シンポジウムⅠ
Walking Reseach
No.12, 2008

運動の役割
—エクササイズガイドのすすめ—

Role of Physical Activity and Exercise
— Exercise Guide 2006 as tool for overcoming metabolic syndrome —

キーワード：メタボリックシンドローム　身体活動　運動
Keywords　：Metabolic syndrome, pysical activity, exercise

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1. はじめに

平成20年度から始まった40歳以上の国民の特定健康診査と、その後の運動指導及び食事指導を中心とした医療保険者による特定保健指導は、厚生労働行政における運動指導の役割を従来よりも飛躍的に大きくすることとなった。その理由は、従来の健康診査による疾病の発見とそれに対する医療指導というのではなく、健康診査後の保健指導にメタボリックシンドロームの概念を取り入れたからである。これは厚生労働行政の大きな変革点である。

2. メタボリックシンドローム

メタボリックシンドロームは、2005年4月に日本血栓止血学会，日本高血圧学会，日本動脈硬化学会，日本循環器学会，日本糖尿病学会，日本肥満学会，日本腎臓学会，日本内科学会の8学会が合同して設置した"メタボリックシンドローム診断基準検討委員会（松澤佑次委員長）"により、その診断基準が定められた1)。

その内容は、内臓脂肪（腹腔内脂肪）蓄積（臍囲　男性85cm以上，女性90cm以上）を必須として、高脂血（高トリグリセライド（150mg／dl以上）かつ／または　低HDLコレステロール（40mg／dl未満），高血圧（収縮期血圧130 mmHg以上　かつ／または拡張期血圧85mmHg以上.），高血糖（空腹時血糖値　110mg／dl以上）の2つ以上を併せ持つ状態とした

メタボリックシンドロームのアウトカムは、心筋梗塞や脳卒中などの心血管及び脳血管疾患である。これらの疾病は、高脂血症，高血圧症，糖尿病などの危険因子が単独での発症に比べて、それらが複数重なると発症率が急増することが特徴である。さらに、メタボリックシンドロームの判定基準の値は、単独の高脂血症，高血圧症，糖尿病と診断される値ではないにもかかわらず（ちなみに、そのような場合，高脂血，高血圧，高血糖と呼んでいる)、それらの値がメタボリックシンドロームの基準であれば、同様に心疾患や脳血管疾患の発症率が増加する。両疾病とも致死性が高く、生存しても発症後のQOLは著しく低くさらに医療費の負担も大きい。したがって、従来の疾病概念である糖尿病などと診断される前に、虚血性心疾患や脳卒中などの予防としてメタボリックシンドロームとういう概念を用いることができる（図1-次頁)。

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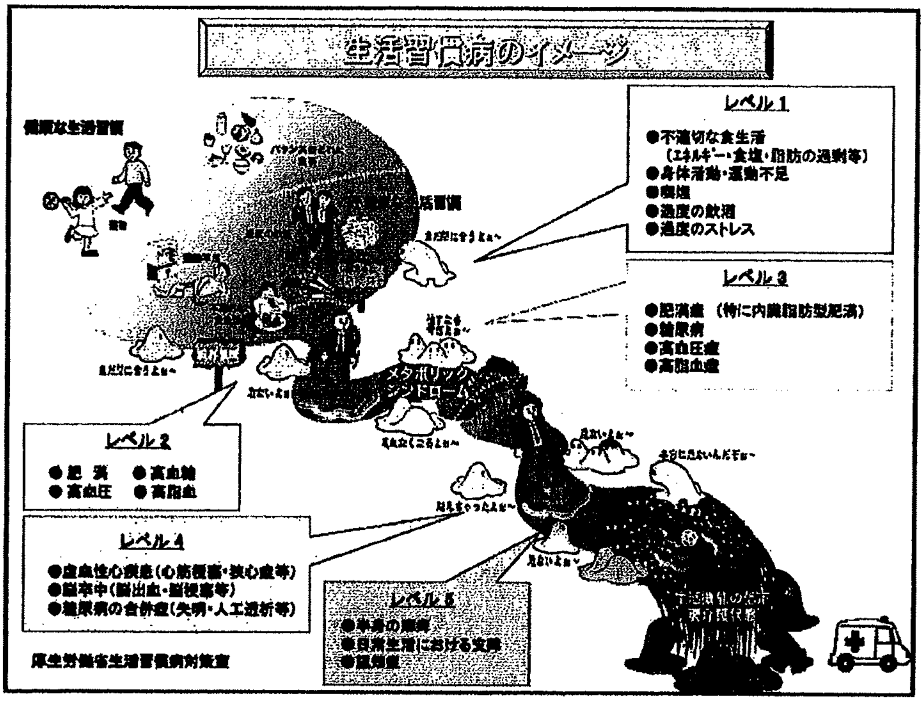


図1．生活習慣病のイメージ（厚生労働省健康局生活習慣病対策室 2006）

3．内臓脂肪症候群（メタボリックシンドロームにおける内臓脂肪の意味）

心疾患や脳血管疾患の発症の危険因子として多くの指標が挙げられている。高脂血症，高血圧，糖尿病，肥満，喫煙，ストレスなどである。我が国のメタボリックシンドロームの判定基準は、肥満の指標である腹囲（日本の基準では内臓脂肪量の指標である臍囲）を必須としている。

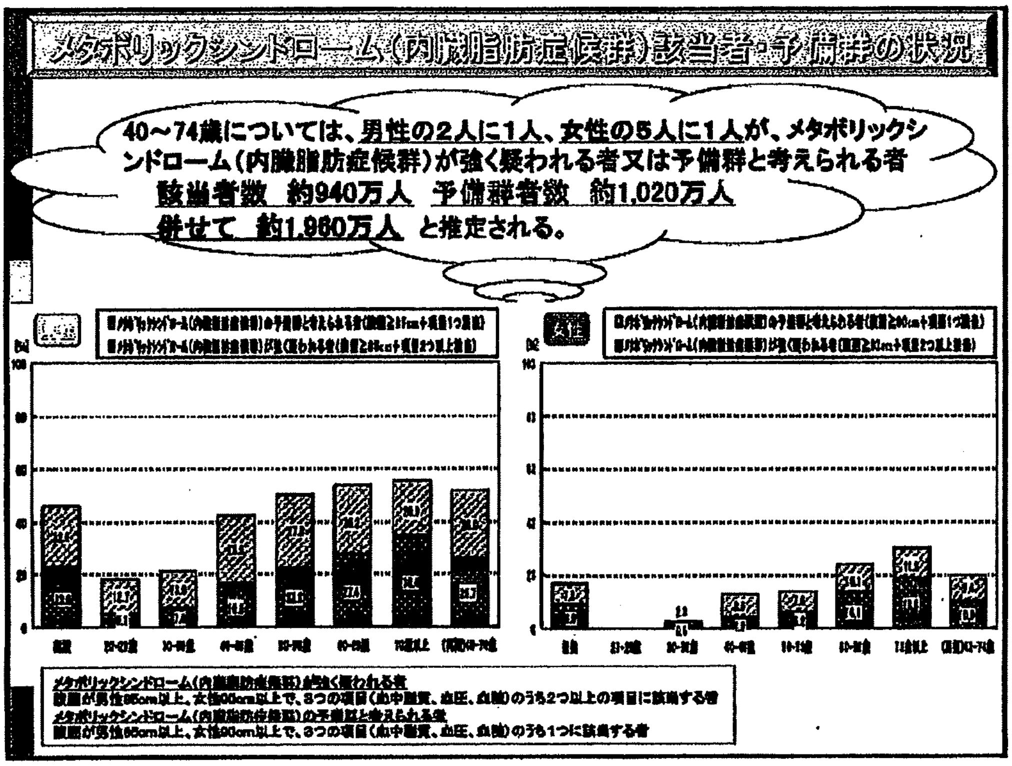
これは、メタボリックシンドロームのアウトカムである心疾患や脳血管疾患の危険因子の上流（発現機序）に内臓脂肪型肥満があるという考え方である。例えば、肥満によるインスリン感受性の低下は、①肥満になると、脂肪細胞から分泌されて骨格筋の糖代謝能を低下させるTNF α やレジスチンが増加すること，②一方、肥満度と反比例して分泌が増加するアディポネクチン（骨格筋の糖代謝能を向上させる）の分泌量が低下することが原因であるという説明である。この論理についても、異論も無いわけではないが、肥満とメタボリックシンドロームの関係を理解するには明解である。

さらに、肥満（身体に脂肪が過剰に蓄積した状態）による心疾患や脳血管疾患発症の危険率や、それらに関する危険因子の数は、内臓脂肪のほうが皮下脂肪より影響が大きいことが示されている。したがって、厚生労働省はメタボリックシンドロームを内臓脂肪症候群と命名した。

次に、日本肥満学会は内臓脂肪が $100cm^2$ を超えると、高血糖，高脂血，高血圧等の合併が多くなる（1つ以上）ことから、"BMI 以上で、肥満による健康障害がある、または内臓脂肪面積 $100cm^2$ である場合を"肥満症の判定基準としている。また、この値を超える男女とも危険因子が急増することからこの値を内臓脂肪症候群（メタボリックシンドローム）の判定基準とした。このようにして得られたメタボリックシンドロームの閾値 $100cm^2$ は、臍囲として男性では約 85cm，女性では 90cm に対応するとされている[1]。

4. メタボリックシンドロームの現状

このような判定基準でメタボリックシンドローム（内臓脂肪症候群）は実際にどれほどいるかというと図2に示すように、メタボリックシンドローム該当者と予備群を含めると40歳代以上の男性2人に1人，女性でも5人に1人いることがわかった（厚生労働省，平成16年度国民健康栄養調査）。国民の男性の半分が予備群であるということは、予防というのではなく、メタボリックシンドローム解消の取り組みが今，必要であり、そのための施策が、健康診査後の運動指導・食事指導を中心とした保健指導である。



