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Gender differences in strength and muscle fiber characteristics

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Summary. Strength and muscle characteristics were examined in biceps brachii and vastus lateralis of eight men and eight women. Measurements included motor unit number, size and activation and voluntary strength of the elbow flexors and knee extensors. Fiber areas and type were determined from needle biopsies and muscle areas by computerized tomographical scanning. The women were approximately 52% and 66% as strong as the men in the upper and lower body respectively. The men were also stronger relative to lean body mass. A significant correlation was found between strength and muscle cross-sectional area (CSA; $P \leq 0.05$). The women had 45, 41, 30 and 25% smaller muscle CSAs for the biceps brachii, total elbow flexors, vastus lateralis and total knee extensors respectively. The men had significantly larger type I fiber areas (4597 vs 3483 μm^2) and mean fiber areas (6632 vs 3963 μm^2) than the women in biceps brachii and significantly larger type II fiber areas (7700 vs 4040 μm^2) and mean fiber areas (7070 vs 4290 μm^2) in vastus lateralis. No significant gender difference was found in the strength to CSA ratio for elbow flexion or knee extension, in biceps fiber number (180620 in men vs 156872 in women), muscle area to fiber area ratio in the vastus lateralis 451468 vs 465007) or any motor unit characteristics. Data suggest that the greater strength of the men was due primarily to larger fibers. The greater gender difference in upper body strength can probably be attributed to the fact that women tend to have a lower proportion of their lean tissue distributed in the upper body. It is difficult to determine the extent to which the larger fibers in men represent a true biological difference rather that a difference in physical activity, but these data suggest that it is largely an innate gender difference.

Key words: Fiber area - Fiber number - Muscle cross-sectional area

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Introduction

Gender differences in absolute muscle strength are well documented (Laubach 1976). Studies indicate that men generally have larger and stronger muscles than women and that differences tend to be more pronounced in muscles of the upper limbs (Levine et al. 1984; Heyward et al. 1986), although considerable overlap has also been shown to exist between the sexes (Maughan et al. 1986). Factors which affect maximum voluntary strength include cross-sectional area (CSA) of the muscle or muscle groups, specific tension (force per unit CSA, which may be affected by the fiber type distribution and the amount of non-contractile tissue present in the muscle), ability of the subject to fully activate the motor units and possible anatomical differences in mechanical advantage of muscles acting across a joint.

Muscle CSA is determined by both the size and number of muscle fibers. While it is generally accepted that untrained women have smaller fiber areas than untrained men in muscles of both upper and lower limbs (MacDougall et al. 1983; Henriksson-Larsen 1985; Sale et al. 1987), as do female athletes and bodybuilders compared to their male counterparts (Costill et al. 1976; Alway et al. 1989), studies in which fiber numbers have been estimated are somewhat contradictory. Several authors have reported significantly fewer muscle fibers in female biceps brachii (Sale et al. 1987) and tibialis anterior (Henriksson-Larsen 1985) compared to males, but such findings have not been supported by investigations of triceps brachii or vastus lateralis (Schantz et al. 1981, 1983) or biceps brachii of female bodybuilders (Alway et al. 1989). Such discrepancies may be related to sampling bias in subject selection and/or problems in precision in estimation of fibers numbers.

Findings of greater specific tensions in muscles of men (Young et al. 1985; Ryushi et al. 1988) suggest a greater ability to generate force by male muscle tissue. If such is the case, however, it is apparently not due to gender differences in the ability to activate motor units (Belanger and McComas 1981; Young et al. 1985) or to differences in fiber type distribution (Schantz et al. 1983; Sale et al.

1987). Moreover, since large inter-individual differences in specific tensions are also found within each gender, the factors responsible for such variability may not be gender specific (Maughan et al. 1983; Maughan and Nimmo 1984).

It is well known that chronic forceful muscular contractions will result in an increase in muscle contractile protein and fiber area (MacDougall et al. 1980). The smaller muscle fibers in women may thus be due to an innate biological limitation or to differences in behavioral (physical activity) patterns or to a combination of both. If a significant gender difference in muscle fiber numbers exists, it probably represents a true biological difference, since fiber number is considered to be established at birth (Van DeGraaff 1984). The purpose of the present study was to examine a variety of muscle parameters in both the upper and lower limbs in a sample of men and women in an attempt to determine whether or not gender differences in muscular strength are more closely linked to differences in physical activity patterns or to innate biological limitations. Subjects were selected to represent a wide range of muscle sizes and physical activity patterns and, in addition to strength, measurements included muscle size, fiber area, fiber number and motor unit number, size and activation.

