain was significantly associated with step width (OR = 0.58, 95%CI = 0.40-0.84) and walking angle (OR = 1.62, 95%CI = 1.30-2.01); moderate/severe urinary incontinence was significantly associated with walking speed (OR = 0.97, 95%CI = 0.96-0.99), walking angle (OR = 1.14, 95%CI = 1.02-1.26), and difference in walking angle between the right and left foot (OR = 1.43, 95%CI = 1.09-1.86); multiple a history of falls was significantly associated with stride length (OR = 0.85, 95%CI = 0.79-0.93) and the difference in walking angle between the right and left foot (OR = 1.36, 95%CI = 1.01-1.85).

Conclusions: The data suggest that combining assessments of walking speed and other gait parameters may be an effective screening method for the early detection of geriatric syndromes.

Key words: *Gait parameters, Knee pain, Urinary incontinence, History of falls*
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ORIGINAL ARTICLE

Accuracy of segmental multi-frequency bioelectrical impedance analysis for assessing whole-body and appendicular fat mass and lean soft tissue mass in frail women aged 75 years and older

M Kim and H Kim

BACKGROUND/OBJECTIVE: We aimed to examine the accuracy of segmental multi-frequency bioelectrical impedance analysis (SMF-BIA) for the assessment of whole-body and appendicular fat mass (FM) and lean soft tissue mass (LM) in frail older women, using dual-energy X-ray absorptiometry (DXA) as a reference method.
SUBJECTS/METHODS: All 129 community-dwelling Japanese frail older women with a mean age of 80.9 years (range, 75–89 years) from the Frailty Intervention Trial were recruited. The agreements between SMF-BIA and DXA for whole-body and appendicular body composition were assessed using simple linear regression and Bland–Altman analysis.
RESULTS: High coefficients of determination (R^2) for whole-body FM ($R^2 = 0.94$, s.e. of estimate (SEE) = 1.2 kg), whole-body LM ($R^2 = 0.85$, SEE = 1.4 kg), and appendicular FM ($R^2 = 0.82$, SEE = 1.1 kg) were observed between SMF-BIA and DXA. The R^2 coefficient for appendicular LM was moderate ($R^2 = 0.76$, SEE = 0.8 kg). Bland–Altman plots demonstrated that there was systematic (constant) bias (that is, DXA minus SMF-BIA) with overestimation of whole-body FM (bias = − 1.2 kg, 95% confidence interval (CI) = − 1.5 to − 0.1) and underestimation of whole-body LM (bias = 2.1 kg, 95% CI = 1.8–2.3) by SMF-BIA. Similar, the appendicular measurements also demonstrated systematic bias with overestimation of appendicular FM (bias = − 0.3 kg, 95% CI = − 0.5 to − 0.1) and underestimation of whole-body LM (bias = 1.5 kg, 95% CI = 1.4–1.7) by SMF-BIA. In addition, the individual level accuracy demonstrated a non-proportional bias for whole-body LM ($r = 0.08$, $P = 0.338$) and appendicular FM ($r = 0.07$, $P = 0.413$).
CONCLUSIONS: SMF-BIA had acceptable accuracy for the estimation of whole-body and appendicular FM and LM in frail older women, although SMF-BIA underestimated LM and overestimated FM relative to DXA.

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Keywords: body composition; bioelectrical impedance analysis; sarcopenia; frailty

INTRODUCTION

Frailty is an important and common geriatric syndrome that is described as a status of increased vulnerability resulting from the loss of complexity in resting dynamics involving multiple physiological systems with advancing age.[1] The prevalence of frailty increases with age, from 3.9% at 65–74 years to 11.6% at 75–84 years and to 25% in people older than 85 years. In addition, frailty is more prevalent in women than in men.[1] Sarcopenia is a loss of skeletal muscle mass and size that occurs with aging.[2] Although many definitions of sarcopenia have been reported,[3–5] current definitions focus on loss of appendicular skeletal muscle mass as well as low muscle strength and low physical performance.[6] The European Working Group on Sarcopenia in Older People consensus definition of sarcopenia is based on three stages: the presarcopenia stage involves low muscle mass with normal muscle strength and physical performance; the sarcopenia stage involves low muscle mass and either diminished muscle strength or physical performance; and severe sarcopenia combines all three factors.[6] Several pathophysiological overlaps between sarcopenia and frailty have been observed.[7] Thus, age-related loss in muscle mass and strength are a major component in the development of frailty in the elderly.[8,9] Moreover, frailty is associated with a decline in muscle mass and quality and a parallel increase in fat mass (FM).[10] Measurement of body composition, including FM and muscle mass in older populations provide important information about their nutritional status. Therefore, the understanding of the body composition of frail elderly populations is an important part of clinical assessment with a goal of optimal prevention and treatment strategies.

Dual-energy X-ray absorptiometry (DXA) is an accepted method for the estimation of whole-body and segmental body fat and fat-free mass (FFM), which includes lean soft tissues and bone minerals.[11–13] However, DXA has disadvantages for use in clinical settings, such as the high cost of equipment, risk of radiation exposure and lack of access to instruments. For clinical use, bioelectrical impedance analysis (BIA) has been used as an attractive alternative method.[4,14,15] BIA is a portable, non-invasive, easy to use and convenient method for the patient, and it is also relatively inexpensive compared with other methods.[16] Of the BIA devices developed over the years, segmental multi-frequency (SMF)-BIA devices have advantages

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over single-frequency BIA devices (50 kHz).[17–19] SMF-BIA avoids the problems encountered in single-frequency BIA by employing both low- and high-frequency electric currents.[20] In recent years, SMF-BIA has been shown to be valid in the estimation of body composition using DXA as a reference standard.[21–23] However, these results were obtained from analysis of healthy populations.

To our knowledge, SMF-BIA has not been evaluated in the assessment of total and appendicular body composition in a specifically targeted frail elderly population. Therefore, the aim of this study was to examine the accuracy of SMF-BIA for the assessment of whole-body and appendicular body composition using DXA as a reference method in frail Japanese women aged 75 years and older.

MATERIALS AND METHODS

Subjects

The subjects were 129 community-dwelling Japanese frail older women with a mean age of 80.9 years (range, 75–89 years). The study population was recruited from participants in the Frailty Intervention Trial (clinical trials registry, number: JMA-IIA00069). The baseline assessment was conducted on 1835 women aged 75 and older at the Tokyo Metropolitan Institute of Gerontology. Three hundred thirty-one were defined as frail, according to Fried's frailty phenotype with the presence of three or more of following criteria: weight loss, weakness, exhaustion, slowness and low physical activity.[1] In the present study, the five different components of the frailty indicators were evaluated as: (1) weight loss: either, answering 'yes' to the question, 'In the last 6 months, have you lost $>2\sim3$ kg unintentionally?' or a body mass index (BMI) <18.5; (2) weakness: hand grip strength <19.0 kg; (3) slowness: usual walking speed <1.10 m/s; (4) exhaustion: answering 'yes' to at least one of two questions, 'I felt that everything I did was an effort' or 'I could not get going'; (5) low physical activity: answering 'true' to at least three of the following four statements, 'I regularly take walks less than once a week,' 'I do not exercise regularly,' 'I do not actively participate in hobbies or lessons of any sort,' and 'I do not participate in any social groups for elderly people or volunteering.' Two hundred (60.4%) of the frail older women were excluded because they were classified into the exclusion criteria or declined participation. The exclusion criteria were: (1) severe knee or back pain; (2) severely impaired mobility; (3) impaired cognition (Mini-Mental State Examination score <24); (4) missing baseline data; and (5) unstable cardiac conditions, such as ventricular dysrhythmias, pulmonary oedema or other musculoskeletal conditions. Of a total of 131 frail older women who participated in the intervention study, body composition was measured in 129 subjects, using SMF-BIA and DXA. The anthropometric assessment of the subjects was conducted at the Tokyo Metropolitan Institute of Gerontology. The participants read and signed the informed consent forms that were approved by the institutional review board before testing. The Clinical Research Ethics Committee of the Tokyo Metropolitan Institute of Gerontology approved the study protocol.