メタボリックシンドローム（内臓脂肪症候群）該当者・予備群の状況

40～74歳については、男性の2人に1人、女性の5人に1人が、メタボリックシンドローム（内臓脂肪症候群）が強く疑われる者又は予備群と考えられる者
該当者数　約940万人　予備群者数　約1,020万人
併せて　約1,960万人　と推定される。

メタボリックシンドローム（内臓脂肪症候群）が強く疑われる者
腹囲が男性85cm以上、女性90cm以上で、3つの項目（血中脂質、血圧、血糖）のうち2つ以上の項目に該当する者
メタボリックシンドローム（内臓脂肪症候群）の予備群と考えられる者
腹囲が男性85cm以上、女性90cm以上で、3つの項目（血中脂質、血圧、血糖）のうち1つに該当する者

図2．メタボリックシンドロームの現状（平成17年度国民健康栄養調査，厚生労働省 2006）

5. メタボリックシンドローム・内臓脂肪症候群の概念と健康づくりのための運動指導の意味

メタボリックシンドロームを内臓脂肪症候群と呼び、腹囲をメタボリックシンドロームの必須項目とし、高脂血，高血糖，高血圧の3つの危険因子がその従属指標であるとしたことにより、臍囲、すなわち内臓脂肪（氷山の全体）を減らすことにより他の3つ（氷山の一角）を根こそぎ改善することができるという論理である。メタボリックシンドロームという国民には難解な概念を、生活習慣病の予防には、"運動と食事に関する生活習慣の改善により、すぐに計れて、また身近に感じられる指標である臍囲を減らすことにより、重篤な疾病にかからなくなりますよ"というメッセージまで落とし込めたことは評価されるべきである。例えば、ベルトのアナ3cmが3kgの内臓脂肪（体重）の減少に相当するということなどは保健指導においてとても有益な情報である。保健指導の効果を次年度の健康診査まで待つことなく自ら感じることができるからである。メタボリックシンドロームの概念というものを用いることにより、包括的な広い保健指導が可能となった。

6. 健康づくりのための運動指針2006（エクササイズガイド2006）

a. エクササイズガイドの内容

国は、特定保健指導における、運動によるメタボリックシンドローム解消のためのツールとしてエクササイズガイド2006を発表した。それには、システマティックレビューを基にした腹部脂肪を低下させるための運動量の基準値が示してある。それによると内臓脂肪を確実に減少させるためには、週に10エクササイズ程度かそれ以上の運動量が必要と考えられる。この運動量は30分間の速歩を週5回行うと10エクササイズの運動量に相当する。あるいは1日約3000歩の歩数増である。

この量は、現行の身体活動量と食事習慣を全く変えずに、それにプラスして運動（エクササイズガイド2006にある運動の定義：身体活動のうち、体力の維持・向上を目的として計画的・意図的に実施するもの）を行う場合の量を示している。内臓脂肪を減少するという"目的"をもって行うので、この場合に行う身体活動は"運動"となる。

b. メタボリックシンドロームと身体活動・運動施策

エクササイズガイド2006にメタボリックシンドロームに関する記述が【参考】として、記載された理由は、平成20年度から始まった40歳以上の国民に義務化された健康診査によりメタボリックシンドローム該当者と判断された国民に保健指導を行う際のツールとして"是非とも"必要であったからである。当時"1に運動　2に食事　しっかり禁煙　最後にクスリ"というスローガンの基に健康づくりに"運動"を第一にもってきた（実際は、"日本人の食事摂取基準が5年ごとに改定さているように食事に関する施策はかなり行われてきた一方、運動の方は1989年の健康づくりのための運動所要量が発表されて以来、改定されていないということが表すように、生活習慣という観点から食事と両輪である運動についての厚生労働省の施策が貧弱だったという自戒の念をもって、今回は運動を1番目とした"といわれている）のに加えて、運動が効果的なメタボリックシンドローム対策ついてのツールを整備する必要があったからである。

c. メタボリックシンドローム対策に対する身体活動・運動の意義

エクササイズガイド2006には、保健指導において食事習慣を変えずに運動量のみを増加させてメタボリックシンドロームを解消させる方法（つまり最低、週当たり10エクササイズの運動を行う）と、運動量の増加と食事からの摂取エネルギーの減少の両面からメタボリックシンドローム解消する方法を示している。これは、運動指導に、食事指導を加えれば、より容易にメタボリックシンドロームの解消ができる可能性を示しているに過ぎない。　言い換えると、両方を一緒に行えば、メタボリックシンドローム解消に良いということを示している。

エネルギーという観点のみで運動を見ると、運動の効果を矮小化することになる。例えば、運動基準では、生活習慣病の予防に4メッツ・時／週の運動量が有効であることが示されているが、この量は体重70kgの対象者にとって一日当たり40kカロリーであり、肥満予防という観点からは有効とは思えない量である。しかし、多くの高いエビデンスをもつ文献により、これらの運動量は、血糖値を下げ、HDLコレステロールを増加させ、中性脂肪を低下させ、さらに血圧も低下させることが知られており、肥満解消の効果は限定的でも、他の3要素にはすべて、良い効果を与え、メタボリックシンドロームの解消につながるからである。

7. 1に運動

エクササイズガイド2006で示されたメタボリックシンドローム解消のための運動量（週当たり10エクササイズ）は、糖尿病学会等の臨床系の学会が示している生活習慣病の治療のための運動療法で必要な運動量とほぼ等しい。つまり、健康運動指導士等がエクササイズガイド2006に示された運動量をメタボリックシンドロームと判定された対象者に指導すると、それは、メタボリックシンドロームに関する腹囲ではないその他の測定項目を確実に改善することが期待され、それによりメタボリックシンドロームが解消されると推測される。言い換えると、メタボリックシンドロームの概念に該当する（つまり生活習慣病と診断される前）者が、特定保健指導により生活習慣病になった後に処方される運動量を行えば、

当然、メタボリックシンドロームの判定に関する血糖値や中性脂肪量が低下する。したがって、特定保健指導に関わる者、特に健康運動指導士はまず"1に運動"という指導を行うべきである。

ちなみに、エクササイズガイド2006に示された腹囲減少のための運動量、すなわち 週10エクササイズの運動によるエネルギー消費量により期待される体重及び腹囲の減少率は体重0.3kg、腹囲0.3cm程度、すなわち年に体重3～4kg，腹囲3～4cmである。これは肥満学会が示しているサンサン運動（体重3kg，腹囲3cm）に相当する量である。

一方、特定保健指導において、対象者により体重及び腹囲をより速く（例えば月に体重1kg，腹囲1cm）減少させる必要がある場合は、上記の計算から運動だけでは難しい。したがって、この様な対象者に対しては週10エクサイズの運動習慣の習得と食事からのエネルギー摂取量を減少させるような指導が求められる。

8. おわりに

平成20年度から始まる保健指導における運動指導はメタボリックシンドロームの概念を基にエクササイズガイド2006をツールとして行われる。運動指導者はメタボリックシンドロームの概念を充分に理解して指導に当たることが期待されている。

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J Bone Miner Metab (2009) 27:182–189
DOI 10.1007/s00774-008-0022-x

ORIGINAL ARTICLE

Good maintenance of physical benefits in a 12-month exercise and nutritional intervention by voluntary, home-based exercise: a 6-month follow-up of a randomized controlled trial

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Received: 31 January 2008 / Accepted: 5 June 2008 / Published online: 27 January 2009

Abstract We assessed the maintenance of physical benefits in a 12-month exercise and nutritional intervention in postmenopausal women (55–75 years of age) after 6-month postintervention follow-up by voluntary, home-based exercise, and examined whether physical factors responded differently to high or low exercise frequency during the 6-month postintervention period. Forty-five women completed the 12-month intervention program, followed by 6-month cessation of intervention, and were compared with 19 matched controls. Twenty-one of the former exercisers reported that they continued exercise training at least 30 min at least 3 days/week (high-frequency exerciser, HFE), while the remaining 24 former exercisers reported that they had done exercise training at least 30 min twice per week or less during the postintervention follow-up (low-frequency exerciser, LFE). The following items were measured at baseline, 12, and 18 months: bone strength, CS-30 test, 10-m obstacle walk, whole-body reaction time, one-leg stance, and grip strength. After 6-month postintervention follow-up, the beneficial effect on bone was not fully maintained. These benefits in physical performance obtained in the 12-month intervention program, except one-leg stance, were fully maintained for 6 months by voluntary, home-based exercise. The gained benefit in one-leg stance was not fully maintained; LFE showed a significant decrease over the 6-month postintervention follow-up period, suggesting that continued exercise training of at least 30 min at least 3 days/week is required to maintain the balance benefit. These findings suggest that a continued exercise program of voluntary, home-based exercise may be effective to maintain the physical benefits of exercise intervention that may lower fracture risk in later life.

Keywords Older women · Bone strength · Physical performance · Home-based exercise · Frequency of exercise

Introduction

Fractures in older people are a major public health concern in terms of morbidity, mortality, and the cost to health and social services. The lifetime risks for wrist, hip, or vertebral fracture have been estimated to be of the order of 30–40% in developed countries, i.e., very close to that of coronary heart disease [1]. Reducing the incidence of fragility fractures among older people requires interventions that not only enhance bone strength and mass but also decrease the risk of falling and the immediate clinical consequences of falls.

There is strong evidence that exercise is beneficial to bone health in pre- and postmenopausal women [2–5], especially when resistance and high-impact exercise are combined [6]. Exercise training appears to significantly reduce the risk and number of falls [7–11]. Regular exercise has also been suggested to prevent falls and fall-related fractures in older adults [12, 13]. Exercise programs overall have been suggested to be effective [14], and a recently updated Cochrane review [15] concluded that home-based

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programs of balance retraining, walking, and strength training may be the most effective. However, important questions remained as to whether the obtained physical benefits could be maintained after exercise intervention and how to maintain these benefits.