Methods

Subjects. Eight men and eight women served as subjects. Their physical characteristics are presented in Table 1. All subjects were aware of the purpose and risks associated with the study and gave informed written consent, in accordance with the requirements of the University's Human Ethics Committee. An attempt was made to match the two groups for total body mass and for their degree of participation in fitness activities and competitive sports over the past 3 years as determined by questionnaire. Three subjects in each group were sedentary and had no previous history of sport participation. The remaining five subjects in each group represented a range in physical activity participation with two subjects in each group also having a history of resistance training.

Measurements. Body density was determined by hydrostatic weighing, with residual lung volumes measured by helium dilution. Percent body fat was calculated from body density (Brozek et al. 1963) and lean body mass was calculated by subtracting fat mass from total body mass.

Limb lengths for each subject were recorded so that the effects of differences in lever-arm length could be considered when interpreting strength measurements. Radius length was measured from the head of the radius at the elbow to the styloid process at the wrist, humerus length from the laterosuperior margin of the head of the radius to the lateral border of the acromion process and femur length from the greater trochanter to the lateral condyle of the tibia.

CSA of the right biceps brachii and the right vastus lateralis was determined from computerized tomography (CT) scans (Ohio Nuclear, model 20/20). The biceps was scanned with the elbow extended, at a level corresponding to 75% of the distance from the tip of the acromion process of the scapula to the medial epicondyle of the humerus. The vastus lateralis was scanned at the midpoint between the greater trochanter and the lateral condyle of the tibia. Muscle areas were determined by manual planimetry of projected slides of the CT scan negative using a custom-made computerized digitizer and a Sigmascan software package (Jandel Scientific, California). Area measurements were made for biceps, total elbow flexors, vastus lateralis and the total knee extensors (quadriceps).

Tissue samples were obtained from the biceps brachii and vastus lateralis by needle biopsy. The biopsy was mounted cross-sectionally in embedding medium using a stereo microscope and then

Table 1. Subjects' physical characteristics

Subject no.	Age (years)	Height (m)	Mass (kg)	Body fat (%)	LBM (kg)	Limb lengths Femur (m)	Total arm (m)
Women							
1	21	1.58	52.3	25.7	38.9	0.36	0.51
2	23	1.66	83.3	34.3	54.7	0.38	0.55
3	31	1.69	70.6	20.4	56.1	0.38	0.52
4	24	1.76	71.5	21.9	55.8	0.42	0.55
5	26	1.61	52.7	10.1	47.4	0.36	0.52
6	22	1.62	55.9	22.4	43.4	0.40	0.49
7	22	1.69	61.2	19.7	49.1	0.44	0.56
8	31	1.67	67.9	25.0	50.9	0.42	0.53
Mean	25.0	1.66	64.4	22.4	49.5	0.40	0.53
SE	1.4	0.02	3.8	2.4	2.2	0.01	0.009
Men							
1	23	1.78	78.9	18.8	64.1	0.44	0.58
2	19	1.70	65.1	6.8	60.7	0.41	0.54
3	21	1.75	77.4	14.2	66.4	0.41	0.58
4	26	1.71	82.0	23.5	62.7	0.41	0.55
5	27	1.87	69.2	12.7	60.4	0.39	0.59
6	29	1.73	60.1	14.3	51.5	0.36	0.56
7	21	1.79	78.0	7.8	71.9	0.36	0.58
8	20	1.84	83.6	8.9	75.6	0.41	0.58
Mean	23.3	1.77*	74.3	13.4*	64.2*	0.40	0.57*
SE	1.3	0.02	3.0	2.0	2.6	0.009	0.007

LBM, lean body mass; * $P \leq 0.01$ for differences between male and female groups

frozen in isopentane cooled in liquid nitrogen. Tissue was sectioned on a cryostat and serial sections were stained for myofibrillar ATPase (Padykula and Herman 1955) following preincubation at pH 10.0 and for collagen and other non-contractile tissue using a modified Gomori trichrome stain (Gomori 1950). Sections were photographed under the light microscope and measurements were made on projected slides. CSA for type I and type II fibers was measured by a custom-made computerized digitizer for an average of 140 fibers of each type per biopsy. Percent fiber type distribution was estimated by counting an average of 278 fibers/biopsy. The proportion of collagen and other non-contractile tissue, expressed as a percentage of the muscle CSA, was calculated in the trichrome-stained sections by means of a 168 point, point-counting technique (Weibel 1972). Mean fiber area was calculated to correct for fiber type distribution as (% type I)(mean type I area) + (% type II)(mean type II area)/100.

