（表紙）

中高年者のローイングによる有酸素運動とレジスタンス運動の効果に関する研究

（課題番号：１３６８００７７）

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平成１３年度	1,600	0	1,600
平成１４年度	800	0	800
平成１５年度	900	0	900
総　計	3,300	0	3,300

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研究成果

A. 研究目的

有酸素性能力が高い中高年者は冠動脈疾患や糖尿病など生活習慣病の罹患率、死亡率が低いことが知られている。また、中高年者では加齢による筋肉の萎縮や骨密度の低下が転倒・骨折などを引き起こす要因として指摘されている。さらに、高齢者では筋量・筋力の低下を予防することがQOLの高い生活を営むうえで重要であることが次第に明らかになってきており、最近では有酸素運動に加えてレジスタンス運動が推奨されている。

全米スポーツ医学会(ACSM)は1978年に公式見解として、「健康な一般人の体力の維持・増進のために望ましい運動の量と質」を発表し、ウオーキングやジョギング、スイミングなどの有酸素運動を推奨し、1990年には有酸素運動に加えて、「除脂肪体重(FFM)の維持・発達に十分な筋力トレーニングが成人の体力プログラムに組み入れられるべきである」との見解を含む勧告を行った。1990年の勧告では運動の様式として「大筋群を使い、持続的でリズミカルな有酸素運動ならどのような運動でもよい」としている。

ローイングは全身の70%の骨格筋を動員する運動であり、その運動様式から有酸素運動とレジスタンス運動の特徴を有しているので、筋量・筋力と有酸素性能力を同時に高めることができる可能性をもった運動であり、健康増進、生活習慣病予防に適している可能性が高いと考えられる。

しかし、中高年者に対する日常規則的なローイング運動が有酸素性能力と筋量・筋力、そして生活習慣病に関連する諸因子に及ぼす影響については、これまでほとんど研究されてこなかった。そこで、本研究では中高年ローイング愛好者の身体組成と筋力、有酸素性能力、さらに糖・脂質代謝プロフィールを同年齢層の運動習慣のない一般人やウォーキング愛好者との対比で明らかにするとともに、若年ボート選手とも比較して、中高年ローイング愛好者の身体組成、筋力、有酸素性能力の加齢変化を検討した。

ローイング運動は座位にて行う運動であるため、強度や頻度に注意を払えば肥満者や膝などに整形外科的疾患を有する人々にも可能な運動である。とくに最近では、ローイングエルゴメータが開発されインドアにてローイング運動を行うことができるようになったので、ローイングは自転車エルゴメータやトレッドミルと同様に健康増進施設、さらには家庭でも広く実行することができる可能性をもった運動である。そこで、座位で行われるローイング運動中の心拍応答についても、中高年ローイング愛好者を対象として検討した。

B．研究方法

研究 1．運動習慣のある中高年男性の身体組成と糖・脂質代謝指標 －ローイング愛好者とウォーキング愛好者の比較－

運動習慣のある健康な中高年男性 23 名（ローイング愛好者 15 名、ウォーキング愛好者 8 名）を被検者とした。各被検者は宿泊施設に宿泊し、起床後排尿し、身長、体重を計測し、BOD POD システムにて体密度を測定して、Brozek の式から体脂肪率を算出した。得られた体重と体脂肪率から除脂肪体重(LBM)を算出した。また、空腹時に採血を行って、糖・脂質代謝パラメータを(株)SRL に委託し分析した。

研究 2．ローイング・トレーニングが中高年男性の呼吸循環器系機能と血中脂質・リポ蛋白プロフィールに及ぼす影響

ローイング（ボート漕ぎ）を日常規則的に行っている中高年男性ボート愛好者（年齢 64±4 歳、体重 69±6kg）、体重をマッチさせた同一年齢層の運動習慣のない中高年男性(65±3 歳、70±7kg)、若年男性ボート選手（22±2 歳、70±4kg)、運動習慣のない若年男性一般人（22±3 歳、69±7kg)、それぞれ 17 名を対象とした。

身体組成は BOD POD システムによる空気置換法にて身体密度を求めて体脂肪率を算出した。ローイング・エルゴメータによる負荷漸増法により Vo_2max を求めた。運動負荷中に心拍数(HR)をモニターし、最高心拍数(HRmax)を求めた。採血は前夜から 12 時間以上の絶食をした後、早朝空腹時に肘静脈から行い、血清を分離した。血清中の総コレステロール(T-C)、HDL-コレステロール(HDL-C)、およびトリグリセリド(TG)の分析は(株)SRL に委託した。血清中の LDL-コレステロール(LDL-C)濃度は計算式で求めた。

研究 3．ローイング・トレーニングが中高年男性の骨格筋の形態と機能に及ぼす影響

ローイングを日常規則的に行っている中高年男性ボート愛好者 15 人（年齢 65±3 歳、身長 171±4cm、体重 68±6kg)、と体格をマッチさせた同一年齢層の運動習慣のない中高年男性 15 人(66±4 歳、身長 170±4cm、67±7kg)を対象とした。

身体組成は空気置換法（BOD POD システム）により身体密度を求めて体脂肪率を算出した。大腿部の横断面積(CSA)を MRI(AIRIS Ⅱ Comfort System 0.3-T, Hitachi Medico Co.,Tokyo,Japan)により測定し、NIH Image Software にて解析した。両脚による最大伸展パワーを Anaeropress 3500(Combi Co.,Tokyo,Japan)により測定した。

すべての被験者に対して、ローイング・エルゴメータによる 2000m のタイムトライアルを実施した。

研究 4．中高年男性の有酸素能力と身体各部の筋量に及ぼすローイング運動の効果

定期的にローイング運動を行っている中高年男性 11 名（年齢：64.7±2.9 歳：ローイング群）とローイング群と年齢、体格を合わせた過去にローイング運動の経験があるが現在は運動習慣のない中高年男性 10 名（年齢：66.0±3.4 歳：対照群）を被験者とした。ローイング群は水上またはエルゴメータでのローイング運動を 1 週間のうち 2～7 日行っており、1 週間の漕距離は 12～52km であった。

身長（cm)、体重（kg）を測定し、MBI を求めた。BOD POD システムにより、体密度を測定し、体脂肪率を算出した。また、得られた体重と体脂肪率から、除脂肪体重を求めた。ローイングエルゴメータでの漸増負荷法によって Vo_2max を測定した。

Vo_2max 測定における漸増負荷運動中の酸素摂取量を x 軸に、発揮パワーを y 軸にとったとき、負荷が小さいときは両者は 1 次直線的に増加するが、最大負荷近くでは無酸素的に増加する範囲の回帰式を求め、その回帰式に最大酸素摂取量の値を代入することによって算出されるパワーの値を有酸素的に発揮される最大のパワーとみなし、最大有酸素パワーとした。

筋量の評価として、磁気共鳴映像化（Magnetic Resonance Imaging 以下 MRI）（AIRIS II Comfort System 0.5-T、日立メディコ）によって、大腿部、上腕部、体幹部の横断面積を測定した。測定部位は、大腿部は右の大転子から大腿骨外側顆までの大腿長において、上腕部は右の肩峰から橈骨点までの上腕長においてそれぞれの 50% に相当する部位にて横断面画像を撮影した。体幹部は第 3 腰椎と第 5 腰椎の間に相当する部位で横断画像を撮影した。得られた画像を筋、脂肪、骨に分類してトレース紙に写し取り、スキャナーによりパーソナルコンピュータに取り込んだ。その後、NIH イメージソフトウェアにより、各部位の全体および筋のみの横断面積を算出した。各部位における筋として、大腿部は膝伸筋と膝屈筋、上腕部は肘伸筋と肘屈筋、体幹部は背筋の横断面積を算出した。

研究 5．中高年者におけるエルゴメトリー・ローイング中の心拍数応答

15 名の男性ローイン愛好者（年齢：62±3 歳、身長：172±4cm、体重：70±5kg、体脂肪率：17±4%、平均±SD）を対象とし、エルゴメトリー・ローイング（座位での腕と

脚を併用した運動）とトレッドミル・ランニング（立位での脚を用いた運動）における酸素摂取量（Vo_2）と心拍数（HR）を評価した。ローイング・エルゴメータとトレッドミルによる負荷漸増法により、最大下と最大時のVo_2を求めた。運動負荷中にHRをモニターし、最大下と最大時のHRを求めた。各最大下と最大時に指先から微量採血を行い、血中乳酸濃度を分析した。

（倫理面への配慮）

すべての研究は、ヘルシンキ宣言による倫理基準に則り、独立行政法人国立健康・栄養研究所「人間を対象とする生物医学的研究に関する倫理委員会」の承認を得て実施した。測定に先だって、被検者に対して、本研究の意義や各種測定に際しての不利益の可能性、具体的な測定内容、被検者としての権利の擁護などについて十分に説明し、文書によるインフォームド・コンセントを得た。

C．研究結果

研究　1．運動習慣のある中高年男性の身体組成と糖・脂質代謝指標
－ローイング愛好者とウォーキング愛好者の比較－

ローイング愛好者は身長、体重ともウォーキング愛好者よりも大きく、LBM も多かったが、BMI、体脂肪率は両グループ間に差が見られなかった（表１）。また、糖・脂質代謝に関連するパラメータはいずれも両グループ間に顕著な差が認められなかった（表２）。

研究　2．ローイング・トレーニングが中高年男性の呼吸循環器系機能と血中脂質・リポ蛋白プロフィールに及ぼす影響

中高年ボート愛好者の最高心拍数（HRmax）は若年のボート選手、及び運動習慣のない一般人よりも低くなっていたが、その値は中高年非運動習慣者よりも高い値であった。また、中高年ボート愛好者のVo_2maxは若年ボート選手の値より有意に低くなっていたが、若年非運動習慣者のVo_2maxと同レベルであり、中高年非運動習慣者よりも顕著に高くなっていた（図１）。

さらに、中高年ボート愛好者の最大酸素脈（Vo_2max /HRmax）は、若年及び高齢の非運動習慣者よりも高い水準であった。なお、中高年ボート愛好者のローイング・エルゴメータによる 2,000m ローイング・パフォーマンス・タイムは若年ボート選手よりも著しく

低いレベルであった（489±16 vs. 451±12 sec, $P<0.05$）。

中高年ボート愛好者のT-C及びLDL-Cは若年ボート選手よりも有意に高くなっていたが、若年、及び中高年の非運動習慣者と同水準であった（T-C: 中高年ボート愛好者 5.2±0.4 vs. 若年ボート選手4.1±0.6, 若年非運動習慣者 4.8±0.6, 中高年非運動習慣者 5.2±0.4 mmol/L, LDL-C: 2.9±0.4 vs. 2.0±0.7, 2.9±0.7, 3.0±0.6 mmol/L）。また、中高年ボート愛好者のTG、及びHDL-Cは、若年ボート選手、若年非運動習慣者、中高年非運動習慣者の３グループの値と顕著な差が認められなかった（TG: 1.4±0.4 vs. 0.9±0.3, 0.9±0.5, 1.3±0.4 mmol/L, HDL-C: 1.7±0.2 vs. 1.6±0.3, 1.4±0.2, 1.5±0.2 mmol/L）。

しかしながら、LDL-C/HDL-C、あるいはT-C/HDL-Cの比率を動脈硬化指数としてみると、中高年ボート愛好者の動脈硬化危険度は、若年ボート選手よりは高くなっていたが、若年及び中高年の非運動習慣者よりは低い水準であった（図２）。

研究　３．ローイング・トレーニングが中高年男性の骨格筋の形態と機能に及ぼす影響

中高年ローイング愛好者の大腿伸展筋群の横断面積は非運動グループよりも明らかに大きく、脚伸展力も著しく高い値であった（図３）。しかし、脚伸展筋群横断面積当たりの脚伸展力には、両グループ間に差がみられなかった（20.9±2.0 vs. 19.9±2.1 W/cm^2）。

中高年ローイング愛好者と元ボート選手であるが現在はローイングを定期的に行っていない中高年者を合わせてみると、大腿伸展筋群の横断面積と脚伸展力との間には高い正の相関関係が認められ、中高年ローイング愛好者の大腿伸展筋群の横断面積(X)と2000mローイング・パフォーマンスタイム(sec)(Y)との間にも高い負の相関関係が認められた（$Y=-1.6X + 619$, $R^2=0.40$、図４）。

本研究により、ローイング運動は加齢に伴う骨格筋の萎縮を予防し、筋力を高い水準に保持させる働きがあることが示唆された。

研究　４．中高年男性の有酸素能力と身体各部の筋量に及ぼすローイング運動の効果

１．身体的および生理的特性

体脂肪率、除脂肪体重には両群間に有意な差は見られなかった（表３）。Vo_2maxは絶対値で約22%、体重あたりでも約19%ローイング群が対照群よりも有意に高い水準であった。同様に最大有酸素パワーもそれぞれ約20%、18%だけローイング群が対照群よりも有意に高くなっていた。一方、脚伸展パワーはローイング群が対照群よりもやや高い値であ

ったが、統計的には有意な差が認められなかった（表３）。

２．横断面積

それぞれの群の被験者によって得られた実際のMRI画像を図５（大腿部）、図６（上腕部）、図７（体幹部）に示した。MRIにより得られた身体各部の横断面積は大腿部、上腕部、体幹部それぞれにおいて、筋、脂肪、骨をあわせた全体の面積には両群間に有意な差はみられなかった（表４）。さらに、筋断明晰について対象部位別にみると、大腿部で約10%、上腕部で17%、体幹部で約13%だけローイング群が対照群よりも大きかったが、統計的な有意差は体幹部のみで認められ、脂肪が占める面積は上腕部においてのみ、ローイング群が対照群よりも有意に低くなっていた（表４）。

次ぎに、計測した身体各部において、全横断面積に占める骨格筋と脂肪それぞれの断面積の比率をみると、大腿部と上腕部では、ローイング群は対照群に比べて骨格筋では有意に高く、脂肪では有意に低くなっていた（図８，９）。また、体幹部は骨格筋のみがローイング群で対照群よりも有意に高い比率になっていた（図10）。

図11はローイング愛好者と非トレーニング・対照群を合わせて、脚筋断面積と脚伸展パワーとの関係をみたものであるが、有意な正の相関関係が認められた（$r=0.539, P<0.05$）。また、図12〜14は大腿部、上腕部、及び体幹部の筋断面積と最大酸素パワーとの関係を示したものであるが、大腿部と上腕部では筋断面積と最大有酸素パワーとの間には有意な正の相関関係が認められたが（大腿部：$r=0.61$, $p<0.05$、上腕部：$r=0.68$, $p<0.05$）、体幹部と最大有酸素パワーとの間には有意な相関関係が認められなかった。

研究５．中高年者におけるエルゴメトリー・ローイング中の心拍数応答

中高年者ローイング愛好者を対象としたエルゴメトリー・ローイング（中のHRは、トレッドミル・ランニング中に比べて、血中乳酸濃度が4 mmol/Lレベル（151±4 beats/min vs. 160±5 beats/min, $P<0.05$）、及び最大強度レベル（171±7 beats/min vs. 177±7 beats/min, $P<0.05$）において、より低い水準であった（図15）。

また、Vo_2は血中乳酸濃度が4mmol/L（3.0±0.4 L/min vs. 2.7±0.4 L/min, $P<0.05$）、及び最大強度（3.4±0.4 L/min vs. 3.1±0.3 L/min, $P<0.05$）において、エルゴメトリー・ローイングがトレッドミル・ランニングよりも高くなっていた。よって、エルゴメトリー・ローイング中の%HRmax、%HR reserveはトレッドミル・ランニング中よりも低くなっていた（図15）。

これらの結果は、中高年者に対するローイングによる運動処方においては、HR と Vo_2 の関係、及びローイングにおける低 HR 応答が考慮されなければならないことを示唆している。

D. 考察

ローイングに関する研究は国内外ともこれまでほとんどが競技力との関係で行われてきた。我々のこれまでの研究によっても、若年成人ボート選手では筋量・筋力、有酸素性能力が高い選手ではローイングの競技力が高いことが明らかになっている。しかし、中高年ローイング愛好者の身体的特徴や生理機能についてはまったくデータがなく、ましてや冠動脈疾患や糖尿病の危険因子との関連については研究されていなかった。

加齢に伴い身体活動が低下すると、骨格筋を中心とした除脂肪体重の減少と相まってQOL が低下し、生活習慣病も発症しやすくなると考えられる。とくに、高齢者はこれまでのライフスタイルの影響を反映して、個々人で健康度が著しく異なっていると考えられる。

本研究においては、日常生活において不自由のない健常な中高年者を対象として、有酸素運動とレジスタンス運動の両効果が期待されるローイング（ボート漕ぎ）に注目して、呼吸循環器系・筋骨格系機能や糖・脂質代謝指標に及ぼす影響について研究を行い、得られた結果から以下に示すような考察を試みた。

研究 1．運動習慣のある中高年男性の身体組成と糖・脂質代謝指標
－ローイング愛好者とウォーキング愛好者の比較－

本研究の結果から、ローイング運動を習慣化している中高年男性の糖・脂質代謝機能はウォーキング愛好者とほぼ同様であることが示され、ローイング運動の健康増進・生活習慣病予防効果が示唆された。

研究 2．ローイング・トレーニングが中高年男性の呼吸循環器系機能と血中脂質・リポ蛋白プロフィールに及ぼす影響

中高年ボート愛好者の呼吸循環器系機能と脂質代謝プロフィールに焦点を当てた本研究から、ローイング・トレーニングを日常規則的に行っている中高年者は、最大有酸素性能力が運動習慣のない若齢一般人と同レベルであり、同年齢層の一般人よりも顕著に高く保持されていると同時に、動脈硬化、冠動脈疾患のリスクが低いことが示された。この結果

は、ローイングは冠動脈疾患のリスクを低減し、長寿をもたらすことと関連していることを示唆するいくつかの研究を支持している。

研究 3．ローイング・トレーニングが中高年男性の骨格筋の形態と機能に及ぼす影響

ローイング愛好者は運動習慣のない一般中高年者よりも脚伸展筋の断面積が大きく、脚伸展パワーも高いことが明らかになるとともに、脚伸展筋断面積と脚伸展パワーとの間には高い相関関係が認められ、ローイング運動のレジスタンス運動効果が示唆された。本研究により、ローイング運動は加齢に伴う骨格筋の萎縮を予防し、筋力を高い水準に保持させる働きがあることが示唆された。

研究 4．中高年男性の有酸素能力と身体各部の筋量に及ぼすローイング運動の効果

本研究においてローイング群の最大有酸素パワーは対照群よりも約 18%高い値を示した。そして、最大有酸素パワーは Vo_2max、除脂肪体重、大腿部、上腕部、体幹部の筋断面積と相関関係がみられた。これらのことは、ローイング運動が呼吸循環器系と筋系の両方の改善に効果的である可能性を示唆している。

ローイング運動はパワー発揮の際の衝撃が小さいため肥満者や膝などに傷害を持つ人でも行うことができ、艇やエルゴメータのシートに体重が支えられているため重大な傷害も引き起こしにくい。本研究により、ローイング運動は中高年者の有酸素能力や身体各部の筋量の低下を予防する効果があり、中高年者の健康増進やリハビリテーションなどに効果的な運動であるということが示唆された。

研究 5．中高年者におけるエルゴメトリー・ローイング中の心拍数応答

一般に、競技スポーツとしてのローイングは、非常にきつい運動と考えられているが、レクレーショナルにローイング運動を行う高齢者は、各ストロークのスピードと強度を変化させることにより、ローイングの強度を容易に調節することができ、呼吸循環器系の機能に適度な負担をかけることができるので、中高年者の健康増進を目的とした運動指導にはローイングが効果的であると考えられる。

しかし、中高年者を対象としたローイング運動における生理学的応答については、必ずしも十分に研究されていない。すでに、我々は若年者を対象とした漸増負荷によるローイング中とランニング中の心拍数と Vo_2 の応答について検討し、ローイングはランニングよ

りも $\dot{V}o_2max$ が高く、同一相対強度でも、より高い $\dot{V}o_2$ を示すが、心拍数は低くなるので、心拍数を強度の指標として運動処方をする場合には、配慮が必要であることを明らかにしている。本研究によって、中高年者を対象としたローイングの場合でも、若年者と同様なことが確認された。

E．結論

ローイング（ボート漕ぎ）は脚、腕、及び体幹を含む身体のほとんどすべての筋肉を動員して行われる有酸素性の運動であり、シートに座って行う運動なので、ランニングに比べて、瞬間的な衝撃はむしろ小さく膝への障害が少ない運動といえる。このようなことと、そのため、肥満者にとっても比較的行いやすい運動と考えられる。このようなことと、本本研究の結果を合わせて考えると、ローイング運動は中高年者の健康増進にとって適切かつ有効な運動であるといえるだろう。

表１．中高年男性のローイング愛好者とウオーキング愛好者の身体的特徴

Physical characteristics of rowers and walkers

		All Subjects n＝23	Rowing n＝15		Walking n＝8	基準値
Age	(year)	67.0±4.0	66.3±3.6		68.5±4.5	50～69
Height	(cm)	170.7±5.6	172.7±3.4	*	166.8±7.0	163.9
Weight	(kg)	67.1±6.6	69.8±5.9	**	62.0±4.7	62.5
BMI	(kg/m2)	23.0±2.2	23.4±2.0		22.4±2.4	23.3
Body Fat	(%)	22.4±4.8	22.6±4.8		22.1±5.0	—
LBM	(kg)	52.0±5.2	53.9±4.8	*	48.3±4.1	—
FM	(kg)	15.1±3.9	15.8±4.1		13.7±3.5	—

Values are means±SD.

BMI : body mass index,　LBM : lean body mass,　FM : fat mass

基準値:第六次改定日本人の栄養所要量ー食事摂取基準ーより

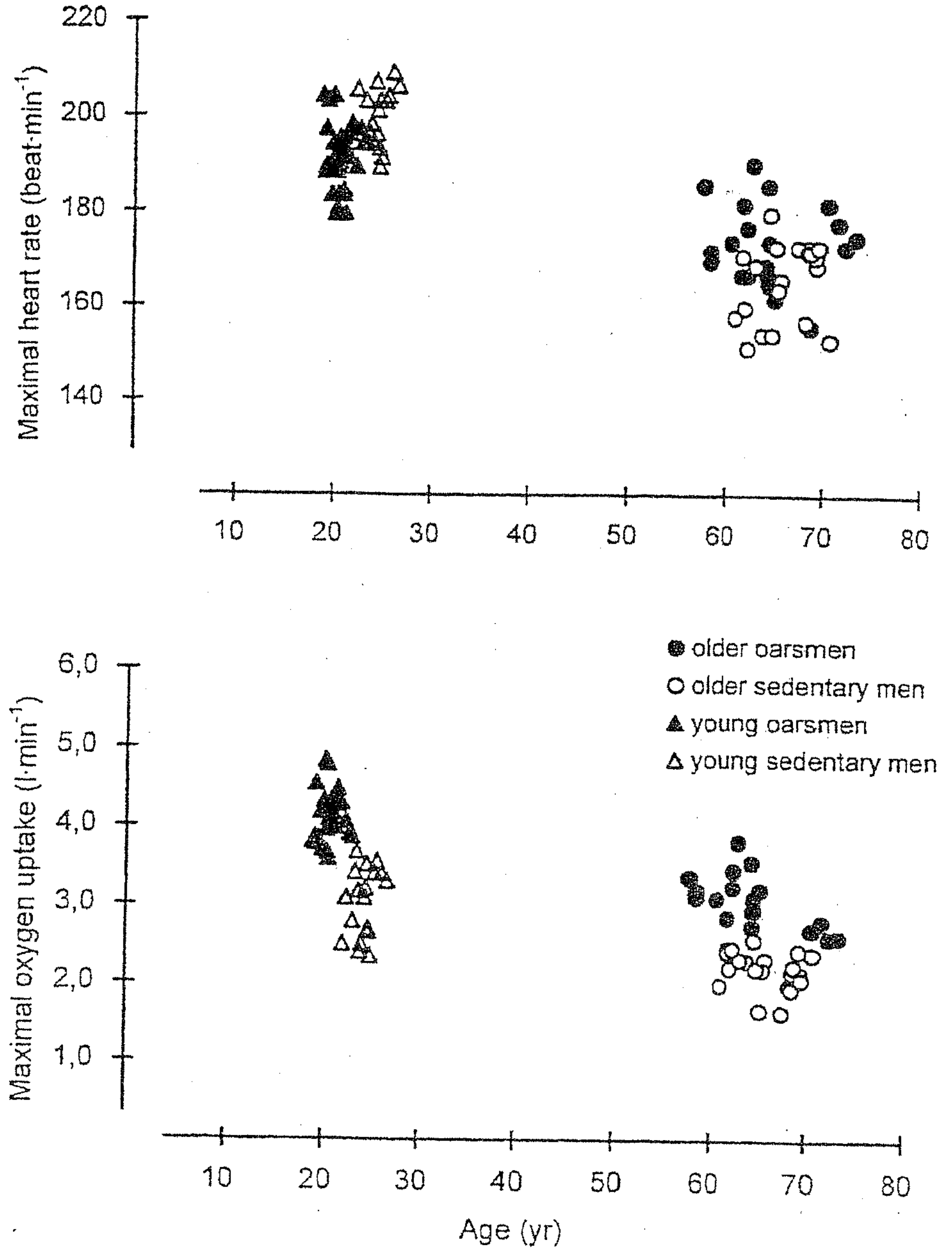
* : vs Walking group　$p<0.05$　** : $p<0.01$