Previous trials in a detraining follow-up period after cessation of exercise intervention have suggested that the exercise-induced bone [16, 17] and physical fitness benefits [16, 18] may be gradually lost. Sinaki et al. [19] also reported a part of the benefits of a 2-year exercise program still remained 8 years after cessation of the exercise intervention. A few studies have evaluated the maintenance effect of low-intensity group-based exercise on bone health and physical performance during the subsequent postintervention period [20, 21]. However, it is not known whether the exercise-induced physical benefits could be maintained through voluntary, home-based exercise and how frequently older adults should exercise to maintain those gains.

The purpose of this study was to assess the maintenance of the physical benefits obtained in a 12-month exercise and nutritional intervention in postmenopausal women after 6-month postintervention follow-up by voluntary, home-based exercise and to determine whether physical factors responded differently to high or low exercise frequency during the 6-month postintervention period.

Subjects and methods

Participants

One hundred twenty-six postmenopausal older women (age 55–75 years) were originally recruited to take part in a randomized intervention trial to investigate the effects of a 12-month exercise combined with nutritional intervention program on physical factors associated with fracture risk [5]. Subjects were volunteers who had been advised to seek medical advice based on the results of bone mineral density (BMD) examination or had experienced subjective symptoms of tripping frequently, and without cardiovascular disease or osteoporosis, living independently in their own homes, performing activities of daily living without mobility aids.

After a 6-month follow-up period, participants were offered follow-up assessments. The researchers sent letters reminding participants of the follow-up assessment and contacted them by telephone. Six-month postintervention follow-up measurements were performed for 24 of the original 48 exercisers in the exercise group (EG), 21 of the original 40 exercisers in the exercise and nutritional group (ENG), and 19 of the 38 control subjects (C). The 43 original exercisers and 19 controls who could not attend the 18-month follow-up measurements did not differ from those who participated with regard to the baseline subject characteristics or the 12-month intervention effects. Reasons for not attending the follow-up assessment included lack of time, did not reply to phone or letter messages, started exercising (controls), or loss of interest.

Exercise intervention

The first phase of the study has been described in detail elsewhere [5]. Briefly, participants performed aerobic exercise, antigravity exercise, circuit training, and muscle strength training in groups combined with home-based exercise training. In the initial 3-month intensified intervention period, the participants were required to attend group exercise training once per week and were encouraged to perform exercise individually at home three times per week. After the initial 3 months, the participants were required to attend group exercise training once per month and were encouraged to perform exercise individually at home three times per week. The antigravity exercises included one-leg stance, sumo-style leg stamping, and lifting the leg (hip and knee) with a ball. In the first 3 months, subjects performed a single set of 20 repetitions or 1 min antigravity exercise; the number of repetitions increased to 30 and number of sets increased to two in the remainder of the intervention period. Muscle strength training using body weight included abdominal, gluteus maximus, quadriceps femoris, iliopsoas, hip abductor, and triceps surae muscle strength training. In the first 3 months, subjects performed a single set of 20 repetitions of muscle strength training; the number of sets increased to two in the remainder of intervention period. After completion of the 12-month exercise combined with nutritional intervention program, the exercisers were recommended to continue their exercise program, but no specific instructions and monitor were provided.

Nutritional intervention

The nutritional intervention was described in detail previously. Briefly, the participants were encouraged to consume at least 600 mg calcium daily, ideally 800 mg daily, together with a daily intake of 65 g protein. During the 3-month intensified intervention period, subjects were required to fill in a diet check sheet each week and were given some nutritional advice by dietitians once per week. After the initial 3 months, the number of nutritional guidance sessions decreased to once per month.

Measurements

All subjects were carefully interviewed about their diet and other living habits, medication, injuries, diseases, and exercise habits during the 6-month cessation of intervention follow-up period. Participants were then categorized into meeting or not meeting our recommended exercise frequency (30 min exercise 3 days per week). Characteristics of subjects, bone strength (speed of sound, SOS) [5], and physical performance (including grip strength, 30-s chair stand test, 10-m obstacle walk, whole-body reaction time, and one-leg stance) [11] were assessed at baseline, after 12 months, and after 18 months. SOS in the right calcaneus was evaluated using an ultrasound measurement device (AOS-100; Aloka, Tokyo, Japan). The AOS-100 measures the ultrasound properties of the calcaneus by the transmission technique using a pair of unfocused broadband ultrasound transducers (25-mm diameter; 0.5-MHz center frequency, range 0.2–1.0 MHz).

Statistical analysis

All data are presented as means ± SD, except in Fig. 1, in which data are expressed as means ± SE. To determine whether physical factors responded differently to high or low exercise frequency during the 6-month postintervention period, before analysis, participants who reported that they continued exercise training for at least 30 min at least 3 days a week were classified into the high-frequency exerciser (HFE) group, and those who reported that they had done exercise training for at least 30 min twice a week or less during the postintervention follow-up were classified into the low-frequency exerciser (LFE) group. Changes in bone strength and physical performance at the end of the intervention and after 6-month cessation of intervention follow-up period are expressed as percentages of the baseline values. Data were analyzed using SPSS version 16.0. One-way analysis of variance (ANOVA) was used to compare baseline values between the groups. Statistical analyses were performed using a two-factor general linear model, incorporating a mixed design, with one between-subject factor of group and one within-subject factor of time.

Post hoc analyses were conducted using paired *t* tests to examine within-group differences between baseline values and those after 12 months of intervention, and after 6-month follow-up cessation of intervention. The Bonferroni correction was applied to set the significance criterion to 0.017 (i.e., 0.05/3).

Results

The interviews revealed no major changes in the subjects' diet or other living habits during the postintervention follow-up period. Eleven former exercisers in ENG and 10

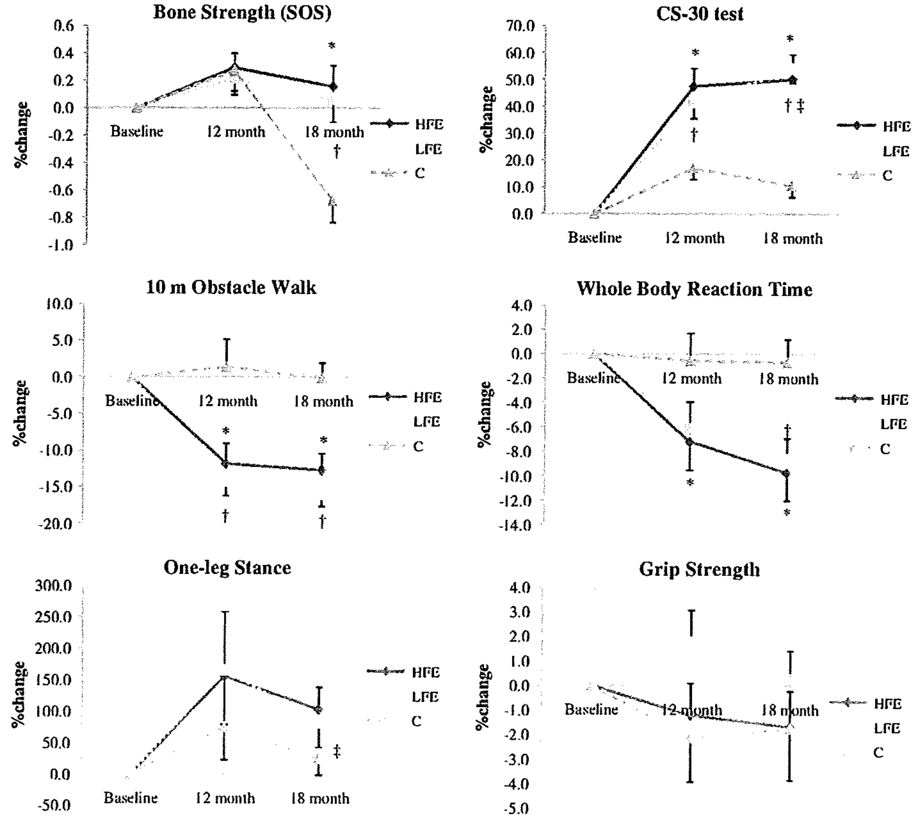

Fig. 1 Percent changes in bone strength and physical performance measures across 12-month intervention and 6-month cessation of intervention follow-up periods (means ± SE). *HFE, significantly different from controls ($P < 0.05$); †LFE, significantly different from controls ($P < 0.05$); ‡change over 6-month cessation of intervention follow-up period significantly different from change over 12-month intervention period within LFE ($P < 0.05$). *HFE* high-frequency exerciser, *LFE* low-frequency exerciser, *C* controls

former exercisers in EG reported that they continued exercise training for at least 30 min at least three days a week (high-frequency exerciser, HFE), while the remaining 10 former exercisers in ENG and 14 former exercisers in EG reported that they had done exercise training for at least 30 min twice a week or less during the postintervention follow-up period (low-frequency exerciser, LFE). The 19 control subjects continued their normal life without exercise training.

The demographic characteristics of the subjects at baseline are presented in Table 1. Significant differences were found in bone strength between EG and C. There were no significant differences in other baseline values of demographic characteristics among the groups.

Within groups, exercisers in the ENG showed significantly increased SOS at the right heel, which remained unchanged in exercisers in the EG and controls after a 12-month intervention period. After 6 months of follow-up cessation of intervention, SOS in the C group was significantly lower compared with baseline and 12-month values (Table 2). Although there were no significant differences between baseline and 18-month SOS values, bone strength of exercisers in ENG still remained above the baseline level, suggesting that the beneficial effect on bone obtained in the 12-month exercise combined with nutritional intervention program was not fully maintained.

