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Factors in maximal power production and in exercise endurance relative to maximal power*

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Summary. The relationship of muscle fiber type and mass to maximal power production and the maintenance of power (endurance time to exhaustion) at 36%, 55%, and 73% of maximal power was investigated in 18 untrained but physically active men. Power output was determined at constant pedalling rate (60 rev·min^{-1}) on a cycle ergometer instrumented with force transducers and interfaced with a computer. Maximal power was determined for each subject as the highest one-revolution average power. Fat-free mass was determined by hydrostatic weighing, fat-free thigh volume by water displacement and skinfold measurement, and percentage and area of type II fibers from biopsy specimens taken from the vastus lateralis. Maximal power averaged 771±149 W with a range of 527-1125 W. No significant correlations were found among percentage of type II fibers, relative area of type II fibers, or fat-free thigh volume and maximal power or endurance times to exhaustion at any percentage of maximal power. Weak but significant relationships were found for fat-free mass with both maximal power ($r=0.57$) and endurance time at 73% of maximal power ($r=-0.47$). These results show maximal power to be more dependent on factors related to body size than muscle-fiber characteristics. The low correlations for so many of the relationships, however, suggest that individuals employ either different combinations of these factors or utilize other strategies for the generation of high power.

Key words: Anaerobic exercise – Muscle fiber type – Fat-free thigh volume – Cycle ergometry

* Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC regulation 70-25 on Use of Volunteers in Research.
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Introduction

One of the most important considerations in human exercise performance is the ability to produce power. Research, however, has principally focused on the energy sources available for muscular contraction rather than upon the resulting mechanical power output. The ability to determine maximal leg power has been limited by the unavailability of ergometers that could provide the resistances adequate to cover the higher exercise intensities of which humans are capable.

Maximal power outputs have been calculated from measurements made during stair-climbing (Margaria et al. 1966) and constant-load cycle ergometry (Bar-Or 1981), but these tests have been criticized because the velocity of muscular contractions was not controlled. The isokinetic dynamometer (e.g., Cybex) has been used extensively to measure maximal torque at various contraction velocities but has also been criticized due to limitations in the interpretability and utility of the data generated (Winter et al. 1981; Froese and Houston 1985). More recently, the development of cycle ergometers fitted with transducers to measure pedal forces has allowed the accurate measurement of maximal leg power during constant-velocity, concentric exercise (Sargeant et al. 1981; Knuttgen et al. 1982; McCartney et al. 1983b; Harman et al. 1987).

Several studies have assessed factors considered important in the ability of humans to produce maximal power, but all have utilized either stair-climbing (Komi et al. 1977), constant-load cycle ergometry (Froese and Houston 1987) or isokinetic dynamometry (Thorstensson et al. 1976, 1977; Clarkson et al. 1982b; Froese and Houston 1985; Ryushi and Fukunaga 1986; Johansson et al. 1987) as the modes of exercise. Skeletal muscle mass and fiber composition are factors that have been found to be significantly correlated with maximal torque or power development (Thorstensson et al. 1976, 1977; Komi et al. 1977; Ryushi and Fukunaga 1986; Froese and Houston 1987; Johansson et al. 1987). However, such significant relationships have not always been observed (Clarkson et al. 1982b; Froese and Houston

1985). Furthermore, significant correlations have often been found when the subject sample consisted solely of highly trained athletes (Komi et al. 1977; Thorstensson et al. 1977; Johansson et al. 1987). To date, no studies are available assessing the contribution of such variables to maximal power during concentric, constant-velocity, cycling exercise in normally active, non-athletic subjects.

In the present study, a specially constructed cycle ergometer was employed which permitted the testing of subjects over a full range of power production at constant pedal-crank velocities. The purposes of this investigation were: (1) to evaluate variables possibly related to the production of maximal leg power; and (2) to identify factors related to be maintenance of power at various percentages of maximum.

Methods

Subjects. Eighteen men volunteered to participate in this study and provided signed informed consent after the experimental procedures and possible risks had been explained. The men were occasionally to moderately active, as most took part in some form of regular physical exercise, but none were actively competing. They were thoroughly familiarized with all testing equipment and procedures before taking part. On separate days during a 2-week period prior to the determination of maximal leg power, measurements were made of aerobic power, anaerobic power, and anthropometry. Muscle biopsy specimens were taken as described below.