Experimental design

The study model was a cross-sectional analysis of baseline data from the Frailty Intervention Trial. The subjects were instructed to refrain from exercise for 12 h and to refrain from eating for 3 h and drinking for 1 h bfore the measurements.[24] Subject body composition was measured by SMF-BIA and DXA. Both investigations were performed on the same day 2 h apart.

Anthropometric measurements

With the subjects wearing light clothes and no shoes, body weight was measured to the nearest 0.01 kg using DXA equipment, and height was determined to the nearest 0.1 cm using a fixed-wall-scale measuring device. BMI was calculated as body weight in kilograms divided by height in metres squared. The calf circumference was measured at the point of greatest circumference.

Dual-energy X-ray absorptiometry (DXA)

As a reference method, DXA (QDR-4500 A scanner; Hologic, Waltham, MA, USA) was used for the measurement of whole and regional body composition, including FM, lean soft tissue mass (LM), bone mineral content and bone mineral density. The subjects were positioned for whole-body scans according to the manufacturer's protocol. The subjects lay in a supine position on the scanner table with their limbs close to their bodies. Their body compositions were analysed manually using DXA analysis software (version 9.03 D; Hologic, Waltham, MA, USA). The segmental analyses of the total body into arm, leg and trunk segments were separated manually with anatomical landmarks by the DXA analysis software. Appendicular skeletal muscle mass[25] was calculated as the sum of the LM of both the right and left arms and legs, with the assumption that all non-fat and non-bone tissue was skeletal muscle. Appendicular muscle index was defined as ASM/body height.[23] The subjects were measured while wearing only a standard light cotton shirt to minimise clothing absorption. The DXA machine was calibrated daily against a spine phantom supplied by the manufacturer before testing. In addition, weekly calibration procedures were performed on a density step phantom. The precision error for bone mineral density and bone mineral content were 0.20–0.77% for the spine phantom. Our laboratory assessment of seven subjects demonstrated that the coefficients of variation for FM, LM and bone mineral content with repeated examinations were $<3.0\%$.

Segmental multi-frequency bioelectrical impedance analysis (SMF-BIA)

SMF-BIA was performed with a body composition analyser (InBody 720, Biospace Co. Ltd, Soul, Korea). A tetra-polar 8-point tactile electrode system was used. The system separately measured the impedance of the subjects' right arm, left arm, trunk, right leg and left leg at six different frequencies (1, 5, 50, 250, 500 and 1000 kHz) for each body segment. In accordance with the manufacturer's guidelines, subjects wiped the bottom of their feet with a proprietary electrolyte tissue before standing on the electrodes embedded in the scale platform of the respective analysers. The subjects were instructed to stand upright and to grasp the handles of the analyser, thereby providing contact with a total of eight electrodes (two for each foot and hand). In our study, the within-day coefficient variances for six different frequencies evaluated in nine subjects were 0–1.9%. Proprietary equations from the manufacturer were used to estimate whole and regional body composition variables.

Statistical analysis

The data are expressed as means, s.d., and range (minimum-maximum). A paired Student's *t*-test was used to compare the difference in body composition measurements between the SMF-BIA and DXA. To assess the agreement in body composition parameters of whole-body measurements of FM and LM and appendicular measurements of FM and LM as measured by SMF-BIA and DXA, linear regression and Bland–Altman analyses were conducted. Simple linear regression analyses were performed with DXA body composition parameters as the dependent variable to determine whether the regression line differed significantly from the line of identity. In the Bland–Altman plots,[26] the systematic bias was calculated as the mean difference between methods, and the 95% limits of agreement were calculated as the bias ± 2 s.d. of the differences between methods. As there was evidence of proportional bias for body composition parameters, a Pearson's correlation was performed to quantify the bias observed in the Bland–Altman plots. Multiple regression analysis was performed to determine physical variables that influenced the bias of appendicular LM between DXA and SMF-BIA. The independent variables were age, body weight, height and appendicular LM as determined by DXA. Statistical analyses were performed using the IBM SPSS software version 20 (SPSS Inc., Chicago, IL, USA) and the SigmaPlot software version 12.0 (Systat Software Inc., Chicago, IL, USA). For all tests, statistical significance was set at $P<0.05$.

RESULTS

The characteristics of the frail older women subjects are described in Table 1 with means $\pm$ s.d. and ranges. Table 2 describes the body composition parameters obtained by using SMF-BIA and DXA. The means of the body composition parameters estimated by SMF-BIA and DXA were significantly different ($P<0.01$), except for the segmental FM in both legs ($P>0.05$).

Figure 1 displays the results of simple linear regression analyses for whole-body FM and LM, in addition to the appendicular FM and LM parameters as determined by SMF-BIA and DXA. The correlations between SMF-BIA and the body composition parameters estimated by DXA for whole-body FM and LM and appendicular FM were high ($r > 0.9$, all $P < 0.001$). High coefficients of determination (R^2) for whole-body FM ($R^2 = 0.94$, s.e. of estimate (SEE) = 1.2 kg or 8%), whole-body LM ($R^2 = 0.85$, SEE = 1.4 kg or 6%) and appendicular FM ($R^2 = 0.82$, SEE = 1.1 kg or 15%) between SMF-BIA and DXA were observed. The R^2 coefficient for appendicular LM was moderate ($R^2 = 0.76$, SEE = 0.8 kg or 6%).

In addition, agreements between the two methods were assessed using Bland–Altman plots at the individual level (Figure 2). There was a narrow limit of agreement on the Bland–Altman plots for the whole-body FM and LM and the appendicular FM and LM measurements. Almost all individual plots were within the 95% limit of agreement (mean difference ± 2 s.d.). There was systematic (constant) bias (that is, DXA minus SMF-BIA) with the overestimation of whole-body FM (bias = − 1.2 kg, 95% confidence interval (CI) = 1.5 to − 0.1) and the underestimation of whole-body LM (bias = 2.1 kg, 95% CI = 1.8–2.3) by SMF-BIA. Proportional bias was noted for whole-body FM measurement, with overestimation of the whole-body FM (SMF-BIA) increasing with increasing whole-body FM ($r = -1.42$, $P < 0.01$). However, the Bland–Altman plots indicated no significant proportional bias in whole-body LM measurement ($r = 0.08$, $P = 0.338$). Similarly, the appendicular parameters were systematically biased, with the overestimation of appendicular FM (bias = − 0.3 kg, 95% CI = − 0.5 to − 0.1) and the underestimation of whole-body LM (bias = 1.5 kg, 95% CI = 1.4–1.7) by SMF-BIA. In contrast, the Bland–Altman plots indicated no significant proportional bias in appendicular FM measurement ($r = 0.07$, $P = 0.413$). In addition, proportional bias was noted for appendicular LM measurement, with SMF-BIA tending to underestimate the appendicular LM in the lower range ($r = -1.42$, $P < 0.01$).

In a multiple regression analysis, age ($\beta = 0.051$), body weight ($\beta = -0.055$), height ($\beta = -0.091$) and appendicular LM as determined by DXA ($\beta = 0.302$) were significant contributors to the appendicular LM bias between DXA and SMF-BIA (all, $P < 0.05$) (data not shown). The R^2 in the multiple regression model was 0.421, indicating that 42.1% of the variability in the appendicular LM bias was explained by all variables ($P = 0.001$).