Since most fibers in the biceps brachii are thought to extend from origin to insertion (Davies et al. 1988), fiber number was estimated by dividing the mean fiber area into the biceps CSA (corrected for connective tissue). The theoretical basis for this technique has been discussed previously (MacDougall et al. 1984). The pennate structure of vastus lateralis prevents actual fiber number from being estimated in this manner and thus, for this muscle, data were expressed as a muscle area to fiber area ratio.

Maximum isotonic strength (1RM) was determined for elbow flexion of the dominant arm and knee extension of the right leg on a custom-made elbow flexion apparatus and a knee extension apparatus (Global Gym). Gradations for loading each apparatus were to the nearest 0.25 kg. Three-minute recovery periods were given between lift attempts and in no case were more than five attempts necessary to determine 1RM.

For measurement of the maximal voluntary isometric contraction (MVC) of the dominant arm elbow flexors, subjects sat in an adjustable chair with their arm in a custom-made dynamometer at 1.92 rad elbow flexion, as has previously been described in detail (Blimkie et al. 1989). For measurement of the MVC of the right knee extensors, subjects sat on an adjustable bench with their right leg in a custom-made dynamometer. The backrest was adjusted so that both the subject's hip and knee were flexed at an angle of 1.57 rad. Subjects were secured to the bench by two large straps, one crossing the hips and the second crossing the thigh. The lower leg was strapped to the support plate of the dynamometer.

For measurements of both arm and leg torque, force was transmitted via straps over the distal and proximal ends of the secured limb to a strain gauge located at the rotational center of the dynamometer. The signal was simultaneously read on-line by computer at a sampling rate of 500 Hz. Subjects were given three trials for both elbow flexion and knee extension. The best trial for each condition was selected for statistical analysis.

Resting twitch torque for elbow flexion and knee extension was determined at the same joint angle and with the same dynamometer as for voluntary isometric strength by percutaneous stimulation of the biceps muscle and the femoral nerve respectively. Resting twitch torque was determined prior to the MVC trials to avoid the effect of potentiation.

Motor unit activation of the elbow flexors and the knee extensors were determining using the interpolated twitch technique (Merton 1954). For this method, a supramaximal stimulus is delivered during MVC and the magnitude of the interpolated twitch, compared to that at rest, is used to calculate motor unit activation (MUA). Three measurements were taken, with the highest value for MUA being selected.

Estimates of motor unit number were made for biceps brachii and vastus medialis using an automated estimation procedure which is routinely used in diagnostic EMG at the McMaster/Chedoke Hospital and has been described previously (Galea et al. 1991). The anatomy of the vastus medialis is such that it yields more reliable measurements with this technique than does the vastus lateralis, and thus it was selected for the present study. The coefficient of variation for estimates "within sessions" ranges from 14 to 26% depending on the muscle examined, with the overall coefficient of variation being 22.0%. For estimates "between sessions", the overall coefficient of variation is 23.8% (Galea et al. 1991).

The same devices used to determine 1RM were used to measure muscular endurance of the elbow flexors and knee extensors. Subjects were required to perform the maximum possible number of repetitions at a cadence of 10 repetitions min^{-1}. A metronome was used to assist the subjects in maintaining the cadence. The test was stopped when the subject could no longer maintain the cadence. Muscular endurance of the elbow flexors was measured at a load corresponding to 60% 1RM and muscular endurance of the knee extensors at loads corresponding to 40 and 60% 1RM.

Gender comparisons were made using a single-factor, between-subjects analysis of variance. In addition, for many of the parameters, male and female data were pooled and subjected to a correlational analysis. The significance level was set at $P=0.05$.

Results

Anthropometry

The men were significantly taller than the women and had greater lean body mass ($P<0.01$) but did not differ significantly in total body mass (Table 1). They also had significantly greater total arm (humerus + radius) lengths than the women ($P<0.01$), but no significant difference in femur length was found.

Physical activity

Subjects were matched so that their frequency of participation in sports or other physical activity did not differ between the two groups. In retrospect, however, it was probable that the competitive level for sport participation was slightly higher for the physically active female subjects than that for their male counterparts.

Voluntary strength

Gender differences in voluntary strength are illustrated in Fig. 1. Men were significantly stronger in both upper and lower limb measurements ($P\leq 0.01$). Knee extension in the women was 62% and 69% that of the male 1RM and MVC respectively. Elbow extension strength of the women was 52% that of the men for both 1RM and MVC.