Cycle ergometer and power production. Torque and power generated during constant-velocity cycling were determined using a specially constructed cycle ergometer (Knuttgen et al. 1982). The ergometer was instrumented with force transducers and interfaced with a computer for data collection and processing, as described previously (Harman et al. 1987). Maximal power was determined for each subject as the highest one-revolution average power generated while pedalling with maximal effort for five revolutions on the cycle ergometer with the pedalling rate maintained at 60 $rev \cdot min^{-1}$. Three tests of five revolutions were performed with 20 min rest between tests. The avarage of the two closest results was taken as maximal power. The subject was seated in a rigid metal armchair behind the crankshaft to provide back support. The distance from the chair to pedal crank was set for each subject so that the knee would never quite fully extend.

On separate days following maximal power determination, subjects were tested in random sequence for endurance times to exhaustion at 36%, 55%, and 73% of maximal power. Subjects were required to generate power at these levels while pedalling at 60 $rev \cdot min^{-1}$. Both a panel meter in front of the subject indicating speed and a metronome were used to maintain pedal cadence. The test ended when pedalling speed decreased to 58 $rev \cdot min^{-1}$ or less for 7 s. The 7 s were subtracted from the total time of exercise. The test, re-test reliabilities for endurance time to exhaustion (performed on ten subjects the week following the completion of all other testing) were 0.92, 0.95, and 0.96 at 36%, 55%, and 73% of maximal power, respectively.

Muscle biopsy procedure. Muscle biopsies were performed as described by Bergstrom (1962) and modified by Evans et al. (1982). Specimens were taken from the lateral portion of the vastus lateralis at least 1 week prior to power testing. Care was taken to approximate a comparable location in all subjects using a depth of 20 mm. When repeat biopsies were performed, no significant variations in fiber-type distribution were observed. The samples were oriented, mounted on a freezing chuck in embedding medium, frozen in isopentane cooled in liquid N_2, and stored at $-120°$ C for subsequent analysis. Cross sections (12 µm) were cut on a cryostat (American Optical, Southbridge, MA, USA) maintained at $-20°$ C. Histochemical reactions were carried out for myofibrillar adenosine triphosphatase (ATPase) activity at pH 4.3, 4.6, and 10.3 (Brooke and Kaiser 1970; Staron et al. 1983). Muscle fibers were divided into three groups (types I, IIA, and IIB) based on the stability of ATPase activity in the pre-incubation medium. Fiber type percentages were computed using a Zeiss Interactive Digital Analysis System (ZIDAS; Zeiss, Thornwood, NY, USA) which involved projection of cross sections onto a digitizing tablet interfaced with a computer. An average of 992 (range 389–1732) fibers per subject were counted to calculate percent fiber type.

The cross-sectional areas of all intact type I and type II fibers were determined using nicotinamide adenine dinucteotide-tetrazolium reductase stained sections (Novikoff et al. 1961) with the aid of a digitizing tablet and the ZIDAS system for computation. The mean area of type I and type II fibers was determined for each subject and the mean area occupied by type II fibers was calculated and expressed as the total area occupied by the type II fibers (Tesch 1980). Capillary density (mm^{-2}) and capillaries per fiber ($cap \cdot fib^{-1}$) were determined from amylase-periodic acid-Schiff stained fibers as previously described (Anderson 1975).

Anthropometry. Height, body mass, body composition, and thigh volume were determined after an overnight fast. Fat-free mass (FFM) was determined by a standard hydrostatic weighing technique using a load cell interfaced with a desktop computer (Fitzgerald et al. 1987). Residual lung volume was determined by the oxygen dilution method as described by Wilmore et al. (1980). Right thigh volume from the gluteal furrow to just above the patella was determined by water displacement (Jones and Pearson 1969). To calculate fat-free thigh volume (FFTV), skinfold thickness was measured on the anterior and posterior thigh in the midline at the one-third subischial height level (Watson and O'Donovan 1977).