表２．中高年男性のローイング愛好者とウオーキング愛好者の
糖・脂質代謝に関する生化学的諸指標

Biochemical parameters of glucose and lipid metabolism in rowers and walkers

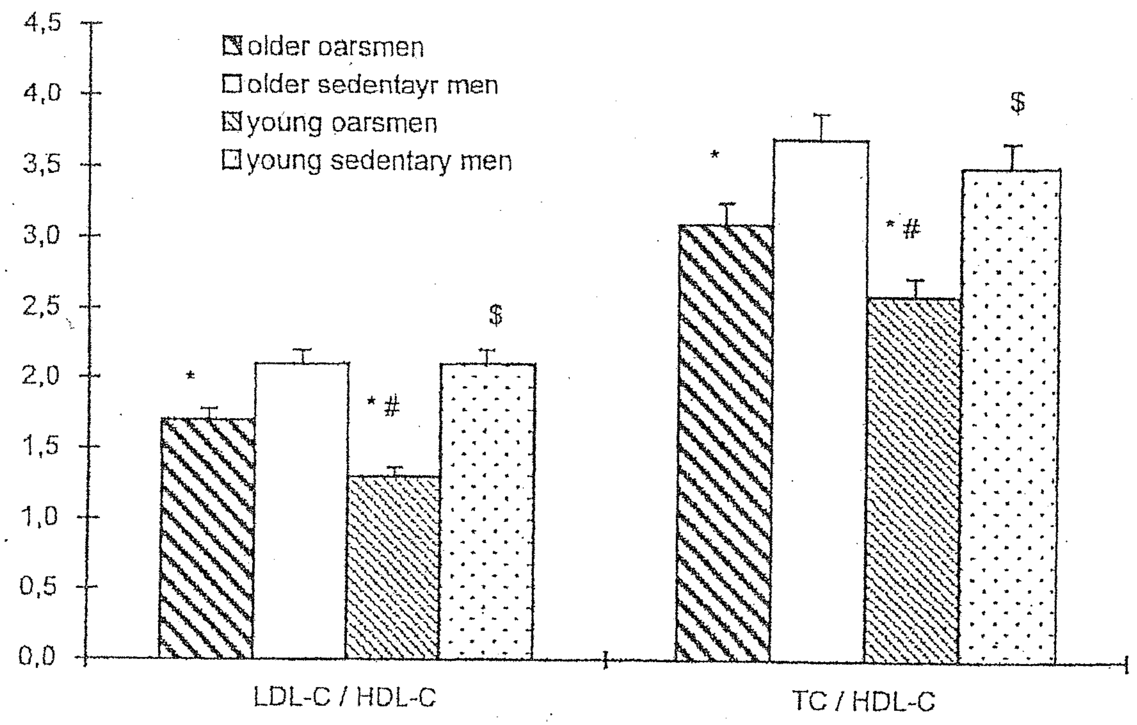
		All Subjects n=23	Rowing n=15	Walking n=8
Glucose	(mg/dl)	102±14	106±15	96±9
HbA1c	(%)	5.0±0.6	5.1±0.7	4.8±0.5
Insulin	(μU/ml)	7.9±5.0	7.8±4.8	8.3±5.5
HOMA−Ra)		2.03±1.3	2.07±1.4	1.95±1.3
Total−Cholesterol	(mg/dl)	209±34	213±36	202±29
LDL−Chol	(mg/dl)	128±30	130±32	126±26
HDL−Chol	(mg/dl)	57±12	58±10	55±15
LDL−/HDL−		2.37±0.8	2.32±0.8	2.46±0.8
Total−/HDL−		3.83±1.0	3.79±1.0	3.91±1.0
Triglycerides	(mg/dl)	122±42	128±48	111±25

Values are means ±SD.
a) HOMA-R = Glucose * Insulin / 405



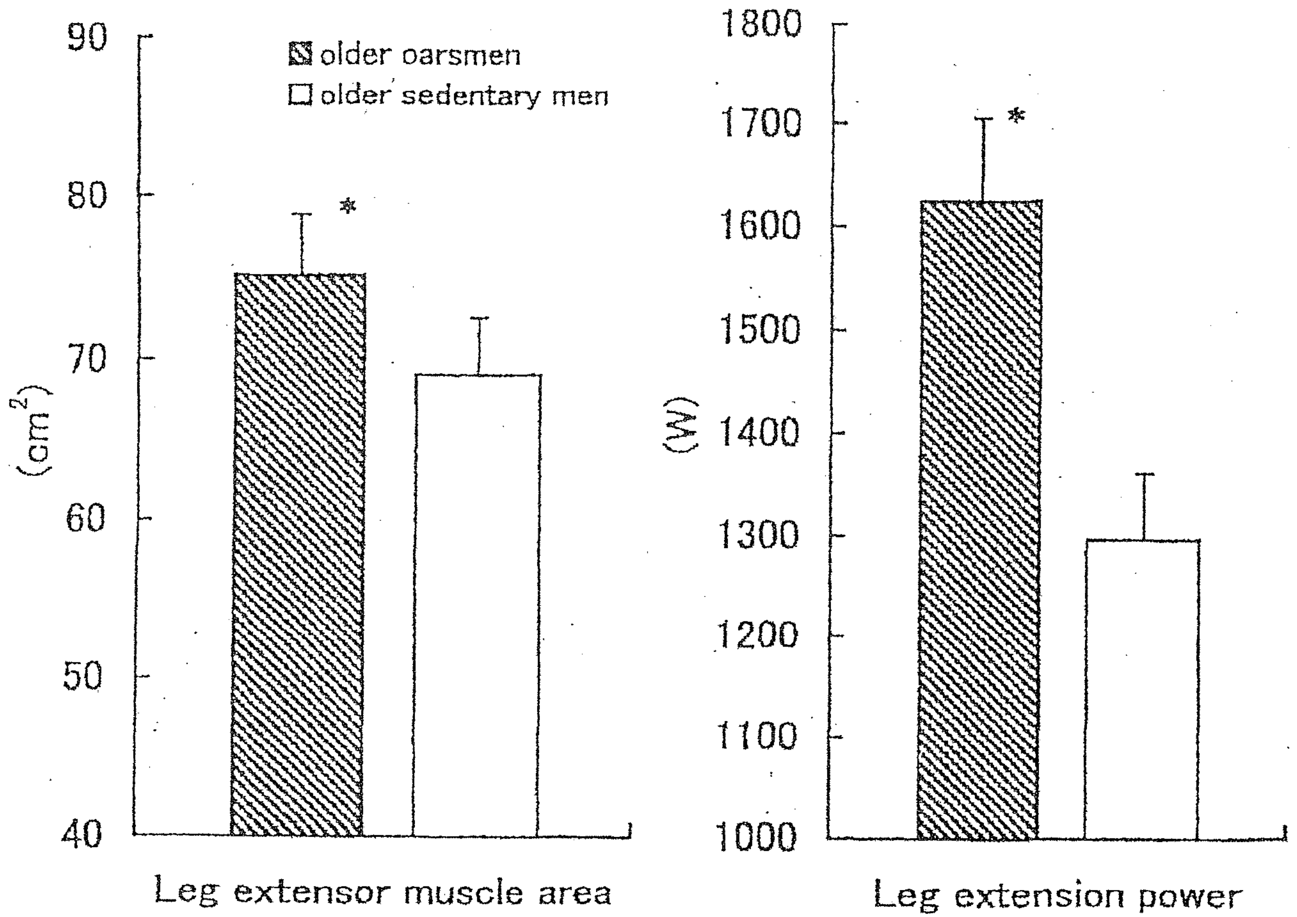
Maximal heart rate and maximal oxygen uptake related to age.

図１．若年男性ボート選手と中高年男性のローイング愛好者、及びそれぞれの年齢層の非トレーニング対照群の最大酸素摂取量と最高心拍数



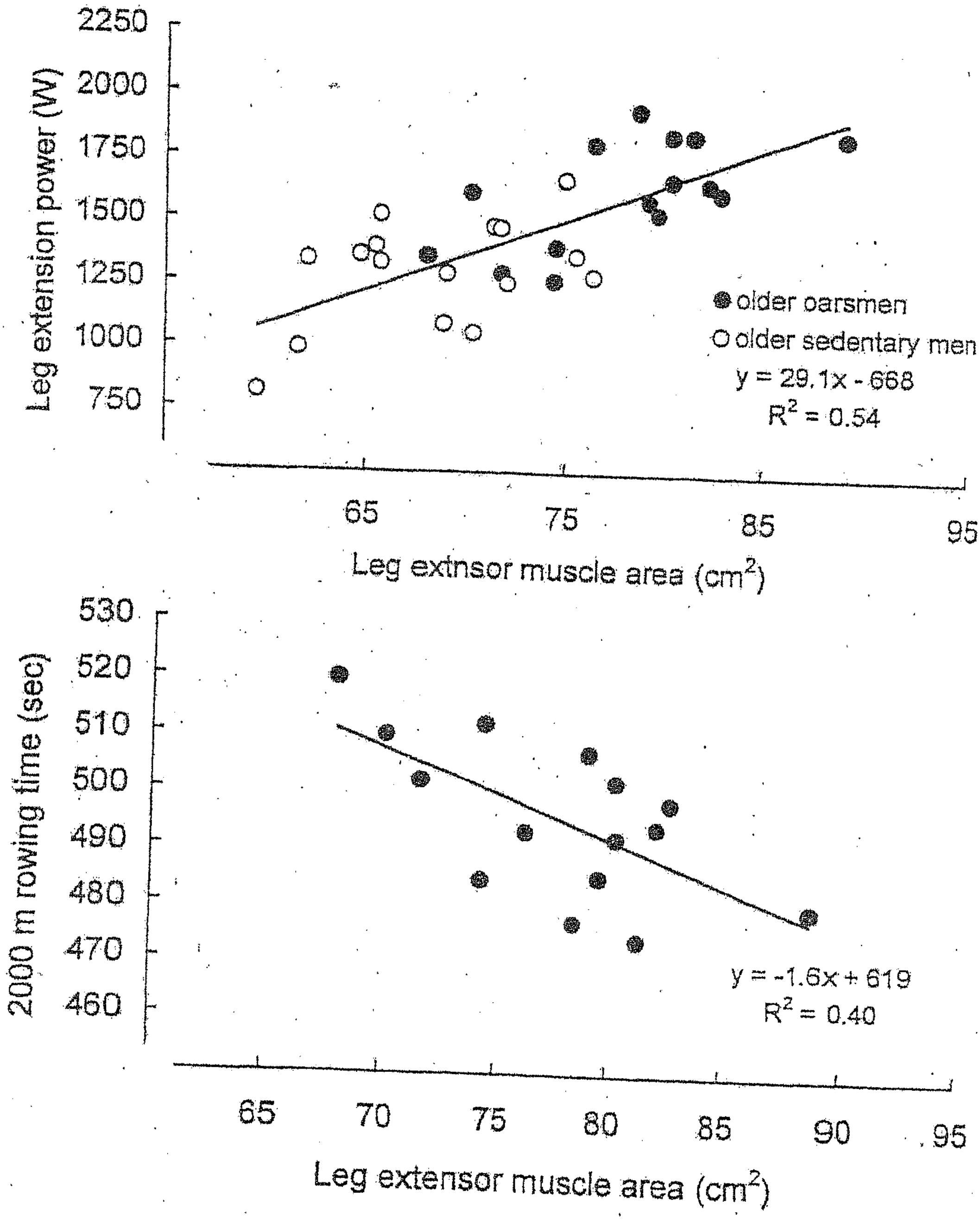
Atheroscleosis Indices (the ratio of low density lipoprotein, LDL−C, to high density lipoprotein−cholesterol, HDL−C, and that of total cholesterol, TC, to HDL−C). *p<0.05 difference between oarsmen and sedentary men in the same age groups, #p<0.05 difference between older oarsmen and young oarsmen, $ difference between older oarsmen and young sedentary men.

図2．若年男性ボート選手と中高年男性のローイング愛好者、及びそれぞれの年齢層の非トレーニング対照群の動脈硬化指数（LDL-C/HDL-C, TC/HDL-C）



Area of the leg extensor muscle and leg extension power.*$p<0.05$ difference between elderly oarsmen and elderly sedentary men.

図3．中高年男性ローイング愛好者と同年齢層の非トレーニング対照群の脚伸展筋群の横断面積と脚伸展力



Relationship between leg extension power, 2,000-m ergometer rowing time and leg extensor muscle area in elderly men

図４．中高年男性（ローイング愛好者と非トレーニング対照群を含む）の脚伸展筋群の横断面積と脚伸展力、及び中高年ローイング愛好者の脚伸展筋群の横断面積と 2000m ローイングタイムの関係

表３．中高年男性ローイング愛好者と非トレーニング対照群の
身体的・生理的特徴

Characteristics of Male Rowers and Untrained Men

	unit	Rowing-Trained (n=11) mean	SD	Untrained Men (n=10) mean	S.D.	
Age	(yr)	64.7	2.9	66.0	3.4	N.S.
Height	(cm)	172.1	3.5	172.6	3.7	N.S.
Weight	(kg)	71.2	4.6	70.1	7.2	N.S.
BMI	(kg/m^2)	24.1	2.0	23.5	2.1	N.S.
Percent of Body Fat	(%)	20.0	4.8	22.6	3.3	N.S.
Fat Free Mass	(kg)	56.9	4.2	54.2	4.5	N.S.
Maximal Oxygen Uptake (VO_2)	(l/min)	2.70	0.38	2.22	0.28	*
	(ml/kg/min)	37.9	4.2	31.8	3.8	*
Leg Extension Power	(W)	1601	240	1456	230	N.S.
	(W/kg)	22.4	2.8	21.0	4.3	N.S.
Maximum Aerobic Power	(W)	194	31	162	26	*
	(W/kg)	2.72	0.40	2.31	0.37	*

Values are means ± S.D.

* : Significantly different between Rowing-Trained and Untrained Men, $p < 0.05$

ローイング群の被験者

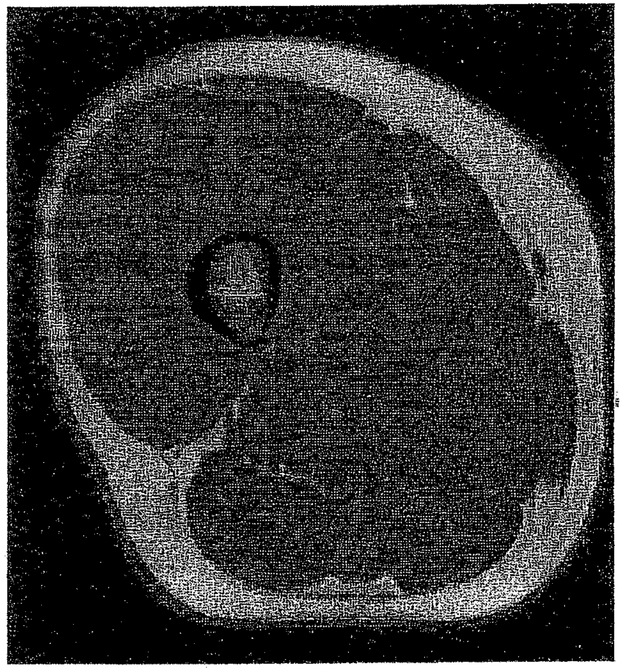
63歳　男性

身長：171cm　体重：75.1kg

体脂肪率：18.3%

全体の面積：222.7 cm^2

筋のみ：186.4 cm^2



対照群の被験者

70歳　男性

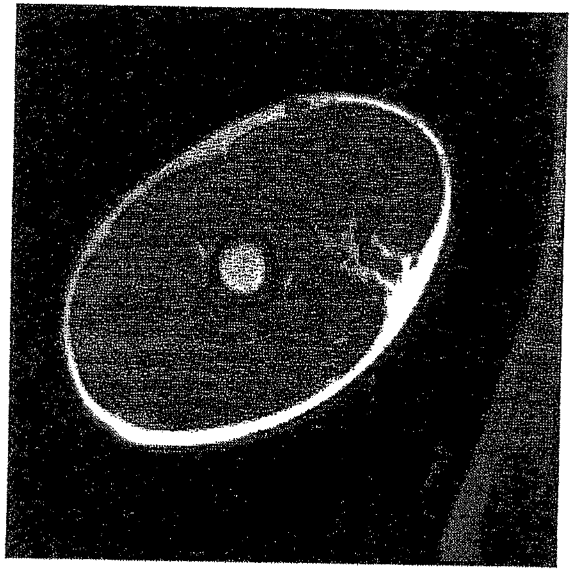
身長：173cm　体重：69.1kg

体脂肪率：25.7%

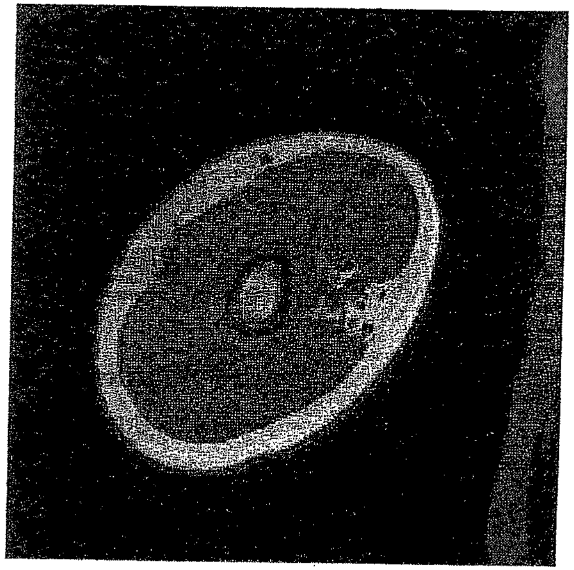
全体の面積：192.8 cm^2

筋のみ：124.1 cm^2

図5．中高年男性ローイング愛好者と非トレーニング対照群の大腿部のMRI画像例



ローイング群の被験者
63歳　男性
身長：171cm　体重：75.1kg
体脂肪率：18.3%
全体の面積：70.4 cm^2
筋のみ：53.0 cm^2



対照群の被験者
70歳　男性
身長：173cm　体重：69.1kg
体脂肪率：25.7%
全体の面積：55.9 cm^2
筋のみ：30.9 cm^2

図6．中高年男性ローイング愛好者と非トレーニング対照群の上腕部のMRI画像例

ローイング群の被験者

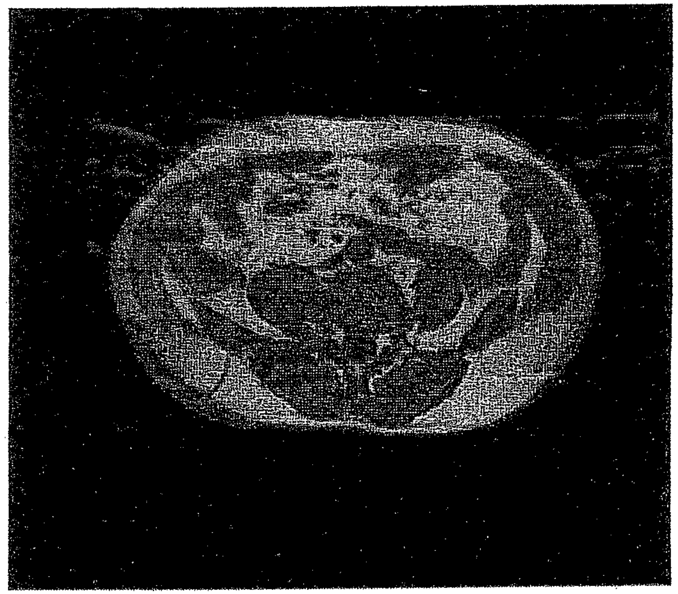
63歳　男性

身長：171cm　体重：75.1kg

体脂肪率：18.3%

全体の面積：379.1 cm^2

筋のみ：45.5 cm^2



対照群の被験者

70歳　男性

身長：173cm　体重：69.1kg

体脂肪率：25.7%

全体の面積：366.6 cm^2

筋のみ：33.9 cm^2

図7．中高年男性ローイング愛好者と非トレーニング対照群の体幹部のMRI画像例

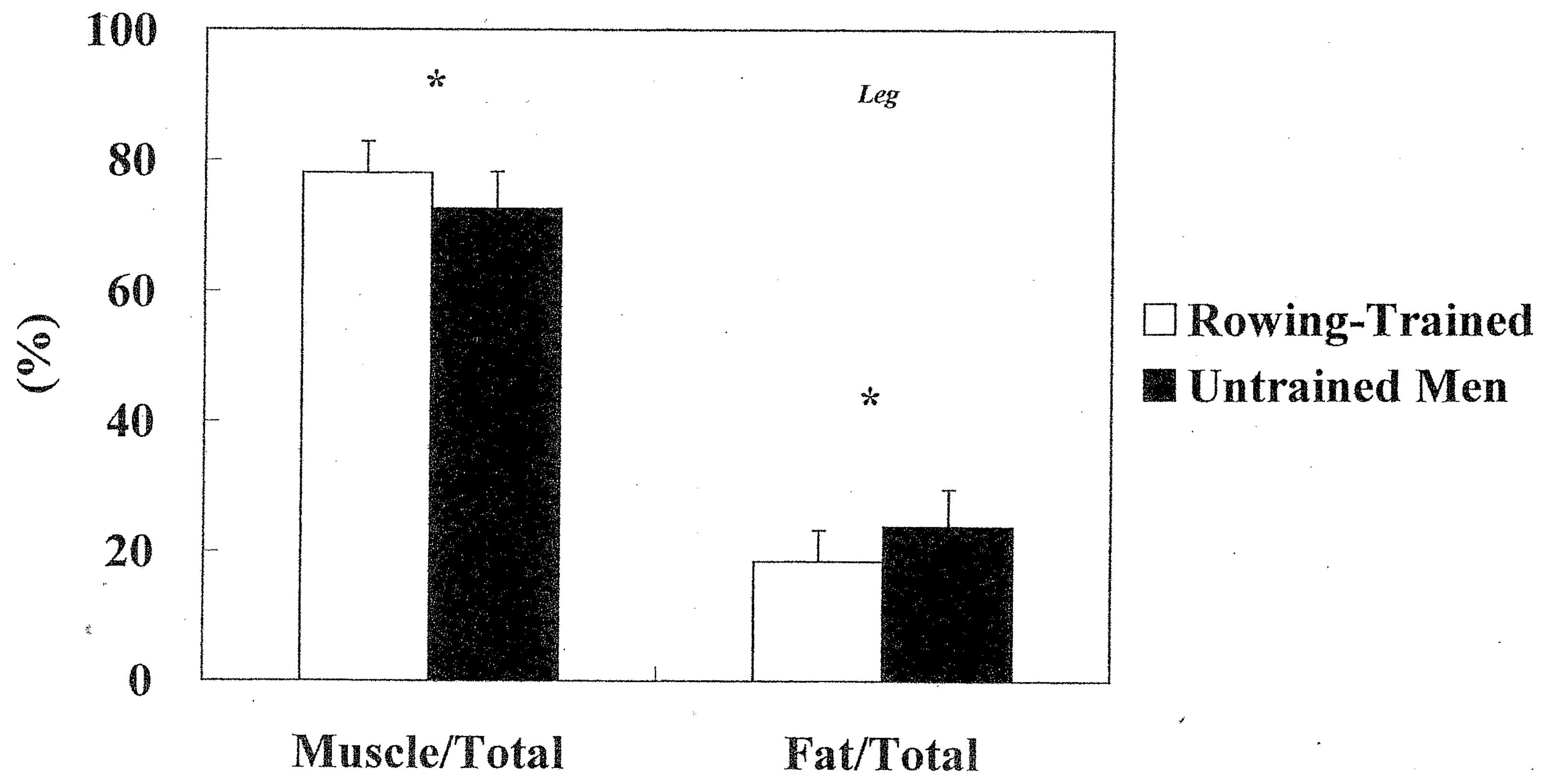
表４．中高年男性ローイング愛好者と非トレーニング対照群の身体各部の全体周囲面積と筋肉、脂肪の横断面積

Cross-Sectional Areas of Leg, Arm and Trunk in Male Rowers and Untrained Men

	Rowing-Trained (n=11)		Untrained Men (n=10)		
	mean	SD	mean	SD	
Leg					
Total	202	18	199	22	N.S.
Muscle	158	15	144	19	N.S.
Fat	38	12	48	13	N.S.
Arm					
Total	60	9	59	6	N.S.
Muscle	41	7	35	4	N.S.
Fat	15	4	19	3	*
Trunk					
Total	353	46	367	56	N.S.
Muscle	118	10	104	18	*
Fat	166	41	169	61	N.S.

Values are means (cm^2) ± S.D.

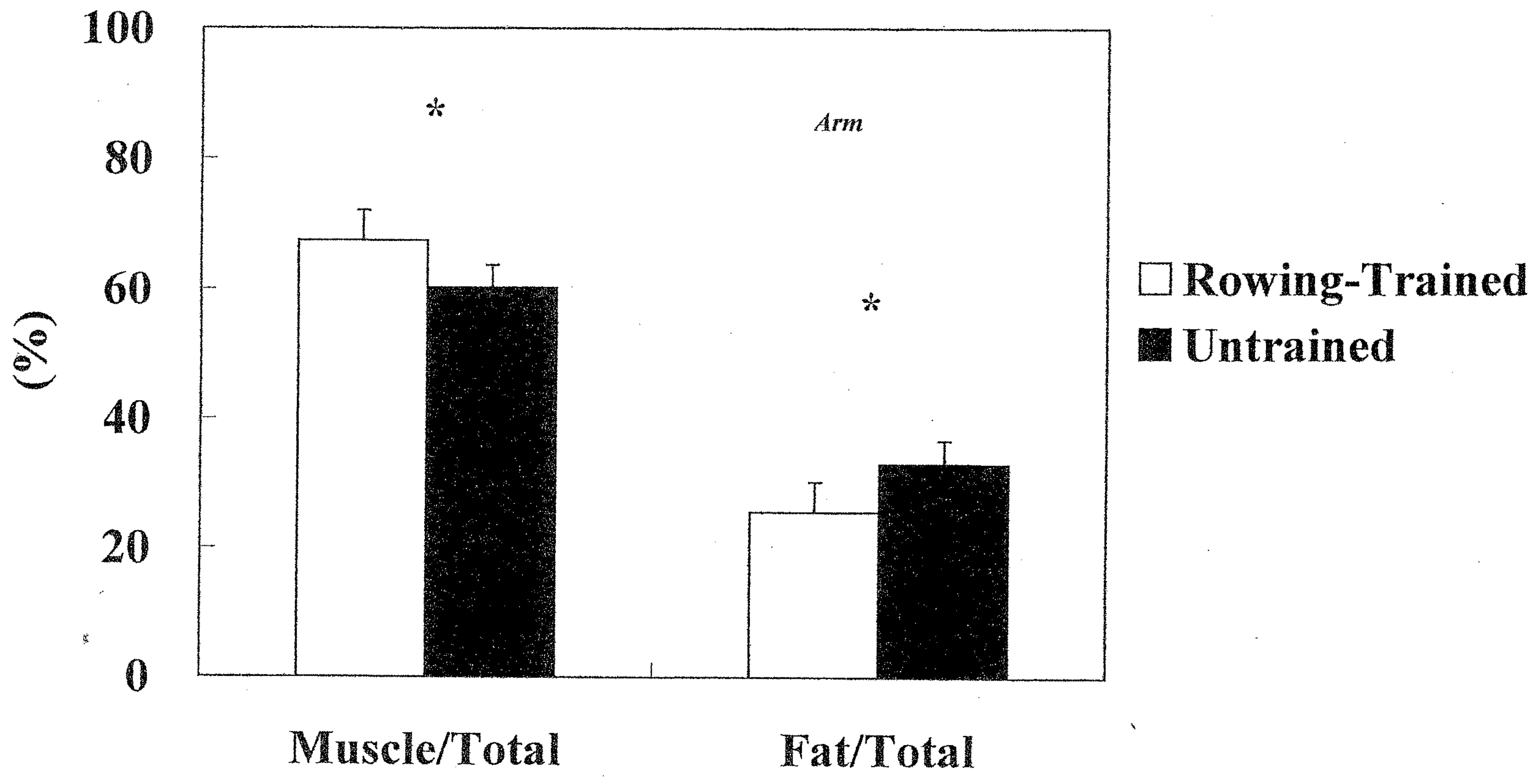
* : Significantly different between Rowing Trained and Untrained Men, $p < 0.05$