Table 1. Characteristics of the subjects

	Mean ± s.d.	*Range*
Age, years	80.9 ± 2.9	75.0–89.0
Body weight, kg[a]	48.5 ± 8.2	29.2–72.4
Height, cm	146.4 ± 6.0	132.2–161.8
BMI, kg/m^2	22.6 ± 3.5	15.6–31.4
<18.5	32 (24.8)	
18.5–24.9	80 (62.0)	
⩾25.0	17 (13.2)	
Calf circumference, cm	32.4 ± 3.0	25.7–41.3
<31.0	46 (35.7)	
Whole-body bone mineral content, g	1111.1 ± 254.0	978.1–1880.1
Whole-body bone mineral density, g/cm^2	0.75 ± 0.10	0.59–1.37

Abbreviation: BMI, body mass index.
Values are means ± s.d., number (%).
[a]Weight derived from whole-body mass measurement by dual X-ray absorptiometry.

DISCUSSION

To our knowledge, this is the first investigation to compare the assessment of whole-body and appendicular body composition from SMF-BIA to DXA device-based measurements in a community-dwelling elderly population of frail women Japanese aged 75 years and older. In particular, our study examined the accuracy of SMF-BIA in the heterogeneous population. Our findings indicate that there was good agreement between the two methods for the estimation of whole-body and appendicular body composition in frail older women subjects, but SMF-BIA underestimated LM and overestimated FM relative to DXA. Moreover, the Bland–Altman plots at the individual level demonstrated non-proportional bias for whole-body LM and appendicular FM.

Table 2. Body composition parameters as determined by DXA and SMF-BIA

Body composition parameters	*DXA*		*SMF-BIA*		*Difference*[a]	
	Mean ± s.d.	*Range*	*Mean ± s.d.*	*Range*	*Mean ± s.d.*	*P-value*[b]
Whole-body measurement						
FM, kg	14.7 ± 5.1	4.4–30.3	16.0 ± 5.7	4.2–33.6	− 1.2 ± 1.5	0.001
LM, kg	32.7 ± 3.6	24.1–42.0	30.6 ± 3.5	23.0–41.5	2.1 ± 1.4	0.001
Percentage of FM, %	29.6 ± 5.9	13.2–41.8	32.0 ± 7.0	12.6–49.7	− 2.5 ± 2.8	0.001
Segmental body mass measurement						
Right arm FM, kg	1.0 ± 0.4	0.3–2.6	1.7 ± 0.5	0.4–3.0	− 0.2 ± 0.2	0.001
Left arm FM, kg	1.0 ± 0.4	0.3–2.5	1.2 ± 0.5	0.4–3.1	− 0.2 ± 0.2	0.001
Trunk FM, kg	6.7 ± 2.7	1.6–15.5	7.6 ± 3.1	0.9–17.1	− 0.8 ± 1.0	0.001
Right leg FM, kg	2.6 ± 2.0	0.6–5.0	2.9 ± 0.8	0.9–4.7	0.1 ± 0.5	0.177
Left leg FM, kg	2.6 ± 0.9	0.6–4.9	2.6 ± 0.8	0.9–4.7	0.0 ± 0.5	0.816
Appendicular FM, kg	7.2 ± 2.6	1.8–13.6	7.5 ± 2.5	2.6–15.2	− 0.3 ± 1.1	0.001
Right arm LM, kg	1.6 ± 0.2	1.1–2.2	1.4 ± 0.3	0.7–2.1	0.2 ± 0.2	0.001
Left arm LM, kg	1.6 ± 0.2	1.0–2.2	1.4 ± 0.3	0.70–2.1	0.2 ± 0.2	0.001
Trunk LM, kg	16.4 ± 2.0	11.7–21.7	13.7 ± 2.0	9.0–18.2	2.7 ± 1.0	0.001
Right leg LM, kg	5.1 ± 0.6	3.8–6.9	4.5 ± 0.8	2.9–7.0	0.6 ± 0.4	0.001
Left leg LM, kg	5.1 ± 0.6	3.7–7.1	4.5 ± 0.8	3.0–7.2	0.6 ± 0.4	0.001
Appendicular LM, kg	13.4 ± 1.6	10.0–18.0	11.9 ± 2.0	7.7–18.3	1.6 ± 0.9	0.001
Appendicular skeletal muscle index, kg/m^2[c]	6.3 ± 0.7	4.8–8.1	5.5 ± 0.7	4.0–7.9	0.8 ± 0.5	0.001

Abbreviations: DXA, dual X-ray absorptiometry; FM, fat mass; LM, lean soft tissue mass; SMF-BIA, segmental multi-frequency bioelectrical impedance analysis. Values are means ± s.d. [a]Mean difference between DXA and BIA (that is, DXA minus SMF-BIA), mean (s.d.) [b]P-values for paired t-test between DXA and SMF-BIA. [c]Appendicular lean soft tissue mass (kg)/height (m^2).

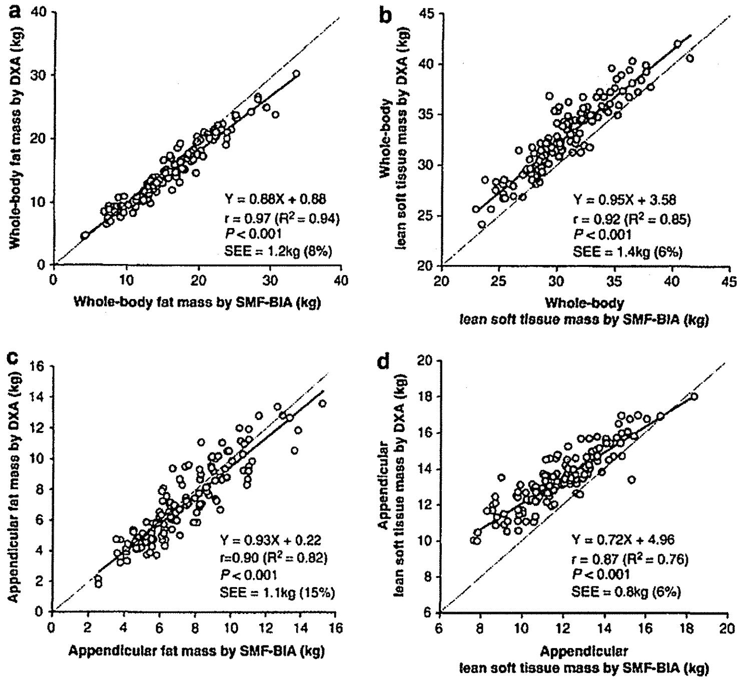

Figure 1. Linear regression between SMF-BIA and DXA. (**a**) Whole-body fat mass, (**b**) whole-body lean soft tissue mass, (**c**) appendicular fat mass and (**d**) appendicular lean soft tissue mass. SEE, s.e. of estimate; solid lines, regression line; dotted lines, identity line.

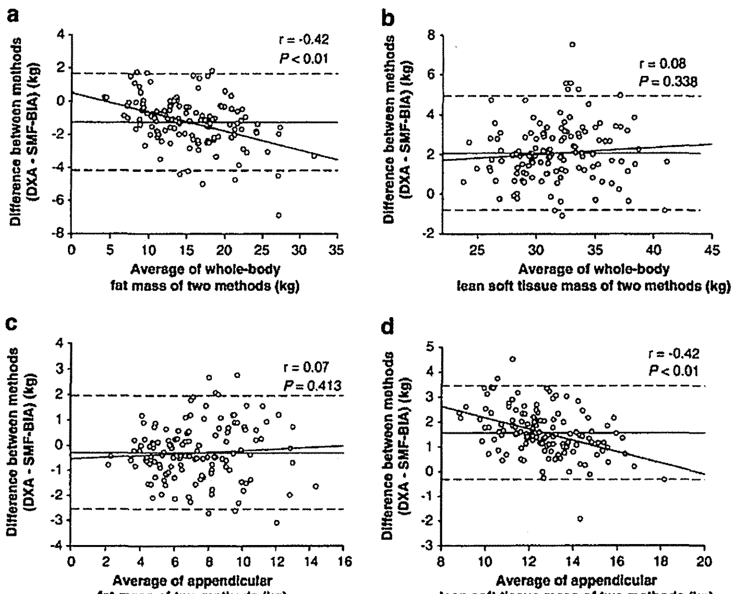

Figure 2. Bland–Altman plots comparing: (**a**) whole-body fat mass, (**b**) whole-body lean soft tissue mass, (**c**) appendicular fat mass and (**d**) appendicular lean soft tissue mass by SMF-BIA and DXA. Solid lines, bias (mean difference); dotted lines, limits of agreement (mean difference ± 2 s.d.).