Aerobic and anaerobic power. Aerobic power ($\dot{V}_{O_{2max}}$) was determined using a discontinuous protocol. Subjects initially pedalled at 235 W for 4–5 min at 60 $rev \cdot min^{-1}$. Intensity was increased in 30 W increments until a plateau occurred in oxygen uptake. Each exercise bout lasted 3–5 min and was followed by a 5- to 10-min rest period. The cycle ergometer and subject positioning were the same as that for determining maximal power. Expired gas was collected in a Douglas bag and analyzed for oxygen (Applied Electrochemistry S3-A) and carbon dioxide (Beckman LB-2). Volume was measured by a chain-compensated gasometer. Heart rate was monitored via electrocardiography using a modified V_5 lead.

Maximal power outputs from the Wingate test (Bar-Or 1981) and an isokinetic endurance test (Thorstensson et al. 1976) were also determined for all subjects. The Wingate test was performed on a mechanically braked cycle ergometer (Monark) modified so that resistance could be instantaneously applied to the flywheel. The subject pedalled maximally for 30 s against a resistance of 0.735 $N\,kg^{-1}$. Mean power output was calculated for the first 5 s (peak power) and the entire 30-s period (mean power). For the isokinetic endurance test, the Cybex dynamometer was set at a velocity of 3.14 $rad \cdot s^{-1}$ (180° $d \cdot s^{-1}$). Subjects performed 50 maximal knee extensions during a 60-s period. Peak torque (N m) was averaged for the first 3 contractions to determine highest peak torque and for the entire 50 contractions to determine mean peak torque. Power output was computed as torque times the angular velocity in $rad \cdot s^{-1}$.

Statistical analysis. For each variable, group data are presented as mean ± standard deviation. Pearson product-moment correlation coefficients were calculated to assess the interrelationships between the independent variables and both maximal power and endurance time for submaximal power production at the three percentages of maximal power. Multivariate regression analysis was

Table 1. Subject descriptive data ($n=18$)

	Mean ± SD	Range
Age (years)	25.4 ± 8.0	20 - 54
$\dot{V}_{O_{2max}}$ (ml·kg^{-1}·min^{-1})	46.6 ± 6.2	32.9 - 59.2
Maximal power (W)	771 ±149	527 -1125
Anthropometry		
Body mass (kg)	77.7 ± 11.6	61.3 - 110.5
% Body fat	15.8 ± 5.6	8.4 - 27.5
Fat-free mass (kg)	65.1 ± 7.8	52.5 - 82.0
Fat-free thigh volume (l)	5.31± 0.98	3.89- 7.90
Muscle-fiber analysis		
% Type II	50.0 ± 11.3	26.1 - 69.8
% Type IIA	37.7 ± 8.9	21.2 - 52.0
% Type II area	52.1 ± 12.9	22.9 - 73.5
Mean type II area (μm^2·100)	59.0 ± 11.6	22.9 - 83.4
Type II area/type I area	1.11± 0.21	0.61- 1.36
Capillary density (cap·mm^{-2})	296.1 ± 54.9	161.7 - 381.9
Wingate test		
Peak power (W)	707 ±133	510 - 961
Mean power (W)	503 ± 95	320 - 710
Isokinetic endurance test		
Highest peak power (W)	458 ±102	313 - 757
Mean peak power (W)	295 ± 51	198 - 421

also utilized to examine selected variable relationships. Statistical significance was set at the $P<0.05$ level.

Results

Subject descriptive data (means ± SD) are presented in Table 1. Maximal power ranged from 527 to 1125 W (mean 771 ± 149 W), while muscle-fiber distribution ranged from 26% to 70% type II in vastus lateralis.

Relationships of the morphological and physiological variables with maximal power production are shown in Table 2. Significant correlations ($P<0.01$) were observed between maximal power and power output values from the Wingate test ($r=0.79$–0.80) and peak powers from the isokinetic endurance test ($r=0.68$–0.70).