Table 1 Demographic characteristics of the study subjects at baseline

Variable	ENG $n = 21$	EG $n = 24$	C $n = 19$
Age (years)	64.5 ± 5.5	63.2 ± 4.5	66.5 ± 4.3
Height (cm)	151.1 ± 6.5	151.5 ± 3.8	150.2 ± 4.6
Weight (kg)	53.6 ± 7.7	54.5 ± 6.0	50.6 ± 5.2
Body fat (%)	30.8 ± 6.8	31.0 ± 5.6	28.5 ± 4.4
BMI (kg/m^2)	23.5 ± 3.1	23.7 ± 2.2	22.5 ± 2.3
SOS (m/s)	1537.1 ± 16.4	1528.4 ± 16.6*	1544.2 ± 20.5

ENG exercise and nutrition group, *EG* exercise group, *C* controls

Values are presented as means ± SD

* $P < 0.05$, significant difference between exercise group and control group

Significant improvements in CS-30 test (ENG, 57.5%; EG, 32.4%), 10-m obstacle walk (ENG, −15.1%; EG, −11.5%), whole-body reaction time (ENG, −8.0%; EG, −5.5%), and one-leg stance (ENG, 177.0%; EG, 146.2%) over the intervention period were observed in both intervention groups versus controls (Table 3). Controls showed lower-leg strength increased by 17.0%, roughly one-third to one-half the increases in both intervention groups. For both exercise and control groups, grip strength did not change during the 12-month intervention period. Over the 6-month postintervention follow-up period, both intervention groups showed no significant changes in lower-leg strength, 10-m obstacle walk, or one-leg stance, and the EG exhibited significant decreases of 8.6% in whole-body reaction time. Over the same 6-month postintervention follow-up period, controls showed a significant decrease in one-leg stance ($P < 0.05$).

Percent changes in HFE, LFE, and C groups in bone strength and physical performance measures across 12-month intervention and 6-month cessation of intervention follow-up periods are presented in Fig. 1. Significant improvements in bone strength ($P < 0.05$), CS-30 test ($P < 0.001$), 10-m obstacle walk ($P < 0.001$), whole-body

Table 2 Demographic characteristics at baseline, 12-month measures, and 18-month measures

Variables	ENG $n = 21$	EG $n = 24$	C $n = 19$	Interaction
Weight (kg)				
Baseline	53.6 ± 7.7	54.5 ± 6.0	50.6 ± 5.2	NS
12-month measures	53.1 ± 7.5	53.1 ± 5.6††	50.1 ± 5.0	
18-month measures	53.2 ± 7.8	53.2 ± 6.1††	49.5 ± 5.0†,‡	
Body fat (%)				
Baseline	30.8 ± 6.8	31.0 ± 5.6	28.5 ± 4.4	$P < 0.01$
12-month measures	29.3 ± 6.6††	28.9 ± 5.0††	28.9 ± 5.0	
18-month measures	29.1 ± 6.8††	29.5 ± 5.1†	26.8 ± 4.9†††,‡‡‡	
BMI (kg/m^2)				
Baseline	23.5 ± 3.1	23.7 ± 2.2	22.5 ± 2.3	NS
12-month measures	23.4 ± 3.0	23.3 ± 2.2†	22.4 ± 2.3	
18-month measures	23.5 ± 3.1	23.4 ± 2.4	22.1 ± 2.3‡	
SOS (m/s)				
Baseline	1537.1 ± 16.4	1528.4 ± 16.6	1544.2 ± 20.5	$P < 0.001$
12-month measures	1542.0 ± 17.1†	1531.1 ± 15.0	1548.3 ± 16.9	
18-month measures	1538.0 ± 18.8	1530.5 ± 15.5	1533.7 ± 17.3†††,‡‡‡	

ENG exercise and nutrition group, *EG* exercise group, *C* controls

Values are means ± SD

† Significant difference from baseline, † $P < 0.05$; †† $P < 0.01$; ††† $P < 0.001$

‡ Significant difference from 12-month measures, † $P < 0.05$; ††† $P < 0.001$

Table 3 Physical performance variables at baseline, 12-month measures, and 18-month measures

Variables	ENG $n = 21$	EG $n = 24$	C $n = 19$	Interaction
CS-30 test (rep)				
Baseline	17.5 ± 2.5***	18.2 ± 3.3**	16.4 ± 2.3	$P < 0.001$
12-month measures	$27.6 \pm 6.4^{\dagger\dagger\dagger}$	$23.6 \pm 4.5^{\dagger\dagger\dagger}$	$19.0 \pm 3.1^{\dagger\dagger\dagger}$	
18-month measures	$29.1 \pm 5.5^{\dagger\dagger\dagger}$	$24.8 \pm 5.6^{\dagger\dagger\dagger}$	$17.9 \pm 3.2^{\dagger}$	
10-m obstacle walk (s)				
Baseline	7.5 ± 0.9***	7.0 ± 0.6***	7.6 ± 1.0	$P < 0.001$
12-month measures	$6.3 \pm 0.8^{\dagger\dagger\dagger}$	$6.2 \pm 0.7^{\dagger\dagger\dagger}$	7.6 ± 1.3	
18-month measures	$6.2 \pm 0.7^{\dagger\dagger\dagger}$	$6.1 \pm 0.6^{\dagger\dagger\dagger}$	7.5 ± 1.1	
Whole-body reaction time (ms)				
Baseline	456.8 ± 55.7	434.2 ± 64.8***	456.0 ± 64.7	$P < 0.05$
12-month measures	$418.9 \pm 53.1^{\dagger\dagger\dagger}$	$405.8 \pm 43.8^{\dagger}$	450.0 ± 54.7	
18-month measures	$411.9 \pm 59.0^{\dagger\dagger\dagger}$	$392.7 \pm 40.9^{\dagger\dagger,\ddagger}$	450.0 ± 51.9	
One-leg stance (s)				
Baseline	73.4 ± 43.5	87.3 ± 40.4	78.2 ± 43.1	NS
12-month measures	$103.9 \pm 30.2^{\dagger\dagger}$	$112.9 \pm 22.7^{\dagger\dagger}$	88.2 ± 44.4	
18-month measures	$96.5 \pm 35.2^{\dagger}$	$103.8 \pm 26.6^{\dagger}$	$73.0 \pm 44.3^{\ddagger}$	
Grip strength (kg)				
Baseline	25.5 ± 3.5**	23.5 ± 3.5	22.4 ± 2.5	NS
12-month measures	25.3 ± 3.1	23.6 ± 3.1	21.9 ± 2.4	
18-month measures	25.2 ± 3.3	23.3 ± 3.2	22.0 ± 3.2	

ENG exercise and nutrition group, *EG* exercise group, *C* controls, *rep* number of repetitions

Values are means ± SD

* Significant group difference between intervention group and control group, ** $P < 0.01$; *** $P < 0.001$

† Significant difference from baseline, † $P < 0.05$; †† $P < 0.01$; ††† $P < 0.001$

‡ $P < 0.05$, significant difference from 12-month measures

reaction time ($P < 0.01$), and one-leg stance ($P < 0.01$) over the intervention period were observed in both HFE and LFE versus controls. There were significant differences between baseline and 18-month measures of CS-30 test ($P < 0.001$), 10-m obstacle walk ($P < 0.001$), whole-body reaction time ($P < 0.001$), and one-leg stance ($P < 0.05$) values, suggesting that physical performance benefit achieved from the intervention program was maintained. However, over the same 6-month postintervention follow-up period, LFE showed a significant decrease in one-leg stance ($P < 0.001$), whereas that in HFE remained unchanged. After 6 months follow-up cessation of intervention, although the difference from baseline was no longer statistically significant, the bone strength of exercisers still remained above the baseline level.

Discussion

This study was designed to assess the maintenance of physical benefits obtained in a 12-month exercise and nutritional intervention in postmenopausal women after 6-month postintervention follow-up by voluntary, home-based exercise, and to determine whether physical factors responded differently to high or low exercise frequency during the 6-month postintervention period. Exercise intervention significantly increased physical performance, including CS-30 test, 10-m obstacle walk, and whole-body reaction time, during the 12-month intervention period, and the benefits in physical performance were fully maintained after 6 months by voluntary, home-based exercise after cessation of the intervention program. However, the gained benefit in one-leg stance was not fully maintained after 6-month postintervention follow-up; especially, although LFE still showed a significant increase from baseline, a significant decrease was observed over the 6-month postintervention follow-up period. The values of bone strength still remained above the baseline level after the 6-month postintervention follow-up, although the difference was not statistically significant, suggesting that the beneficial effect on the bone of exercise combined with nutritional intervention was not fully maintained.

To our knowledge, this is the first study to evaluate maintainable effects of voluntary, home-based exercise on bone health and physical performance, and to evaluate the effects of exercise frequency on maintenance of bone health and physical performance in older women during 6-month postintervention follow-up. Some previous studies evaluated the effects of detraining on physical factors associated with fracture risk have suggested that the exercise-induced bone [16, 17] and physical fitness benefits [16, 18] may be gradually lost. A few studies have evaluated the maintenance effects of low-intensity group-based exercise on bone health and physical performance during the subsequent postintervention period [20, 21]. Heinonen et al. reported that the significant BMD increase obtained by a supervised

18-month high-impact jumping training was effectively maintained (continued to increase) during the subsequent 8 months by unsupervised regular step-aerobic classes [20]. In the present study, however, the benefit of exercise combined with nutritional intervention on bone strength was not fully maintained. Differences in the time of exercise in both studies (decreased vs. unchanged) during the post-intervention follow-up period may explain the inconsistent findings. The time of exercise in the 6-month postintervention follow-up period was one-third of that in the 12-month intervention period and may be insufficient to produce an adequate impact on bone to fully maintain the beneficial effect on the bone in the present study. Therefore, to either maintain bone health at the same level as that after intervention or to increase bone health, continuation of exercise with adequate exercise time per session is needed.