Previous studies have demonstrated that SMF-BIA provides a valid estimation of body composition using DXA as a reference standard.[21–23] Ling *et al.*[22] reported that SMF-BIA (InBody 720, Biospace Co. Ltd) had a good agreement with DXA (the same device as used in this study, the Hologic QDR-4500A) in the assessment of total body composition of 484 general middle-aged

Dutch subjects. In that study, the coefficients of determination for whole-body FM ($R^2 = 0.94$) and whole-body FFM ($R^2 = 0.95$) in linear regression equations with adjusted gender was significantly greater. Anderson *et al.*[18] found that whole-body FM ($R^2 = 0.95$) and LM ($R^2 = 0.88$) measured with SMF-BIA in 25 women aged 18–45 years had a high correlation and small SEE when using DXA (Lunar DPX-iQ2288) as a reference standard. Houtkouper *et al.*[27] reported that an SEE of 2.0–2.5 kg in men and 1.5–1.8 kg in women is considered ideal in the FFM as calculated by the BIA equations. Whole-body LM, as measured by DXA, is bone mineral-free LM (total FFM − total bone mineral content). Previous studies have reported good correlations between DXA-derived LM and skeletal muscle mass when MRI was used as the criterion ($r = 0.94$–0.97).[11,28–30] Chen *et al.*[11] reported that DXA-derived LM was highly correlated with MRI-derived whole-body skeletal muscle mass ($r = 0.94$) in 101 older women aged 50–79 years. Our study found that the Bland–Altman plots indicated no significant proportional bias in whole-body LM measurement. Therefore, SMF-BIA may provide a valid method for assessing whole-body body composition, particularly for the whole-body skeletal muscle mass, assuming that the LM from DXA is skeletal muscle mass in the frail older women.

We found in our study that SMF-BIA underestimated whole-body LM and overestimated whole-body FM relative to DXA (see Figure 1). In our study, a subanalysis of the FFM indicated that SMF-BIA underestimated the whole-body FFM (bias, 1.2 kg, 95% CI, 0.9–1.5) (data not shown). These results are consistent with a previous study. The method's bias indicated that SMF-BIA underestimated whole-body FFM and overestimated whole-body FM in women with a mean age of 61.2 ± 6.4 years and a mean BMI of 26.1 ± 4.4 kg/m^2.[22] However, Völgyi *et al.*[31] demonstrated the validity of SMF-BIA compared with DXA (GE Lunar Prodig) in 86 Finnish women aged 37–81. These researchers observed that SMF-BIA overestimated FFM in normal and overweight groups by 3.2 and 2.9 kg, respectively. Discrepancies between studies are most likely due to differences in the specificity of subject populations (for example, age, gender, body shape, ethnic groups). In our study, SMF-BIA was used to analyse body composition (InBody 720 device). The measurement of FFM with an InBody 720 device was estimated as TBW/0.73. In addition, FM was calculated as the difference between total body weight and FFM. However, FFM hydration of 0.73 has been shown to be remarkably stable in healthy individuals.[32] The change of FFM hydration has been controversial because of the presence of systematic differences in regards to growth, aging, adiposity, gender, body size and acute or catabolic illness.[33] Heymsfield *et al.*[34] suggest that FFM hydration increases slightly in old age, resulting in a slight, systematic decrease in FFM density. Physiological ageing is associated with several changes that may affect water balance and expose older adults to the risk of dehydration. These changes include a decline in renal function and thirst perception and a reduction of TBW.[35] Thus, SMF-BIA may lead to underestimation of FFM with DXA in the dehydrated state. The extracellular water to intracellular water (ECW/ICW) ratio is a parameter of cellular hydration state. The ECW/ICW ratio ranges from 0.80–1.20 in healthy adults.[33] However, elderly patients displayed chronic cellular dehydration associated with relative extracellular overhydration, which was not evidently related to ageing because healthy elderly volunteers and healthy adults had similar water space distributions.[36] Notably, overhydration is a frequent consequence of organ failures such as kidney impairment, heart failure, chronic obstructive pulmonary disease and liver disease.[37–41] Basrends *et al.*[38] reported that chronic obstructive pulmonary disease patients with extreme FFM wasting are characterised by an increased ECW/ICW ratio despite the relative sparing of FM. Therefore, SMF-BIA is dependent on proprietary regression equations to estimate conductor volume (for example, FFM). As these equations have been formulated from healthy populations, they may contribute to error in body composition measurements in specific populations.

This study measured coefficients of determination for appendicular FM ($R^2 = 0.82$) and appendicular LM ($R^2 = 0.76$) between SMF-BIA and DXA. Our findings are supported by previous studies that indicate SMF-BIA has excellent agreement in the measurement of the segmental LM as both the right and left arms when using DXA as the reference method (interclass correlation coefficient ⩾0.83).[22] Anderson *et al.*[21] found that the measurement of appendicular LM by SMF-BIA devices (InBody 720 and InBody520) was moderately to strongly associated ($R^2 = 0.62$–0.87) with DXA in men and women aged 18–49. In our study, the appendicular FM was in better agreement between SMF-BIA and DXA than the appendicular LM. To our knowledge, no comparative studies exist that evaluate the accuracy of assessing the segmental body composition at the individual level by SMF-BIA (InBody 720 device) in a population of elderly subjects.

In the present study, despite the significant SMF-BIA overestimation of appendicular FM and the underestimation of appendicular LM with DXA, the Bland–Altman plots indicated a non-proportional bias in appendicular FM measurement. However, we observed a proportional bias in appendicular LM, with SMF-BIA tending to underestimate appendicular LM in the lower range (see Figure 2). These results are in contrast to the results of previous studies evaluating SMF-BIA in healthy adults. Anderson *et al.*[21] found a non-proportional bias for appendicular LM as measured by two types of SMF-BIA devices in 25 women with a mean BMI of 26.1 kg/m^2 and aged 18–45. These different findings are probably the result of methodological differences, with the previous data confined to small subject numbers dispersed over a wide age range. In particular, the findings may be the result of a combination of physical factors such as different body sizes. Bedogni *et al.*[17] found that eight-polar SMF-BIA was precise and gave accurate estimates of TBW in healthy subjects with a BMI range from 18.5–29.9 kg/m^2. In our study population, the prevalence of underweight subjects (BMI values below 18.5 kg/m^2) in the frail older women population was 24%, with a TBW-to-body weight ratio of 44.8%. Thus, the Fried's definition includes weight loss criteria.[1] We found that in multiple regression analysis, the age, body weight, height and appendicular LM determined by DXA were associated with the bias of appendicular LM between DXA and SMF-BIA among the frail older women subjects. Therefore, SMF-BIA may tend to underestimate appendicular LM in the lower range as underweight when using DXA as the reference method.

Our study has some limitations. First, although DXA is a validated 'gold standard' reference method, it is still only an estimate of body composition. Therefore, validation against DXA is not the most accurate analysis possible.[42–44] However, it is included as a reference method because of its wide availability and previous validation. Second, it is likely that the focus of our study on frail older women in communities may not be applicable to populations in nursing homes, hospitals and other institutions. Finally, the hydration status of the study subjects was not determined before the body composition assessment.