Table 2. Correlation coefficients and P values between maximal power and various morphological and physiological variables

Variable	r	P
Wingate test		
Peak power	0.79	0.001
Mean power	0.80	0.001
Isokinetic endurance test		
Highest peak power	0.70	0.001
Mean peak power	0.68	0.01
Body mass	0.54	0.02
%Body fat	0.09	0.71
Fat-free mass	0.57	0.02
Fat-free thigh volume	0.11	0.68
% Type II fibers	0.16	0.52
% Type IIA fibers	0.33	0.19
% Type II area	0.09	0.72
Type II area/type I area	0.16	0.54
Capillary density	−0.35	0.15
$\dot{V}_{O_{2max}}$ (ml·kg^{-1}·min^{-1})	−0.40	0.10

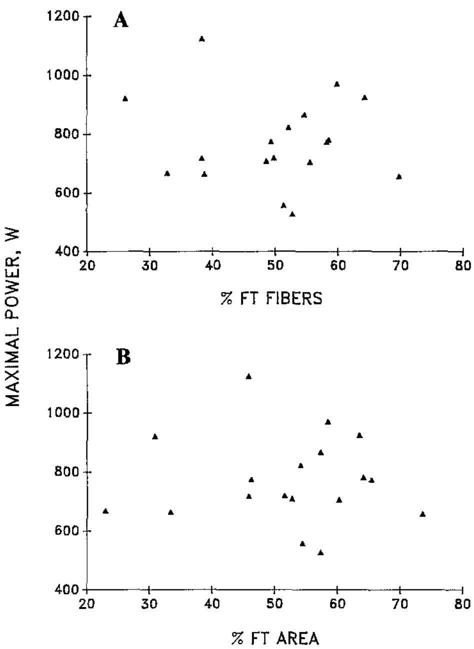

Fig. 1. Relationship between maximal power production and muscle-fiber characteristics. **A** $r=0.16$; $P<0.52$. **B** $r=0.09$; $P<0.72$

Morphological variables yielding the highest positive correlations with maximal power were body mass and FFM ($r=0.54$ and 0.57, respectively, $P<0.02$). No significant relationships were found between maximal power and FFTV, percent type II or IIA fiber composition and percent type II fiber area. Multivariate regression analysis did not significantly improve any of the bivariate relationships between maximal power and the variables presented in Table 2. All two-factor combinations of the above variables were performed and significant multivariate r's were found for body mass and percent type II fibres ($r=0.55$) and FFM and percent type II fibers ($r=0.59$). Combining FFTV and percent type II fiber composition yielded a multivariate r of only 0.15.

The individual data points for maximal power and the morphological variables are illustrated in Figs. 1 and 2. It is apparent that there was no significant relationship between either muscle-fiber composition or fiber area and maximal power production (Fig. 1). Similarly, FFTV showed no significant relatioship to maximal power (Fig. 2).

The mean endurance times (± SD) to exhaustion at 36%, 55%, and 73% of maximal power were 3.81 ± 1.53 min, 1.15 ± 0.69 min, and 0.42 ± 0.25 min, respectively. The corresponding power output values (means ± SD) were: 280 ± 54 W, 423 ± 85 W, and 560 ± 108 W. These exercise intensities were approximately 104%, 157%, and 207%, respectively, of those which elicited maximal oxygen uptake. Thus maximal oxygen uptake occurred at about 35% of maximal power output.

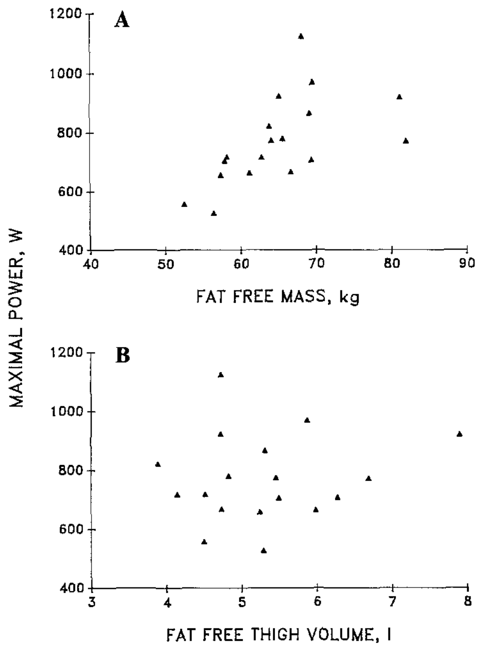

Fig. 2. Relationship between maximal power production and anthropometric measures. **A** $r=0.57$; $P<0.02$. **B** $r=0.11$; $P<0.68$