% Leg Cross-Sectional Areas

* $P < 0.05$ difference between Rowing-Trained and Untrained Men

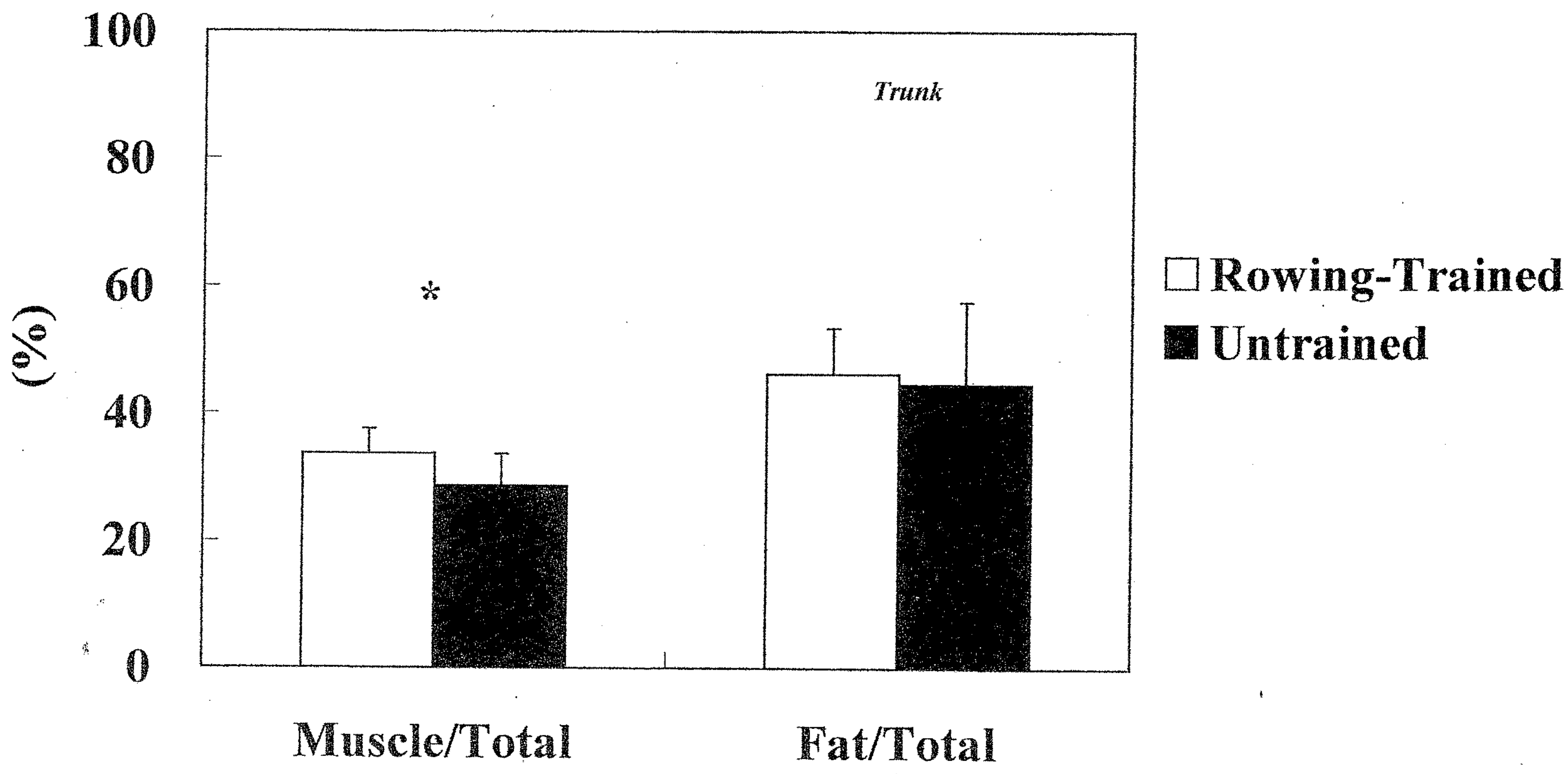
図８．中高年男性ローイング愛好者と非トレーニング対照群の大腿部の全体周囲面積に対する筋肉と脂肪の面積比率



%Arm Cross-Sectional Areas

* P < 0.05 difference between Rowing-Trained and Untrained Men

図9．中高年男性ローイング愛好者と非トレーニング対照群の上腕部の全体周囲面積に対する筋肉と脂肪の面積比率



%Trunk Cross-Sectional Areas

* $P < 0.05$ difference between Rowing-Trained and Untrained Men

図 10. 中高年男性ローイング愛好者と非トレーニング対照群の体幹部の全体周囲面積に対する筋肉と脂肪の面積比率

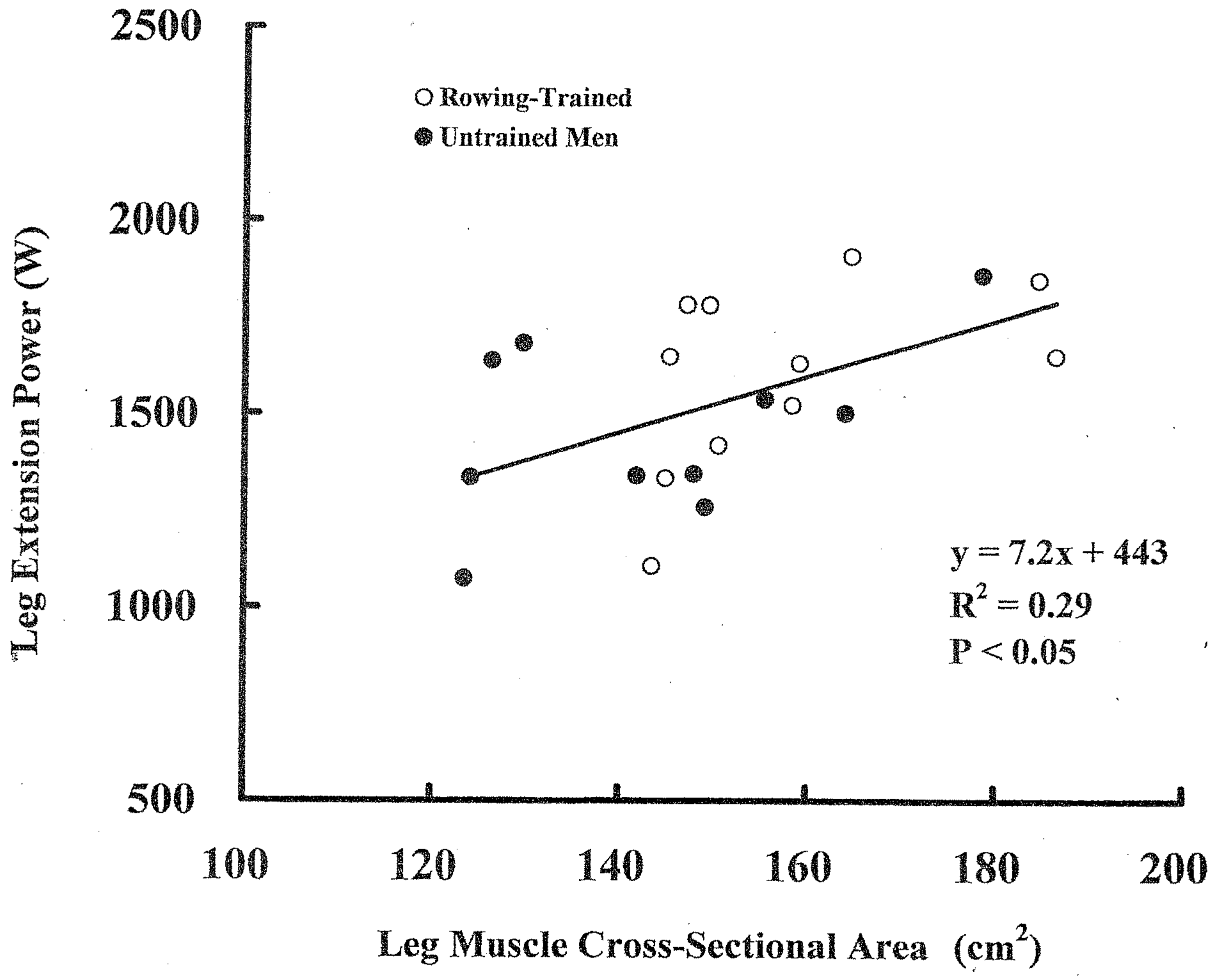


図 11. 中高年男性（ローイング愛好者と非トレーニング対照群を含む）の
脚伸展筋群の横断面積と脚伸展力の関係

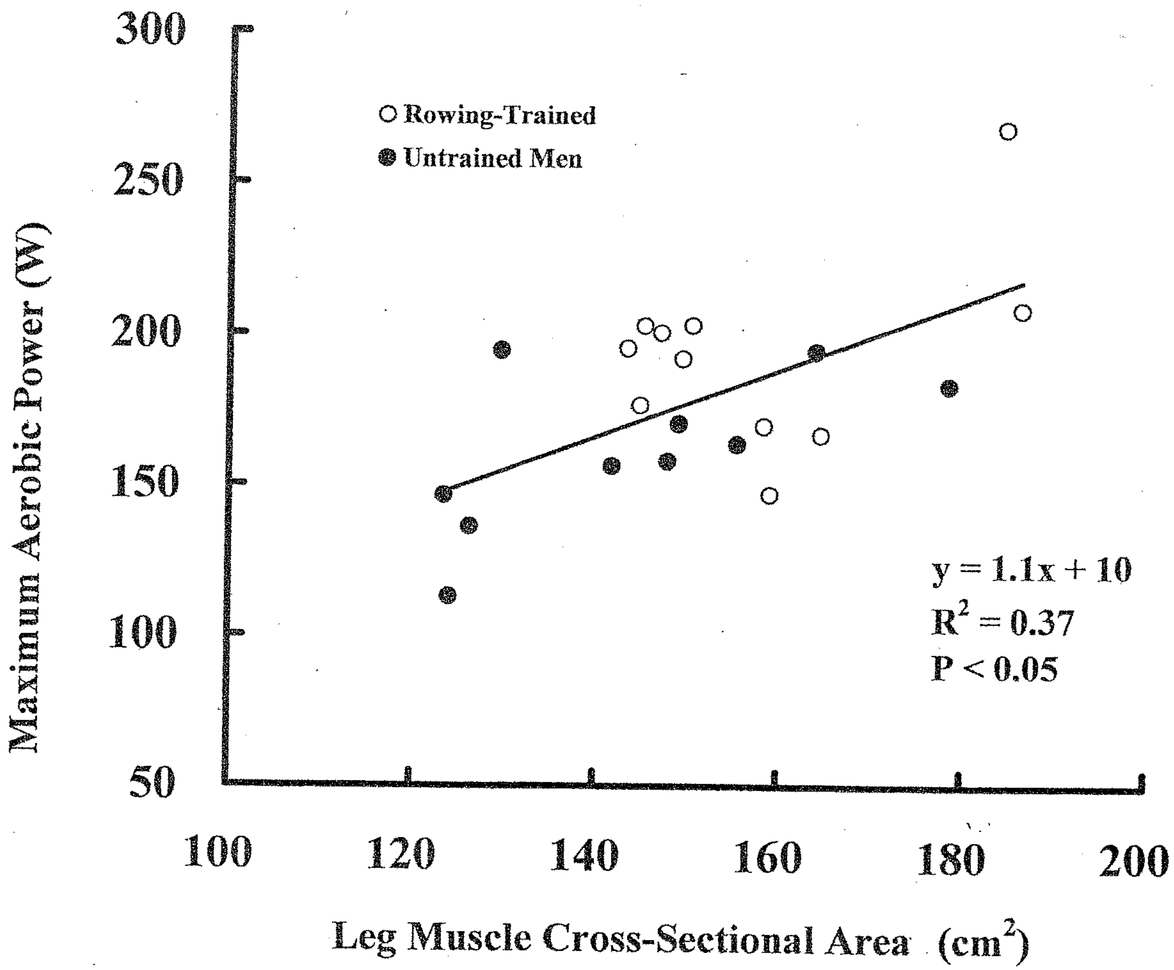


図 12. 中高年男性（ローイング愛好者と非トレーニング対照群を含む）の脚伸展筋群の横断面積と最大有酸素パワーの関係

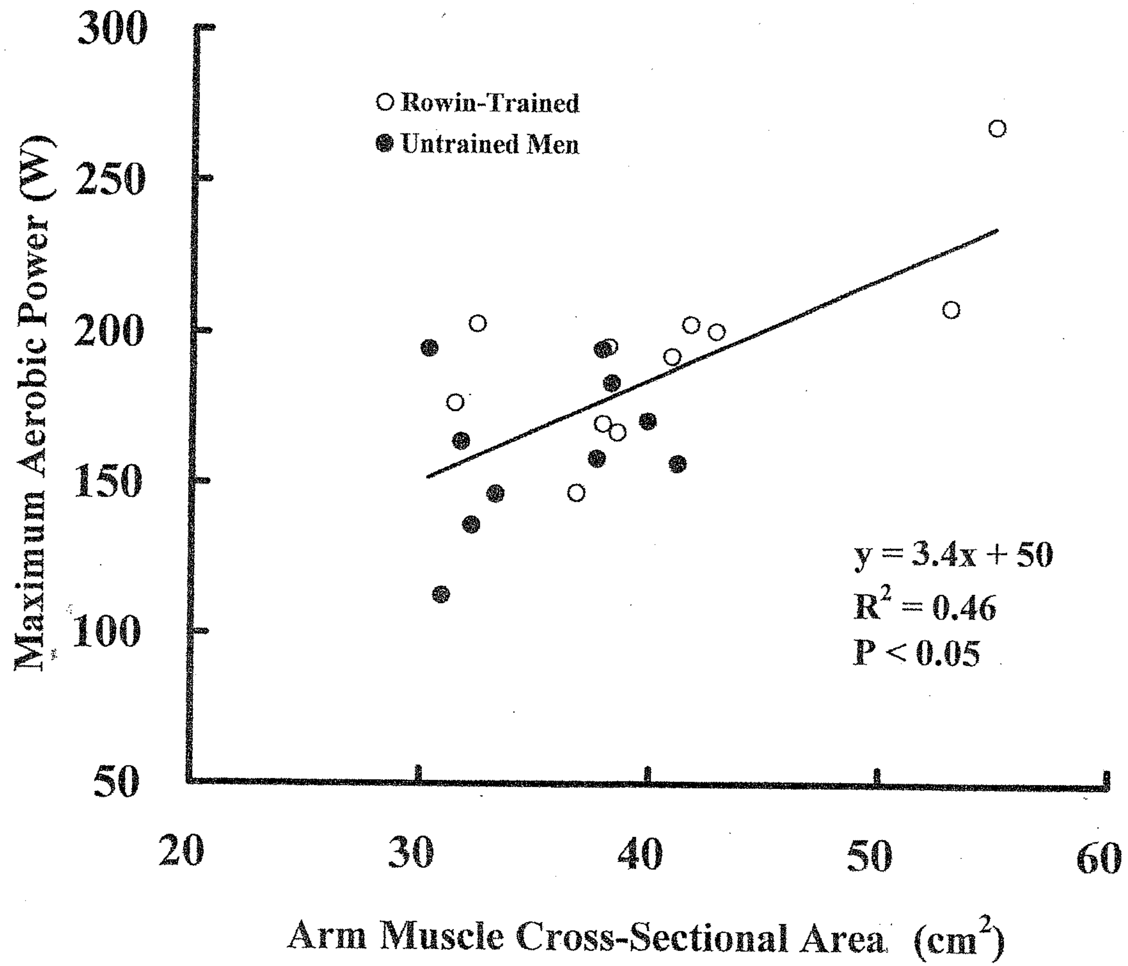


図 13. 中高年男性（ローイング愛好者と非トレーニング対照群を含む）の上腕筋群の横断面積と最大有酸素パワーの関係

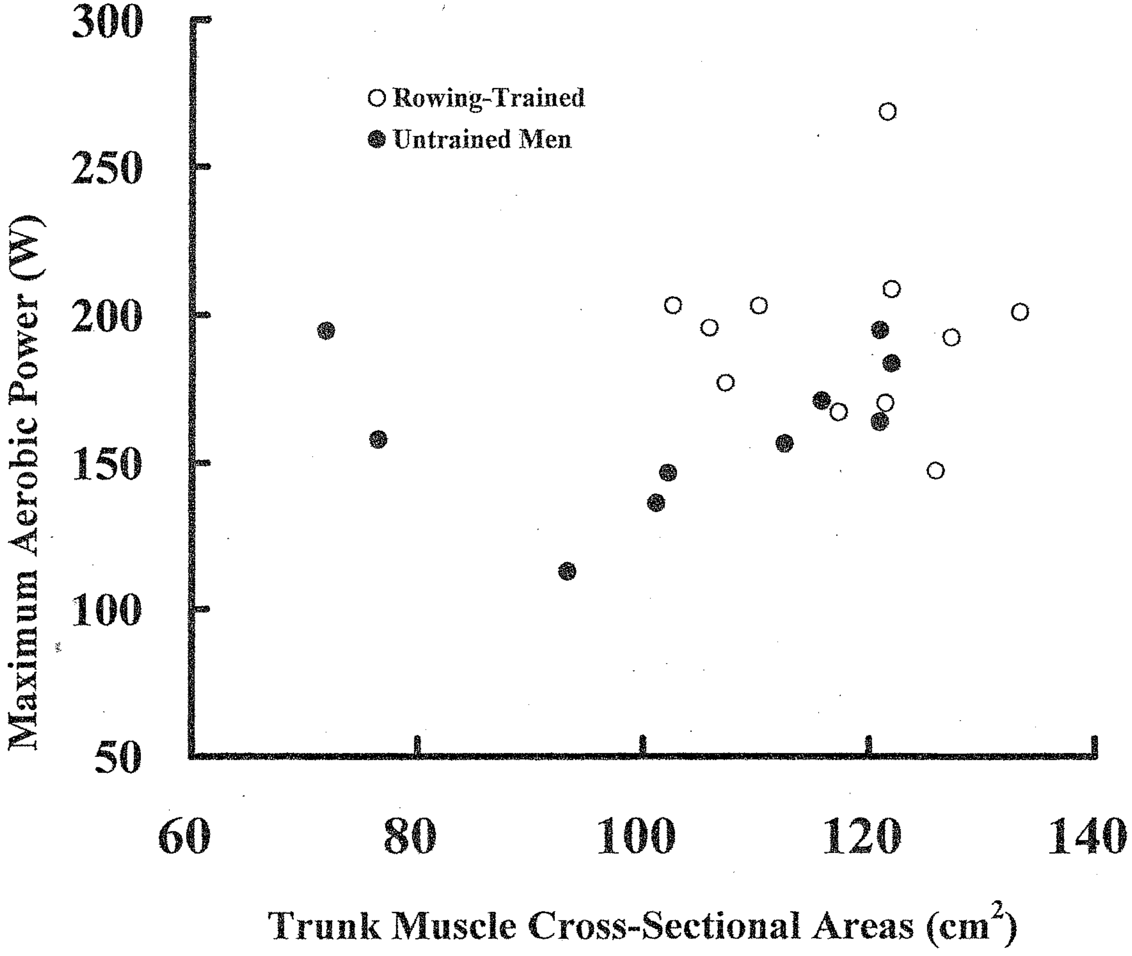
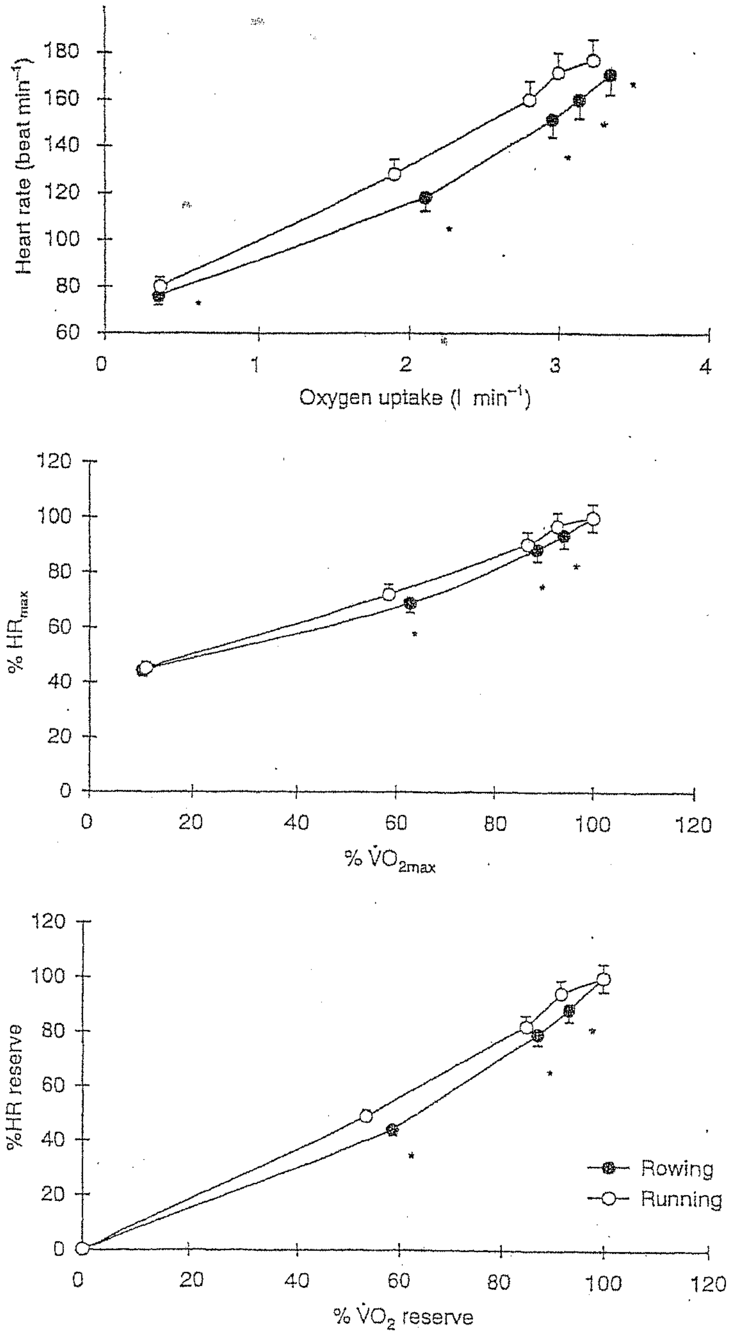


図 14. 中高年男性（ローイング愛好者と非トレーニング対照群を含む）の体幹筋群の横断面積と最大有酸素パワーの関係



Relation between heart rate and oxygen uptake, between percentage of maximal oxygen uptake and percentage of maximal heart rate, and between percentage of heart rate reserve and percentage of oxygen uptake reserve. *$p<0.05$ difference between rowing and running.

図 15. 中高年男性ローイング愛好者がエルゴメータによるローイング、及びトレッドミルランニングによる漸増負荷テストを行った際の酸素摂取量と心拍数、%VO2max と%HRmax, %V02reserve と%HRreserve の関係の比較

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ORIGINAL ARTICLE

Chie C. Yoshiga · Mitsuru Higuchi

Heart rate is lower during ergometer rowing than during treadmill running

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Abstract This study evaluated whether the heart rate (HR) response to exercise depends on body position and on the active muscle mass. The HR response to ergometer rowing (sitting and using both arms and legs) was compared to treadmill running (upright exercise involving mainly the legs) using a progressive exercise intensity protocol in 55 healthy men [mean (SD) height 176 (5) cm, body mass 71 (6) kg, age 21 (3) years]. During rowing HR was lower than during running at a blood lactate concentration of 2 $mmol \cdot l^{-1}$ [145 (13) compared to 150 (11) $beat \cdot min^{-1}$, $P < 0.05$], 4 $mmol \cdot l^{-1}$ [170 (10) compared to 177 (13) $beat \cdot min^{-1}$, $P < 0.05$], and 6 $mmol \cdot l^{-1}$ [182 (10) compared to 188 (10) $beat \cdot min^{-1}$, $P < 0.05$]. Also during maximal intensity rowing, HR was lower than during maximal intensity running [194 (9) compared to 198 (11) $beat \cdot min^{-1}$, $P < 0.05$]. These results were accompanied by a higher maximal oxygen uptake during rowing than during running [rowing compared to running, 4.50 (0.5) and 4.35 (0.4) $l \cdot min^{-1}$, respectively, $P < 0.01$]. Thus, the oxygen pulse, as an index of the stroke volume of the heart, was higher during rowing than during running at any given intensity. The results suggest that compared to running, the seated position and/or the involvement of more muscles during rowing facilitate venous return and elicit a smaller HR response for the same relative exercise intensity.

Keywords Exercise · Oxygen uptake · Oxygen pulse

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Introduction

Oxygen uptake ($\dot{V}O_2$) increases as the muscle mass involved increases (Secher et al. 1974, 1977; Mitchell 1990). During arm-and-leg exercise $\dot{V}O_2$ is higher than during exercise involving only the arms or only the legs (Secher et al. 1974, 1977). Also, maximal oxygen uptake ($\dot{V}O_{2max}$) is higher during rowing than during running (Secher 1983). Rowing involves both upper and lower body exercise, while running mainly involves the legs (Secher 1983; Clifford et al. 1994).

It is controversial whether the magnitude of the heart rate (HR) response to exercise follows $\dot{V}O_2$. For example, during two-legged exercise HR is higher than during one-legged exercise (Davis and Sargeant 1974; Klausen et al.1982). The magnitude of the HR response to isometric leg extension (Leonard et al. 1985) and handgrip (Mitchell et al. 1989; Mitchell 1990) depends on the amount of the active muscle mass taking part. On the other hand, HR for combined arm and leg exercise is similar to that elicited during leg exercise (Toner et al. 1983). An indication of an influence of specific training on the HR response to exercise is that in arm-trained subjects, the HR response to arm, leg, and combined arm-and-leg exercise is different (Secher et al. 1974). Thus, it is not clear which type of exercise elicits the highest HR response. An increasing active muscle mass facilitates venous return, and thereby increases the central blood volume and therefore reduces the HR response (Ray et al. 1993; Van Lieshout et al. 2001). Differences in posture affect HR by way of the central blood volume (Ray et al. 1993; Wilmore and Costill 1999; Van Lieshout et al. 2001).

We examined the HR response to both rowing and running at various intensities and also determined $\dot{V}O_2$

as an index of the amount of the active muscle mass (Secher et al. 1974, 1977; Savard et al. 1989).

Methods

Subjects

We examined the HR and $\dot{V}O_2$ responses to two periods of progressive exercise, rowing on an ergometer (Concept II model C, Morrisville, Vt., USA) and running at an incline of 3.0% on a treadmill. A group of 55 male subjects were thoroughly informed of all methods and procedures and consented to participate in this study as approved by the Ethics Committee at the National Institute of Health and Nutrition. The same subjects took part in both types of exercise and none had any cardio-respiratory illness or injury. Percentage body fat was derived according to the equation of Brozek et al. (1963) using body density determined by the BOD POD system (Life Measurement Instruments, Concord, Calif., USA; Dempster and Aitkens 1995). The physical characteristics of the subjects were as follows [mean (SD)] height 176 (5) cm, body mass 71 (6) kg, body fat 11 (3)%, age 21 (3) years].