Wolfson et al. [21] reported that balance performance (Single Stance Time) improvements of participants in a supervised 3-month balance training group reverted significantly toward baseline values after a 6-month Tai Chi maintenance program (three times per week), whereas the gains seen in participants who implemented a 3-month balance plus strength training program were retained. Our study extends the previous findings of Wolfson et al., showing that voluntary, home-based exercise can effectively maintain the benefits of not only balance performance but also lower-leg strength, reaction time, and walking performance after 6-month postintervention follow-up. Interestingly, we found that significant increases in one-leg stance from baseline were retained in both HFE and LFE groups. However, LFE showed a significant decrease over the 6-month cessation of intervention follow-up period, whereas no significant change was seen in HFE. This finding indicates that there is an exercise frequency-independent association with maintenance of balance performance benefit gained by the exercise intervention program during the postintervention follow-up period. Some previous studies evaluated the effects of exercise frequency on functional fitness in older women [22, 23]. With regard to the effects of exercise frequency on balance performance, Nakamura et al. [23] reported that only exercisers participating in a 12-week exercise intervention program three times a week showed increased balance performance (Functional Reach). They suggested that to improve functional fitness, older individuals should endeavor to participate in exercise at least three times a week. Our study extends their findings, showing that not only in the intervention period but also in the postintervention follow-up period, exercise at least three times a week would have been needed in older women to improve and maintain balance performance.

Previous studies that included men and women have investigated the relationship between BMD and physical performance and have shown inconsistent results [24–26]. Taaffe et al. [24] reported that balance performance and chair-rise performance correlated with hip BMD in white women aged 70–79 years. However, Lindsey et al. [25] reported that balance performance correlated with hip BMD in healthy postmenopausal women aged 55.4–88.6 years, whereas chair-rise performance did not correlate with hip BMD. Differences in the age and physical fitness of subjects may explain the difference of the relationship between chair-rise performance and hip BMD [25]. The age of subjects in our study was similar to that reported by Lindsey et al. [25]. Thus, it is no surprise that change of bone strength in our exercisers showed the same tendency as that of one-leg stance whereas the change showed a different tendency from that of the CS-30 test.

The recommendation for balance exercise has been reported by clinical practice guidelines published in 2001 [27]. This guideline recommended that balance exercise three times per week is needed, as this approach was effective in a series of four fall prevention studies. Campbell et al. [28] reported that in community-dwelling older women, individually designed exercise programs in the home that incorporated strength and balance training reduced both falls and injuries; for those who continued to exercise, the benefits were evident after a 2-year period. In the present study, exercisers performed home-based balance, strength, and weight-bearing exercises, and the types of exercise were similar to those in the study of Campbell et al. Thus, if adopted as part of the normal lifestyle, this type of voluntary exercise three times per week may provide a valuable tool for primary prevention of fall and fracture.

This study has some limitations. First, we had no follow-up data from the intervention subjects and controls who did not participate in the 18-month measurements, and the follow-up rate was extremely low in our study. What led to this very low follow-up rate? For controls, one possible explanation was that the results of the measurements were returned to the controls after 1 year, which may have led controls to engage in exercise voluntarily. It suggested that controls tended to become highly conscious of their health and physical fitness and have positive ideas about health promotion. No clear answers for exercisers were forthcoming, although a speculation could be made. One can speculate on the reasons for the low follow-up rate of exercisers in the current study, as center-based group instruction has been stopped. A 2003 study examined the influence of a home-based or center-based exercise program on participant dropout among a group of 40- to 65-year-old women [29]. The authors noted that the center-based group had higher retention than the home-based group at 6 months. This difference might be that organized group exercise programs are an important aspect of the social life of elderly people, because they offer the chance to make new social contacts. However, the follow-up rate in the present study was similar to that (58%) reported by Heinonen et al. [20]. Furthermore, these subjects who withdrew from the study did not differ from those who attended the 18-month measurements in terms of baseline characteristics. Thus, we believe that there is no bias in our current findings. Second, we did not assess bone strength using the criterion measure of BMD with dual-energy X-ray absorptiometry (DXA), as it may weaken the accuracy of the beneficial effect on the bone. However, although quantitative ultrasound (QUS) is not the best measure for BMD, QUS may identify aspects of bone quality not captured by DXA [30, 31], and the value of QUS lies in its convenience for screening bone mass and ease of performance. Most hip fractures occur in women who are not osteoporotic by BMD testing [32]. Previous studies have reported an association between low SOS at the calcaneus and hip fracture [33, 34]. Furthermore, it has been suggested that bone parameters measured by QUS provide independent information about fracture risk [35, 36]. Third, we did not measure other parameters of QUS, such as broadband ultrasound attenuation (BUA) and quantitative ultrasound index (QUI), simply because of the inability to test these variables using our QUS device. However, a previous prospective study in a Japanese population has reported that SOS is a better predictor of hip fracture than is BUA [34].

In conclusion, the results of this study showed that those benefits in physical performance, with the exception of one-leg stance, were fully maintained for 6 months by voluntary, home-based exercise. With regard to one-leg stance, the gained benefit was not fully maintained; especially, although a significant increase from baseline still remained in LFE, a significant decrease was observed over the 6-month postintervention follow-up period, suggesting that continued exercise training for at least 30 min at least 3 days a week is required to maintain the balance benefit. The values of bone strength still remained above the baseline level after the 6-month postintervention follow-up, although the difference was not statistically significant, suggesting that the beneficial effect on the bone of exercise combined with nutritional intervention was not fully maintained. These findings suggest that a continued program of voluntary, home-based exercise may be an effective approach to maintain the physical benefits from exercise intervention that may lower fracture risk in later life.

Acknowledgments We sincerely appreciate the work performed by the staff of the Health Service Center and their outstanding cooperation in carrying out this study.

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Clin Physiol Funct Imaging (2009) 29, pp128–135 doi: 10.1111/j.1475-097X.2008.00847.x

Low-intensity resistance training with slow movement and tonic force generation increases basal limb blood flow

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Accepted for publication
Received 26 March 2008;
accepted 10 November 2008

Key words
hemodynamics; muscle hypertrophy; resistance exercise; ultrasonic; vascular resistance

Metabolic syndrome is associated with reductions in basal limb blood flow. Resistance training increasing muscle mass and strength increases basal limb blood flow. Low-intensity resistance exercise with slow movement and tonic force generation (LST) has been proposed as one of the effective methods of resistance training increasing muscle mass and strength. The hypothesis that LST training increases basal femoral blood flow as well as traditional high-intensity resistance training at normal speed (HN) was examined. Thirty-six healthy young men without a history of regular resistance training were randomly assigned to the LST [~55–60% one repetition maximum (1RM) load, 3 s lifting and 3 s lowering with no relaxation phase, n = 12], HN (~85–90% 1RM, 1 s lifting and 1 s lowering with 1 s relaxation, n = 12) or sedentary control (CON, n = 12) groups. Participants in the training groups underwent two whole-body training sessions per week for 13 weeks. Basal femoral blood flow increased significantly by +18% in LST and +35% in HN (both $P<0{\cdot}05$), while there was no such change in CON. There were no significant differences between these increases induced by LST and HN, although the increase in LST corresponded to about half that in HN. In conclusion, not only resistance training in HN but in LST as well, were effective for increasing basal limb blood flow, and that this effect was evident even in healthy young men.

Introduction

Basal limb blood flow decreases with advancing age in healthy men and women (Dinenno *et al.*, 2001a,b; Moreau *et al.*, 2003; Miyachi *et al.*, 2005), which is related to corresponding reductions in leg fat-free mass and estimated leg oxygen demand (Dinenno *et al.*, 2001a,b). Reductions in peripheral blood flow have been suggested to be mechanistically involved in metabolic syndrome, a cluster of disease states including hyperinsulinemia, dyslipidaemia and hypertension (Lind & Lithell, 1993). Accordingly, the prevention and treatment of age-related reductions in basal femoral blood flow may be of clinical importance.

Habitual aerobic exercise is regarded as an important component of preventing and treating cardiovascular disease and functional disability (Pate *et al.*, 1995). However, habitual aerobic exercise does not appear to modulate the age-related reductions in basal limb blood flow (Dinenno *et al.*, 2001a,b). Several recent studies showed that resistance training, which increases muscle mass and strength (MacDougall *et al.*, 1977; Staron *et al.*, 1984), is associated with increased basal femoral blood flow in middle-aged men and women (Miyachi *et al.*, 2005; Anton *et al.*, 2006). Resistance training is known to have some additional favourable health promoting effects aside from muscular hypertrophy and strength gain, such as improving insulin sensitivity (Dela & Kjaer, 2006). Increasing basal femoral blood flow by resistance training is considered one such favourable effect.

In general, traditional high-intensity (~80% 1RM) resistance training has been regarded as optimal for gaining muscular size and strength (McDonagh & Davies, 1984). However, such strenuous exercise may be associated with a risk of orthopaedic injury. In addition, a marked increase in systolic blood pressure (over 300 mmHg) has been reported to occur during high-intensity resistance exercise (~8RM) involving large muscle groups (MacDougall *et al.*, 1985; Fleck, 1988). These problems must be considered in high-intensity resistance exercise regimens especially for high-risk populations.

Relatively low-intensity (~50–60% 1RM) resistance training with slow movement and tonic force generation (LST) is another method of resistance exercise. Previously, we reported that LST training resulted in a significant increase in muscular size and strength as high-intensity (~80–90% 1RM) resistance training with normal speed (HN) in knee extension training (Tanimoto & Ishii, 2006) and in a whole-body training regimen (Tanimoto *et al.*, 2008), and LST was not associated with either generation of large force or marked elevation of blood pressure (Tanimoto & Ishii, 2006). Therefore, LST would be one of the useful methods of resistance training for promoting muscular hypertrophy and strength gain, which is relatively safe for a larger population.