In conclusion, the present study confirmed that SMF-BIA had acceptable accuracy in the estimation of whole-body and appendicular FM and LM in frail women subjects aged 75 years and older, although SMF-BIA underestimated LM and overestimated FM relative to DXA. In addition, the individual level accuracy revealed non-proportional bias for whole-body LM and appendicular FM measurement. This may suggest that SMF-BIA can be used in intrapersonal comparisons, with the understanding that SMF-BIA measurements will include errors. Our findings indicate that SMF-BIA would be useful for community-based research in measuring body composition in frail older women populations. Future research efforts should examine the validity of the SMF-BIA models in predicting body composition changes in frail elderly populations with diverse body shapes and compositions.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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ORIGINAL ARTICLE: EPIDEMIOLOGY, CLINICAL PRACTICE AND HEALTH

Effects of a comprehensive intervention program, including hot bathing, on overweight adults: A randomized controlled trial

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Aim: The objective of this study was to evaluate the effects of a comprehensive overweight intervention program, which utilizes hot bathing, on overweight, community-dwelling middle-aged and older adults in a randomized controlled trial.

Methods: The program was carried out in a hot bath facility and included 66 community-dwelling middle-aged and older Japanese adults (mean age 61.6 years, SD 7.5, 77.3% were women). The participants were randomly assigned to an exercise, diet and hot bathing intervention group (group A), exercise and diet intervention group (group B), a hot-bathing intervention group (group C) and a control group (group D). The participants in groups A and B participated in a comprehensive intervention program (including exercise and diet classes) twice a week for 3 months, and groups A and C had hot bathing.

Results: After 3 months, the participants in group A showed a reduction in weight, abdominal circumference, body mass index and body fat percentage compared with the other intervention groups. And the lower extremity function (i.e. walking speed) had greater improvement in the participants in groups A and B compared with groups C and D. In group C, in which only hot bathing was the intervention, there were no significant improvements in measurement items.

Conclusions: Our study provides preliminary evidence that a comprehensive intervention program, including hot bathing, is useful for community residents with a tendency toward overweight. **Geriatr Gerontol Int 2013; 13: 638–645.**

Keywords: hot bath, intervention program, middle-aged and older adults, overweight, randomized controlled trial.

Introduction

The increasing prevalence of obesity, which might lead to diabetes and cardiovascular disease, is an important global issue in middle-aged and older adults.[1–3] In Japan, 28.6% of men and 20.6% of women are obese or overweight, and the prevalence rate of obesity has increased on a yearly basis.[1] Approximately half of these obese individuals, however, are actively exercising to lose weight.[4] Thus, the development of an effective intervention program could contribute to reduce the prevalence of obesity.

In recent years, the Most Obesity kNown Are Low In Sympathetic Activity (MONA-LISA) hypothesis has proposed that degeneration of the sympathetic nervous system (SNS) by the effect of long-term inactivity on lipid metabolism and energy consumption systems leads to the onset or progression of obesity.[5,6] As the sympathetic branch of the nervous system contributes significantly to coordinating energy homeostasis, the alteration of SNS activity is widely assumed to promote the onset and development of obesity.[7] Sympathetic activity is also altered by food intake, and a previous study found a highly significant inverse relationship between sympathetic activity and spontaneous food intake.[8] Therefore, it is argued that sympathetic activity is strongly associated with excessive weight gain and the development of obesity.

Additional interventions that activate the SNS could therefore effectively enhance the effects of traditional

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exercise and dietary modifications for weight loss. A relatively simple way to activate the SNS is to take a hot bath at over 42°C or sauna.[9–11] Previous studies have shown that taking a hot bath or sauna has various positive effects on diabetes,[12] autoimmune disease,[13,14] skin disease[15,16] and osteoarthritis[17,18] because of the elevation in body temperature. We therefore hypothesized that an intervention consisting of exercise and dietary modification for weight loss, which also included bathing in hot water, could have synergistic effects on aging obese and overweight individuals. Furthermore, it is unclear that an intervention consisting exclusively of hot bathing independently contributes to the weight reduction in obese and overweight individuals. If so, hot bath regimens might be beneficial for aging obese and overweight individuals who cannot participate in traditional dietary and exercise programs because of physical or psychosocial reasons. Previous studies have reported little regarding the positive effects of comprehensive programs including healthy lifestyle education, exercise, and hot bathing for middle-aged women and white-collar employees using a randomized controlled trial.[19,20] However, it is uncertain if there are synergistic effects of hot bathing on overweight individuals.

Therefore, we carried out a randomized controlled trial to show: (i) the effect of the comprehensive intervention program composed of exercise, diet and hot bathing on overweight individuals with risk factors for cardiovascular diseases, such as metabolic syndrome; and (ii) to test whether hot bath intervention had any independent positive effects on overweight individuals.

Methods

Participants

The participants were recruited from community-dwelling middle-aged and older adults by using a community newsletter; 127 individuals participated in a baseline assessment and agreed to participate in the study. The exclusion criteria prevented the participation of those who: (i) had major severe conditions or injury (e.g. stroke, heart disease or bone fracture) within a 3-month period before the study; (ii) had mental disorders or cognitive impairment; and (iii) showed evidence of use of or addiction to psychoactive substances or tranquilizers. Additionally, individuals who were overweight (a body mass index [BMI] of more than 25)[21] or who showed any two of the following clinical findings were included: (i) raised triglycerides >150 mg/dL or who were receiving treatment for this specific lipid abnormality; (ii) reduced HDL cholesterol <40 mg/dL or who were receiving treatment for this specific lipid abnormality; (iii) raised blood pressure (BP), systolic BP >130 mm Hg or diastolic BP >85 mm Hg, or treatment of previously diagnosed hypertension; and (iv) increased abdominal circumference >85 cm in men and >90 cm in women.[21] We selected 66 participants (mean age 61.6 years, SD 7.5, 77.3% were women).

Written informed consent was obtained from each participant. The study was carried out in accordance with the ethical standards set forth by the Declaration of Helsinki (1983). The study was approved by the ethics committee of Tokyo Metropolitan Institute of Gerontology.

Study design

The study was a four-arm, parallel group, randomized control trial. The participants were randomly assigned to either an exercise, diet and hot bathing intervention group (group A; mean age 59.9 years, SD 8.9); an exercise and diet intervention group (group B; mean age 61.0 years, SD 7.3); a hot bathing intervention group (group C; mean age 64.7 years, SD 7.6); or a monthly health class that served as a control group (group D mean age 61.3 years, SD 6.3). One week after a 3-month intervention period, the participants received a follow-up assessment.

Intervention

All assessments and interventions were held in a hot bath facility. The participants in groups A and B exercised for 75 min twice a week for 3 months under the supervision of exercise, health and medical staff (consisting of a training instructor, physical therapist and nurse). Before exercise, the participants were assessed for BP and health conditions using a health check sheet. If any of the checklist items were positive, the participants were prohibited from joining the exercise class. The participants who had a systolic BP above 180 mm Hg or a diastolic BP above 110 mm Hg were also prohibited from participating in the exercise class.

The exercise period consisted of several stages. First, the participants did warm-up exercises for a period of 10 min. Then, the participants carried out a muscle-strengthening routine (10 different resistance training, 2 sets of 12 repetitions) and exercise using resistance bands (Thera-Band, Hygenic Corporation, Akron, OH, USA) for a period of 40 min. Afterwards, the participants did balance and aerobic exercise training for a period of 20 min. Finally, the participants were instructed to cool down for a period of 5 min. During the exercise, the participants were asked to carry out a subjective intensive exercise (ratings of perceived exertion [RPE]), and we confirmed that participants' intensive exercise corresponded to a rating of "somewhat hard" to "hard" (13–15) according to the Borg conventional (6–20 points) scale.[22] Exercise classes comprised a total of 17 lessons.