A significant positive correlation ($P=0.01$) was found between lean body mass and both measures of arm and leg strength (Fig. 2). When expressed relative to lean body mass, the men also had significantly greater arm and leg strength (Fig. 3D), with the women being 70% and 80% as strong as the men in the arms and legs respectively.

Evoked twitch torque

A significant gender difference in twitch torque was found between the elbow flexors of the men [mean (SE):

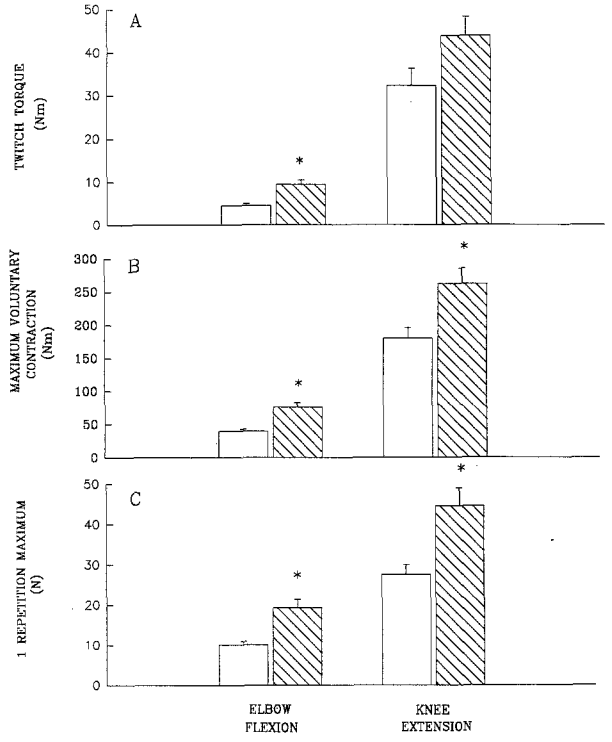

Fig. 1A–C. Strength measurements of the elbow flexors and knee extensors. **A** Twitch torque. **B** Maximum voluntary contraction. **C** 1 repetition maximum. * $P<0.05$; □, women; ▨, men

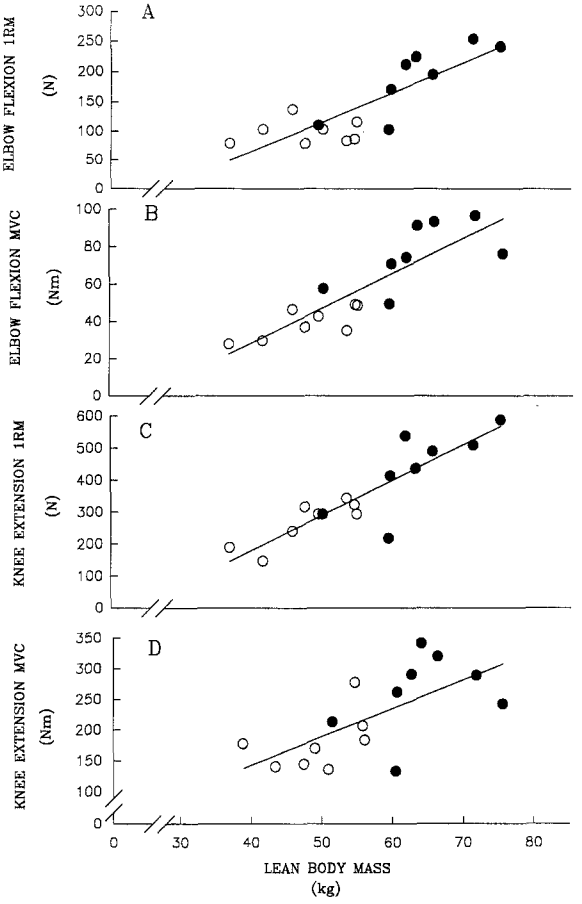

Fig. 2A–D. Correlation of lean body mass and strength. **A** Elbow flexion, 1 repetition maximum (*1RM*; $r=0.83$). **B** Elbow flexion maximum voluntary contraction (*MVC*; $r=0.86$). **C** Knee extension, 1RM ($r=0.88$). **D** Knee extension MVC ($r=0.67$). All correlations are significant ($P\leq0.01$). ○, Women; ●, men

9.5 (1.0) Nm] and the women [4.6 (0.5) Nm; $P\leq0.01$] but not for the knee extensors (Fig. 1A).

Muscular endurance

Females performed significantly more elbow flexion repetitions [37 (6)] than the males [21 (5)] at a load corresponding to 60% of the 1RM ($P\leq0.01$). No significant gender differences were found in the number of knee extension repetitions that could be performed at loads corresponding to 40 and 60% of the 1RM.