With regard to the hypothesis of the effects of LST in promoting muscle hypertrophy, LST exercise movement was configured to achieve continuous force generation throughout the exercise movement. Continuous force generation at >40% maximum voluntary contraction has been shown to suppress both blood inflow to and outflow from the muscle due to an increase in intramuscular pressure (Bonde-Petersen *et al.*, 1975). Resistance training regimens with restricted muscular blood flow were considered to induce increases in muscular size and strength mediated by the following processes due to oxygen insufficiency in muscle: (i) stimulated secretion of growth hormone by intramuscular accumulation of metabolic by-products, such as lactate (Takarada *et al.*, 2000a); (ii) moderate production of reactive oxygen species promoting tissue growth (Takarada *et al.*, 2000b); and (iii) additional recruitment of fast-twitch fibres under hypoxic conditions (Shinohara & Moritani, 1992).

The present study was performed to investigate whether resistance training even in LST also increases basal femoral blood flow as well as in HN, and whether resistance training in LST and HN increase basal femoral blood flow even in healthy young men.

The present study examined whether LST training can safely increase basal limb blood flow in healthy young people as a preventive effect, before such investigations are carried out in patients with metabolic syndrome or others and in older people as a curative effect.

Methods

Subjects

Thirty-six healthy young men without a history of regular exercise training volunteered as subjects in the present study. All subjects were non-smokers, normotensive (blood pressure <140/90 mmHg), non-obese (body mass index <30 kg m^{-2}) and free of overt chronic diseases as assessed by medical history, physical examination and complete blood chemistry and haematological evaluation. Candidates showing signs of peripheral artery disease [ankle-brachial index (ABI) <0·90] were excluded. The subjects were assigned at random into three experimental groups (n = 12 for each group: LST, HN, CON defined below). Groups were matched for physical parameters, such as height, weight and age (Table 1). All subjects were fully informed about the experimental procedures as well as the purpose of the study, and each subject provided written informed consent before participating in the study. The study protocol was approved by the Ethics Committee for Human Experiments, National Institute of Health and Nutrition.

Regimens for exercise training

The subjects in each training group performed whole-body resistance training regimens consisting of five types of exercise: vertical squat, chest press, latissimus dorsi pull-down, abdominal bend and back extension, as described previously (Tanimoto *et al.*, 2008). The subjects performed the following training regimens.

LST group: low-intensity (55~60% of 1RM) training with slow movement and tonic force generation [3 s for concentric

Table 1 Characteristics of the subjects.

	LST		HN		CON	
	Pretraining	**Post-training**	**Pretraining**	**Post-training**	**Pretraining**	**Post-training**
Age, year	19·0 ± 0·2		19·5 ± 0·1		19·8 ± 0·2	
Height, cm	174·1 ± 1·6		174·8 ± 1·2		174·3 ± 2·1	
Body mass, kg	62·5 ± 1·4	64·1 ± 1·5	63·8 ± 1·2	65·3 ± 1·2	64·2 ± 1·2	64·7 ± 1·1
LSTM, kg	53·9 ± 3·9	55·2 ± 3·7[a,b]	53·7 ± 3·0	55·6 ± 3·4[a,c]	54·6 ± 2·7	55·2 ± 2·6[a]
%Fat, %	13·7 ± 3·6	13·7 ± 3·8	15·7 ± 3·2	14·8 ± 2·9[a]	14·8 ± 3·6	14·6 ± 3·5
Left leg muscle mass, kg	8·82 ± 0·21	9·07 ± 0·19[a,b]	8·80 ± 0·19	9·19 ± 0·21[a,c]	8·89 ± 0·18	8·98 ± 0·18

Values are means ± SE; n = 12 for each group.

LST, low-intensity exercise with slow movement and tonic force generation; HN, high-intensity exercise with normal speed; CON, sedentary control; LSTM, lean soft tissue mass.

[a] Significant difference (P<0·05) between pretraining and post-training.

[b] Increase in LST was significantly higher (P<0·05) than that in CON.

[c] Increase in HN was significantly higher (P<0·05) than that in CON.

(lifting phase) and eccentric (lowering phase) actions, and no relaxation phase; LST].

HN group: high-intensity (85~90% 1RM) training with normal speed (1 s for concentric and eccentric actions and 1 s for relaxation; HN). CON group: sedentary controls.

The training intensity was determined at 8RM in both LST and HN. 8RM means the load which person is only able to perform 8 correct form repetitions with. Subjects performed each type of training with 8RM intensity. Exercise intensities of LST and HN were adjusted to the same RM (8RM). Mechanical load in LST training was much lower than that in HN training (~55–60% 1RM in LST versus ~80–90% 1RM in HN). The difference in mechanical load under the same 8RM intensity between the two groups may have been due to differences in the type of movement. Subjects performed one warm-up set and three regular sets with an interest rest period of 60 s for each type of exercise. A 3-min rest was taken between exercise events. Training sessions were performed twice a week for 13 weeks.

All subjects were advised to maintain their usual physical activity and dietary habits to avoid any influence of physical activity outside the training session and nutritional influence.

Measurements

Before they were tested, subjects abstained from caffeine and alcohol, and fasted for 12 h overnight. All testing, except muscular strength testing, was conducted under comfortable laboratory conditions early in the morning. Subjects were studied 4 or 5 days after their last exercise session to avoid any acute effects of exercise.

Arterial blood flow

A duplex ultrasound machine (model 180 Plus; Sonosite, Bothell, WA, USA) equipped with a high-resolution (5–10 MHz) linear-array transducer was used to measure vessel diameter and blood velocity on the left common femoral artery and right common carotid artery, as described previously (Dinenno *et al.*, 1999, 2001a,b; Ozdemir *et al.*, 2006). Mean blood velocity measurements were performed with an insonation angle <60°. The mean diameter [D = D(systole/3) + D(diastole 2/3)] based on the relative time periods of the systolic (1/3) and diastolic (2/3) blood pressure phases was used to represent the cross-sectional area. Femoral blood flow was calculated as: mean blood velocity (MBV) × π × (femoral arterial radius)^2 × 60. The data reported were time averages of 10 measurements for all variables and were analysed by the same investigator, who was blinded to the identity of the subject. Vascular conductance and resistance were calculated as arterial blood flow/mean blood pressure and mean blood pressure/arterial blood flow, respectively. In our laboratory, the day-to-day reproducibility of the measurements for arterial diameter, mean blood velocity and absolute blood flow were 3 ± 1, 7 ± 2 and 6 ± 2% (average ± SD), respectively.

Arterial blood pressure at rest

Arterial blood pressure at rest was measured with a semiautomated device (Form PWV/ABI; Colin Medical Technology, Komaki, Japan) over the brachial and dorsalis pedis arteries. Recordings were made in triplicate with subjects in the supine position. ABI was then calculated and used as a measure of atherosclerosis in leg arteries.

Left ventricular function

Echocardiography was used to measure left ventricular (LV) function, according to established guidelines (Sahn *et al.*, 1978; Cheitlin *et al.*, 2003). Stroke volume (SV) was measured from LV end-diastolic and end-systolic volumes calculated from LV internal dimensions (Miyachi *et al.*, 2004). Cardiac output was calculated as SV × heart rate. Systemic vascular resistance was calculated by the following formula: brachial mean blood pressure/cardiac output. All image acquisition and image analyses were performed by the same investigator, who was blinded to the group assignment of subjects. At least 10 measurements of cardiac output were taken and the mean values were used for analysis.

Muscle thickness by B-mode ultrasound imaging

The muscle thickness (MT) was measured by B-mode ultrasound (5 MHz scanning head) at six sites from the anterior and posterior surfaces of the body, in principle following the standard method described by Abe *et al.* (Abe *et al.*, 1994). The sites were: chest, anterior and posterior upper arm, abdomen, subscapula and anterior and posterior thigh. Six anatomical landmarks for the sites were noted in our previous study (Tanimoto *et al.*, 2008).

Muscle thickness was scanned using a real-time linear electronic scanner with a 5 MHz scanning head (SSD-500; Aloka, Tokyo, Japan). The scanning head was prepared with water-soluble transmission gel that provided acoustic contact without depression of the skin surface. The scanner was placed perpendicular to the tissue interface at the marked sites.

Body composition determined by dual energy X-ray absorptiometry scan

Lean soft tissue mass (LSTM: body mass minus bone and fat mass) and fat mass were determined for the whole body using dual energy X-ray absorptiometry (DXA) (Hologic QDR-4500A scanner; Hologic, Waltham, MA, USA). Subjects were positioned for whole-body scans according to the manufacturer's protocol. Participants lay in the supine position on the DXA table with the limbs close to the body. To minimize interobserver variation, all scans and analyses were carried out by the same investigator. The whole body was divided into several regions, i.e. arms, legs, trunk and head. The body compositions were analysed using manual DXA analysis software (version 11.2:3; Waltham, MA, USA). The arm region was defined as the region extending from the head of the humerus to the distal tip of the fingers. The reference point between the head of the humerus and the scapula was positioned at the glenoid fossa. The leg region was defined as the region extending from the inferior border of the ischial tuberosity to the distal tip of the toes. The whole body was defined as the region extending from the shoulders to the distal tip of the toes. A reference point that could be visualized clearly on the DXA system terminal was selected.

Muscular strength

Maximal muscular strength was tested with the five types of exercise used in the training regimen. Values were obtained for 1RM according to the established guidelines (Baechle *et al.*, 2000).

Metabolic risk factors for coronary heart disease

To screen for the presence of coronary heart disease, fasting plasma concentrations of total cholesterol, HDL cholesterol, LDL cholesterol, triglycerides and glucose were determined with enzymatic techniques (Tanaka *et al.*, 2000).