Protocol

The subjects performed a discontinuous incremental intensity protocol on a rowing ergometer. The initial intensity was 150 W and was increased by 50 W every 2 min. The subjects stopped rowing for 20 s between each stage so that blood samples could be drawn. Exercise was terminated when the subjects were no longer able to maintain the required intensity. On another day, the subjects exercised on a treadmill. The initial velocity was 160 m·min^{-1} and increased by 20 m·min^{-1} every 2 min. Exercise was terminated when the subjects could not complete a given running speed.

It was required that each subject met each of the following criteria to ensure that $\dot{V}O_{2max}$ was reached:

1. A plateau in $\dot{V}O_2$ against exercise intensity
2. A respiratory exchange ratio exceeding 1.15
3. Blood lactate concentration exceeding 8–9 mmol·l^{-1}
4. Achievement of age-predicted maximal HR (HR_{max})
5. A rating of perceived exertion of 19 or 20 (Bassett and Howley 2000)

The expired gas was collected in Douglas bags during the last 1 min of each stage, and the volume was measured using a dry gas meter and the concentrations of O_2 and CO_2 were determined (Respiromonitor RM-300i, Minato Medical Science Co., Tokyo, Japan). The HR was determined electrocardiographically (Nihon Kohden Co., Tokyo, Japan). Blood samples were taken using heparinized glass capillaries from the fingertips immediately after each stage and at the termination of exercise. Blood lactate concentration ($[La^-]_b$) was analysed by an enzymatic membrane method using a 1500 Analyser (Yellow Springs, Ohio, USA).

Statistics

Data are reported as means and standard deviations (SD). The *oxygen pulse* ($\dot{V}O_2$/HR) was calculated as an index of stroke volume (Heath et al. 1981). For comparison of variables between rowing and running, a paired Student's *t*-test was used. Statistical significance was set at $P < 0.05$.

Results

At rest HR was lower when sitting on an ergometer than when standing on a treadmill [70 (12) compared to 78 (11) beat·min^{-1}, $P < 0.05$; Fig. 1]. During rowing HR was also lower than during running [145 (13) compared to 150 (11) beat·min^{-1} at a $[La^-]_b$ of 2 mmol·l^{-1}, 170 (10) compared to 177 (13) beat·min^{-1} at 4 mmol·l^{-1}, and 182 (10) compared to 188 (10) beat·min^{-1} at 6 mmol·l^{-1}, all $P < 0.05$]. Also, during rowing HR_{max} was lower than during running [194 (9) compared to 198 (11) beat·min^{-1}, $P < 0.05$].

Whereas $\dot{V}O_2$ at rest was similar for the two postures, during rowing $\dot{V}O_2$ was higher than during running [2.79 (0.7) compared to 2.42 (0.8) l·min^{-1} at a $[La^-]_b$ of 2 mmol·l^{-1}, 3.89 (0.5) compared to 3.65 (0.7) l·min^{-1} at 4 mmol·l^{-1}, 4.18 (0.5) compared to 4.01 (0.5) l·min^{-1} at 6 mmol·l^{-1}, all $P < 0.01$]. Also, during rowing $\dot{V}O_{2max}$ was higher than during running [4.50 (0.5) compared to 4.35 (0.4) l·min^{-1}, $P < 0.01$; Fig. 2]. Immediately after the maximal effort, $[La^-]_b$ was higher following rowing than following running [10.6 (1.5) compared to 9.3 (1.9) mmol·l^{-1}, $P < 0.05$]. The oxygen pulse was higher during rowing than during running at any $[La^-]_b$ and also during maximal exercise (Fig. 1).

Discussion

The main finding was that during rowing HR was lower than during running at both submaximal and maximal exercise intensities. Thus, the results indicate that the mode of exercise and/or the muscle mass affect the HR response to exercise.

During rowing, subjects use both arms and legs while during running they use mainly their legs (Secher 1983; Hagerman 1994). Also, during rowing, the upper body is used with the involvement of trunk, back, and abdominal muscles (Secher 1983; Clifford et al. 1994). The finding of a higher $\dot{V}O_2$ during rowing than during running supported the contention that rowing involved a larger muscle mass than did running (Secher et al. 1974, 1977; Sarvard et al. 1989). This study was conducted to evaluate the HR response to exercise involving an increase in the active muscle mass that could be of importance by way of enhancing central blood volume. At the same time, it was considered that the central blood volume would be larger during the seated position of rowing than during running. These assumptions of a larger central blood volume during rowing than during running seemed to be confirmed as the oxygen pulse, as an index of the stroke volume of the heart, was larger during rowing than during running.

Active muscle mass is a powerful pump and provides a force to assist returning blood to the right ventricle of the heart during exercise (Sheriff et al. 1993; Van Lieshout et al. 2001). Additionally, during dynamic exercise an increase in active muscle mass leads to an increased venous return and central blood volume (Davis and Sargeant 1974; Klausen et al. 1982; Toner et al. 1983). Standing up displaces blood from the chest to lower parts of the body by gravity, blood pressure is augmented as sympathetic nervous activity increases HR, and vascular resistance increases (Pedersen et al. 1995;

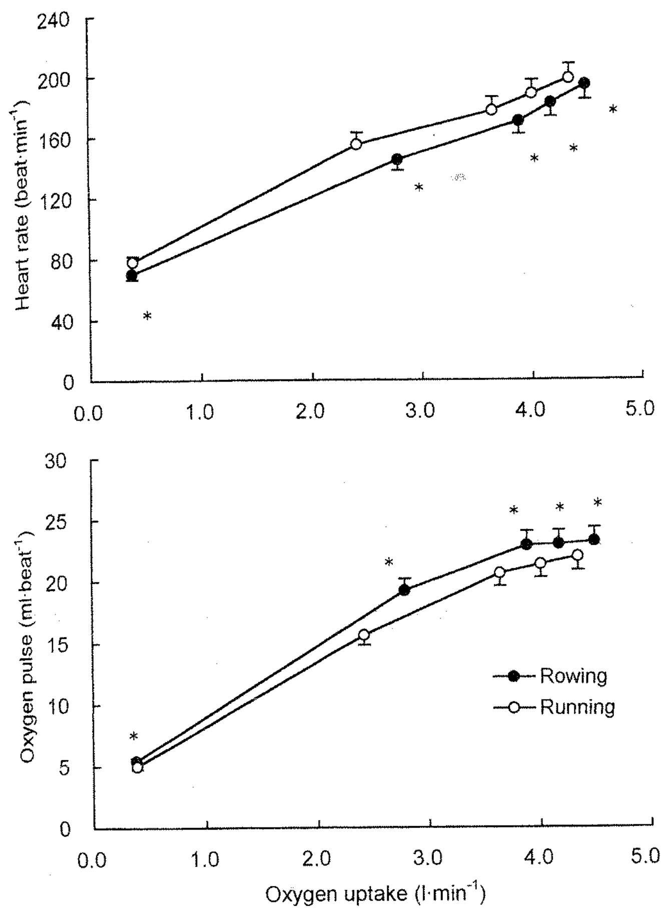

Fig. 1. Relationship between heart rate and oxygen pulse and oxygen uptake during rowing and running. $*P < 0.05$ Significantly different between rowing and running

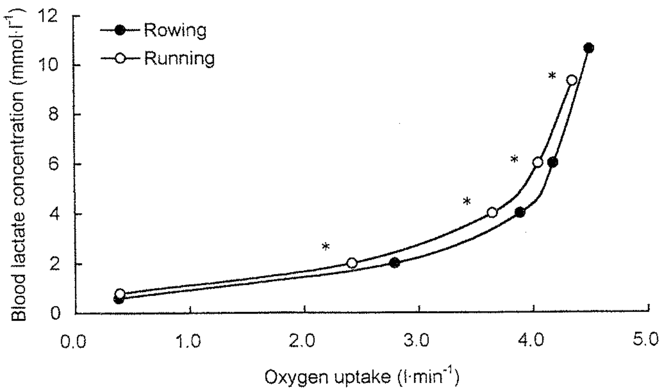

Fig. 2. The responses of oxygen uptake at a given blood lactate concentration and maximal effort during rowing and running. $*P < 0.05$ Significantly different between rowing and running

Tanaka et al. 1999; Wilmore and Costill 1999). During seated leg exercise (Ray et al. 1993) and upright leg exercise (Ten Harkel et al. 1994; Van Lieshout et al. 2001), the central blood volume increases due to an effect of the muscle pump with a resulting decrease in sympathetic nerve activity.

By the Frank-Starling mechanism, enhanced venous return stretches the ventricle, which results in an augmented stroke volume (Ray et al. 1993; Tate et al. 1994; Wilmore and Costill 1999). An elevated central blood volume enhances central venous pressure and stretches the venous and arterial vessels, and this stimulates the cardiopulmonary baroreceptors to slow HR and dilate the peripheral vasculature (Gabrielsen et al. 1993; Ray et al. 1993). This is so because an elevated central blood volume is accompanied by a decrease in sympathetic nerve activity (Ray et al. 1993; Saito et al. 1993; Van Lieshout et al. 2001). Thus, it is considered that increasing the active muscle mass during exercise may elevate the central blood volume and stroke volume as indicated by oxygen pulse, and thereby attenuate the increase in HR during rowing.

During rowing, mean blood pressure is similar to other types of exercise including running (Clifford et al. 1994), and the exercise-induced increase in blood pressure is not affected by posture or by gravity (Ray et al. 1993). It is unlikely that the arterial baroreflex was of major influence on the HR response in this study. Metaboreceptors may sense an increase in $[La^-]_b$ and pH, which induce sympathetic nerve activity and increase HR (Mitchell 1990; Mostoufi-Moab et al. 1998; Ray 1999). To avoid the complications of the metaboreflex in the present study, the HR responses to rowing and running were compared at submaximal intensities at similar $[La^-]_b$ instead of at similar percentages of $\dot{V}O_{2max}$. During rowing $\%\dot{V}O_{2max}$ was higher than during running at any submaximal $[La^-]_b$. However, HR was lower during rowing both at any given submaximal intensity and at maximal intensity despite a higher $[La^-]_b$ compared to running. During rowing a Valsalva-like manoeuvre is used to stabilize the upper body while both legs are vigorously extended and this could diminish the ventricular preload (Cunningham et al. 1975; Rosiello et al. 1987). In spite of this oxygen pulse was higher during rowing than during running.

This study showed that the HR response to (seated) ergometer rowing is attenuated compared to (upright) treadmill running. This finding was accompanied by a higher $\dot{V}O_2$ and thus oxygen pulse during rowing compared to running. The results suggest that compared to running, the seated position and the involvement of more muscles during rowing facilitate venous return and elevate the central blood volume.

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ORIGINAL ARTICLE

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Serum lipoprotein cholesterols in older oarsmen

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Abstract We evaluated effects of age and rowing on concentrations of lipids and lipoprotein cholesterols in the blood. Maximal oxygen uptake ($\dot{V}O_{2max}$), and concentrations of total cholesterol (TC), triglyceride (TG), low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (HDL-C) were measured in 17 oarsmen [mean (SD)] [age 64 (4) years, body mass 69 (6) kg] and in sedentary men [age 65 (3) years, body mass 70 (7) kg] who were matched on the basis of body size. Also the variables were obtained from young oarsmen [age 22 (2) years, body mass 70 (4) kg] and young sedentary men [age 22 (3) years, body mass 69 (7) kg]. The percentage body fat of the older oarsmen was lower than that of the older sedentary men [18 (4)% compared to 23 (4)%, $P<0.05$], but it was similar to that of the young sedentary men [17 (4)%]. Although older oarsmen possessed a lower $\dot{V}O_{2max}$ than the young oarsmen [3.0 (0.4) l·min^{-1} compared to 4.1 (0.3) l·min^{-1}, $P<0.01$], they showed a $\dot{V}O_{2max}$ similar to that of the young sedentary men [3.1 (0.5) l·min^{-1}] but a higher value than obtained from the older sedentary men [2.2 (0.3) l·min^{-1}, $P<0.05$]. Although the indices of risk factors for coronary artery disease in the older oarsmen were higher than those in the young oarsmen [LDL-C/HDL-C 1.7 (0.2) compared to 1.3 (0.4), TC/HDL-C 3.1 (0.2) compared to 2.6(0.4), $P<0.05$], they were lower than those in both the older [2.1 (0.3), 3.6 (0.3), $P<0.05$] and the young sedentary men [2.1 (0.4), 3.5 (0.4), $P<0.05$]. The results suggest that rowing is an appropriate type of exercise for the promotion of health.

Keywords Rowing · Aerobic capacity · Low density/high density lipoprotein cholesterol · Total cholesterol/high density lipoprotein cholesterol · Life expectancy

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Introduction

Dyslipoproteinaemia is a primary risk factor for coronary artery disease, i.e. elevated concentrations of total cholesterol (TC), triglyceride (TG), and low-density lipoprotein cholesterol (LDL-C), and a reduced high-density lipoprotein cholesterol (HDL-C) (Thompson et al. 1995). Age is a secondary risk factor, but age-related changes in blood lipids are less clear. The TC and TG increase from puberty through middle age, but reach a plateau or even decline in the final years of life (Hazzard and Ettinger 1995). In cross-sectional studies, the death of older people with hypercholesterolaemia may affect the artherosclerosis indexes (LDL-C/HDL-C or TC/HDL-C) (Thompson et al. 1995). Also, physical inactivity is a risk factor for coronary artery disease (Blair et al. 1995). This study was undertaken to evaluate the interaction between age and physical activity on blood lipid concentrations in men of similar body size.

The consideration that the rigorous training required for rowing and the sustained exertion of the race bring about serious damage and occasional early death had been widespread until Morgan (1873) indicated that oarsmen lived about 2.0 years longer than the British life expectancy at that time. Later investigations have conformed to Morgan's report. Oarsmen participating in the Oxford-Cambridge boat race lived 2.0 years longer than typical of the British life expectancy (Hartley and Llewellyn 1939) and equally the Harvard University crew members lived 2.9 years longer than typical of the American life expectancy (Meylan 1904). Also, varsity oarsmen from the Harvard and Yale crews, when compared with a random control group, lived 6.3 years longer (Prout 1972).

Rowing involves both the lower and upper body, e.g. almost all the muscles in the body, and consists of rhythmical muscle contractions and demands a high aerobic capacity (Secher 1983). In the American College of Sports Medicine Position Stand (1998), activities with such characteristics are recommended. This study was undertaken to evaluate the serum concentrations of lipid and lipoprotein cholesterols, body composition, and maximal oxygen uptake ($\dot{V}O_{2max}$) of older men trained for rowing and the results were compared to those obtained in older and young sedentary men and young trained men.

Methods

Subjects

A group of 17 older trained men [mean (SD)] [age 64 (4) years, height 172 (6) cm, body mass 69 (6) kg, percentage fat 18 (4)%] were matched to both older sedentary [age 65 (3) years, height 172 (7) cm, body mass 70(7) kg, percentage fat 23 (4)%] and to young trained men [age 22 (2) years, height 174 (5) cm, body mass 70 (4) kg, percentage fat 12 (4)%] on the basis of body size. Also the older oarsmen were matched to young sedentary men [age 22(3) years, height 172 (6) cm, body mass 69 (7) kg, percentage fat 17 (4)%] for body size and composition. The older trained men had rowed for 40–50 years, and they rowed 2 days a week on the water or on an ergometer, each session lasting 90–120 min including warm-up, 12–16 km of rowing, and recovery. The young trained men rowed at least 3–5 days a week on the water or on an ergometer (median training distance, 60–100 km·week^{-1}). All subjects provided informed consent as approved by the Ethics Committee of the National Institute of Health and Nutrition. None of the subjects had any known cardiovascular disease or took any medication and none of them smoked.

Procedure

Percentage body fat was derived according to Brozek et al. (1963) (BOD POD system, Life Measurement Instruments, Concord, Calif., USA; Dempster and Aitkens 1995). Fat free mass was taken as the difference between the body and fat masses.

The young sedentary men underwent treadmill running while the other three groups of subjects rowed on an ergometer (Concept II model C, Morrisville, Vt., USA). During treadmill running the initial speed was 120 m·min^{-1} and it was increased by 120 m·min^{-1} every 2nd min. During ergometer rowing the initial intensity was 100 W and it was increased by 50 W every 2nd min. Exercise was terminated when the subject could not maintain a required intensity.

Expired gas was collected in Douglas bags during the last minute of each stage. The volume of the expired gas was measured using a dry gas meter, and the O_2 and CO_2 content of the gas were analysed (Respiromonitor RM-300i, Minato Medical Science Co., Tokyo, Japan). The heart rate (HR) was monitored using an electrocardiogram. The rating of perceived exertion (RPE) was noted at every stage of the test. To ensure that the $\dot{V}O_{2max}$ was reached, each subject was required to meet each of the following criteria:

1. A plateau in oxygen uptake ($\dot{V}O_2$) against exercise intensity
2. A respiratory exchange ratio exceeding 1.15
3. A blood lactate concentration exceeding 8–9 mmol·l^{-1}
4. Achievement of age-predicted maximal heart rate (HR_{max})
5. An RPE of 19 or 20 (Bassett and Howley 2000).

Blood samples were taken in heparinized glass capillary tubes from a fingertip at the termination of exercise. Blood lactate was analysed using an enzymatic membrane method (1500 Analyser, Yellow Springs, Ohio, USA). Oxygen pulse ($\dot{V}O_2$/HR) was calculated as indication of the stroke volume of the heart (Heath et al. 1981).

Each subject completed a 3 day food log using food scales. A dietitian reviewed the food records with each subject upon their completion. A computerized dietary assessment was used to calculate daily energy intake, and the percentage of nutrients from carbohydrate, fat, and protein.

Following a 12 h overnight fast, blood was collected from an antecubital vein in the early morning and the plasma was separated by centrifugation to be used for the lipid analysis. The TC was analysed using an enzymatic method (L-type Wako), HDL-C using a selective inhibition method (Daiich Chemical Pharmacy), and TG using an enzymatic method (L-type Wako). The LDL-C was calculated according to Friedewald et al. (1972) and the ratios of HDL-C to LDL-C and that of TC to HDL-C were calculated.

Statistics

Data are presented as mean (SD). Comparisons were performed using a one-way analysis of variance with Turkey's post-hoc validation. A P value <0.05 was considered significant.

Results

The HR_{max} of the older oarsmen was lower than for both young oarsmen and young sedentary men [176 (13) compared to 198 (8), and 201 (9) beat·min^{-1}, $P<0.01$], but itwas higher than that of the older sedentary men [166 (9) beat·min^{-1}, $P<0.05$]. The $\dot{V}O_{2max}$ of the older oarsmen was lower than that of the young oarsmen [3.0 (0.4) l·min^{-1} compared to 4.1 (0.3) l·min^{-1}, $P<0.01$], but it was similar to that in the young sedentary men [3.1 (0.5) l·min^{-1}] and it was higher than that of the older sedentary men [2.2 (0.3) l·min^{-1}, $P<0.05$] (Fig. 1). Also, in the older oarsmen oxygen pulse was higher than in both young and older sedentary men. Older oarsmen possessed a lower rowing performance than the young oarsmen [2,000 m ergometer rowing time 489 (16) compared to 451 (12) s, $P<0.05$].

The TC and LDL-C of the older oarsmen were higher than for the young oarsmen, but they were similar to those of both the young and the older sedentary men (Table 1). The TG and HDL-C of the older oarsmen were not significantly different from those of the other three groups of subjects. Although in the older oarsmen the indices of risk factors for coronary artery disease were higher than those in the young oarsmen [LDL-C/HDL-C 1.7 (0.2) compared to 1.3 (0.4), and TC/HDL-C 3.1 (0.2) compared to 2.6 (0.4), $P<0.05$], they were lower than those in both the older [2.1 (0.3), 3.6 (0.3);

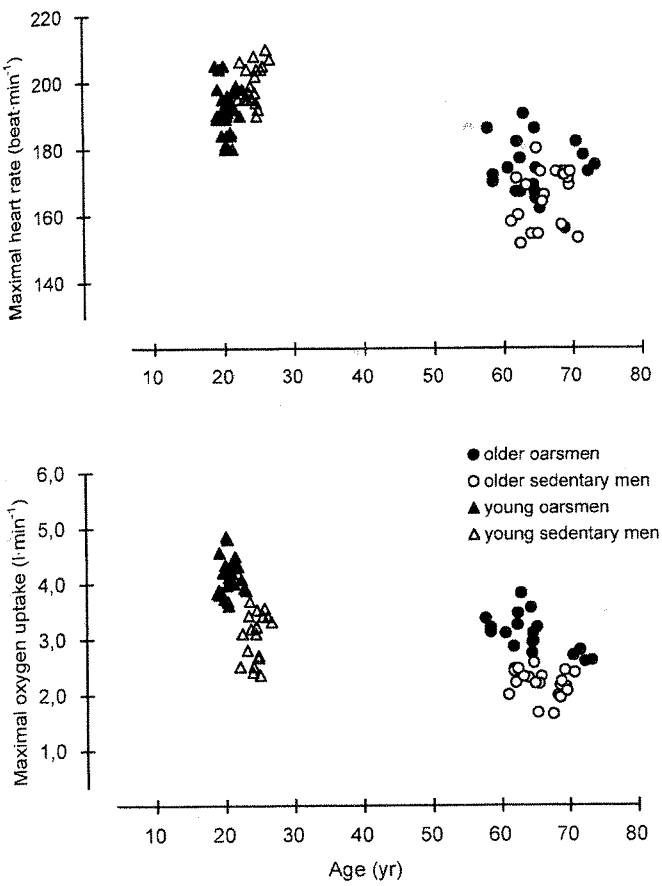

Fig. 1. Maximal heart rate and maximal oxygen uptake related to age

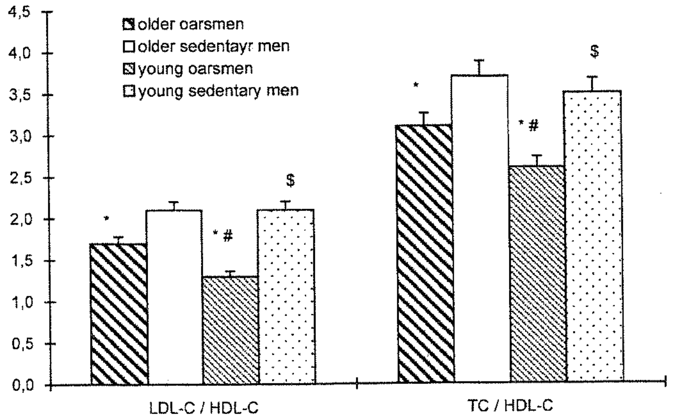

Fig. 2. Atherosclerosis indices (the ratio of low density lipoprotein, *LDL-C*, to high density lipoprotein-cholesterol, *HDL-C*, and that of total cholesterol, *TC*, to HDL-C). $^{*}P < 0.05$ difference between oarsmen and sedentary men in the same age groups, $^{\#}P < 0.05$ difference between older oarsmen and young oarsmen, $^{\$}P < 0.05$ difference between older oarsmen and young sedentary men

$P < 0.05$] and the young sedentary men [2.1 (0.4), 3.5 (0.4), $P < 0.05$] (Fig. 2).

Energy intake of the older oarsmen was similar to that of both older and young sedentary men [2,887 (187) compared to. 2,822 (197), 2,912 (198) kcal·day^{-1}], but it was less than that of the young oarsmen [3,724 (205) kcal·day^{-1}, $P < 0.01$]. In the older oarsmen, 70% of energy intake came from carbohydrate, 13% from fat, and 17% from protein, and this nutrient profile was similar to those of the other three groups of subjects.

Discussion

The main findings of this study are that in the older men trained in rowing risk factors for coronary artery disease were lower than those obtained in both older and young sedentary men. Second, the older oarsmen possessed an aerobic capacity similar to that of young sedentary men but had a higher aerobic capacity than obtained in the older sedentary men. These findings indicate that rowing, which is an aerobic type of exercise and involves a large muscle mass (Secher 1983), is associated with a low risk factor index for coronary artery disease. The results therefore support the suggestion that rowing is associated with a prolonged life expectancy (Morgan 1873; Meylan 1904; Hartley and Llewllyn 1939; Prout 1972).

The ratio of LDL-C to HDL-C or that of TC to HDL-C is relevant for evaluating individual risks for coronary artery disease because LDL-C is implicated in plaque formation in blood vessels, while HDL-C is involved in plaque removal and transport to the liver to be metabolized (Gordon et al. 1977). Physical exercise influences the lipid profile by changes in the activities of hepatic lipase and lipoprotein lipase of adipose tissue that control the rates of synthesis, transport, and clearance of lipids and lipoproteins from blood (Patch et al. 1987). Regular physical exercise increases muscle lipoprotein lipase activity, which is an important factor in the down-regulation of triglyceride rich lipoproteins and the up-regulation of HDL-C (Leaf et al. 1997). For older people, physical exercise induces a reduction of risk factors with an increase in $\dot{V}O_{2max}$ (Schwartz et al. 1992)

Table 1. Mean (SD) profiles of serum lipid and lipoprotein concentrations.. *TC* Total cholesterol, *TG* triglyceride, *LDL-C* low density lipoprotein cholesterol, *HDL-C* high density lipoprotein cholesterol

	TC (mmol·l^{-1})	TG (mmol·l^{-1})	LDL-C (mmol·l^{-1})	HDL-C (mmol·l^{-1})
Older oarsmen	5.2 (0.4)	1.4 (0.4)	2.9 (0.4)	1.7 (0.2)
Older sedentary men	5.2 (0.4)	1.3 (0.4)	3.0 (0.6)	1.5 (0.2)
Young oarsmen	4.1 (0.6)^{a,b}	0.9 (0.3)	2.0 (0.7)^{a,b}	1.6 (0.3)
Young sedentary men	4.8 (0.6)	0.9 (0.5)	2.9 (0.7)	1.4 (0.2)

$^{a}P < 0.05$ difference between oarsmen and sedentary men in the same age groups
$^{b}P < 0.05$ difference between older oarsmen and young oarsmen

and it also increases fat oxidation at rest because of an increase in the activity of the sympathetic nervous system (Poehlman et al. 1994).

The decay in cardiorespiratory function with age is reflected in the decline in $\dot{V}O_{2max}$ (Heath et al. 1981; Pollock et al. 1997). As the daily demands of living remain unchanged throughout life, a decrease in aerobic capacity results in a decrease in capacity above the daily demands for older people, which increases the risk of injury (Wilmore and Costill 1999). However, the older oarsmen possessed a similar level of aerobic capacity as the young sedentary men. Endurance exercise enhances aerobic capacity in older people through an increase in stroke volume (Heath et al. 1981; Hagberg et al. 1985), in blood volume (Hunt et al. 1998), in the arterio-venous difference in O_2 concentration (Spina et al. 1993), and in endothelium-dependent vasodilatation (Rinder et al. 2000). In older men, the cardiorespiratory function adapts to training to the same extent as in young men (Proctor and Joyner 1997). Also, the oxygen pulse of the older oarsmen was higher than that of both the young and older sedentary men perhaps because the left ventricular mass of the older oarsmen exceeded that of age-matched sedentary men (Gustafsson et al. 1996). The results indicate that rowing attenuates the decline of $\dot{V}O_{2max}$ by maintaining oxygen pulse to compensate for a decline of HR_{max}.