Muscle CSA

A significant positive correlation was found between knee extensor 1RM and CSA ($r=0.84$; $P\leq0.01$), as was found for elbow flexor 1RM and CSA ($r=0.95$; $P\leq0.01$) (Fig. 4A, B). Strength, measured as torque, is a function of muscular force and muscle moment arm length. In the present study, the moment arm length was considered proportional to limb length. Correction of torque values for arm or leg length did not alter the above relationship.

Gender differences in muscle CSA are illustrated in Fig. 5. CSAs of the female biceps brachii, elbow flexors, vastus lateralis and knee extensors respectively were 55%, 59%, 70% and 75% that of the men ($P\leq0.01$). The women also had significantly higher proportions of non-contractile tissue in the vastus lateralis (18.6% vs 14.8%; $P\leq0.05$) than the men, but this was not found in biceps brachii. Differences in muscle CSA were significant whether or not muscle area was corrected for non-contractile tissue.

Muscle fiber characteristics

Fiber areas of the biceps are illustrated in Fig. 6. In women type II fibers were about 19% ($P<0.05$) larger than the type I fibers [4306 (556) vs 3483 (339) μm^2]. Male type II fibers were approximately 44% larger than type I fibers [8207 (1832) vs 4597 (396) μm^2], but because of their greater range in size, this difference did not achieve statistical significance. The men had significantly larger type I fibers than the women ($P\leq0.05$), and although type II fiber area was almost twice as large as that for the women, this difference again was not statistically significant. Mean fiber area in men [6632 (1160) μm^2] was significantly larger than that in the women [3963 (450) μm^2; $P\leq0.05$; Fig. 7B].

No significant difference was found in fiber type distribution in male [57.0% (1.7) type II] and female biceps [56.5% (3.3) type II], nor did the percentage of total

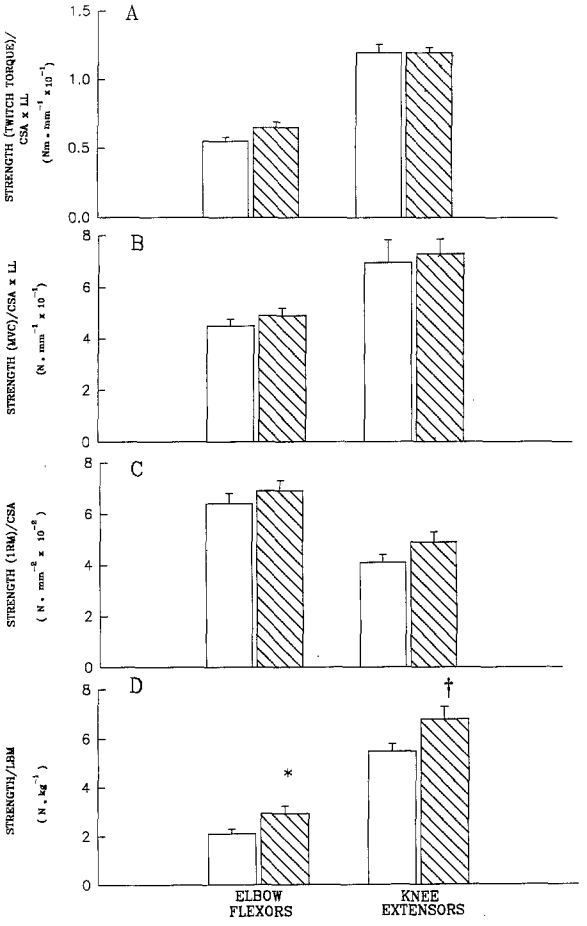

Fig. 3A–C. Strength to cross-sectional area (*CSA*) ratios with strength expressed as **A** twitch torque, **B** maximum voluntary contraction (*MVC*), **C** 1RM. **D** strength to lean body mass (*LBM*) ratio *,† $P<0.05$. □, Women; ▨, men