Table 3 presents correlation coefficients for endurance times at each percentage of maximal power and the morphological variables. As seen, endurance times demonstrated only significant negative relationships with body mass, FFM and maximal oxygen uptake at 55% and 73% maximal power. No significant correlations with any of the variables occurred at 36% maximal power. As in the case of maximal power, multivariate regression analysis did not significantly improve any of the bivariate relationships shown in Table 3.

Table 3. Correlation coefficients for endurance times at percentages of maximal power and morphological variables

Variable	36%	55%	73%
Body mass	−0.24	−0.47*	−0.49*
%Body fat	−0.05	−0.21	−0.22
Fat-free mass	−0.25	−0.44	−0.47*
Fat-free thigh volume	0.20	0.10	0.12
% Type II fibers	−0.19	−0.15	−0.07
% Type IIA fibers	−0.44	−0.44	−0.39
% Type II area	−0.24	−0.16	−0.06
Type II area/type I area	−0.21	−0.09	−0.01
Capillary density	0.29	0.40	0.42
$\dot{V}_{O_{2max}}$ (ml·kg^{-1}·min^{-1})	0.24	−0.51*	−0.51*

* $P<0.05$

Discussion

The maximal power developed (771 W) was strikingly similar to mean values reported by Sargeant et al. (1981) and McCartney et al. (1983a) (approximately 750 and 758 W at 60 rev·min^{-1}, respectively), who also employed constant-velocity cycle ergometers. These authors, however, obtained the highest power outputs for one revolution cycling at between 110 and 120 rev·min^{-1}. Despite such findings, a velocity of 60 rev·min^{-1} was chosen for the present study, since this is the frequency most often employed in cycle ergometer tests.

In agreement with the findings of McCartney et al. (1983a), considerable intersubject differences were observed in the ability to generate power. Several studies have suggested that these differences are related to such factors as the composition of fibers in exercising muscle and the absolute mass of the active musculature. The results of this study, however, show these factors to be poorly related to maximal power in normally active men and thus support the recent data of Froese and Houston (1985) and others (Clarkson et al. 1982b; Schantz et al. 1983) who found no significant relationship between type II fibers and peak knee-extension torque. In contrast, a positive correlation has been reported between type II fiber composition of the vastus lateralis and either peak torque during maximal isokinetic knee extension (Thorstensson et al. 1976; Komi et al. 1977; Thorstensson et al. 1977; Ryushi and Fukunaga 1986; Johansson et al. 1987) or power outputs from the Wingate test (Bar-Or et al. 1980; Froese and Houston 1987). Discrepancies in studies relating fiber type to maximal torque or power may be due to factors such as inconsistencies among studies employing the Cybex dynamometer which fail to correct peak torque for impact artifact or gravity (Winter et al. 1981), limitations in fiber-type assessment from single biopsy samples (Elder et al. 1982), and selection of the subject population to be measured. With regard to the latter, several studies (Komi et al. 1977; Thorstensson et al. 1977; Johansson et al. 1987) have utilized various athletic groups, including power- and endurance-trained athletes, where the former generally have moderate to high percentages of type II fibers and the latter high percentages of type I fibers (Saltin et al. 1977). Thus a wide range of values is obtained from subjects who comprise the extremes in athletic performance. While a fairly heterogeneous group was studied herein, particularly with respect to fiber type and body size, the subjects did not represent the extremes in athletic endeavors which characterized the other studies.