The HR_{max} is commonly used in both medicine and physiology (Wilmore and Costill 1999; Tanaka et al. 2001) and is often predicted as $HR_{max} = 220$ minus age in years, but the equation has been modified to $HR_{max} =$ 208 minus 0.7 age (Tanaka et al. 2001). The HR_{max} of the older oarsmen was higher than the value estimated by the traditional equation (160 beat·min^{-1} at age of 60 years, Wilmore and Costill 1999), but it fitted the modified equation (Tanaka et al. 2001). The decrease in HR_{max} with age may have been brought about by a decrease in the activity of the sympathetic nervous system and to alterations in the cardiac conduction system (Wilmore and Costill 1999; Tanaka et al. 2001).

Rowing uses almost all muscles including those of the legs, arms, back, and trunk, and it is an aerobic type of exercise (Secher 1983; Gustfsson et al. 1996). Subjects can easily modify rowing intensity by changing speed and strength of each stroke. Body mass is supported by the seat of the ergometer or boat (Secher 1983), and rowing is therefore unlikely to induce serious damage or injury, e.g. to the knee. The results of this study suggest that rowing is an appropriate type of exercise for health promotion with respect to the risk factors associated with coronary artery disease.

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ORIGINAL ARTICLE

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Rowing prevents muscle wasting in older men

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Abstract We evaluated the effects of rowing on the morphology and function of the leg extensor muscle in old people. The area and the power of the leg extensor muscle were measured in 15 oarsmen – age [mean (SD)] 65 (3) years; height 171 (4) cm, body mass 68 (6) kg – and in 15 sedentary men – age 66 (4) years, height 170 (4) cm, body mass 67 (7) kg – who were matched on the basis of their body size. The leg extensor muscle area of the oarsmen was larger than that of the sedentary men [77.8 (5.4) vs 68.4 (5.1) cm^2, $P<0.05$]. Also the bilateral leg extension power of the oarsmen was larger than that of the sedentary men [1,624 (217) vs 1,296 (232) W, $P<0.05$]. Thus, the leg extension power per the leg extensor muscle area was not significantly different between two groups [20.9 (2.0) vs 19.9 (2.1) W·cm^{-2}) and leg extension power was correlated to the leg extensor muscle area (59–89 cm^2, $r=0.74$, $P<0.001$). Also the 2,000-m rowing ergometer time of the oarsmen [495 (14) s; range 479–520 s] was related to leg extensor muscle area (68–89 cm^2, $r=0.63$, $P<0.01$). The results suggest that rowing prevents age-related muscle wasting and weakness.

Keywords Aging · Leg extensor muscle · Leg extension power

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Introduction

With age, leg muscle size declines with subsequent decrements in leg muscle functional ability (Kraemer et al. 1999; Martin et al. 2000; Goodpaster et al. 2001; Klein et al. 2001). For older people, the ability of the leg extensor muscles to develop power is important for tasks of daily life such as climbing stairs, walking, and recovering balance, and the decline in the leg extensor muscle increases the risks of falls and limb disability (Rubenstein et al. 2000; Lamoureux et al. 2001). Falling, fracture, and limb disability leads to premature morbidity and mortality (Tseng et al. 1995; Larsson et al. 2001).

Oarsmen live 2–3 years longer than the British (Hartley and Llewellyn 1939) or the American (Meylan 1904) life expectancy. Also, rowing has favorable effects on lowering risk factors of coronary artery diseases in old people (Yoshiga et al. 2002). As rowing involves rhythmical muscle extensions of both legs (Secher 1983; Gustafsson et al. 1996), it may have a positive influence not only on risk factors for coronary artery diseases but also for limb disability and falling. This study was undertaken to evaluate effects of rowing on the morphology and strength of the leg extensor muscle in old people.

Methods

Fifteen elderly trained men – age [mean (SD)] 65 (3) years, height 171 (4) cm, body mass 68 (6) kg, percent fat 19 (4)%] – were matched for their body size to older sedentary men – age 66 (4) years, height 170 (4) cm, body mass 67 (7) kg, percent fat 21 (5)%]. The trained men had rowed for 40–50 years and they rowed 2 days week^{-1} on water or on an ergometer (12–16 km day^{-1}). The subjects were carefully informed about the procedure and possible risks of this study and provided written informed consent. This study was approved by the Ethics Committee of the National Institute of Health and Nutrition. Subjects were free from any known neuromuscular disease and were taking no medication.

Percentage body fat was derived according to Brozek et al. (1963) using body density (BOD POD system, Life Measurement Instruments, Concord, Calif., USA). The cross-sectional area of the main leg extensor, the quadriceps femoris, was measured by proton-magnetic resonance imaging (AIRIS II Comfort System 0.3-T, Hitachi Medico Co., Tokyo, Japan) and analysed with NIH Image software (Yarasheski et al. 2001). Subjects were supine within the MR imager. With a T1-weighted spin-echo sequence, the middle of the thigh was evaluated between the greater trochanter and the lateral condyle (Yarasheski et al. 1993).

Maximal bilateral leg extension power was determined using a dynamometer (Anaeropress 3500, Combi Co., Tokyo, Japan; Kawakami et al. 1993). The apparatus is suitable for evaluation of bilateral leg extension power in healthy people aged 6–90 years. All subjects were familiar with this apparatus and they were able to press the applied load with both legs. After a warm-up, the subjects were seated and pressed their feet as hard as possible horizontally onto a plate until their legs were fully extended. The velocity of the movement was measured using a rotary encoder attached to a wheel that set a constant load to the footplate through a wire. The bilateral leg extension power (W) was the set load (N) times the velocity ($m \cdot s^{-1}$).

On a separate day, all subjects completed an all-out 2,000 m row on an ergometer (Concept II model C, Morrisville, Vt., USA) designed to simulate the duration, intensity, and stroke rate of an actual race on the water (Secher 1983). All subjects were familiar with the rowing ergometer.

Data are presented as mean (SD). Comparisons were performed using a one-way analysis of variance with Turkey's post hoc validation. Linear regression analysis was used to evaluate the relationship between leg extension power and leg extensor muscle area and between 2,000-m ergometer rowing performance and leg extensor muscle area. A P value <0.05 was accepted as being statistically significant.

Results

The leg extensor muscle of the oarsmen was larger than that of the sedentary men [77.8 (5.4) vs 68.4 (5.1) cm^2] (Figs. 1, 2). Also, the bilateral leg extension power of the oarsmen was larger than that of the sedentary men [1,624 (217) vs 1,296 (232) W]. Thus, the leg extension power per leg extensor muscle area was not significantly different between the oarsmen and the sedentary men [20.9 (2.0) vs 19.9 (2.1) $W \cdot cm^{-2}$].

Leg extension power was related to the leg extensor muscle area (59–89 cm^2, $r=0.74$, $P<0.001$, Fig. 3). For the oarsmen as well, 2,000-m rowing ergometer time [495 (14) s; range 479–520 s] was related to the leg extensor muscle area (68–89 cm^2, $r=0.63$, $P<0.01$).

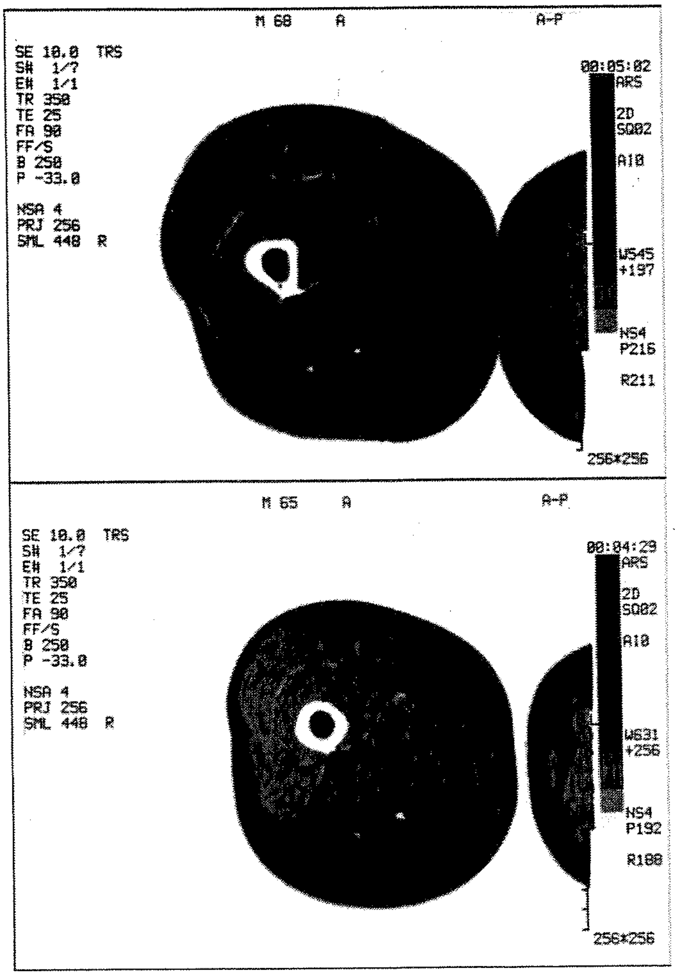

Fig. 1. Representative magnetic resonance images of an elderly trained rower (*upper*) and an elderly sedentary man (*bottom*)

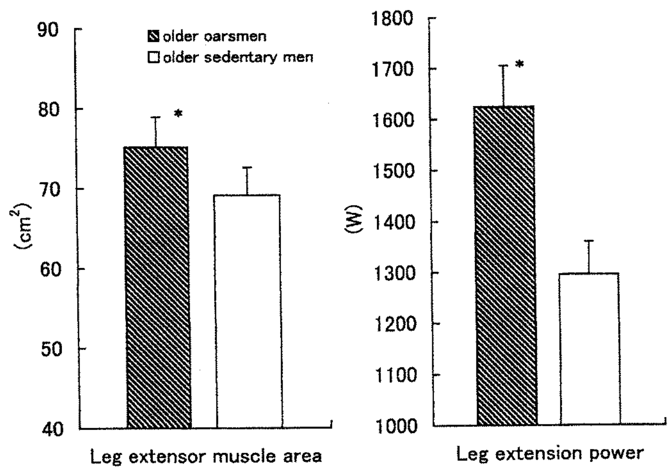

Fig. 2. Area of the leg extensor muscle and leg extension power. *$P<0.05$ difference between elderly oarsmen and elderly sedentary men

Discussion

The main finding was that in older oarsmen both morphological and functional risk factors for falling or limb disability were lower than in sedentary men. With age, the decline in leg muscle size and power are related to decline in the quantity and/or intensity of daily physical activity (Izquierdo et al. 1999, 2001). The older oarsmen possessed a larger leg extensor muscle area and power than the sedentary men. The results indicate that rowing involving extension of both legs (Secher 1983) favourably affects the condition of the leg extensor muscles of older people.

Skeletal muscle size declines with advancing age and also there is a lower protein turnover in aging muscles (Campbell et al. 1995; Short and Nair 2001). With age, the plasma concentrations of anabolic hormones and growth factors including growth hormone, testosterone, and insulin-like growth factor-I are diminished

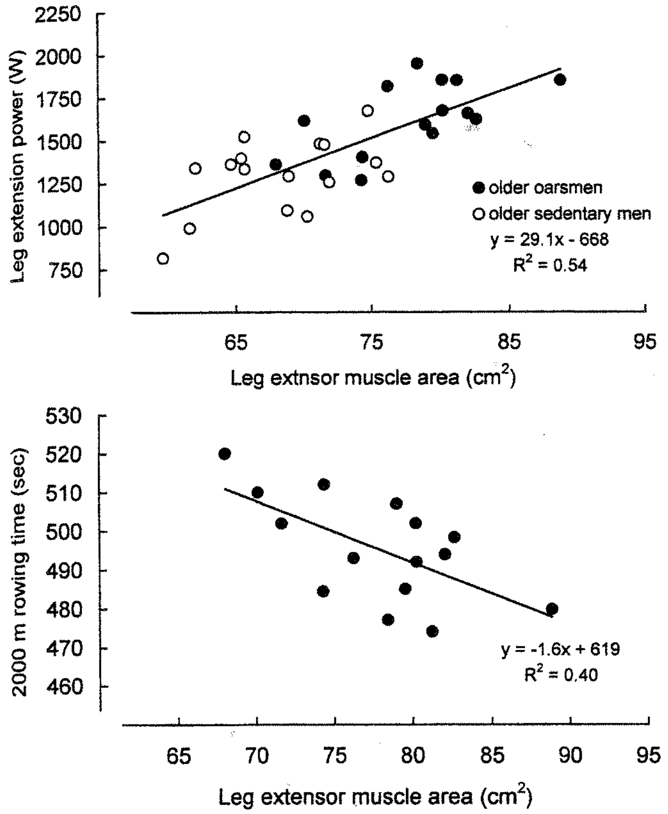

Fig. 3. Relationship between leg extension power, 2,000-m ergometer rowing time and leg extensor muscle area in elderly men

(Lambers et al. 1997; Kraemer et al. 1999). These changes are considered to influence the decrease in muscle size of 3–5% per decade after the age of 30 years and over the age of 60 years the decline accelerates (Tseng et al. 1995).

Even in old people skeletal muscles adapt to physical activity by metabolic and hormonal processes. Physical activity enhances the synthesis rate of the major muscle contractile protein (Schulte and Yarasheski 2001; Short and Nair 2001), nitrogen retention, and muscle protein metabolism (Campbell et al. 1995). Also, physical activity increases serum testosterone in older men (Kraemer et al. 1999). Because of a loss of type II muscle fibres with age, muscle hypertrophy relies on hypertrophy of especially type I muscle fibres in older people (Larsson 1982). However, after the age of 60 years, the type II fibre area is reported to increase with physical activity (Campbell et al. 1999). In the current study, the oarsmen possessed a 14% larger muscle area than the sedentary men. Also, the muscle area of the leg extensors in the oarsmen was larger than in middle-aged men (Häkkinen et al. 1998b; Izquierdo et al. 2001). The larger leg muscle fibre areas of young oarsmen compared to sedentary men (Larsson and Forsberg 1980; Secher 1983) indicate that hypertrophy of muscle fibres was manifest in the older participants of this study.

Not only the decrease in leg muscle size (Goodpaster et al. 2001; Klein et al. 2001) but also the deterioration in the neuromuscular function (Häkkinen et al. 1998b; Klein et al. 2001) affect the decrease in the power of the legs. During leg extension, there may be an increase in the neural drive to the antagonist muscles with advancing age (Häkkinen et al. 1998a, b; Izquierdo et al. 1999). Also, the decline in daily physical activities with age influences leg muscle power (Häkkinen et al. 1998b; Goodpaster et al. 2001; Klein et al. 2001). In this study, the bilateral leg extension power of the oarsmen was 25% greater than that of the sedentary men. The finding indicates that rowing, which activates both legs (Secher 1983), attenuates the decline in leg extension power.

In older people, the force (Häkkinen et al. 1998a, b; Kraemer et al. 1999; Izquierdo et al. 2001) and torque (Goodpaster et al. 2001; Lamoureux et al. 2001) of knee extensors increase as the area of leg muscle mass increases. We found a correlation between leg extension power and extensor muscle area, supporting the finding that muscle weakness with age is paralleled by a reduction in muscle size (Goodpaster et al. 2001; Lamoureux et al. 2001; Schulte and Yarasheski 2001).

In young men, Larsson and Forsberg (1980) and Secher (1983) reported a relation between rowing performance and morphological muscle characteristics. The type I and II fibre areas of the legs are larger in oarsmen competing at international level than at national level. Also, in the elderly oarsmen there was a relation between rowing performance and leg extensor muscle area. Both findings support the hypothesis that the legs develop a large proportion of rowing power as rowing involves almost all the muscles in the body (Secher 1983; Gustafsson et al. 1996).

The loss of leg muscle power increases the dependence on others to accomplish routine activities of daily life and furthermore contributes to a loss of self-value and satisfaction (Martin et al. 2000; Schulte and Yarasheski 2001). The maintenance of the morphology and function of the leg extensor muscle is significant for a healthy and independent life in older people.

Physical exercise is the only non-pharmacological treatment for a reduction of muscle size (Short and Nair 2001). The effect of physical exercise on muscle size and function is considered an intervention to offset the effects of aging (Schulte and Yarasheski 2001; Short and Nair 2001). Rowing activates almost all muscles (Secher 1983; Yoshiga and Higuchi 2002) and is unlikely to cause serious injury as the body is supported by the seat of the ergometer or the boat (Secher 1983). Also, rowing might maintain or enhance lipoprotein lipase activity in skeletal muscle of old people (Yoshiga et al. 2002). The results suggest that rowing prevents age-related muscle wasting and weakness.

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Lower heart rate response to ergometry rowing than to treadmill running in older men

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Summary

For older people exercise intensity is often determined based on heart rate (HR) or the percentage of maximal HR (%HR_{max}). This study evaluated oxygen uptake ($\dot{V}O_2$) and HR during ergometry rowing (combined arm and leg; sitting exercise) and treadmill running (leg; upright exercise) for 15 older people [age, (mean ± SD) 62 ± 3 years]. The HR was lower during ergometry rowing than during treadmill running at a blood lactate concentration of 4 mmol l^{-1} (151 ± 4 beat min^{-1} versus 160 ± 5 beat min^{-1}, $P<0{\cdot}05$) and at a maximal effort (171 ± 7 beat min^{-1} versus 177 ± 7 beat min^{-1}, $P<0{\cdot}05$). This was the case although the $\dot{V}O_2$ was higher during ergometry rowing than during treamill running both at a blood lactate concentration of 4 mmol l^{-1} (3·0 ± 0·4 l min^{-1} versus 2·7 ± 0·4 l min^{-1}, $P<0{\cdot}05$) and at a maximal effort (3·4 ± 0·4 l min^{-1} versus 3·1 ± 0·3 l min^{-1}, $P<0{\cdot}05$]. %HR_{max} and %HR reserve were lower during ergometry rowing than during treadmill running. The results suggest that, in prescription of rowing for older people, the relation between HR and $\dot{V}O_2$ for rowing and the attenuated HR response to rowing should be taken into consideration.

Introduction

In prescription of exercise heart rate (HR) is accounted for (Pate et al., 1991; American College of Sports Medicine,1998), assuming that there is a given relation between percentage of maximal HR (%HR_{max}) and the percentage of maximal oxygen uptake (%$\dot{V}O_{2max}$) (Pate et al., 1991; Londeree et al., 1995) and between percentage of heart rate reserve (%HR reserve) and percentage of oxygen uptake reserve (%$\dot{V}O_2$ reserve) (Panton et al., 1996; Rotstein & Meckel, 2000). Direct measurement of HR_{max} or $\dot{V}O_{2max}$ is often not feasible for older people because they tend to be unable to work at a maximal effort. Thus, exercise may be terminated when the subject reaches an arbitrary percentage of their age-predicted HR_{max} as expressed by the equation of 220 − age (Åstrand & Rohdahl, 1986; Pate et al., 1991; Bassett & Howley, 2000) or the exercise intensity is determined based on the age-predicted HR_{max} (American College of Sports Medicine, 1998; Wilmore & Costill, 1999).

Besides exercise involving the legs such as treadmill running, other modes of activity are used including arm cycling or combined arm and leg exercise or ergometer rowing. The relation between %HR_{max} and %$\dot{V}O_{2max}$ is different among exercises for young (Londeree et al., 1995) and older men (Aminoff et al., 1998). Also, the HR response to exercise is affected by the central blood volume and sympathetic activity that are influenced by the muscle mass engaged during exercise (Ray et al., 1993; van Lieshout et al., 2001). This study evaluated the relation between HR and $\dot{V}O_2$ during ergometry rowing and treadmill running for older people.

Methods

Fifteen older men [age, (mean ± SD) 62 ± 3 years; height, 1·72 ± 0·04 m; body mass, 70 ± 5 kg; percentage body fat, 17 ± 4%] received a comprehensive explanation of the proposed study, methods and procedures, its benefits, inherent risks and expected commitments with regard to time. After explanation, the participants signed an informed consent document. The study protocol was approved by the Ethics Committee at the National Institute of Health and Nutrition. We examined the HR and $\dot{V}O_2$ responses to progressive rowing on an ergometry (Concept II model C, Morrisville, VT, USA) and running at an incline of 3·0% on a treadmill. All subjects were familiar with both types of exercise and none had any cardio-respiratory illness or took any medication. Percentage body fat was derived according to Brozek et al., (1966) using body density (BOD POD system, Life Measurement Instruments, Concord, CA, USA).

Subjects performed a discontinuous incremental intensity protocol, in random order, both on a rowing ergometry and on a treadmill running. The initial intensity on a rowing ergometry is yet small, no chest pain or ECG changes have been provoked. However, we have excluded subjects with dysrythmia (2–3% of this population), so that constitutes a limitation of this method.

Thus, taken together, the results in the present study indicate that changes in the height of the IP of the radial artery pulse wave obtained by applanation tonometry following β2-adrenergic stimulation with terbutaline could be used as an index of NO production, making this minimally invasive measurement an attractive way to explore endothelium-dependent vasodilation in different patient groups or to investigate the effects of drugs on the NO system. As the technique is simple and fairly fast to perform (20 min), it is also suitable for large-scale epidemiological studies.

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was at 100 W and it was increased by 25 W every second minute. Subjects stopped rowing for 20 s between each stage so that a blood sample could be drawn. Exercise was terminated when the subjects were no longer able to maintain the required intensity. On another day, the subjects exercised on a treadmill. The initial velocity on a treadmill was 100 m min^{-1} and it was increased by 20 m min^{-1} for every second minute. Exercise was terminated when the subjects would not complete a given running velocity.

It was required that the subject met each of the following criteria to ensure that $\dot{V}O_{2max}$ was reached: (1) a plateau in $\dot{V}O_2$ despite increasing exercise intensity; (2) a respiratory exchange ratio exceeding 1·15; (3) a blood lactate concentration exceeding 8–9 mmol l^{-1}; (4) achievement of age-predicted HR_{max}; and (5) a rating of perceived exertion of 19 or 20 (Åstrand & Rohdahl, 1986; Animoff et al., 1996; Bassett & Howley, 2000). The expired gas was collected in Douglas bags during the last 1 min of each stage and the volume was measured using a dry gas meter and the concentrations of oxygen and carbon dioxide were determined (Respiromonitor RM-300i, minato Mediccal Science Co., Tokyo, Japan). The HR was determined by an ECG (Nihon Kohden Co., Tokyo, Japan). Blood samples were taken in heparinized glass capillaries from the fingertips immediately after each stage and at termination of exercise. Blood lactate concentration $[La-]_b$ was analyzed by an enzymatic membrane method using a 1500 Analyzer (Yellow Springs, OH, USA).

Data are reported as mean and SD. %HR reserve was calculated as the percentage of HR − HR_{rest} from HR_{max} − HR_{rest}, and $\%\dot{V}O_2$ reserve was as the percentage of $\dot{V}O_2 - \dot{V}O_{2rest}$ from $\dot{V}O_{2max} - \dot{V}O_{2rest}$ (Rotstein & Meckel, 2000). Comparisons were performed using a one way analysis of variance with Turkey's post hoc validation. Linear regression analysis was used to evaluate the relationship between HR and $\dot{V}O_2$, $\%HR_{max}$ and $\%\dot{V}O_{2max}$, and %HR reserve and $\%\dot{V}O_2$ reserve. A significant level of $P<0{\cdot}05$ was used.

Results

At rest HR was lower when sitting on a rowing ergometry than when standing on the treadmill (72 ± 5 beat min^{-1} versus 80 ± 4 beat min^{-1}), while $\dot{V}O_2$ was similar (0·4 ± 0·2 l min^{-1}). The HR was also lower during rowing than during running (118 ± 4 beat min^{-1} versus 128 ± 4 beat min^{-1} at a $[La-]_b$ of 2 mmol l^{-1}, 151 ± 4 beat min^{-1} versus 160 ± 5 beat min^{-1} at a $[La-]_b$ of 4 mmol l^{-1}, 160 ± 6 beat min^{-1} versus 171 ± 4 beat min^{-1} at a $[La-]_b$ of 6 mmol l^{-1}). Also, during rowing HR_{max} was lower than during running (171 ± 7 beat min^{-1} versus 177 ± 7 beat min^{-1}) (Fig. 1).

The $\dot{V}O_2$ at rest was similar for two postures, sitting and standing (0·4 ± 0·2 l min^{-1} versus 0·4 ± 0·2 l min^{-1}). The $\dot{V}O_2$ was higher during rowing than during running (2·2 ± 0·3 l min^{-1} versus 1·9 ± 0·4 l min^{-1} at a $[La-]_b$ of 2 mmol l^{-1}, 3·0 ± 0·4 l min^{-1} versus 2·7 ± 0·4 l min^{-1} at a $[La-]_b$ of 4 mmol l^{-1}, 3·2 ± 0·2 l min^{-1} versus 2·9 ± 0·4 l min^{-1} at a $[La-]_b$ of 6 mmol l^{-1}, $P<0{\cdot}05$). Also, during

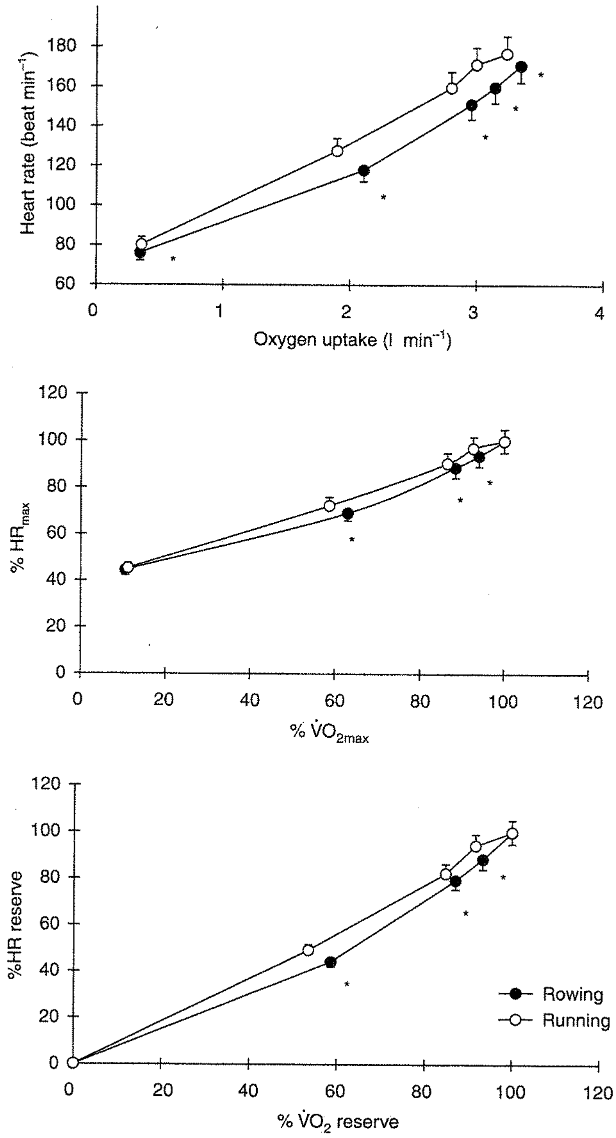

Figure 1 Relation between heart rate and oxygen uptake, between percentage of maximal oxygen uptake ($\%\dot{V}O_{2max}$) and percentage of maximal heart rate ($\%HR_{max}$), and between percentage of heart rate reserve (%HR reserve) and percentage of oxygen uptake reserve ($\%\dot{V}O_2$ reserve). *$P<0{\cdot}05$ difference between rowing and running.

rowing $\dot{V}O_{2max}$ was larger than during running (3·4 ± 0·4 l min^{-1} versus 3·1 ± 0·3 l min^{-1}). Immediately after maximal exercise a $[La-]_b$ was higher following rowing than following running (8·4 ± 1·5 mmol l^{-1} versus 8·0 ± 1·9 mmol l^{-1}). The relation between HR and $\dot{V}O_2$ were as follows for ergometry rowing HR (beat min^{-1}) = $30{\cdot}9{\cdot}\dot{V}O_2$ (l min^{-1})+61·4 (r = 0·99) and for treadmill running HR (beat min^{-1}) = $34{\cdot}2{\cdot}\dot{V}O_2$ (l min^{-1}) + 66·3 (r = 0·99).