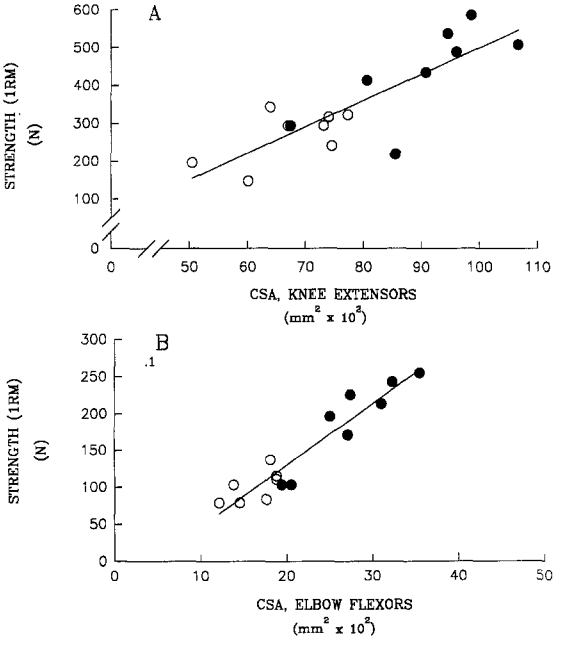

Fig. 4A, B. Correlation of strength (*1RM*) and muscle cross-sectional area (*CSA*). **A** Knee extensors ($r=0.84$). **B** Elbow flexors ($r=0.95$). Both correlations are significant ($P\leq 0.01$). ○, Women; ●, men

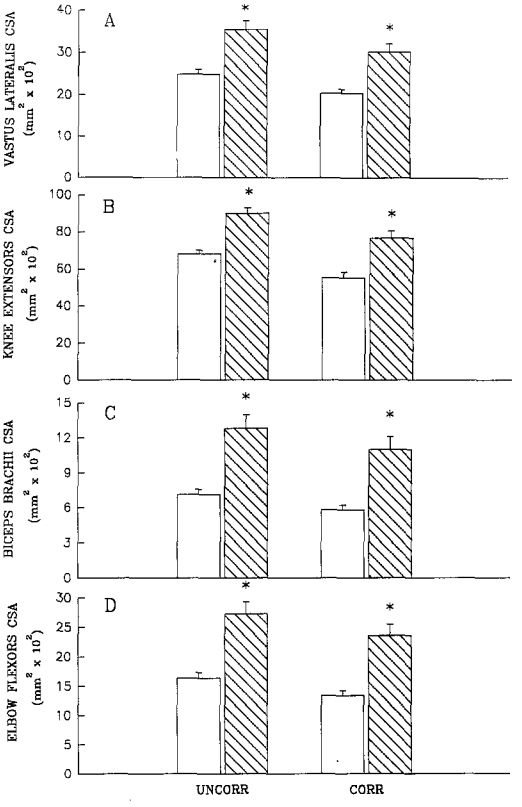

Fig. 5A–D. Muscle cross-sectional area (*CSA*), uncorrected (*UNCORR*) and corrected (*CORR*) for noncorrective tissue. **A** Vastus lateralis. **B** Total knee extensors. **C** Biceps brachii. **D** Elbow flexors (biceps + brachialis). * $P<0.05$. □, Women; ▨, men

muscle CSA occupied by type II fibers differ significantly between the sexes (Fig. 6A, B).

Average fiber number in biceps for the male subjects was 180620 (24294) fibers and 156872 (17595) fibers for the female subjects (Fig. 7A), but this difference was not statistically significant. Although a significant positive correlation was found between biceps mean fiber area and biceps CSA ($r=0.56$; $P\leq 0.05$; Fig. 8A), the correlation between biceps fiber number and biceps CSA was not significant (Fig. 8B).

Fiber areas of the vastus lateralis are illustrated in Fig. 6. In the men, type II fibers were about 20% ($P<0.05$) larger than the type I fibers [7700 (799) vs 6142 (747) μm^2]. The 11% difference between type II and type I area in the women [4531 (806) vs 4040 (618) μm^2] was not significant. Men had significantly larger type II fibers than the women ($P\leq 0.01$) but did not differ as to type I fiber area. Mean fiber area in the men [7070 (699) μm^2] was significantly larger (Fig. 9B) than that in the women [4290 (655) μm^2; $P\leq 0.05$].

Men had a significantly ($P<0.01$) higher proportion of type II fibers in vastus lateralis (Fig. 6A) compared to women [61.9 (2.2) vs 50.2 (3.1)%]. As a result, the percentage of total muscle CSA occupied by type II fibers (Fig. 6B) was also significantly greater in the men [67.4 (2.6)] than in the women [47.4 (4.4)%; $P\leq 0.01$].