In addition to muscle-fiber composition, a number of studies have found such indicators of body size as body mass (Clarkson et al. 1982b; Nutter and Thorland 1987), FFM (Nutter and Thorland 1987) and leg mass measured anthropometrically (Nutter and Thorland 1987) or by computed tomography (McCartney et al. 1983a; Johansson et al. 1987) to be related to maximal torque development. With the exception of the study by McCartney et al. (1983a), all used the Cybex isokinetic dynamometer. The present results agree with the above regarding body mass and FFM but failed to show a significant relationship between FFTV and maximal power production, as previously shown with peak torque (McCartney et al. 1983a; Johansson et al. 1987). Reasons for this inconsistency are not clear but may be related to involvement of different muscle groups in the exercise, the type of muscular contraction performed, or the method used to measure thigh volume.

Despite the significant correlations of body mass and FFM with peak torque and power, these variables account for less than 35% of the shared variance, suggesting that anthropometric measures are relatively poor predictors of maximal torque or power. However, results from this study agree with others (Clarkson et al. 1982a, b) that maximal power or torque are more dependent on characteristics of body size than on fiber-type composition.

The second major purpose of this investigation was to identify factors important in submaximal exercise endurance (relative to maximal power). To our knowledge, no data are available on endurance times to exhaustion at levels of power production considerably higher than those which elicit maximal oxygen uptake. As in the case with maximal power, no muscle-fiber characteristic (percent fiber type, percent fiber area, capillary density) showed any significant relationship to endurance time at any percentage of maximal power. These results agree with those of Litchfield et al. (1984), who reported no significant correlations between muscle-fiber composition and isometric endurance sustained to exhaustion at forces corresponding to 20%, 50%, and 80% of maximal voluntary contraction in untrained men. These findings suggest, therefore, that the assessment of such characteristics in untrained men is not particularly useful for detecting those with high anaerobic potential.

The significant correlations of body mass and FFM with endurance times to exhaustion as they did with maximal power also suggest that the maintenance of high percentages of maximal power is more dependent on body size than muscle-fiber composition. The inverse relationship further shows that larger subjects are less able to maintain power and thus fatigue faster, which agrees with the results of Clarkson et al. (1982a), who found a negative relationship between body weight and fatigue.

In summary, muscle-fiber characteristics and indicators of body size are poorly related to the production of maximal power and the ability to maintain power at high percentages of maximum in normally active men. Many complex factors, including biomechanical considerations, neuromuscular elements controlling recruitment and firing of motor units, and motivation, in addition to the above, undoubtedly contribute to the development of power. It is concluded, therefore, that individuals use either different combinations of the factors measured herein or employ other performance strategies to generate high levels of power.

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References

Anderson P (1975) Capillary density in skeletal muscle of man. Acta Physiol Scand 95:203–205

Bar-Or O (1981) Le test anaerobic de Wingate. Symbioses 13:157–172

Bar-Or O, Dotan R, Inbar O, Rothstein A, Karlsson J, Tesch P (1980) Anaerobic capacity and muscle fiber type distribution in man. Int J Sports Med 1:82–85

Bergstrom J (1962) Muscle electrolytes in man. Scand J Clin Lab Invest [Suppl] 68:1–110

Brooke MH, Kaiser KK (1970) Three "myosin ATPase" systems: the nature of pH lability and sulfhydryl dependence. J Histochem Cytochem 18:670–672

Clarkson PM, Johnson J, Dextradeur D, Leszczynski W, Wai J, Melchionda A (1982a) The relationships among isokinetic endurance, initial strength level, and fiber type. Res Q Exerc Sport 53:15–19

Clarkson PM, Kroll W, Melchionda AM (1982b) Isokinetic strength, endurance and fiber type composition in elite American paddlers. Eur J Appl Physiol 48:67–76

Elder GCB, Bradbury K, Roberts R (1982) Variability of fiber type distributions within human muscles. J Appl Physiol 53:1473–1480

Evans WJ, Phinney SD, Young VR (1982) Suction applied to a muscle biopsy maximizes sample size. Med Sci Sports Exerc 14:101–102

Fitzgerald PI, Vogel JA, Miletti J, Foster JM (1987) An improved portable hydrostatic weighing system for body composition. US Army Research Institute of Environmental Medicine Tech Rep T4-88

Froese EA, Houston ME (1985) Torque-velocity characteristics and muscle fiber type in human vastus lateralis. J Appl Physiol 59:309–314