During both rowing and running, the HR_{max} was higher than the age-predicted HR_{max} using the equation of 220 − age (171 ± 7, 177 ± 7 beat min^{-1} versus 158 ± 5 beat min^{-1}). During rowing both $\dot{V}O_2$ and $\%\dot{V}O_{2max}$ were larger than during running. On the other hand, $\%HR_{max}$ was lower during rowing than that during running when using the HR_{max} measured in this study and the age-predicted HR_{max} (Fig. 1). The relation between $\%HR_{max}$ and $\%\dot{V}O_{2max}$ was as follows for ergometry rowing $\%HR_{max} = 0{\cdot}61{\cdot}\%\dot{V}O_{2max} + 35{\cdot}9$ ($r = 0{\cdot}99$) and for treadmill running $\%HR_{max} = 0{\cdot}62{\cdot}\%\dot{V}O_{2max} + 37{\cdot}5$ ($r = 0{\cdot}99$).

During rowing $\%\dot{V}O_2$ reserve was larger than during running. On the other hand, %HR reserve was lower during rowing than during running (Fig. 1). The relation between %HR reserve and $\%\dot{V}O$ reserve was as follows for ergometry rowing %HR reserve $= 0{\cdot}98{\cdot}\%\dot{V}O_2$ reserve $- 3{\cdot}98$ ($r = 0{\cdot}99$) and for treadmill running %HR reserve $= 1{\cdot}01{\cdot}\%\dot{V}O_2$ reserve $-1{\cdot}50$ ($r = 0{\cdot}99$).

Discussion

The primary finding was that the HR response to ergometry rowing was attenuated compared with treadmill running in older individuals, accompanied with a higher $\dot{V}O_2$ during ergometry rowing than during treadmill running. Secondly, $\%HR_{max}$ and %HR reserve during ergomery rowing was lower than during treadmill running in older people. The HR is used often for monitoring exercise intensity because it reflects the work of the heart (e.g. myocardial oxygen consumption and coronary blood flow) (Wilmore & Costill, 1999). Thus, the HR response to exercise has clinical implications for older people.

In older healthy men, at the level of $50\%\dot{V}O_{2max}$ during arm cranking, HR is lower than during leg cycling, but at the level of $75\%\dot{V}O_{2max}$, HR is higher during arm exercise than during leg exercise (Aminoff et al., 1998). In this study for older men, during ergometry rowing HR was lower than during treadmill running both at submaximal and maximal exercise intensity. In young people, during exercise in which body mass is supported (e.g. rowing, cycling and arm exercise), the relation between $\%HR_{max}$ and $\%\dot{V}O_{2max}$ is different from that obtained during body mass bearing exercise (i.e. exercise in which subjects have to lift their body mass on their feet such as running or skiing) (Londeree et al., 1995). Also, during arm cycling %HR reserve is higher than during running in young men (Rotstein & Meckel, 2000). In the present study of older people, during ergometry rowing $\%HR_{max}$ and %HR reserve were attenuated compared with during treadmill running.

Subjects use both arms and legs during rowing while during running they use mainly their legs (Secher, 1983; Yoshiga & Higuchi, 2002). A higher $\dot{V}O_2$ during ergomery rowing than during treadmill running supports that rowing involves a larger muscle mass than running (Secher et al., 1974, 1977; Yoshiga & Higuchi, 2002). During dynamic exercise the active muscle mass works as a pump and facilitates venous return and thereby enhances the central blood volume (Toner et al., 1963; Davies & Sargeant, 1974; Klausen et al., 1982; van Lieshout et al., 2001). Enhanced venous return results in an augmented stroke volume of the heart (Ray et al., 1993; Wilmore & Costill, 1999). Also an elevated central blood volume enhances central venous pressure and deactivates the cardiopulmonary baroreceptors to slow HR (Ray et al., 1993; Ray, 1999) as sympathetic activity during exercise is reduced (Ray et al., 1993; Wilmore & Costill, 1999). The results indicate that the mode of exercise and/or the involved muscle mass affect the HR response to exercise for older people.

The heart volume is well maintained with age but HR_{max} declines as a result of changes in the sinus node and conductive system of the heart (Åstrand & Rohdahl, 1986; Wilmore & Costill, 1999; Yoshiga et al., 2002a). The limitation of the formula, the age-predicted $HR_{max} = 220 - \text{age}$, is that older individuals often exceed the age-predicted HR_{max} (Lester et al., 1968; Bruce et al., 1974; Londeree & Moeshberger, 1982; Åstrand & Rohdahl, 1986; Whaley et al., 1992; Tanaka et al., 2001; Yoshiga et al., 2002a). The difference between measured HR_{max} and the age-predicted HR_{max} has a clinical implication for older people. The results suggest that a prescription of aerobic exercise based on the age-predicted HR_{max} results in a target HR below the intended intensity that would be considered optimal for producing health benefit. As $\dot{V}O_{2max}$ is commonly estimated by extrapolating submaximal HR to the age-predicted HR_{max} (Åstrand & Rohdahl, 1986; Pate et al., 1991; Tanaka et al., 2001), the present findings also indicate that using the age-predicted HR_{max} results in an underestimate of aerobic power for older people.

Rowing contributes to aerobic fitness (Secher, 1983; Boland & Hosea, 1991; Shephard, 1998; Yoshiga et al., 2002a) and has a low injury rate (Budgett & Fuller, 1989; Shephard, 1998). Use of larger muscle mass during combined arm and leg exercise than during leg exercise allows a greater cardio-respiratory training effect (Hoffman et al., 1996). Rowing involves both arms and legs, whereas walking and running involve mainly legs (Secher, 1983; Yoshiga & Higuchi, 2002). A rowing ergomerty is not as expensive as a walking and running treadmill (Boland & Hosea, 1991; Seiler et al., 1998). Like running and swimming, senior and master rowing has a large and growing participants in the world, with national and world veteran championships conducted annually (Gustafsson et al., 1996; Seiler et al., 1998; Yoshiga et al., 2002a,b). Subjects row not only on an ergometry but also on the water (Secher, 1983; Yoshiga et al., 2002a,b) and make rowing trips travelling along familiar and unknown waters (Fritsch, 2000). Also, rowing is one of the social sports that provides the individual contact with the social environment, recognition from and with others (Fritsch, 2000). Thus older people may be encouraged to row (Boland & Hosea, 1991). Aerobic exercises that use large muscle groups are to be recommended as prescribed modes of exercise and rowing is included in such types of exercise (American College of Sports Medicine,1998; Wilmore & Costill, 1999). Older oarsmen possess higher left ventricular mass and myocardial wall thickness (Gustafsson et al., 1996), larger aerobic power (Yoshiga et al., 2002a), larger leg muscle area (Yoshiga et al., 2002b) and more favorite lipoprotein profile (Yoshiga et al., 2002a) than age-matched sedentary men.

The findings of this study provide information about exercise prescription using a rowing ergometry for older people. Despite larger $\dot{V}O_2$, $\%\dot{V}O_{2max}$ and $\%\dot{V}O_2$ reserve during ergometry rowing than during treadmill running, the HR, $\%HR_{max}$ and %HR reserve were lower during rowing than during running in older individuals. The present study indicates that this lower HR response to ergometry rowing compared with treadmill running should be taken into consideration when prescribing ergometery rowing for older people.

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Rowing performance of female and male rowers

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This study evaluated the rowing performance of female and male rowers with regard to their body size. Body height, body mass, fat-free mass, maximal oxygen uptake (VO_{2max}), and "2000-m" rowing ergometer performance were measured in 71 females (age range 18–24 years, height 153–173 cm, body mass 43–69 kg, fat-free mass 34–55 kg; VO_{2max} 2.1–3.9 L min^{-1}; 2000-m time 437–556 s) and 120 males (age 18–24 years, height 164–193 cm, body mass 58–95 kg, fat-free mass 50–81 kg; VO_{2max} 3.4–5.6 L min^{-1}; 2000-m time 378–484 s). Rowing performance was correlated to body height ($r = -0.81$, $P<0.001$), body mass ($r = -0.85$, $P<0.001$), fat-free mass ($r = -0.91$, $P<0.001$), and VO_{2max} ($r = -0.90$, $P<0.001$). However, rowing time was slower in the females than in the males with a similar body height (by ~10%) and body mass (by ~9%), but the sex difference was smaller when the fat-free mass (by ~4%) and VO_{2max} (by ~4%) were matched. This study suggests that individuals with large body size and aerobic capacity possess an advantage for a 2000-m row on an ergometer. However, among females and males the variation in body size and aerobic capacity cannot explain the entire sex difference in ergometer rowing performance.

For women, the international rowing championships were established in 1954 and the distance was increased from 1000 to 2000 m in 1983, which is the distance rowed by men (Secher, 2000). When competing in similar events, for women the rowing time on the water is about 10% longer than for men (Secher, 2000). Equally, on the basis of the World records for "2000-m" rowing on an ergometer, the winning time for the females is about 16% slower than for the males. This gap of athletic performance among females and males is observed in other sports, although it becomes smaller as the number of female athletes increases (Wilmore & Costill, 1999).

During rowing, body mass is supported by the sliding seat in the boat or on an ergometer, and large individuals possess an advantage (Secher, 1983, 2000; Secher & Vaage, 1983). Obviously, female athletes are in general lighter than their male counterparts (Ingjer, 1991; Jensen et al., 2001), and it was hypothesised that rowing performance for females is influenced by their small body size. Rowing involves almost all muscles (Secher, 1983, 2000) and rowing performance is related to the size of the leg muscles (Yoshiga et al., 2002b). In general, the fat-free mass for females is smaller than that for males (Hunt et al., 1998), and it was considered that the slow rowing time for the female rowers results from their small fat-free mass.

A direct relationship exists between the average maximal oxygen uptake (VO_{2max}) of the crew and their placing in an international regatta (Secher et al., 1982; Secher, 1983, 2000). The VO_{2max} relates to body size (Secher, 1983; Secher et al., 1983; Jensen et al., 2001), and the VO_{2max} for female rowers is about 20–27% below that of male rowers (Secher, 2000; Jensen et al., 2001). Accordingly, it was also assumed that the rowing performance of females lags behind that of males because of their smaller VO_{2max}.

Methods

Seventy-one female rowers (age range 18–24 years; mean (SD) 19 (2) years, body height 153–173 cm; 163 (5) cm, body mass 43–69 kg; 57 (6) kg, 2000-m time 437–556 s; 498 (32) s) and 120 male rowers (age 18–24 years; 21 (2) years, body height 164–193 cm; 176 (5) cm, body mass 58–95 kg; 70 (7) kg, 2000-m time 378–484 s; 424 (19) s) volunteered for this study. Both the female and the male subjects rowed at least 5 days a week on the water or on an ergometer (median training distance 60–100 km per week; Yoshiga et al., 2001, 2002a). All subjects received a comprehensive explanation of the study and signed an informed consent. This study was approved by the Ethical Committee of the National Institute of Health and Nutrition in Japan. None of the subjects had any known cardiovascular disease or took any medication.

The percent body fat was derived according to Brozek et al. (1963) with evaluation of body density (BOD POD, Life Measurement Instruments, Concord, CA, USA; Dempster & Aitkens, 1995). The fat-free mass was the difference between the body and the fat mass.

The subject completed an all-out 2000-m row on an ergometer (Concept II model C, Morrisville, VT, USA) designed to simulate an actual race on the water (Secher, 1983). On a separate day, the subjects performed a progressive run on a treadmill. The initial velocity was $140\,m\,min^{-1}$ for the females and $160\,m\,min^{-1}$ for the males and, at an incline of 3.0%, increased by $20\,m\,min^{-1}$ every second minute (Hermansen & Saltin, 1969; Yoshiga et al., 2000, 2002a; Yoshiga & Higuchi, 2002). Exercise was terminated when the subjects could not complete a given running speed. It was required that each subject met each of the following criteria to ensure that VO_{2max} was reached: (1) a plateau in VO_2 against exercise intensity; (2) a respiratory exchange ratio exceeding 1.15; (3) achievement of an age-predicted maximal heart rate (HR_{max}); and (4) a rating of perceived exertion (RPE) of "19" or "20" (Åstrand & Rodahl, 1986; Basset & Howley, 2000). The expired gas was collected in Douglas bags during the last 1 min of each stage. The volume of the gas was measured with a dry gas meter and O_2 and CO_2 were determined (Respiromonitor RM-300i, Minato Medical Science Co., Tokyo, Japan). The HR was determined electrocardiographically and RPE was expressed every second minute (Borg, 1982).

Data are reported as mean (standard deviation) with range. Comparisons were performed using a one-way analysis of variance with Tukey's post hoc validation. Linear and curvilinear regression analyses were used to evaluate the relationship between rowing performance and body size, fat-free mass, and VO_{2max}. Also, comparison of the linear and curvilinear regression equations was performed by a general F-test (Kleinbaum & Kupper, 1978; Seiler et al., 1998; Montgomery & Runger, 1999). Statistical significance was set at $P<0.05$.

Results

The average body height and mass were smaller for the female than for the male rowers ($P<0.01$) and rowing performance was correlated to both body height ($r=-0.81$, $P<0.001$) and body mass ($r=-0.85$, $P<0.001$; Fig. 1). Also, the average fat-free mass was smaller for the female than for the male rowers (45.1 (4.4) (34.0–55.2) vs. 61.7 (5.5) (50.2–80.8) kg, $P<0.01$) and rowing performance was related to the fat-free mass ($r=-0.91$, $P<0.001$). Equally, the average VO_{2max} was lower for the female than for the male rowers (2.9 (0.4) (2.1–3.9) vs. 4.3 (0.4) (3.4–5.6) $L\,min^{-1}$, $P<0.01$) and rowing performance was related to VO_{2max} ($r=-0.91$, $P<0.001$).

Regarding the relationship between rowing performance and body mass, a curvilinear regression provided a better fit to the variances of rowing performance compared to a linear regression (77% of the variance "explained" compared with 73% for the linear regression; $F>F_{1,188}$). Similarly, curvilinear regressions fitted rowing performance to body height, fat-free mass, and VO_{2max} better than linear relationships ($F>F_{1,188}$).

In order to evaluate whether there was a difference in rowing performance between the female and male rowers of similar body size, fat-free mass, and VO_{2max}, the results for selected subjects were compared. In such comparisons, rowing performance was slower for the females than for the males with a similar body height (females, $n=26$; height 168 (3) (164–173) cm; rowing time, 478 (20) (437–537) s; males, $n=25$; height 170 (3) (164–173) cm; rowing time, 433 (18) (397–480) s) (Fig. 2). Also, rowing performance was smaller for females than for males with a similar body mass (females, $n=37$; body mass 62 (3) (58–69) kg; rowing time, 477 (21) (437–537) s; males, $n=57$; body mass 63 (3) (58–69) kg; rowing time 436 (16) (409–487) s).

Equally, there was a difference when the subjects were matched with regard to both fat-free mass (females, $n=10$; fat-free mass 51 (2) (50–55) kg; rowing time 466 (20) (437–511) s; males, $n=20$; fat-free mass 52 (2) (50–55) kg; rowing time 446 (17) (419–484) s) and VO_{2max} (females, $n=11$; VO_{2max} 3.5 (0.2) (3.4–3.9) kg; rowing time 460 (15) (437–490) s; males, $n=27$; VO_{2max} 3.7 (0.2) (3.4–3.9) kg; rowing time 441 (17) (414–484) s). Thus, the difference in the rowing time between the females and the males with a similar fat-free mass and VO_{2max} was about half that obtained when the subjects were matched based on body size.

Discussion

The main finding of this study is that rowing performance increased with body size. More specifically, a large fat-free mass and a large VO_{2max} resulted in a high level of rowing performance, supporting the fact that rowing is an aerobic type of exercise that demands activation of almost all muscles in the body (Secher, 1983, 2000; Yoshiga et al., 2003). However, differences in body size and aerobic capacity did not explain the entire difference in rowing performance between the female and the male rowers. There remained about 10% difference in rowing performance when the subjects were matched with regard to body size. However, the sex difference in rowing performance was reduced to about 4% when the fat-free mass and VO_{2max} were taken into consideration.

Secher (1975) reports that isometric rowing strength is correlated to body height in male rowers, but in a relatively homogeneous group with less than 30 rowers, rowing performance is not related to body height (Kramer et al., 1994; Jensen et al., 1996; Russell et al., 1998; Cosgrove et al., 1999). However, the present findings including 191 rowers support the fact that tall height is beneficial for the level of rowing performance. This finding supports the fact that tall height secures a long length of the rowing stroke (Secher, 1983) and a long stroke length is related to a high level of rowing performance (Ingham et al., 2002).

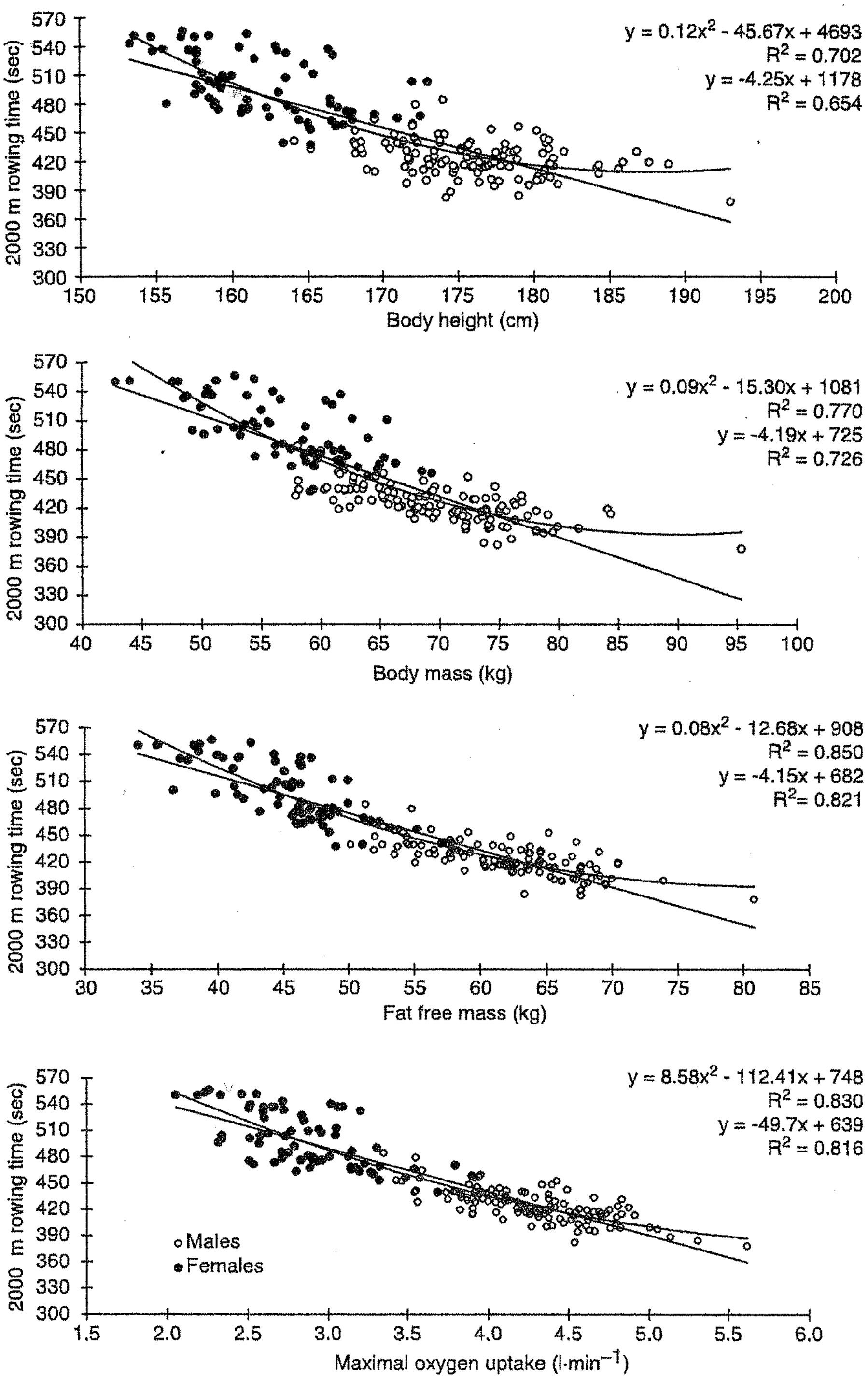

Fig. 1. Relationship between rowing performance and body height, body mass, fat-free mass, and VO_{2max}.

Also, Secher (1975) reports that the body mass of internationally competitive rowers is larger than that of club rowers and that isometric rowing strength is correlated to body mass. This is because during rowing the sliding seat in the boat or an ergometer bears body mass (Secher, 1983, 2000; Secher & Vaage, 1983). On the other hand, no relationship has been reported between rowing performance and body mass (Kramer et al., 1994; Jensen et al., 1996; Cosgrove et al., 1999). As for body height, the present results support the fact that a large body mass has a favourable influence on rowing performance (Secher, 1975; Secher & Vaage, 1983; Russell et al., 1998; Yoshiga et al., 2000; Ingham et al., 2002).

During rowing almost every muscle is used (Secher, 1983, 2000) and performance is related to

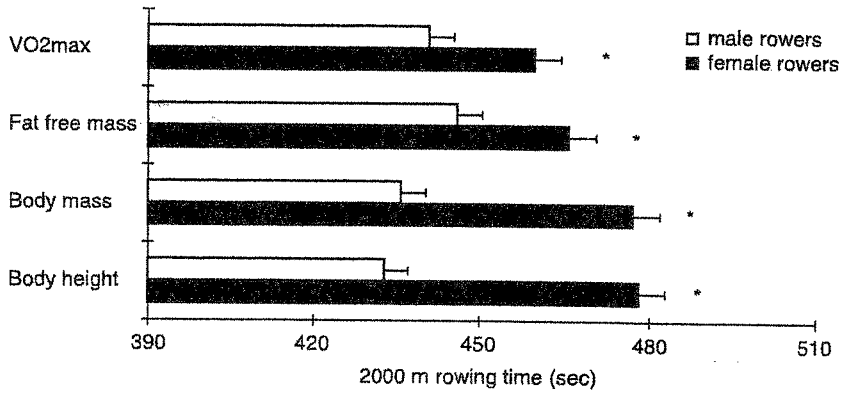

Fig. 2. Comparison of rowing performance between the female and the male rowers with similar physiological characteristics. * difference between the female and the male rowers, $P<0.05$.

fat-free mass (Cosgrove et al., 1999; Yoshiga et al., 2000). A correlation between rowing performance and fat-free mass may be because there is an association between the fat-free mass and blood volume and stroke volume of the heart, i.e., a large fat-free mass is associated with a high aerobic capacity (Hunt et al., 1998). Also, the fat-free mass relates to the mass of the skeletal muscles, which represent a large vascular bed and facilitate venous return by the muscle pump during exercise (Van Lieshout et al., 2001). Also, rowing demands a large cardiac output (Secher, 2000). Accordingly, these findings suggest that an enhanced venous return and the increased central blood volume via the muscles pump might influence rowing performance so as to secure cardiac output and enough blood flow to active skeletal muscles.

Secher et al. (1982) found that the VO_{2max} of the first place was 6.1 L min^{-1} and that of the 13th place was 5.1 L min^{-1} in an international regatta. Also, the correlation between 2000-m ergometer rowing results and VO_{2max} for rowers is reported (Secher et al., 1983; Kramer et al., 1994; Russell et al., 1998; Cosgrove et al., 1999; Pripstein et al., 1999; Yoshiga et al., 2000; Ingham et al., 2002). In the present study, VO_{2max} was determined during treadmill running and therefore expected to be about 3% lower than the value obtained during ergometer rowing (Yoshiga & Higuchi, 2002; Yoshiga et al., 2003). Yet, the findings of this study support the relevance of VO_{2max} for rowing performance.

Even when matching the female and the male rowers based on their body size, the females maintained a 9% slower rowing performance time than the males. Part of this difference was because the female rowers had a lager body fat content than their male counterparts (22 (3)% vs. 11 (2)%). A large body fat content deteriorates 2000-m ergometer rowing performance (Secher, 1983; Ingham et al., 2002). Thus, the sex difference in rowing performance among the subjects of similar body mass was in part because the female rowers had a smaller fat-free mass and also VO_{2max} than the male rowers (48 (3) vs. 58 (3) kg; 3.0 (0.3) vs. 4.0 (0.3) L min^{-1}).

Matching the female and the male rowers with regard to their VO_{2max}, the body mass for the females was similar to that for the males (63 (3) vs. 63 (4) kg) and the sex difference in rowing performance was reduced to about 4%. However, after matching VO_{2max}, the fat-free mass and body height were smaller in the females than in the males (49 (3) vs. 57 (4) kg; 165 (3) vs. 173 (5) cm). Equally, matching the female and the male rowers based on their fat-free mass, the VO_{2max} and body height were smaller in the females than in the males (3.4 (1.4) vs. 3.8 (1.4) L min^{-1}; 166 (3) vs. 171 (3) cm).

The difference in body size between the female and the male rowers explains a large part of the sex difference in rowing performance. Yet, a lower haemoglobin concentration may also account for a lower aerobic capacity of women than of men after considering differences in body and fat-free mass, reflecting that testosterone stimulates the production of haemoglobin (Keller & Katch, 1991; Wilmore & Costill, 1999).

It is also to be considered that rowing consists of rhythmical extensions of both legs (Secher, 1983) and that rowing performance is associated with the size of the leg muscle (Yoshiga et al., 2002b). In general, women possess smaller leg muscle compared to men (Wilmore & Costill, 1999). Thus, although body size and aerobic capacity are major determinants of rowing performance, the performance of the female rowers remains inferior to that of the male rowers when the major determinants are taken into consideration.