Statistical analyses

All values are expressed as means ± SE. One-way analysis of variance (ANOVA) with Fisher's protected least significant difference (PLSD) was used to determine the significance of any differences among the initial parameters of the three groups. Two-way ANOVA repeated measures (group × period) with Newman-Keuls method was used to examine differences in changes in any parameters between groups. For all statistical tests, $P<0{\cdot}05$ was considered significant.

Results

Before the intervention period, there were no significant differences in any of the variables among the three groups.

Changes in muscle mass and strength

The percent changes in total MT in ultrasound imaging, defined as the sum of the values for all six measurement sites, after the experimental period were +6·8 ± 3·4% in LST, +9·1 ± 4·2% in HN and +1·3 ± 2·2% in CON. The absolute changes in LSTM (body mass minus fat and bone mass) in DXA were 1·4 ± 0·4 kg in LST, 1·8 ± 0·4 kg in HN and 0·6 ± 0·2 kg in CON. The percent changes in left leg LSTM, defined as leg muscle mass, were 3·0 ± 1·0% in LST, 4·4 ± 1·0% in HN and 1·1 ± 0·8% in CON. On measurement of muscular strength, the percent changes in total 1RM strength, defined as the sum of values for all five types of exercise used in the training regimen, were +33·0 ± 8·8% in LST, +41·2 ± 7·8% in HN and +1·3 ± 2·4% in CON. For all changes in muscle mass and strength shown above, increases in the LST and HN groups after the experimental period were significantly greater than those in CON, and there were no significant differences between the changes in LST and HN. Our previous study provided detailed data regarding changes in muscle mass and muscular strength (Tanimoto *et al.*, 2008).

Metabolic risk factors for coronary heart disease

There were no significant changes in fasting plasma concentrations of total cholesterol, HDL cholesterol, LDL cholesterol, triglycerides, fasting glucose or ABI (Table 2). All metabolic risk factors were well within clinically normal levels in all subjects. Brachial blood pressure, cardiac output and systemic vascular resistance (total peripheral resistance: TPR) did not change in any group (Table 3).

Changes in arterial blood flow

Figure 1 shows basal femoral (top) and carotid (bottom) blood flow and basal femoral blood flow per unit volume of leg muscle mass (middle) in the three groups before and after the experimental period. Figure 2 shows femoral and carotid vascular conductance (upper) and both femoral and carotid vascular resistance (lower).

In the LST and HN groups, basal femoral blood flow increased significantly after the experimental period, while there was no such change in CON. The percent changes in basal femoral blood flow were +18·0 ± 4·7% in LST and +34·8 ± 8·3% in HN. There were no significant differences between these changes induced by LST and HN, although the increase in basal

Table 2 Metabolic risk factors.

	LST		HN		CON	
	Pretraining	**Post-training**	**Pretraining**	**Post-training**	**Pretraining**	**Post-training**
Total cholesterol, mg dl^{-1}	185·9 ± 7·2	182·3 ± 9·8	164·4 ± 6·3	162·4 ± 5·4	162·6 ± 7·4	153·1 ± 7·4
HDL cholesterol, mg dl^{-1}	63·2 ± 2·3	62·3 ± 3·7	61·4 ± 5·3	63·1 ± 4·1	56·3 ± 3·0	56·3 ± 3·7
LDL cholesterol, mg dl^{-1}	106·8 ± 5·4	104·2 ± 5·8	90·2 ± 5·5	88·0 ± 5·1	93·5 ± 6·0	84·9 ± 5·1
Triglycerides, mg dl^{-1}	79·6 ± 6·5	79·6 ± 9·9	64·0 ± 7·4	56·9 ± 6·3	63·9 ± 7·6	59·8 ± 5·1
Fasting glucose, mg dl^{-1}	88·1 ± 1·7	87·4 ± 1·4	90·1 ± 1·5	89·0 ± 1·8	87·2 ± 1·3	84·8 ± 1·1

Values are means ± SE; n = 12 for each group.

LST, low-intensity exercise with slow movement and tonic force generation; HN, high-intensity exercise with normal speed; CON, sedentary control.

Table 3 Hemodynamic characteristics.

	LST		HN		CON	
	Pretraining	**Post-training**	**Pretraining**	**Post-training**	**Pretraining**	**Post-training**
Brachial systolic BP, mmHg	111·3 ± 1·6	111·4 ± 2·8	108·3 ± 1·8	110·3 ± 1·3	108·4 ± 2·1	107·6 ± 2·6
Brachial mean BP, mmHg	80·3 ± 1·6	80·0 ± 2·2	77·8 ± 0·9	81·3 ± 1·4	77·8 ± 1·9	77·9 ± 2·0
Brachial diastolic BP, mmHg	60·7 ± 1·5	60·3 ± 2·4	59·4 ± 1·7	61·8 ± 1·9	59·3 ± 1·7	60·0 ± 1·5
Femoral artery lumen diameter, mm	8·5 ± 0·2	8·7 ± 0·2	8·4 ± 0·1	8·6 ± 0·2	8·3 ± 0·2	8·5 ± 0·2
Femoral artery IMT, mm	5·4 ± 0·8	5·6 ± 0·8	5·4 ± 0·7	5·4 ± 0·8	5·2 ± 0·7	5·3 ± 0·5
Femoral artery MBV, cm s^{-1}	13·9 ± 0·8	15·2 ± 0·7[a,b]	12·2 ± 0·8	15·7 ± 1·4[a,c]	15·3 ± 1·5	14·7 ± 0·8
Carotid artery lumen diameter, mm	6·1 ± 0·1	6·1 ± 0·1	6·2 ± 0·1	6·1 ± 0·1	6·1 ± 0·1	6·2 ± 0·1
Carotid artery IMT, mm	4·8 ± 0·5	4·9 ± 0·3	4·7 ± 0·4	4·9 ± 0·5	4·7 ± 0·4	4·7 ± 0·5
Carotid artery MBV, cm s^{-1}	31·0 ± 1·3	32·5 ± 1·0	29·3 ± 1·1	32·1 ± 1·1	31·0 ± 1·2	31·3 ± 1·3
Cardiac output, l min^{-1}	3·7 ± 0·6	3·8 ± 0·6	3·9 ± 0·7	4·1 ± 0·9	4·2 ± 0·8	3·9 ± 0·7
systemic vascular resistance, U	22·4 ± 3·4	21·4 ± 4·4	20·8 ± 1·1	21·0 ± 1·7	19·4 ± 1·4	20·4 ± 0·8

Values are means ± SE; $n = 12$ for each group.

LST, low-intensity exercise with slow movement and tonic force generation; HN, high-intensity exercise with normal speed; CON, sedentary control; MBV, mean blood velocity; IMT, intima-media thickness.

[a] Significant difference ($P<0{\cdot}05$) between pretraining and post-training.

[b] Increase in LST was significantly higher ($P<0{\cdot}05$) than that in CON.

[c] Increase in HN was significantly higher ($P<0{\cdot}05$) than that in CON.

femoral blood flow in LST corresponded to about half that in HN.

Basal femoral blood flow per unit volume of leg muscle mass changed after the experimental period in a manner similar to the basal femoral blood flow changes described above. The percent changes in basal femoral blood flow per unit volume of leg muscle mass were +15·0 ± 4·8% in LST and +29·1 ± 8·2% in HN. Percent changes in leg muscle mass after the experimental period were not related to those in basal leg blood flow in either training group (LST and HN; Fig. 3). Furthermore, percent changes in cardiac output after the experimental period were not related to those in basal leg blood flow in ether training group (LST and HN; Fig. 4).

These changes were associated with a significant increase in femoral vascular conductance and a significant reduction in femoral vascular resistance in the LST and HN groups, respectively. The increases in femoral blood flow in the LST and HN group were primarily dependent on an increase in mean blood velocity, not on artery lumen diameter (see Table 3). There were no significant changes in any carotid parameter (blood flow, vascular conductance or vascular resistance) after the experimental period in any of the three groups.

Discussion

The present randomized-control intervention study is the first to document the effect of low-intensity (~50–60% 1RM) resistance training with slow movement and tonic force generation (LST) on basal femoral blood flow and vascular conductance. The salient findings of the present study were that basal femoral blood flow and vascular conductance significantly increased even after 13 weeks of LST training, as well as after 13 weeks of traditional high-intensity (~85–90% 1RM) resistance training with normal speed (HN) in young men.

In addition, LST resulted in increases in muscular size and strength comparable to those associated with HN (Tanimoto et al., 2008). LST met the requirement of the primary purpose of resistance training, which is to be effective for gaining muscular size and strength. Meeting this requirement is essential for any study investigating the additional effects of resistance training methods.