Muscle area to fiber area ratio in vastus lateralis was the same in men [451468 (41528)] as in women [465007

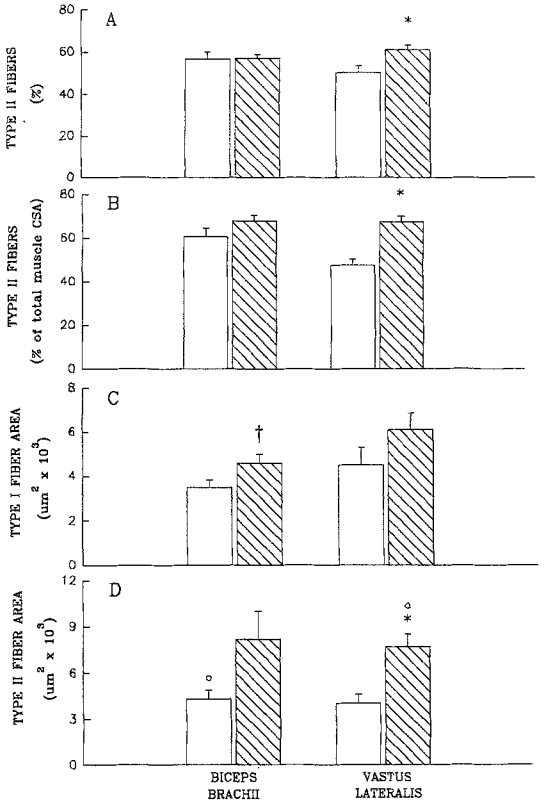

Fig. 6A–D. Fiber characteristics of the biceps brachii and vastus lateralis. **A** Percent type II fibers. **B** Percent of total muscle cross-sectional area (*CSA*) occupied by type II fibers. **C** Type I fiber area. **D** Type II fiber area. * $P<0.05$. □, Women; ▨, men

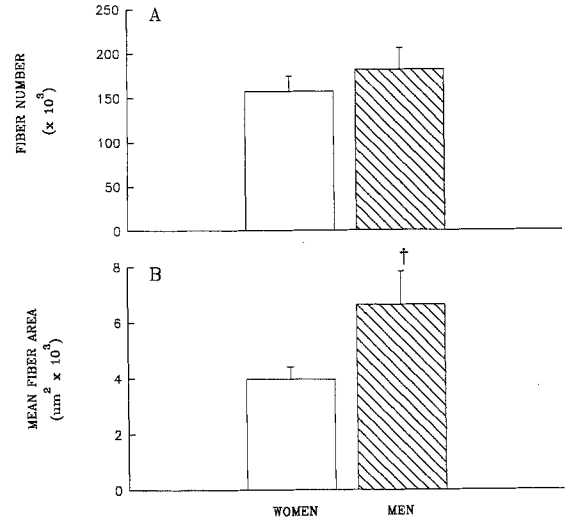

Fig. 7. A Fiber number in the biceps brachii. **B** Mean fiber area in biceps brachii. † $P<0.05$. □, Women; ▨, men

(41757); Fig. 9A]. A significant positive correlation was found between mean fiber area and vastus lateralis CSA ($r=0.69$; $P\leq 0.01$; Fig. 10), but the correlation between the muscle area to fiber area ratio and vastus lateralis CSA was not significant.

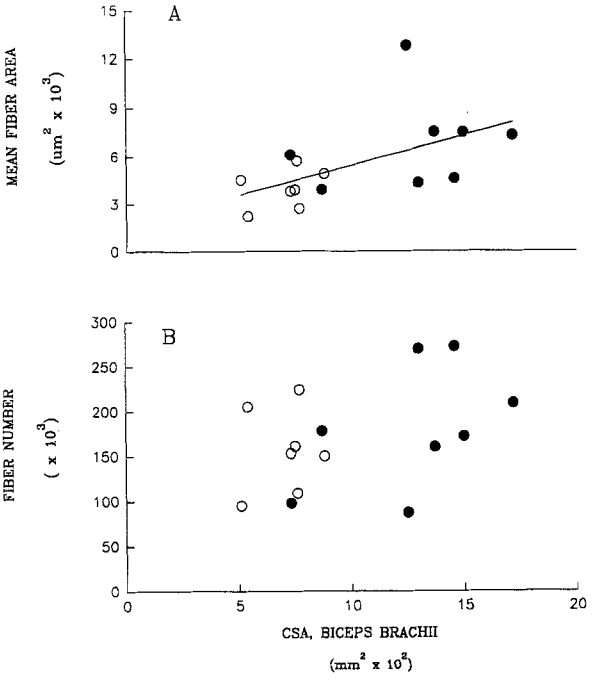

Fig. 8. A Correlation of mean fiber area and cross-sectional area (*CSA*) of the biceps brachii. **B** Correlation of fiber number and CSA of the biceps brachii. Correlation is significant in **A** ($r=0.56$; $P<0.05$) but not in **B.** ○, Women; ●, men