Perspectives

The findings support the fact that large body dimensions and a high aerobic capacity provide an advantage in rowing (Secher, 1983; Yoshiga et al., 2000; Ingham et al., 2002). Thus, a large part of the difference in rowing performance relates to the fact that women are smaller and possess a lower maximal oxygen uptake than men. Yet, some influences of sex on ergometer rowing time remain after considering the differences in body dimension and aerobic capacity between female and male rowers.

Key words: body height; body mass; fat-free mass; maximal oxygen uptake.

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Oxygen uptake and ventilation during rowing and running in females and males

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This study evaluated if the ventilatory response to exercise is impaired by the cramp position of rowing. Maximal oxygen uptake ($\dot{V}O_{2max}$), maximal expiratory volume ($\dot{V}_{Emax}$), and maximal heart rate (HR_{max}) during rowing and running were compared in 55 males (age, mean ± SD, 21 ± 3 years; height 176 ± 5 cm; body mass 72 ± 6 kg) and 18 females (age 20 ± 2 years; height 164 ± 5 cm; body mass 61 ± 4 kg). $\dot{V}_{Emax}$ was larger during rowing than during running (males, 157 ± 16 vs. 147 ± 13 L min^{-1}; 114 ± 9 vs. 105 ± 11 L min^{-1}, $P<0.01$). Also $\dot{V}O_{2max}$ was larger during rowing than during running (males, 4.5 ± 0.5 vs. 4.3 ± 0.4 L min^{-1}; females, 3.3 ± 0.4 vs. 3.2 ± 0.4 L min^{-1}, $P<0.01$). However, HR_{max} was lower during rowing than during running (males, 194 ± 8 vs. 198 ± 11 beats min^{-1}; females, 192 ± 6 vs. 196 ± 8 beats min^{-1}, $P<0.05$). $\dot{V}_{Emax}$ was correlated to body mass and fat-free mass, as was $\dot{V}O_{2max}$. Thus, the oxygen pulse ($\dot{V}O_{2max}/HR_{max}$) was larger during rowing than during running, while the ventilatory equivalent for oxygen ($\dot{V}_{Emax}/\dot{V}O_{2max}$) was similar. We showed that bending the body during rowing does not seem to impair ventilation either in males or in females. The results indicate that $\dot{V}_{Emax}$ and $\dot{V}O_{2max}$ relate to body size and fat-free mass for both females and males. The findings indicate that the involvement of more muscles, the entrainment, and the body position during rowing facilitates ventilation and venous return and lowers maximal heart rate.

Periodic contraction of muscles and movement during rowing elevates pleural pressure (Rosiello et al., 1987; Siegmund et al., 1999). An increased pleural pressure reduces venous return, end-diastolic volume, and the stroke volume of the heart (Cunningham et al., 1975; Rosiello et al., 1987; Wilmore & Costill, 1999). Also the increased intra-abdomen pressure impairs ventilation at stroke catch (Cunningham et al., 1975) or stroke finish (Siegmund et al., 1999). These physiological changes are considered to impair the expiratory volume ($\dot{V}_E$) and oxygen uptake ($\dot{V}O_2$) at maximal rowing effort (Cunningham et al., 1975; Rosiello et al., 1987).

On the other hand, during the drive phase the knee and hips extend and ventilation is assisted (Siegmund et al., 1999). During rowing a high ventilatory response is elicited (Szal & Schoene, 1989) and ventilatorylocomotion coupling appears to lead adequate ventilation (Siegmund et al., 1999). Rowing involves both upper- and lower-body exercise, while running mainly involves the legs (Secher, 1983; Clifford et al., 1994). $\dot{V}O_2$ increases as the muscle mass involved increases (Secher et al., 1974; Secher et al., 1977). We hypothesized that ventilation and oxygen consumption during rowing are larger than during running.

Specifically, $\dot{V}_E$ is reported to be limited during rowing in females (Mahler et al., 1987). As both the maximal expiratory volume ($\dot{V}_{Emax}$) and maximal oxygen uptake ($\dot{V}O_{2max}$) depend on body size (Secher et al., 1983; Rodgers et al., 1995; Jensen et al., 2001), the low $\dot{V}_E$ of females was considered to reflect their small body size rather than the position used during rowing.

In both males and females we examined $\dot{V}_{Emax}$, $\dot{V}O_{2max}$, and the maximal heart rate (HR_{max}) during ergometer rowing and treadmill running. Also, the maximal oxygen pulse ($\dot{V}O_{2max}/HR_{max}$) was calculated as an index of stroke volume of the heart (Heath et al., 1981). We also hypothesized that the cardiorespiratory response to exercise is similar between males and females, but that body size affects the response.

Methods

We studied 55 males (age mean ± SD, 21 ± 3 years; height 176 ± 5 cm; body mass 72 ± 6 kg, percentage body fat 11 ± 3%)

and 18 females (age 20±2 years; height 164±5 cm; body mass 61±4 kg; percentage body fat 22±4%). The subjects were informed of the design and risks of the study and provided written informed consent. This study was as approved by the Ethical Committee of the National Institute of Health and Nutrition, and provided written informed consent.

All subjects completed two bouts of exercise: progressive running on a treadmill and rowing on an ergometer (Concept II model C, Morrisville, VT, USA). All subjects are regularly running on a treadmill and rowing on an ergometer and were familiar with both type of exercise. During treadmill running, the initial speed was $160\,m\,min^{-1}$ for the males and $140\,m\,min^{-1}$ for the females, and it was increased by $20\,m\,min^{-1}$ every 2 min with a 3.0% incline of the treadmill. Exercise was terminated when the subjects could not complete a given running speed. During ergometer rowing, the initial load was 150 W for the males and 125 W for the females, and it was increased by 50 W for males and by 25 W for females every 2 min. Exercise was terminated when the subjects were no longer able to maintain the required intensity. It was required that each subject met each of the following criteria to ensure that $\dot{V}O_{2max}$ was reached: (1) a plateau in $\dot{V}O_2$ against exercise intensity; (2) a respiratory exchange ratio exceeding 1.15; (3) blood lactate concentration exceeding 8–9 $mmol\,L^{-1}$; (4) achievement of age-predicted HR_{max}; and (5) the rating of perceived exertion of 19 or 20 (Bassett & Howley, 2000).

The expired gas was collected in Douglas bags during the last 1 min of each stage, and the volume was measured using a dry gas meter and the concentrations of oxygen and carbon dioxide were determined (Respiromonitor RM-300i, Minato Medical Science Co., Tokyo, Japan). The HR was determined electrocardiographically (Nihon Kohden Co., Tokyo, Japan). The rating of perceived exertion was expressed every 2 min (Borg, 1982). Blood samples were taken using heparinized glass capillaries from the fingertip at the termination of exercise. Blood lactate concentration was analyzed by an enzymatic membrane method using a 1500 Analyzer (Yellow Springs, OH, USA).

Percentage body fat was derived according to the Brozek equation (Brozek et al., 1963) using body density determined by the BOD POD air displacement system (Life Measurement Instruments, Concord, CA, USA; Dempster & Aitkens, 1995).

Data are reported as mean±standard deviations (SD). The ventilatory equivalent for oxygen ($\dot{V}_{Emax}/\dot{V}O_{2max}$) was calculated (Wilmore & Costill, 1999). Student's *t*-test was performed for comparison of data obtained in males and females between rowing and running. Linear regression analysis was used to evaluate the relationship of each variable between rowing and running. The level of significance was set at $P<0.05$.

Results

The rating of perceived exertion during rowing was similar to during running (19.5±1.2 vs. 19.4±1.3). $\dot{V}_{Emax}$ was larger during ergometer rowing than during treadmill running (males, 157±16 vs. 147±13 $L\,min^{-1}$; females, 114±9 vs. 105±11 $L\,min^{-1}$, $P<0.05$). Also $\dot{V}O_{2max}$ was larger during rowing compared to during running (males, 4.5±0.5 vs. 4.3±0.4 $L\,min^{-1}$; females, 3.3±0.4 vs. 3.2±0.4 $L\,min^{-1}$, $P<0.05$).

$\dot{V}_{Emax}$ during rowing was correlated to $\dot{V}_{Emax}$ during running ($r=0.74$, $P<0.001$; Fig. 1). $\dot{V}_{Emax}$ during rowing was correlated to body mass ($r=0.78$, $P<0.001$; Fig. 2) and fat-free mass ($r=0.84$, $P<0.001$; Fig. 3). Also $\dot{V}_{Emax}$ during running was correlated to body mass ($r=0.67$, $P<0.001$) and fat-free mass ($r=0.77$, $P<0.001$).

$\dot{V}O_{2max}$ during ergometer rowing was correlated to $\dot{V}O_{2max}$ during treadmill running ($r=0.96$, $P<0.001$). $\dot{V}O_{2max}$ during rowing was related to body mass ($r=0.82$, $P<0.001$) and fat-free mass ($r=0.86$, $P<0.001$). Also $\dot{V}O_{2max}$ during running was related to body mass ($r=0.80$, $P<0.001$) and fat-free mass ($r=0.89$, $P<0.001$).

The ventilatory equivalent for oxygen during rowing was similar to that derived during running (males, 34.9±1.6 vs. 33.8±2.1; females, 34.1±2.2 vs. 32.6±3.7), and there was no significant gender difference. Also, the ventilatory equivalent for oxygen during rowing was correlated to that obtained during running ($r=0.47$, $P<0.001$; Fig. 1).

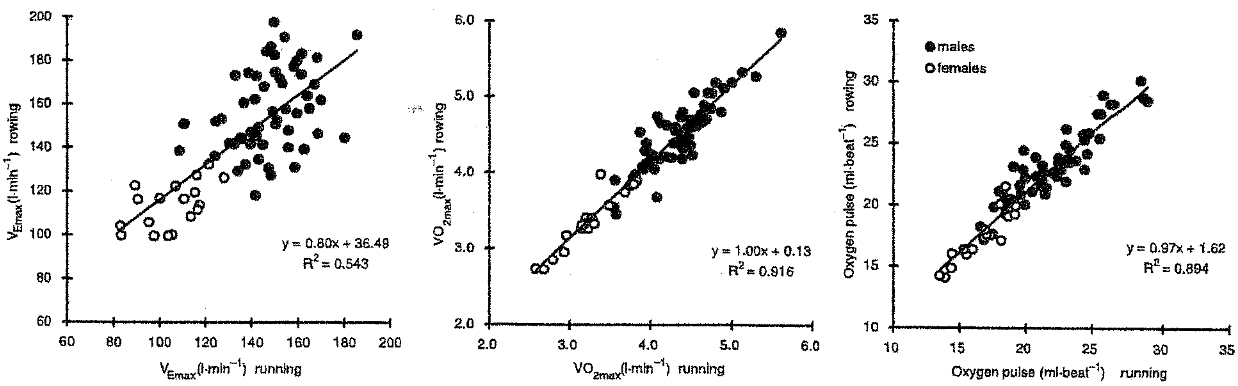
HR_{max} was lower during ergometer rowing than during treadmill running (males, 194±8 vs. 198±11 $beats\,min^{-1}$; females, 192±6 vs. 196±8 beats min^{-1}, all $P<0.05$), and there was no gender difference. HR_{max} during rowing was correlated to that obtained during running ($r=0.67$, $P<0.001$; Fig. 1).

Oxygen pulse was larger during rowing than during running (males, 23.2±2.9 vs. 22.0±2.8 $mL\cdot beat^{-1}$; females, 17.4±1.8 vs. 16.7±1.9 $mL\cdot beat^{-1}$, $P<0.05$). The oxygen pulse during rowing was correlated to that achieved during running ($r=0.95$, $P<0.001$; Fig. 1). Oxygen pulse during rowing was correlated to body mass ($r=0.78$, $P<0.001$; Fig. 2) and fat-free mass ($r=0.86$, $P<0.001$; Fig. 2). Also oxygen pulse during running was correlated to body mass ($r=0.76$, $P<0.001$) and fat-free mass ($r=0.83$, $P<0.001$).

Discussion

It has been suggested that the cramp position of rowing might impede the contraction of the diaphragm, attenuate the decrease in lung pressure during inspiration, and thereby also decrease preload of the heart, resulting in not only impaired breathing but also a reduced cardiac output (Cunningham et al., 1975; Rosiello et al., 1987). Also, during rowing the Valsalva-like maneuver used to stabilize the upper body while both legs are extended (Clifford et al., 1994) could diminish the ventricular preload during rowing (Cunningham et al., 1975; Rosiello et al., 1987). However, the findings of a higher $\dot{V}_{Emax}$ and $\dot{V}O_{2max}$ during rowing than running irrespective of sex do not support these suggestions.

During rowing, locomotion drives ventilation and this phenomenon is called entrainment (Siegmund



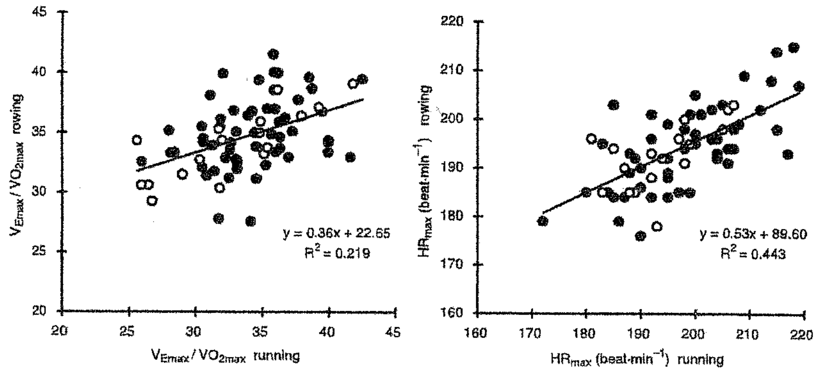


Fig. 1. Relationship for maximal minute ventilatory volume ($\dot{V}_{Emax}$), maximal oxygen uptake ($\dot{V}O_{2max}$), ventilatory equivalent for oxygen ($\dot{V}_{Emax}/\dot{V}O_{2max}$), maximal heart rate, and oxygen pulse ($\dot{V}O_{2max}/HR_{max}$) between rowing and running.

et al., 1999). Rowing leads to a high ventilatory response that is a product of a lower tidal volume and a high respiratory frequency, resulting in a high $\dot{V}_E$ (Szal & Schoene, 1989). The position during rowing increases in central respiratory drive (Szal & Schoene, 1989). The entrainment as well as the position used during rowing causes hyperventilation (Szal & Schoene, 1989; Siegmund et al., 1999).

The Frank–Starling mechanism indicates that enhanced venous return, i.e. enhanced preload, stretches the ventricle and augments stroke volume (Tate et al., 1994; Wilmore & Costill, 1999). The oxygen pulse is an index of stroke volume of the heart (Heath et al., 1981). Therefore, the higher oxygen pulse during rowing than running does not support the suggestion that preload of the heart is lower during rowing than during running (Cunningham et al., 1975; Rosiello et al., 1987).

HR_{max} is reported to be stable during rowing (Secher, 1983). HR_{max} does not seem to be affected by sex (Wilmore & Costill, 1999). In this study there were no significant differences of HR_{max} between females and males during the two types of exercise. HR_{max} does not depend on the type of exercise (Wilmore & Costill, 1999). However, we observed a lower HR_{max} during ergometer rowing than during treadmill running. During rowing the subjects use both the lower and upper body, while during running they use mainly their legs (Secher, 1983). A higher $\dot{V}O_{2max}$ during rowing than during running supports the fact that rowing involved a larger muscle mass than running (Secher et al., 1974; Secher et al., 1977; Savard et al., 1989). During exercise, an increase in active muscle mass enhances venous return and central blood volume because of the muscle pump (Davies & Sargeant, 1974; Klausen et al., 1982; Toner et al., 1983), which enhances stroke volume of the heart (Tate et al., 1994). Also, an elevated central blood volume slows HR with a decrease in sympathetic activity due to the cardiopulmonary reflex (Ray et al., 1993; Van Lieshout et al., 2001).

Body size affects $\dot{V}_E$ and aerobic capacity (Secher et al., 1983; Rodgers et al., 1995; Jensen et al., 2001), and this was observed regardless of sex. In this study $\dot{V}_{Emax}$ and $\dot{V}O_{2max}$ increases as fat-free mass increases. Fat-free mass is related to blood volume and to stroke volume of the heart, indicating that a large fat-free mass is associated with a high aerobic capacity (Hunt et al., 1998). Also, oxygen pulse as an indication of stroke volume of the heart (Heath et al., 1981) was correlated to body mass and fat-free mass independent of sex. The results are consistent with the data from West et al. (1997).

For females their breast has been considered to pressurize air in the lung while bending the body forward during rowing (Cunningham et al., 1975; Mahler et al., 1987). However, females possessed a ventilatory equivalent for oxygen similar to that of the males during both types of exercise, indicating that a mechanical impairment on ventilation is not substantiated.

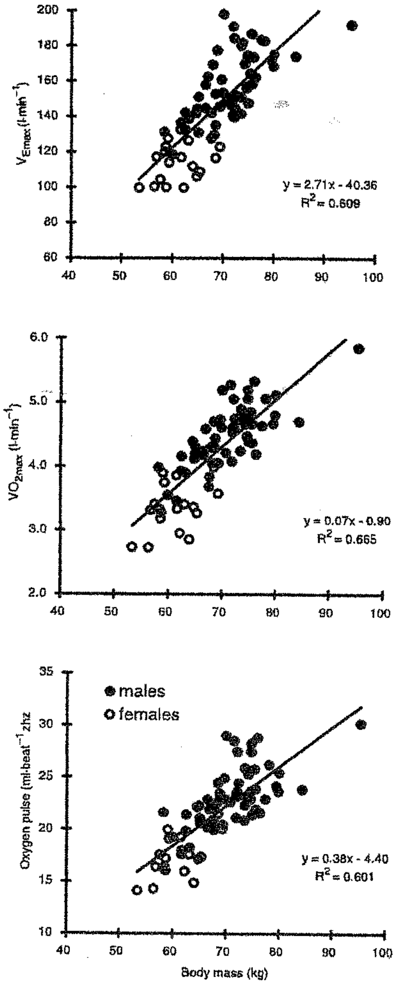


Fig. 2. Maximal minute ventilatory volume ($\dot{V}_{Emax}$), maximal oxygen uptake ($\dot{V}O_{2max}$), and oxygen pulse ($\dot{V}O_{2max}/HR_{max}$) during rowing related to body mass.

We showed that bending the body during rowing does not seem to impair ventilation either in males or in females. The findings suggest that ventilation, oxygen consumption during exercise, and delivery of blood to active muscles relate to body size and fat-free mass rather than to the sex of the subjects. The results of this study showed that the cardiorespiratory response to (seated) ergometer rowing is enhanced compared to (upright) treadmill running. Also ergometer rowing attenuates an increase in maximal heart rate compared to treadmill running. The findings indicate that the involvement of more muscles, the entrainment, and the position during rowing facilitates ventilation and venous return for both females and males.

Perspective

The present study indicates that rowing does not impair the $\dot{V}_{Emax}$, $\dot{V}O_{2max}$, and oxygen pulse at

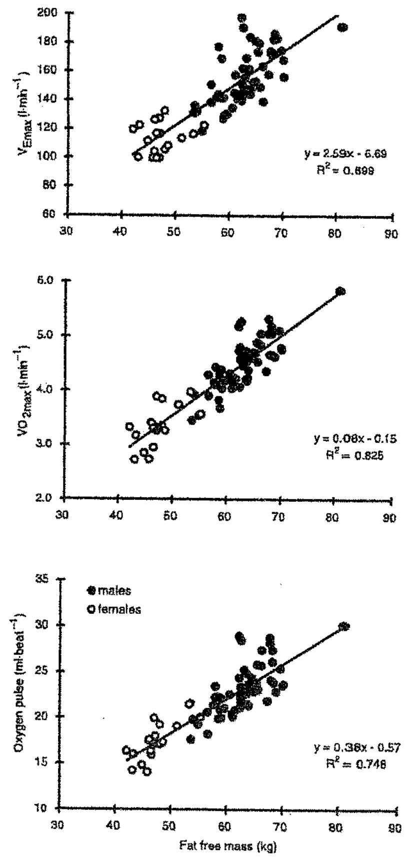


Fig. 3. Maximal minute ventilatory volume ($\dot{V}_{Emax}$), maximal oxygen uptake ($\dot{V}O_{2max}$), and oxygen pulse ($\dot{V}O_{2max}/HR_{max}$) during rowing related to fat-free mass.

maximal effort. These findings do not support suggestions that the contraction of the diaphragm and abdominal muscles during rowing reduces ventilation and oxygen consumption (Cunningham et al., 1975; Rosiello et al., 1987). Our findings are in part explained by the fact that the locomotion and ventilation coupling elicits high ventilation during rowing (Siegmund et al., 1999). This study also indicates a lower HR_{max} and a higher oxygen pulse during (seated) rowing compared to (upright) running. The findings are not in agreement with the fact that the movement during rowing elevates a pleural pressure and reduces venous return and the stroke volume of the heart (Rosiello et al., 1987). Our results appear to be responsible for the fact that the involvement of more muscles increases venous return as a muscle pump (Klausen et al., 1982), enhances the stroke volume (Tate et al., 1994), and slows HR due to the cardiopulmonary response (Ray et al., 1993; Van Lieshout et al., 2001). The current study also showed that cardiorespiratory response to rowing related to body size irrespective of the sex of subjects.

Key words: rowing, cardiorespiratory responses, heart rate, oxygen pulse, venous return, muscle pump, locomotion and ventilation coupling, body size.

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Bilateral leg extension power and fat-free mass in young oarsmen

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We evaluated the impact of bilateral leg extension power and fat-free mass on 2000 m rowing ergometer performance in 332 young oarsmen (age 21 ± 2 years, height 1.76 ± 0.05 m, body mass 62 ± 6 kg; mean $\pm s$). The 2000 m rowing performance time was correlated with height (1.62–1.93 m; $R^2 = 0.23$, $P < 0.001$), body mass (53–95 kg; $R^2 = 0.53$, $P < 0.001$), fat-free mass (47–82 kg; $R^2 = 0.58$, $P < 0.001$) and bilateral leg extension power (1202–3302 W; $R^2 = 0.38$, $P < 0.001$). Multiple regression analysis selected fat-free mass and bilateral leg extension power as regressor variables. Fat-free mass explained 58% of the variability in rowing performance and the inclusion of bilateral leg extension power improved the power of prediction by 5%. The results suggest that rowing involves almost every muscle in the body and that bilateral leg extension power is very important during this activity.

Keywords: lower limbs, muscle mass, rowing.

Introduction

During rowing, the activated muscle mass is larger than during leg exercise (e.g. running), since rowing engages both the upper and the lower body musculature (Secher, 1983, 2000). In particular, rhythmic extensions of the leg muscles produce the propulsive power required during rowing (Secher, 1983, 2000). This involvement is illustrated when the strength of one- and two-legged extension is compared. For both sedentary males and active males who engage in physical activities other than rowing, bilateral leg strength is lower than the sum of the left and right leg strength, denoted the 'bilateral strength deficit' by Secher (1975, 1983). However, oarsmen possess the unique ability to develop a bilateral leg strength that exceeds the sum of the strength of the two legs (Secher, 1975, 1983). In the light of the rowing motion, we hypothesized that the ability to produce a high bilateral leg extension power and a large fat-free mass are important for rowing.

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Methods

Participants

Altogether, 332 young oarsmen [age 19–24 (21 ± 2) years, height 1.62–1.93 (1.76 ± 0.05) m, mass 53–95 (70 ± 6) kg; range (mean $\pm s$)] volunteered to participate in this study. The participants had 2–8 years experience of rowing and had trained 5 days a week on water or on a rowing ergometer (16–20 km rowed each day; Yoshiga *et al.*, 2002a). The participants were free from any known neuromuscular disease and were not taking any medication. All participants were informed of the procedure and possible risks of the study before signing a consent form. The study was approved by the Ethics Committee of the National Institute of Health and Nutrition.

Procedures and apparatus

Percent body fat was derived by the equation of Brozek *et al.* (1963) using body density (BOD POD System, Life Measurement Instruments, Concord, CA, USA; Dempster and Aitkens, 1995). Fat-free mass was assessed as the difference between body mass and fat mass.

Maximal bilateral leg extension power was determined using a dynamometer (Anaeropress 3500, Combi Co., Tokyo, Japan). This movement involves

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knee and hip extensions in a coordinated manner. The apparatus is suitable for evaluation of bilateral leg extension power in healthy people based on evaluation in individuals aged 6–90 years (Yoshiga *et al.*, 2002b). The participants were familiarized with the apparatus for 8 weeks before evaluation and were able to press the applied load using both legs. After a warm-up session involving submaximal exercise, the participants assumed a seated position with back supported. The hips, knees and ankles were flexed 90° with the arms resting on a bar. The participants were instructed to press as hard as they could in a horizontal direction against the plate, with the movement continuing until both legs were fully extended. The power of this bilateral leg extension was calculated from the set load and the velocity averaged for the best two of five trials. The time between trials was 20 s. If the two values differed by more than 5%, the participant was requested to repeat the trial.

On a separate day, the participants completed an all-out 2000 m row on an ergometer (Concept II Model C, Morrisville, VT, USA) designed to simulate the duration, intensity and stroke rate of a race on water (Secher, 1983). All participants were familiar with the rowing ergometer from their daily training.

Statistical analysis

The data are reported as the mean ± standard deviation (*s*). Linear regression analysis was used to evaluate the relationship between rowing performance time and the physiological characteristics of the rowers. Forward stepwise multiple regression analysis was used to determine independent physiological correlates of rowing performance time. Comparison of linear and curvilinear regression equations was performed using a general *F*-test (Kleinbaum and Kupper, 1978; Seiler *et al.*, 1998; Montgomery and Runger, 1999). Additionally, as rowing speed provides a more plausible regression model than rowing performance time (Ingham *et al.*, 2002), both linear and curvilinear regression analyses were performed to examine the relationship between rowing speed and the physiological characteristics of the rowers. Statistical significance was set at $P < 0.05$.

Results

The range of 2000 m rowing performance times on the ergometer was 378–498 s (425 ± 20 s). Rowing performance was related to height ($r = -0.48$, $P < 0.001$), body mass ($r = -0.73$, $P < 0.001$), fat-free mass (62 ± 6 kg, range 47–82 kg; $r = -0.76$, $P < 0.001$) and bilateral leg extension power (2260 ± 367 W, range 1202–3302 W; $r = -0.62$, $P < 0.001$) (Fig. 1).

Multiple regression revealed that fat-free mass was the strongest independent predictor of rowing performance. Bilateral leg extension power accounted for an additional 5% of the variance in rowing performance, while body height and mass were not selected as regressor variables. Thus, 2000 m rowing time (s) was predicted as 598 minus 2.24 times the fat-free mass (kg) minus 0.02 times the bilateral leg extension power (W) ($R^2 = 0.63$, $P < 0.001$).

For the relationship between rowing performance and bilateral leg extension power, a curvilinear regression provided a better fit to the variance in rowing performance than a linear regression (41% of variance 'explained' by the curvilinear regression compared with 38% for the linear regression; $F > F_{1,329}$). Similarly, a curvilinear regression showed an improvement in the relationship between rowing performance and body height, mass and fat-free mass ($F > F_{1,329}$).