These findings extend our understanding of the relation between resistance training and basal limb blood flow in at least two additional ways. First, by establishing that traditional high-intensity resistance training is effective for increasing basal femoral blood flow (Miyachi et al., 2005; Anton et al., 2006), the findings presented here indicate that resistance training even in LST, which used a relatively low mechanical load, is effective for increasing basal femoral blood flow. However, we should emphasize that although not significantly different, the change in basal femoral blood flow in LST corresponded to about half that in HN. Second, by establishing that resistance training increases basal femoral blood flow in middle-aged men and women whose basal femoral blood flow decreases with the advancing age (Dinenno et al., 2001a,b; Moreau et al., 2003), the findings of the present study indicated that in both the LST and HN groups, resistance training increases basal femoral blood flow even in young men. With regard to the intergenerational differences in basal femoral blood flow changes, changes in basal femoral blood flow in young men caused by resistance training in the present study (15% in LST and 29% in HN) were lower than those in middle-aged men and women in the previous study (over 50%). This age-related difference would be due to differences in the baselines of basal femoral blood flow before the training intervention period. These findings suggest that LST training may be one of the effective strategies for increasing basal limb perfusion, and that regular resistance training from a

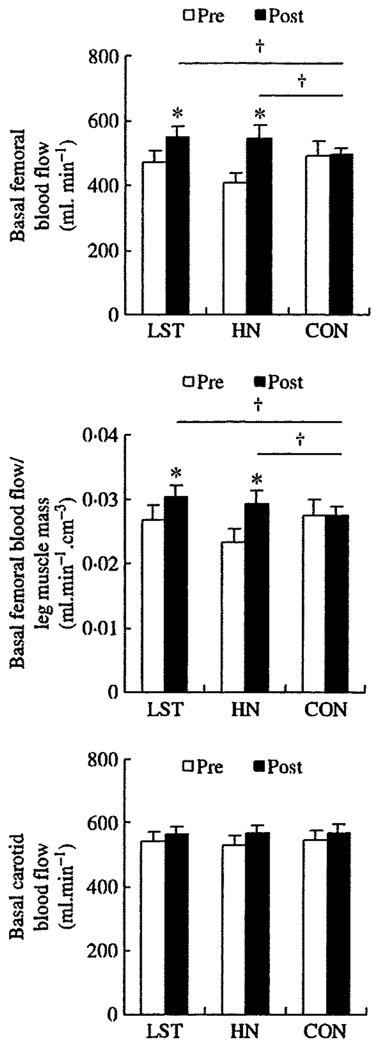

Figure 1 Basal femoral and carotid blood flow before and after the intervention period. Means ± SE ($n = 12$ for each group) in basal femoral blood flow (top), femoral blood flow/leg muscle mass (middle) and basal carotid blood flow (bottom). *Significant difference ($P<0·05$) between pretraining and post-training values. †Significant differences ($P<0·05$) between groups. Absolute basal femoral blood flow and that per unit volume of leg muscle mass in both training groups (LST and HN) increased significantly after experimental period.

young age may contribute to preservation of basal limb blood flow.

Potential mechanisms

What are the physiological mechanisms that would explain the increases in basal limb blood flow following resistance training? A previous study indicated that leg oxygen demand and leg muscle mass are associated with basal femoral blood flow (Dinenno *et al.*, 2001a,b). Therefore, it was initially hypothesized that resistance training, which promotes muscular hypertrophy, increases basal femoral blood flow because muscle mass is strongly related to energy consumption (Evans & Cyr-Campbell, 1997). However, in the present study, increases in leg muscular size (3·0% in LST, 4·4% in HN) were much lower than the increases in basal femoral blood flow (18% in LST, 35% in HN), and percent changes in leg muscle mass after the experimental period were not related to those in whole-leg basal blood flow in the two training groups (LST and HN, $r = -0·05$; Fig. 3). Moreover, increases in the relative blood flow to leg muscle mass in the two training groups were quantitatively the same as increases in whole-leg blood flow (Fig. 1). These findings suggest that qualitative changes in leg muscles by resistance training (LST and HN) have a more immediate and/or potent influence than quantitative changes (gain in muscle mass).

The muscle metabolic rate and capillary density may be qualitative factors contributing to increased basal femoral blood flow. Resistance training is known to be a strong stimulus that increases skeletal muscle turnover (syntheses and degradation) (Hasten *et al.*, 2000) and basal metabolic demands (Ades *et al.*, 2005), which may have acted to increase blood flow independent of muscle mass. Muscular metabolic rate was not measured, while basal metabolic rate (BMR) was measured. BMR increased after the experimental period in HN ($P<0·01$) and in LST ($P<0·1$) (data not shown).

An additional possible cause of the changes in leg blood flow is that peripheral blood flow may be a simple reflection of changes in systemic blood flow (cardiac output) (Leithe *et al.*, 1984). However, there were no obvious changes in cardiac output or TPR after the intervention period, and there was no significant relation between percent changes in cardiac output and those in basal whole-leg blood flow in either training group (LST and HN, $r = 0·19$; Fig. 4). Furthermore, basal carotid blood flow did not increase after LST and HN training. These findings suggest that the increase in basal femoral blood flow after both types of resistance training was affected not by systemic cardiovascular changes but by peripheral vascular and metabolic adaptations.

Physiological and practical implications

The present findings have potentially important physiological and practical implications. Traditional high-intensity resistance training increases muscle mass and strength. It is widely accepted that such training also facilitates performance of daily tasks, and promotes spontaneous physical activity especially in the elderly and in subjects with low physical capacity (Borst, 2004; Hunter *et al.*, 2004). Several recent studies showed the beneficial influence of high-intensity resistance training on vascular function, contributing to increases in basal whole leg blood flow (Miyachi *et al.*, 2005; Anton *et al.*, 2006). The present study in healthy young men suggested that the resistance training program in the LST group promoted muscular hypertrophy without high mechanical load and increased basal femoral blood flow as efficiently as the regimen performed by the HN group. The LST regimen was not associated with either the generation of large force or marked elevation of blood

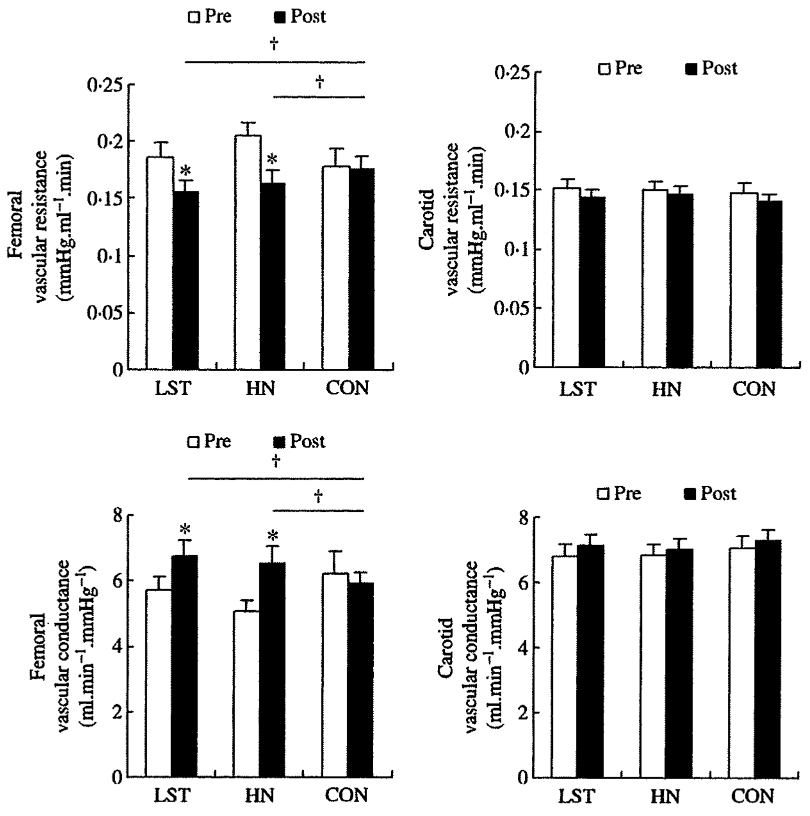

Figure 2 Femoral and carotid vascular resistance and conductance before and after the intervention period. Means ± SE ($n = 12$ for each group) in femoral and carotid vascular conductance (upper), femoral and carotid vascular resistance (lower) in the three experimental groups. *Significant difference ($P<0{\cdot}05$) between pretraining and post-training values. †Significant differences ($P<0{\cdot}05$) between groups. Femoral carotid resistance in both training groups (LST and HN) decreased, and femoral carotid conductance in both training groups (LST and HN) increased significantly after experimental period.

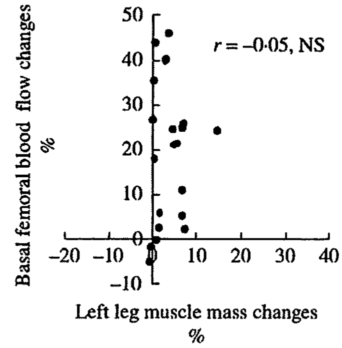

Figure 3 Relations between leg muscle mass changes and basal femoral blood flow changes in the two trained groups ($n = 24$). Left leg LSTM (lean soft tissue mass) is defined as left leg muscle mass. Change in leg muscle mass was not related to that in femoral leg blood flow ($r = -0{\cdot}05$).

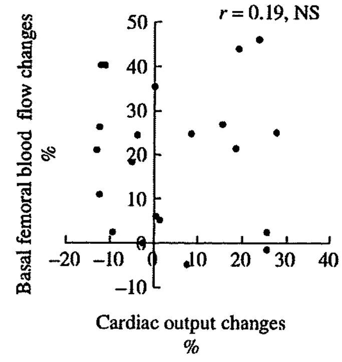

Figure 4 Relations between cardiac output changes and basal femoral blood flow changes in trained group subjects ($n = 24$). Change in cardio output was not related to that in basal femoral blood flow ($r = 0{\cdot}19$).

pressure (Tanimoto & Ishii, 2006), and so it would be a safe and useful method of exercise for increasing peripheral blood flow. The reduction in leg blood flow may limit peripheral glucose uptake and contribute to glucose intolerance and hyperinsulinemia (Lind & Lithell, 1993). In addition, it may also impair the clearance of atherogenic lipids and contribute to chronic dyslipidaemia (Baron *et al.*, 1990). Regular resistance training in the LST group may contribute to a lower incidence of cardiovascular disease through its influence on basal femoral blood flow.

Conclusion

The results of the present study indicated that resistance training, even in LST, increased basal femoral blood flow and vascular conductance as in HN, and that regular resistance training from a young age may contribute to preservation of basal limb blood flow. LST promotes muscular hypertrophy and strength gain comparable to those in HN without high mechanical load. LST is proposed as a safe and useful exercise method not only for muscular hypertrophy and strength gain, but also for increasing peripheral blood flow and vascular conductance as an additional