Dietary modification consisted of a series of four 75-min nutrition guidance classes that were carried out under the supervision of a nationally registered dietitian. The classes involved a comparison of the participants' dietary intake with a healthy, balanced dietary intake, and encouraged the participants' to increase their awareness of a healthy diet through using a food model. In addition, the participants discussed problems of dietary habits and settled issues in a group setting. Nutrition guidance classes comprised a total of five lessons.

In group A, the participants took an artificial hot bath for 20 min (bath temperature at 42°C in a half bath; water level at the chest while seated)[19,20] after exercise or dietary modification. As a safety precaution, their blood pressure was monitored before and after the bath to ensure safe management.

The participants belonging to groups C and D took classes that had little conceptual relationship to the present study, such as geriatric diseases once a month. The members of group C were also given a hot bath twice a week for 3 months, similar to group A.

Measurement items

Morphometric assessment (main outcomes)

The body weight, body fat percentage and BMI were measured using a Body Composition Analyzer using the impedance method (InBody 720; Biospace, Seoul, Korea).[23] Abdominal circumference (AC) was measured using two separate measurers level with the umbilicus using an anthropometric tape. A casual BP was determined on the right arm after 3 min of seated rest.

Medical histories, physiological data and blood tests

Participants were interviewed to assess their medical history (use of outpatient care, history of hospitalization, medication use and history of chronic medical conditions were used for exclusion criteria). Non-fasted blood samples were collected from the seated participants. Blood cell counts were obtained and routine tests of biochemical markers,[24] nearly unaffected by a meal (excluding blood glucose or triglyceride), were carried out using a sequential autoanalyzer.

Physical ability

The peak grip strength of the dominant hand was measured twice with a handheld Smedley-type dynamometer, and the highest value was recorded as the participant's maximum grip strength. In the Timed Up & Go test (TUG), the participants were asked to sit on a chair and were then asked to stand up from the chair, walk forward to a marker at a distance of 3 m from the chair, turn around the marker, return to the chair and sit down as fast as possible. The elapsed time of the completion of this procedure of standing, walking and finally sitting on the chair was measured in seconds. This test was carried out twice, and the fastest speed was recorded.[25] In the Multiple-Sit-To-Stand test (MSTS), the participants were asked, while sitting at the front of a chair, to rise until they reached full-knee extension and then sit back down five times as fast as possible. This test was carried out twice, and the fastest time was recorded.[26] The Stepping Test for 20 s (ST) was carried out using bilateral back and forth alternate stepping. The participants stood behind a line, then stepped over the line (forwards) and then stepped back alternately for 20 s as fast as possible. This test was carried out once. The number of steps taken in 20 s was recorded.

Quality of life measurements

Quality of life (QOL) was measured using the psychometrically sound Medical Outcomes Study Short-Form (SF-8; range: 0 worst, –100 best) with norm-based scoring methods used to calculate the mental and physical QOL summary scores.[27] The WHO-Five Well-being Index (WHO-5) was used to measure health-related conditions. The WHO-5 scale contains five items, which are all positively worded. A maximum score of "25" indicates optimal well-being, whereas a score of "0" indicates minimal well-being.[28]

Statistical analysis

The measurement variables are shown in terms of means and SD or percentages, as appropriate according to each variable. On the basis of the status of the four groups at baseline, multivariate analysis of variance and χ^2-tests were carried out to compare the results of the outcome measures among the four groups. The intervention effects were assessed by repeated measure analysis of variance (ANOVA), adjusted for age and sex. ANOVA analyses were carried out in accordance to the intention-to-treat principle; that is, all the randomized participants were included in the analyses, with missing values substituted with carried baseline measured variables. The Kolmogorov–Smirnov test and logarithmic transformation were used to test the normality of distributions and convert non-normal distributions to normal distribution. When significant interaction was identified, we carried out post-hoc analysis. All statistical analyses were computed using the PC-compatible version of SPSS 17.0 (SPSS, Chicago, IL, USA).

Results

A scheme of the study design is presented in Figure 1, and Table 1 shows the results of baseline measurements of the four groups. The groups were not significantly

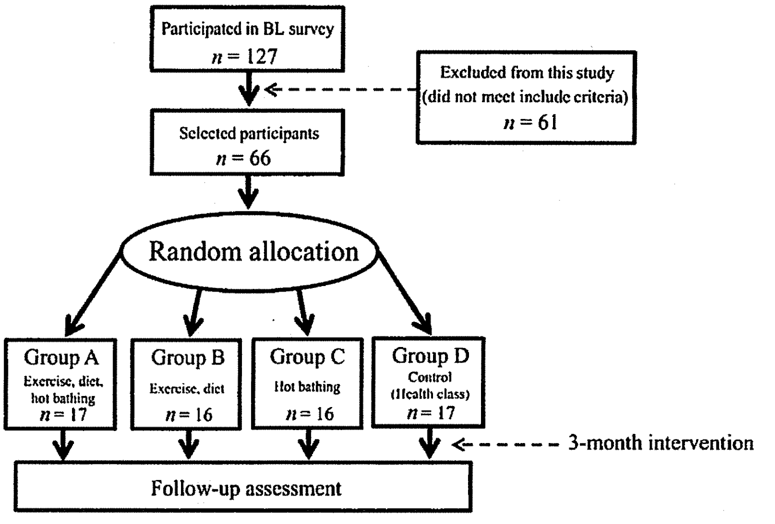

Figure 1 Scheme of the study design. BL, baseline

Table 1 Characteristics of study participants at baseline

Variables	Group A $n = 17$	Group B $n = 16$	Group C $n = 16$	Group D $n = 17$	P-value
Sex (% female)	62.5	80.0	81.0	81.0	0.521
Age (years)	59.9 ± 8.9	61.0 ± 7.3	64.7 ± 7.6	61.3 ± 6.3	0.328
Height (cm)	158.8 ± 6.9	153.9 ± 7.0	155.3 ± 7.7	155.0 ± 6.1	0.226
Abdominal circumference (cm)	90.1 ± 7.2	90.3 ± 9.2	91.5 ± 9.3	92.6 ± 8.4	0.832
Weight (kg)	63.6 ± 12.5	60.7 ± 11.4	61.8 ± 7.8	60.8 ± 6.8	0.838
BMI	25.1 ± 3.5	25.5 ± 4.1	25.7 ± 3.5	25.3 ± 2.6	0.962
Body fat percentage (%)	31.5 ± 7.4	33.3 ± 8.5	34.0 ± 9.5	33.9 ± 5.0	0.776
Systolic blood pressure (mmHg)	122.9 ± 14.3	128.5 ± 17.8	133.9 ± 13.8	128.6 ± 21.1	0.355
Diastolic blood pressure (mmHg)	72.0 ± 9.8	74.7 ± 11.4	81.8 ± 12.5	76.3 ± 10.1	0.094
Heart rate (no. times)	71.7 ± 11.7	70.9 ± 8.6	70.3 ± 10.5	71.9 ± 9.9	0.969
Grip strength (kg)	28.6 ± 10.7	26.3 ± 5.8	26.7 ± 6.3	27.3 ± 7.2	0.851
Timed Up & Go test (s)	5.94 ± 0.95	5.42 ± 0.36	5.91 ± 0.72	5.57 ± 0.73	0.132
Multiple-Sit-To-Stand test (s)	8.1 ± 4.6	7.3 ± 1.9	7.7 ± 1.2	7.2 ± 1.1	0.787
Step Test for 20 s (no. times)	13.6 ± 3.1	13.7 ± 2.0	12.6 ± 2.2	13.6 ± 2.0	0.549
WHO-5	17.6 ± 5.0	17.4 ± 4.1	17.2 ± 5.5	16.4 ± 5.4	0.912
SF-8: physical QOL summary scores	47.6 ± 6.3	47.3 ± 7.2	47.0 ± 7.9	48.3 ± 5.7	0.960
SF-8: mental QOL summary scores	50.5 ± 6.1	51.9 ± 5.6	52.7 ± 6.2	50.7 ± 5.8	0.690
Gamma-GTP (IU/L)	24.0 ± 12.7	29.4 ± 19.8	35.2 ± 28.4	32.8 ± 29.8	0.575
Total cholesterol (mg/dL)	211.5 ± 33.3	204.7 ± 34.4	215.6 ± 41.0	205.4 ± 31.4	0.793
HDL cholesterol (mg/dL)	50.1 ± 14.8	52.0 ± 8.1	58.6 ± 17.5	61.9 ± 12.4	0.062
LDL cholesterol (mg/dL)	130.3 ± 23.5	129.8 ± 32.3	134.1 ± 43.1	125.8 ± 32.6	0.919