Froese EA, Houston ME (1987) Performance during the Wingate anaerobic test and muscle morphology in males and females. Int J Sports Med 8:35–39

Harman E, Knuttgen HG, Frykman P (1987) Automated data collection and processing for a cycle ergometer. J Appl Physiol 62:831–836

Johansson C, Lorentzon R, Sjostrom M, Fagerlund MK, Fugl-Meyer AR (1987) Sprinters and marathon runners. Does isokinetic knee extensor performance reflect muscle size and structure? Acta Physiol Scand 130:663–669

Jones PRM, Pearson J (1969) Anthropometric determination of leg fat and muscle plus bone volumes in young male and female adults. J Physiol 204:63–66p

Knuttgen HG, Patton JF, Vogel JA (1982) An ergometer for concentric and eccentric muscular exercise. J Appl Physiol Respir Environ Exercise Physiol 53:784–788

Komi PV, Rusko H, Vos J, Vihko V (1977) Anaerobic performance capacity in athletes. Acta Physiol Scand 100:107–114

Litchfield PE, Maughan RJ, Nimmo MA (1984) Isometric endurance capacity and muscle fibre composition in man. J Physiol (Lond) 354:73

Margaria R, Aghemo P, Rovelli E (1966) Measurement of muscular power (anaerobic) in man. J Appl Physiol 21:1661–1669

McCartney N, Heigenhauser GJF, Jones NL (1983a) Power output and fatigue of human muscle in maximal cycling exercise. J Appl Physiol Respir Environ Exercise Physiol 55:218–224

McCartney N, Heigenhauser GJF, Sargeant AJ, Jones NL (1983b) A constant-velocity cycle ergometer for the study of dynamic muscle function. J Appl Physiol Respir Environ Exercise Physiol 55:212–217

Novikoff AB, Shin WY, Drucker J (1961) Mitochondrial localization of oxidative enzymes: staining results with two tetrazolium salts. J Biophys Biochem Cytol 9:47–61

Nutter J, Thorland WJG (1987) Body composition and anthropometric correlates of isokinetic leg extension strength of young adult males. Res Q Exerc Sport 58:47–51

Ryushi T, Fukunaga T (1986) Influence of subtypes of fast-twitch fibers on isokinetic strength in untrained men. Int J Sports Med 7:250–253

Saltin B, Henriksson J, Nygaard E, Anderson P, Jansson E (1977) Fiber types and metabolic potentials of skeletal muscles in sedentary men and endurance runners. Ann NY Acad Sci 301:3–29

Sargeant AJ, Hoinville E, Young A (1981) Maximum leg force and power output during short term dynamic exercise. J Appl Physiol Respir Environ Exercise Physiol 51:1175–118

Schantz P, Randall-Fox E, Hutchison W, Tyden A, Astrand P-O (1983) Muscle fibre type distribution, muscle cross-sectional area and maximal voluntary strength in humans. Acta Physiol Scand 117:219–226

Staron RS, Hikida RS, Hagerman FC (1983) Myofibrillar ATPase activity in human muscle fast-twitch subtypes. Histochemistry 78:405–408

Tesch P (1980) Muscle fatigue in man with special reference to lactate accumulation during short term intense exercise. Acta Physiol Scand [Suppl] 480:1–40

Thorstensson A, Grimby G, Karlsson J (1976) Force-velocity and fiber composition in human knee extensor muscles. J Appl Physiol 40:12–16

Thorstensson A, Larsson L, Tesch P, Karlsson J (1977) Muscle strength and fiber composition in athletes and sedentary men. Med Sci Sports 9:26–30

Watson AWS, O'Donovan DJ (1977) Factors relating to the strength of male adolescents. J Appl Physiol Respir Environ Exercise Physiol 43:834–838

Wilmore JH, Vodak PA, Parr RB, Girondola RN, Betting JE (1980) Further simplification of a method for determination of residual lung volume. Med Sci Sports Exerc 12:216–218

Winter DA, Wells RP, Orr GW (1981) Errors in the use of isokinetic dynamometers. Eur J Appl Physiol 46:397–408