The range of rowing speeds over a 2000 m ergometer row was 4.06–5.29 $m \cdot s^{-1}$ (4.71 ± 0.22 $m \cdot s^{-1}$). Rowing speed was related to height ($r = 0.49$, $P < 0.001$), body mass ($r = 0.74$, $P < 0.001$), fat-free mass ($r = 0.77$, $P < 0.001$) and bilateral leg extension power ($r = 0.63$, $P < 0.001$) (Fig. 2). Also, a curvilinear regression revealed an improvement in the relationship between rowing speed and body height, mass, fat-free mass and bilateral leg extension power ($F > F_{1,329}$).

Discussion

Our results suggest that rowing requires the involvement of almost all muscles in the body, including those in the legs, arms, back and trunk (Secher, 1983, 2000; Yoshiga *et al.*, 2003). The rhythmic extensions of both legs are a unique attribute of rowing (Secher, 1975, 1983). The main finding of this study is that both fat-free mass and bilateral leg extension power were independent physiological correlates of 2000 m ergometer rowing performance in young oarsmen.

Successful oarsmen tend to be tall with long arms and legs so as to secure the length of the stroke (Secher, 1975, 1983). However, studies including less than 30 oarsmen have not yielded a relationship between rowing performance and height (Jensen *et al.*, 1996; Russell *et al.*, 1998; Cosgrove *et al.*, 1999). In the present study, we assessed a large cohort of young oarsmen and our results demonstrate the advantage of being tall for high-level rowing performance.

For weight-bearing physical activities such as long-distance running, a large body mass hinders exercise performance (Hagberg *et al.*, 1985; Sjödin and Svedenhag, 1985). However, the results of the present study indicate that a large body mass contributes to favourable rowing performance, possibly because the

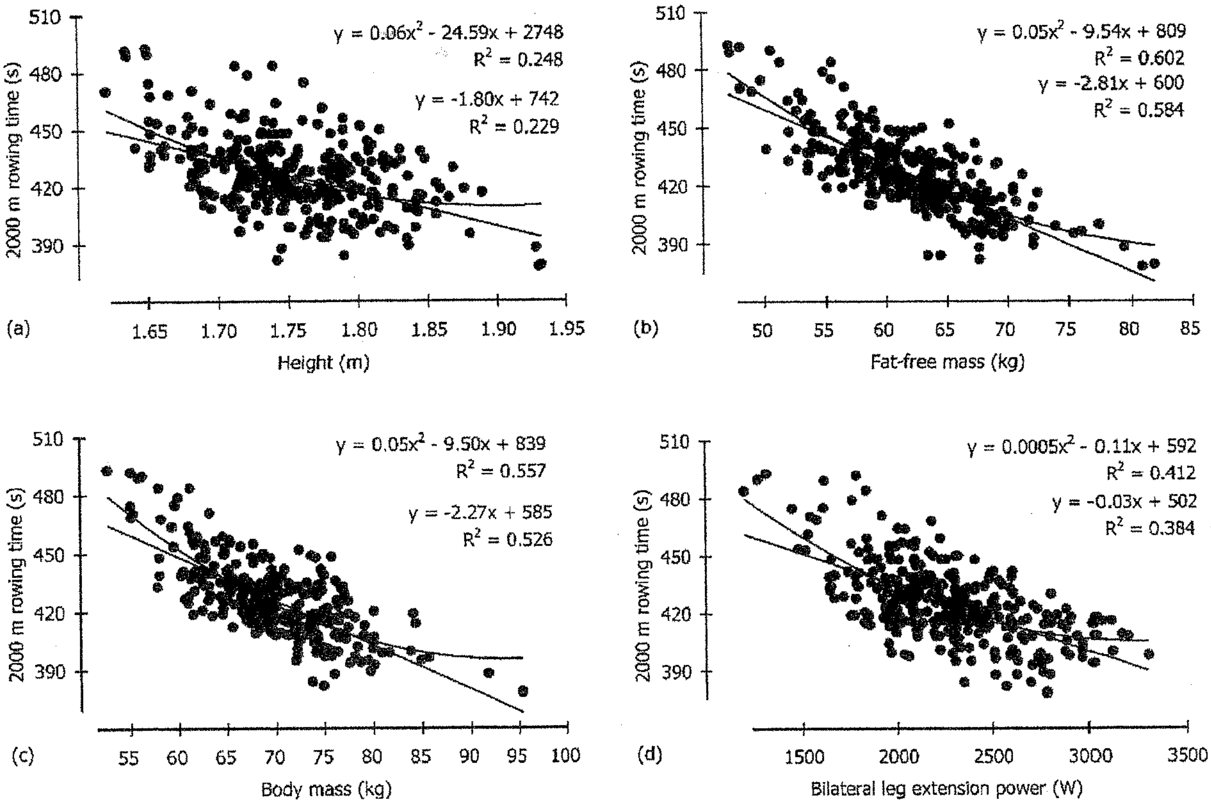

Fig. 1. Relationship between 2000 m rowing ergometer performance time and (a) height, (b) fat-free mass, (c) body mass and (d) bilateral leg extension power.

body is supported during rowing (Secher, 1983). Moreover, Secher and Vaage (1983) concluded that a 23 kg larger body mass gained an advantage of 10 s in a 2000 m international rowing competition. These findings confirm that body mass contributes to a favourable rowing performance on an ergometer. It is believed that the beneficial influence of body size on rowing performance is due to the volume of the respiratory system (West *et al.*, 1997; Jensen *et al.*, 2001), which is important because rowing is a type of physical activity that requires the maintenance of a high ventilation (Secher, 1983; Volianitis *et al.*, 2001).

Secher (1983) noted a significant difference in fat-free mass between winning oarsmen at international regattas and internationally competitive oarsmen (87 *vs* 77 kg). Similarly, the present study involving 323 young oarsmen provides supporting evidence that a large fat-free mass helps an individual achieve a good performance on a rowing ergometer (Secher, 1983; Cosgrove *et al.*, 1999; Yoshiga *et al.*, 2000; Ingham *et al.*, 2002). This finding relates to the fact that more muscles are involved in rowing (combined arm and leg exercise) than in running (leg exercise) (Secher, 1983; Yoshiga and Higuchi, 2002; Yoshiga *et al.*, 2003). Not only is fat-free mass an indication of muscle mass and, therefore, the energy source during exercise (Khosla, 1983; Nevill and Holder, 1997; Wilmore and Costill, 1999), but it is also related to blood volume and to stroke volume of the heart (Hunt *et al.*, 1998). Thus rowing enhances fat-free mass in both young and old individuals (Yoshiga *et al.*, 2001, 2002a,b). Equally, rowing increases the volume and the wall thickness of the heart in both young (Kuel *et al.*, 1982; Pelliccia *et al.*, 1991) and older oarsmen (Gustafsson *et al.*, 1996). Unlike running and cycling, which activate the legs alternately, rowing combines intense dynamic exercise with a need for the development of a large power output during each stroke and, in particular, rowing involves the simultaneous extension of both legs to develop propulsive power (Secher, 1983, 2000). Physical activity consisting of bilateral leg extension increases bilateral leg strength so that it exceeds the sum of the values obtained for unilateral leg strength (Secher, 1975; Shantz *et al.*, 1989). As a result of regular rowing, the bilateral leg extension strength and power of oarsmen are greater than those of young (Secher, 1983; Yoshiga *et al.*, 2001) and older sedentary individuals (Yoshiga *et al.*, 2002b). Moreover, there is

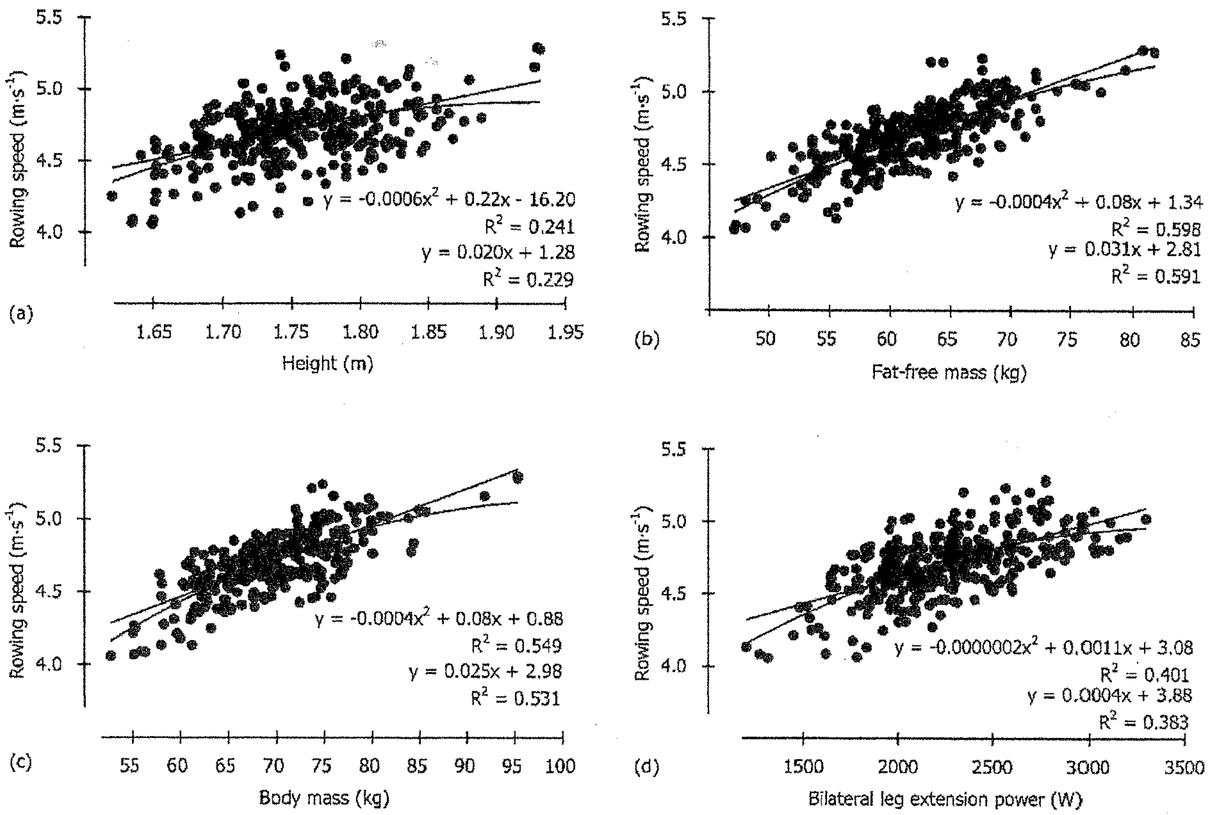

Fig. 2. Relationship between rowing speed over a 2000 m ergometer row and (a) height, (b) fat-free mass, (c) body mass and (d) bilateral leg extension power.

a notable difference in bilateral strength between elite and club oarsmen (Secher, 1975, 1983). These observations help to explain why there is no significant relationship between rowing performance and unilateral leg strength or power (Secher, 1975, 1985; Kramer *et al.*, 1994) but there is an association between rowing performance and bilateral leg extension power. The results of the present study suggest that the ability to produce power by engaging both legs together is a requirement for successful rowing performance (Secher, 1975, 1983, 2000) and that the major portion of the propulsive phase takes place during the leg drive among experienced oarsmen (Secher, 1983; Jensen *et al.*, 1996).

In conclusion, both 2000 m rowing performance and bilateral leg extension power are correlated with the size of the leg extensor muscles in oarsmen (Yoshiga *et al.*, 2002b). Qualified oarsmen tend to possess many slow-twitch fibres and muscle fibres of large size in their leg extensor muscles (Larsson and Forsberg, 1980; Secher, 1983, 2000; Roth *et al.*, 1993). The findings of the present study demonstrate the relevance of bilateral leg extension power and fat-free mass for rowing performance.

Acknowledgements

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脂質代謝を高めるトレーニング

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特集 新しいトレーニングの視点

脂質代謝を高めるトレーニング

樋口　満

1 生体内での脂質の役割と運動トレーニング

脂質のなかでトリグリセリドは体内での貯蔵エネルギー源の代表であり，有酸素性の運動中には遊離脂肪酸を経て，骨格筋でエネルギー源として利用され，運動に必要なエネルギーを生み出すのに重要な役割を果たしている．しかし，過剰に蓄積されたトリグリセリドは肥満を引き起こし，さまざまな生活習慣病の発症にかかわっている．また，コレステロールは細胞膜の構成成分であり，各種ホルモンの材料としても不可欠な脂質であるが，その血中濃度，とくにLDL-コレステロール濃度の上昇による高脂血症は動脈硬化・冠動脈疾患を引き起こす主たる要因となっている．

アメリカスポーツ医学会（ACSM）[1]は「健康な成人が体力を増強し，維持するために必要な推奨される運動の質と量」に関する公式見解（1978）を発表し，その後，筋力と筋持久力の発達に関する項目を加えたガイドラインを作成している（1990）．そのなかでトレーニングの持続時間，運動の様式，レジスタンストレーニングについては以下のことが示されている（抜粋）．

・**トレーニングの持続時間：**連続的な有酸素運動を20―60分，一般の成人には軽度から中等度の長めの運動が勧められる．

・**運動の様式：**大筋群を使い，持続的でリズミカルな有酸素運動なら何でもよい．

・**レジスタンストレーニング：**除脂肪体重の維持・発達に十分な中等度の筋力トレーニングが成人の体力プログラムに組み入れられるべきである．

これまでの多くの実験的，および疫学的研究によって，有酸素的持久性運動が脂質を基質とするエネルギー代謝を高め，血清中のトリグリセリドやコレステロールの濃度を低下させることによって，肥満や冠動脈疾患を予防する効果があることが明らかになっている[2]．生活習慣病予防に果たす運動の効果には対象となる人々の年齢や体力による限界もあるが，このガイドラインを原則として，日常生活における運動・スポーツを実践すればよいと考えられている．

本稿ではローイング（ボート漕ぎ）トレーニングが血中脂質・リポ蛋白プロフィールに及ぼす影響と，高強度トレーニングが脂質代謝関連酵素活性に及ぼす影響について，われわれが行なってきた研究データを紹介する．

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表1　中年男性レジスタンス・トレーニング群と同年齢層の非運動・一般人の血中脂質・リポ蛋白プロフィール

		レジスタンス・トレーニング群	非運動・一般人
被験者数		10	10
総コレステロール（T-C）	mg/dL	205 ± 37	191 ± 21
HDL-コレステロール（HDL-C）	mg/dL	63 ± 15 **	46 ± 10
T-C/HDL-C	unit	3.35 ± 0.87 *	4.32 ± 0.83
トリグリセリド	mg/dL	80 ± 36 *	121 ± 47

（平均±標準偏差）* P ＜ 0.05，** P ＜ 0.01

2 運動・スポーツが血中脂質・リポ蛋白プロフィールに及ぼす影響

1）レジスタンス運動の効果

すでに，Hurleyら[3]は強度が中等度で高頻度による長時間のレジスタンス運動を行なっている成人男性ボディビルダーの血中脂質・リポ蛋白プロフィールを，高強度で低頻度のレジスタンス運動を行なっているウェイトリフター，および有酸素運動を行なっている持久性ランナーと比較検討している．その結果から，中等度・高頻度でインターバルが短く，長時間にわたって行なわれる筋力トレーニングは呼吸循環器系機能も向上させ，血中脂質・リポ蛋白プロフィールを改善するが，高強度・低頻度でインターバルの長いレジスタンス運動はそのような効果がみられないことが示唆されている．

われわれも以前に，週に3，4回トレーニングジムに通い，レジスタンス運動を行なっている中高年男性の血中脂質・リポ蛋白プロフィールを検討したことがある[4]．表1に示すように，彼らの血中脂質・リポ蛋白プロフィールは運動習慣のない一般人よりも抗動脈硬化型であった．しかし，彼らはレジスタンス運動以外にもトレッドミル走や自転車エルゴメータ漕ぎによる有酸素運動プログラムも取り入れており，血中脂質・リポ蛋白プロフィールが抗動脈硬化型になっているのはレジスタンス運動の効果であるとは断定できなかった．さらに，われわれは若年成人男性・ウェイトリフター（N = 15，BMI：24.7kg/m^2）の血中脂質・リポ蛋白プロフィールを運動習慣のない同年齢層の一般男性（N = 15，BMI：21.8kg/m^2）と比較検討したことがある．その結果，ウェイトリフターの動脈硬化指数（LDL-コレステロール/HDL-コレステロール比）は一般男性よりもむしろ高くなっていた（1.74 vs 1.20）．

これらの研究結果から，中等度・高頻度で長時間行なわれるレジスタンス運動は血中脂質・リポ蛋白プロフィールを抗動脈硬化型にするが，高強度・低頻度のレジスタンス運動にはその効果が認められないことが示された．

2）ローイング運動の効果

先に示したACSMのガイドラインにも例としてあげられているが，ローイング（ボート漕ぎ）は“大筋群を使い，持続的でリズミカルな有酸素運動”であり，中高年者の健康増進に有効な運動であると考えられている．ローイングは脚伸展，上体のスイング，上腕のプルからなる一連の動作によってパワーが発揮されるリズミカルな大筋群の運動であり，通常は1分間に20～40回の頻度で，数十秒から数分，長い場合には数十分にわたって持続して行なわれる．

ボート選手の水上での乗艇トレーニングの内容はローイング直後の血中乳酸濃度を基準とした強度によって以下のように4カテゴリーに分けられている．カテゴリーⅠ：血中乳酸濃度が8mM以上，Ⅱ：4～8mM，Ⅲ：2～4mM，Ⅳ：2mM以下．一般的に，ボート選手の水上での練習は，実際のボートレースとは異なり，ボートシーズン

表2 若年成人男性ボート選手と同年齢層の非運動・一般人の血中脂質・リポ蛋白プロフィール

		ボート選手	非運動・一般人
被験者数		41	31
総コレステロール	mg/dL	152 ± 24 ***	184 ± 25
LDL-コレステロール（LDL-C）	mg/dL	79 ± 20 ***	112 ± 23
HDL-コレステロール（HDL-C）	mg/dL	60 ± 12 ***	59 ± 9
LDL-C/HDL-C	unit	1.41 ± 0.48 ***	2.00 ± 0.56
トリグリセリド	mg/dL	69 ± 23	64 ± 31

（平均±標準偏差）*** $P < 0.001$

（試合期）ではカテゴリーⅢが20％前後となっているものの，年間を通してみるとほとんどが低強度から中等度のカテゴリーⅢ，Ⅳであり，高強度のカテゴリーⅠ，Ⅱは非常にわずかな比率でしかない[5]．もちろん，水上での練習以外に，陸上での筋力（レジスタンス）トレーニングは行なわれているが，ボート選手のおもなトレーニングは筋力発揮を伴う有酸素性トレーニングであるといえるだろう．

われわれは大学ボート部に入部した男子学生（N＝10）を対象として，水上での乗艇練習，およびインドアでのローイング・エルゴメータなどによる3カ月間のトレーニング前後で身体的・生理的諸指標を検討した[6]．その結果，体重は変化しなかったが体脂肪率の低下（10.3→7.9％），除脂肪体重（LBM）の増加（66.5→67.1kg）を観察するとともに，体重当たりの$\dot{V}O_2max$の増加（54.8→58.5mL/kg/min）を認めた．このように，ローイング運動は有酸素性能力を高めるだけでなく，骨格筋などLBMを増加させる効果があることから，レジスタンス運動の要素もあわせもっている運動であるといえる．実際，上記の3カ月間のローイング・トレーニングによって，血清HDL-コレステロール濃度の上昇（63→72mg/dL），LDL-コレステロールの低下（69→66mg/dL）が顕著に認められ，彼らの血中脂質・リポ蛋白プロフィールがより抗動脈硬化型へと変化したことが観察されている．

またわれわれは，ローイング・トレーニングを日常規則的に行なっている大学男性ボート選手の身体的・生理的特徴と血中脂質・リポ蛋白プロフィールを，運動習慣のない一般男子学生と比較して検討した[7]．その結果，表2に示すように大学ボート選手は一般学生に比べてLBMが多く，$\dot{V}O_2max$も非常に高くなっており，彼らの動脈硬化指数（LDL-コレステロール/HDL-コレステロール比）は一般学生に比べて明らかに低くなっていた．

今日では，ローイングはローイング・エルゴメータの開発により，自転車漕ぎやトレッドミルによるウォーキング・ジョギングと同様にインドアでもできる運動となっている．水上でのボートレースと同様に，ローイング・エルゴメータを用いて2,000mのタイムトライアルによるパフォーマンスを競う大会が世界的規模で行なわれており，中高年者を中心に欧米諸国ではローイング・エルゴメータはフィットネス・クラブで健康機器として広く利用されている．

若年成人で確認されたローイングの有酸素性レジスタンス運動の効果を中高年者で明らかにするために，われわれは中高年男性でローイングを愛好している人々を対象として，同年齢層の運動習慣のない人々との対比で血中脂質・リポ蛋白プロフィールを検討した[8]．週に2回程度の水上練習かインドアでのローイング・エルゴメータ漕ぎを日常規則的に行なっている中高年男性ローイング愛好者は運動習慣のない一般人よりも，体脂肪率がやや低く，$\dot{V}O_2max$は著しく高くなっており，

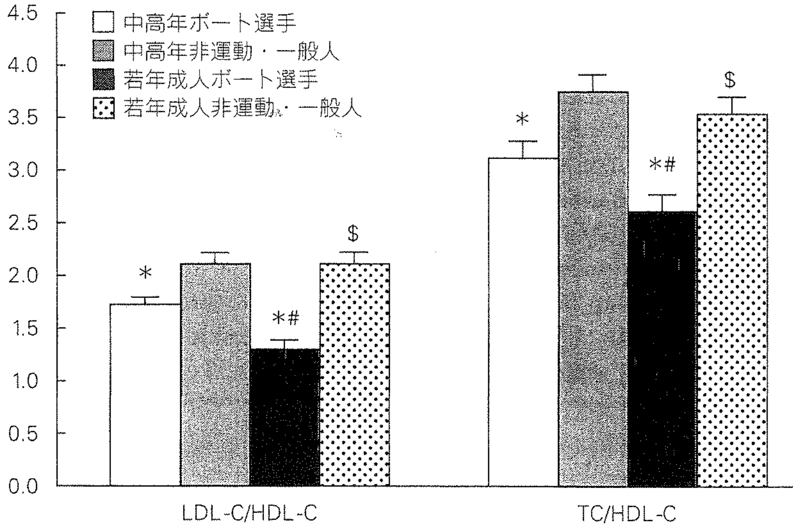

図1　若年，および中高年男性のボート選手と非運動・一般人の動脈硬化指数
LDL-C：LDL-コレステロール，HDL-C：HDL-コレステロール，TC：総コレステロール
*$p < 0.05$ 同年齢層内での有意差，#$p < 0.05$ 若年と中高年のボート選手の間での有意差，
$$p < 0.05$ 中高年ボート選手と若年成人非運動男性の間での有意差

図1に示すように動脈硬化指数（LDL-コレステロール/HDL-コレステロール比，総コレステロール/HDL-コレステロール比）は低かった．

これらの結果から，有酸素運動とレジスタンス運動の要素をあわせもつローイング運動は中高年者の健康増進のために推奨される運動・スポーツの1つと考えてよいことが示唆された．

3 高強度トレーニングによる骨格筋の脂質代謝改善効果—ラットを用いたトレーニング研究—

有酸素性能力を高めるトレーニングは有酸素運動であるとの認識が一般にはあるが，近年，有酸素性能力の生理学的指標である最大酸素摂取量（$\dot{V}O_2max$）を高めるトレーニングとして，高強度トレーニングが注目されている[9]．このトレーニングは$\dot{V}O_2max$の170％の強度での運動負荷を短時間の休息を挟んで10セット程度繰り返すものである．このトレーニングが有酸素的な持久性運動トレーニングと同様に，骨格筋のミトコンドリアに局在するTCAサイクルの酸化系酵素であるクエン酸合成酵素（CS）活性を高めると同時に，糖代謝機能にかかわる骨格筋グルコーストランスポーター（GLUT4）含量を高めることが，最近になって動物実験により明らかにされた[10]．ミトコンドリアにはTCAサイクルの酸化系諸酵素のみならず，脂質のエネルギー代謝にかかわる酵素である3-ヒドロキシアシルCoA脱水素酵素（HAD）も局在しており，有酸素的な持久性運動トレーニングによって，HADの酵素活性も上昇することはすでによく知られている．そこで，われわれは，ラットを用いたスイミングによる高強度トレーニングが骨格筋のHAD活性に及ぼす効果を検討した[11]．その結果，図2に示すように高強度トレーニングも骨格筋の脂質代謝にかかわるHADの活性をCSと同様に著しく高める可能性があることを明らかにした．

有酸素性トレーニングにより脂質代謝機能が改善され，長時間運動中の貯蔵脂肪の利用が高まり，骨格筋や肝臓の貯蔵グリコーゲンの消費が節約されることはすでによく知られている．この脂質代謝機能の改善の生化学的根拠として，トレーニングによる骨格筋HAD活性の上昇が考えられる．

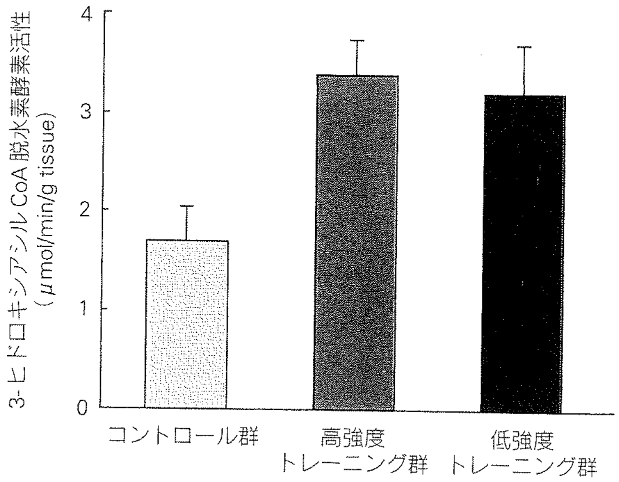

図2　高強度，および低強度のトレーニングを行なったラット骨格筋の脂質代謝関連酵素活性

適度に処方された高強度トレーニングが有酸素性能力を高めることができるとしても，高強度な一過性運動のみによるトレーニングでは総エネルギー消費量も少ないので，大きな貯蔵脂肪燃焼効果を期待することはできない．そこで，高強度トレーニングによって得られた，より高い有酸素性能力を基盤として，長時間の有酸素運動を行なえば運動中の貯蔵脂肪の燃焼を亢進させることができ，抗動脈硬化型の血中脂質・リポ蛋白プロフィールを保持するのに効果的である可能性が考えられる．しかし，さまざまな生活習慣病の危険因子を潜在させている可能性のある運動習慣のない中高年者に対して，はじめから高強度トレーニングを処方することが適切でないことはいうまでもない．

今後，若年成人から中高年者に至る健康増進やさまざまな生活習慣病予防のために処方されるレジスタンス運動や高強度運動の効果に関する研究が進展することを期待したい．

[文　献]

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