Values are mean ± SD or percentage of them in the group. Multivariate analysis of variance and χ^2-tests. BMI, body mass index; GTP, glutamyl transpeptidase; HDL, high-density lipoprotein; LDL, low-density lipoprotein; QOL, quality of life; WHO-5, WHO-Five Well-being Index.

different in age, sex, current disease, medication use or other measurement items. One participant who was in group A dropped out for personal reasons, and two participants in group B and C, respectively, were absent from the follow-up assessment.

Figure 2 shows the results of effects at 3 months in the main outcomes. Participants in group A had significantly greater improvements in the main outcome measures, including weight (group A 63.6 ± 12.5 *vs* 61.2 ± 11.5, $P < 0.01$; group B 60.7 ± 11.4 *vs* 60.1

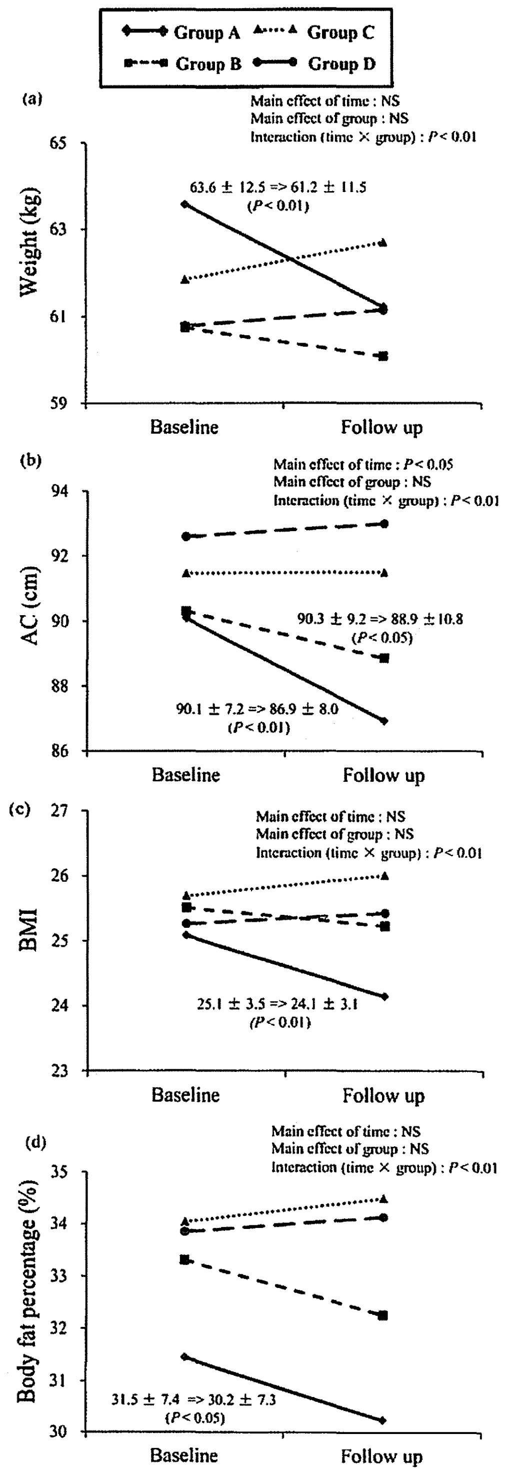

Figure 2 Comparison of main outcome measures (a) weight, (b) abdominal circumference (AC), (c) body mass index (BMI) and (c) body fat percentage before and after intervention among the four groups (the baseline and follow up are shown only for groups that were significantly different between baseline and follow up). NS, not significant.

± 11.9, not significant; group C 61.8 ± 7.8 *vs* 62.7 ± 8.1, not significant; group D 60.8 ± 6.8 *vs* 61.1 ± 6.9, not significant), AC (group A 90.1 ± 7.2 *vs* 86.9 ± 8.0, $P < 0.01$; group B 90.3 ± 9.2 *vs* 88.9 ± 10.8, $P < 0.05$; group C 91.5 ± 9.3 *vs* 91.5 ± 9.6, not significant; group D 92.6 ± 8.4 *vs* 93.0 ± 8.4, not significant), BMI (group A 25.1 ± 3.5 *vs* 24.1 ± 3.1, $P < 0.01$; group B 25.5 ± 4.1 *vs* 25.2 ± 4.2, not significant; group C 25.7 ± 3.5 *vs* 26.0 ± 3.5, not significant; group D 25.3 ± 2.6 *vs* 25.4 ± 2.6, not significant), body fat percentage (group A 31.5 ± 7.4 *vs* 30.2 ± 7.3, $P < 0.05$; group B 33.3 ± 8.5 *vs* 32.3 ± 7.6, $P < 0.1$; group C 34.0 ± 9.5 *vs* 34.5 ± 9.2, not significant; group D 33.9 ± 5.0 *vs* 34.1 ± 5.5, not significant) compared with the other groups (post-hoc analysis that compare before with after intervention). In measures of physical ability, there was a significant time by group interaction for grip strength ($P < 0.05$), TUG ($P < 0.01$), MSTS ($P < 0.01$) and ST ($P < 0.01$). In particular, the TUG, MSTS and ST had greater improvement in groups A and B compared with groups C and D, although groups C and D also improved their physical performance (Table 2). Groups A and B also improved the mean of total cholesterol and gamma-glutamyl transpeptidase (GTP), respectively ($P < 0.05$). Group C had significantly higher levels of total cholesterol compared with the measurements taken before the intervention ($P < 0.05$), and group D had significantly higher levels of gamma-GTP ($P < 0.05$). In group C, in which hot bathing was the only intervention, there were no significant improvements in measurement items.

Discussion

After a 3-month intervention, group A, in which the intervention program consisted of exercise, diet and hot bathing, positively influenced weight reduction more than the interventions in the other three groups. One possible reason for this result is sympathetic activation by the hot bathing, which resulted in body temperature elevation and facilitation of blood circulation and metabolism. A previous study reported that a 12-week exercise intervention improved heart rate recovery and blood pressure associated with SNS activation.[29,30] Thus, exercise intervention could have a beneficial

Table 2 Comparison of various outcome measures before and after intervention among the four groups

Variables		Group A $n = 17$	Group B $n = 16$	Group C $n = 16$	Group D $n = 17$	Time	*P*-value Group	Interaction
Systolic blood pressure (mmHg)	Baseline	122.9 ± 14.3	128.5 ± 17.8	133.9 ± 13.8	128.6 ± 21.1	0.866	0.704	0.630
	Follow up	121.8 ± 14.2	121.7 ± 14.6	126.3 ± 9.9	125.6 ± 16.6			
Diastolic blood pressure (mmHg)	Baseline	72.0 ± 9.8	74.7 ± 11.4	81.8 ± 12.5	76.3 ± 10.1	0.245	0.240	0.051
	Follow up	73.1 ± 10.9	67.7 ± 8.8	75.3 ± 9.7	75.3 ± 10.6			
Heart rate (no. times)	Baseline	71.7 ± 11.7	70.9 ± 8.6	70.3 ± 10.5	71.9 ± 9.9	0.011	0.630	0.156
	Follow up	71.6 ± 7.9	69.4 ± 9.4	66.6 ± 11.2	72.3 ± 8.3			
Grip strength (kg)	Baseline	28.6 ± 10.7	26.3 ± 5.8	26.7 ± 6.3	27.3 ± 7.2	0.617	0.555	0.015
	Follow up	28.7 ± 10.3	28.2 ± 6.5*	26.8 ± 5.8	25.9 ± 7.5*			
Timed Up & Go test (s)	Baseline	5.94 ± 0.95	5.42 ± 0.36	5.91 ± 0.72	5.57 ± 0.73	0.560	$p < 0.01$	$p < 0.01$
	Follow up	3.70 ± 0.65**	3.92 ± 0.55**	5.40 ± 0.71*	5.34 ± 0.65			
Multiple-Sit-To-Stand test (s)	Baseline	8.1 ± 4.6	7.3 ± 1.9	7.7 ± 1.2	7.2 ± 1.1	0.731	0.460	$p < 0.01$
	Follow up	5.4 ± 2.1**	4.8 ± 1.0**	6.9 ± 1.1	6.4 ± 1.2			
Step Test for 20 s (no. times)	Baseline	13.6 ± 3.1	13.8 ± 2.0	12.7 ± 2.2	13.6 ± 2.0	0.078	0.011	$p < 0.01$
	Follow up	17.9 ± 3.8**	18.9 ± 3.0**	14.0 ± 2.9*	14.2 ± 2.2			
WHO-5	Baseline	17.6 ± 5.0	17.4 ± 4.1	17.2 ± 5.5	16.4 ± 5.4	0.497	0.186	0.281
	Follow up	19.6 ± 5.5	16.4 ± 4.9	17.8 ± 3.0	16.2 ± 6.0			
SF-8: physical QOL summary scores	Baseline	48.2 ± 6.1	47.3 ± 7.2	47.0 ± 7.9	48.3 ± 5.7	0.974	0.988	0.153
	Follow up	48.6 ± 4.9	49.6 ± 6.1	51.3 ± 5.0	47.9 ± 6.3			
SF-8: mental QOL summary scores	Baseline	50.8 ± 6.2	51.9 ± 5.6	52.7 ± 6.2	50.7 ± 5.8	0.533	0.892	0.275
	Follow up	53.8 ± 6.7	50.4 ± 7.8	51.5 ± 6.9	50.8 ± 4.6			
Gamma-GTP (IU/L)	Baseline	24.0 ± 12.7	29.4 ± 19.8	35.2 ± 28.4	32.8 ± 29.8	0.749	0.452	0.037
	Follow up	21.7 ± 13.4	24.5 ± 10.1*	34.6 ± 23.9	38.1 ± 39.9*			
Total cholesterol (mg/dL)	Baseline	211.5 ± 33.3	204.7 ± 34.4	215.6 ± 41.0	205.4 ± 31.4	0.331	0.502	0.007
	Follow up	201.0 ± 38.5*	199.8 ± 37.8	229.0 ± 47.0*	205.3 ± 27.5			
HDL cholesterol (mg/dL)	Baseline	50.1 ± 14.8	52.0 ± 8.1	58.6 ± 17.5	61.9 ± 12.4	0.877	0.112	0.084
	Follow up	55.9 ± 14.7	53.5 ± 10.4	60.6 ± 17.2	62.3 ± 12.1			
LDL cholesterol (mg/dL)	Baseline	130.3 ± 23.5	129.8 ± 32.3	134.1 ± 43.1	125.8 ± 32.6	0.866	0.753	0.058
	Follow up	122.7 ± 30.0	121.7 ± 35.7	142.2 ± 50.8	122.3 ± 29.7			

Values are mean ± SD. Repeated measures ANOVA adjusted for age and sex. $*P < 0.05$, $**P < 0.01$: within group. GTP, glutamyl transpeptidase; HDL, high-density lipoprotein; LDL, low-density lipoprotein; QOL, quality of life; WHO-5, WHO-Five Well-being Index effect because of sympathetic involvement. From the standpoint of the MONA-LISA hypothesis, sympathetic activation or maintained sympathetic activation by 42°C baths immediately after exercise would lead to hypermetabolism and thus facilitate weight reduction. In fact, previous studies suggest that 42°C baths enhanced activity of the SNS because of body temperature elevation and increasing circulatory blood flow.[31,32]

These results could also be attributed to increased aspiration activity because of water pressure, and to rising calorie consumption induced by body temperature elevation.[9] In contrast, group C showed no effects on weight reduction or mental and physical function. Although hot bathing has a lot of positive effects as an alternative medicine, our results suggest that hot bathing twice a week for 3 months did not have an independent effect on overweight community-dwelling adults.

Additionally, after a 3-month intervention, groups A and B showed a reduced level of total cholesterol or gamma-GTP. A previous study has reported that exercise might improve saccharometabolism, lipid metabolism and hepatic function.[33] Therefore, the present results of improved total cholesterol and gamma-GTP would not likely be attributed to any synergistic effect of hot bathing and other interventions, but rather to traditional exercise or diet effects.

Groups A and B also showed significant improvement in physical abilities, such as TUG, MSTS and ST, compared with groups C and D. Individuals who are overweight or obese tend to have a reduced frequency of exercise (sedentary lifestyle) and thus might show a decline in their physical abilities.[34,35] Such a decline in physical abilities could cause these individuals to fall into an inactive lifestyle and cause systemic disorders in energy consumption. Conversely, improvement of physical ability could lead to a fitness habit and also reduce the risk of inactivity. However, group A did not show any synergistic effects of hot bathing on physical ability in comparison with group B. Thus, the synergistic effects of hot bathing would likely prove to be of limited effect on weight reduction because of the changes in metabolism.

Japan has a scattering of hot bath (hot spring) facilities that serve as regional resources. Hot bath facilities are also closely related to multifaceted fields of health, medicine and community centers in Japan. Use of a hot bath facility, which contains these diverse aspects and is accessible to the community residents, might promote health self-awareness, similar to the way in which the intervention program was carried out in the present study. It is argued that such kinds of intervention programs would be widely accepted all over Japan.

The present study had some potential limitations. First, considering program generalization, the present study's sample size might be considered small. Despite its small size, however, the present results show that hot bathing had a dependent effect on weight reduction in middle-aged and older individuals. To the best of our knowledge, these results provide the first evidence of the effects of hot bathing on weight reduction. Our similar pilot study of older adults also suggested a comparable result; therefore, an intervention program that utilizes hot bathing is considered useful for health promotion among all ages.[36] Second, we used an artificial hot bath for convenience of location, and the present study did not compare the effect of spring quality. Currently, little is known regarding the effects of spring quality on weight reduction and other health effects. However, even an artificial hot bath had a dependent effect on weight reduction in the present study, and our results suggest that other bathing styles (e.g. jacuzzi spa) would also provide similar benefits.

In conclusion, the present study provides preliminary evidence that a comprehensive intervention program, consisting of exercise, diet and hot bathing improved participants' weight, AC, BMI and body fat percentage, in comparison with the other intervention groups. Thus, the synergistic effect of hot bathing could lead to hypermetabolism and then facilitate weight reduction. Comprehensive intervention programs in hot bath facilities can be considered useful for community residents.

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Disclosure statement

The authors declare that there are no conflicts of interest.

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