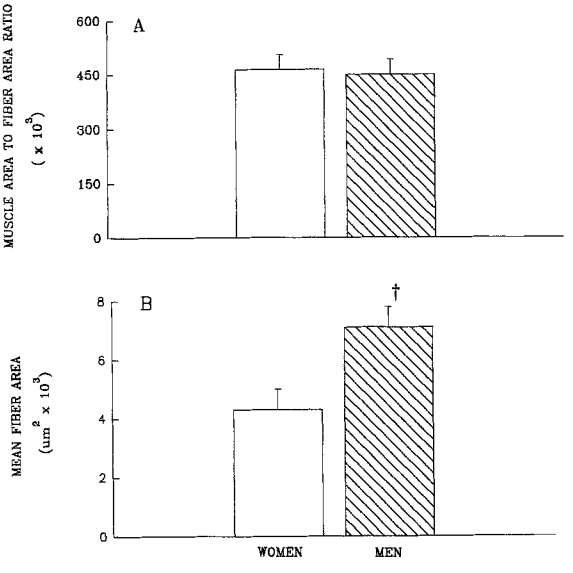

Fig. 9. A Muscle area to fiber area ratio in the vastus lateralis. **B** Mean fiber area in the vastus lateralis. † $P<0.05$

Specific tension

No significant gender difference was found to exist in the strength to muscle CSA ratios for either the elbow flexors or the knee extensors, whether strength was expressed as 1RM (N), MVC (Nm) or twitch torque (Nm) (Fig. 3). Percent type II fiber area of the biceps brachii failed to correlate with the strength/CSA ratios for elbow flexion. When strength was expressed as a 1RM, a significant positive correlation ($r=0.75$; $P\leq 0.01$) was

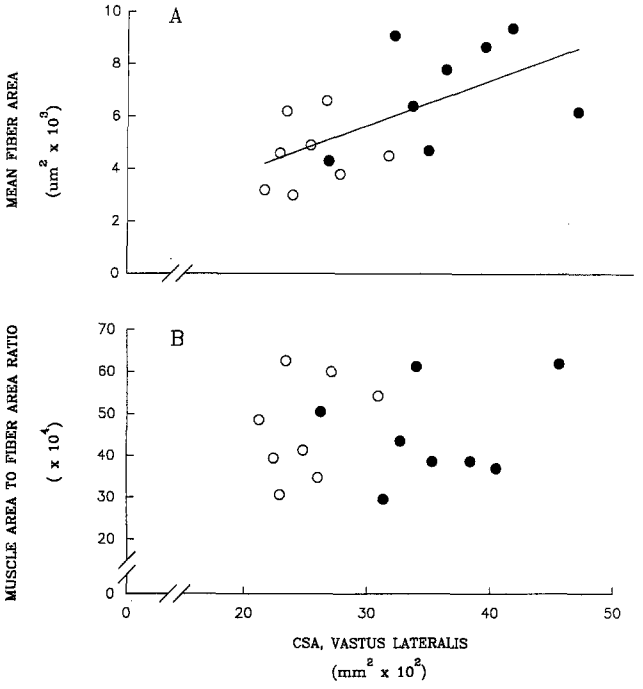

Fig. 10. **A** Correlation of mean fiber area and cross-sectional area (*CSA*) of the vastus lateralis. **B** Correlation of muscle area to fiber area ratio and CSA of the vastus lateralis. Correlation is significant in **A** ($r=0.69$; $P \leq 0.05$) but not in **B**. ○, Women; ●, men

found between percent type II fiber area of the vastus lateralis and the strength/CSA for knee extension. This correlation did not exist when knee extension strength was expressed as an MVC.

Motor unit characteristics

The estimated number of motor units in male biceps [126 (21.0)] and vastus medialis [282 (53.5)] did not differ significantly from that in female biceps [110 (9.1)] and vastus medialis [229 (87.7)]. In addition, men and women did not differ in the number of fibers per motor unit (motor unit size) in the biceps brachii. MUA was also similar for men [98.0 (1.3)% in biceps and 96.8 (2.3)% in vastus medialis] and women [99.0 (1.0)% in biceps and 95.7 (2.2)% in vastus medialis].

Discussion

Our subjects were matched for age, body mass and physical activity backgrounds, but exactly how representative they are of the general male and female populations is not known. We are thus aware that our conclusions apply only to the sample which was investigated.

Our data confirm earlier reports of significant gender differences in absolute strength in muscles of both the upper and lower limbs (Laubach 1976; Levine et al. 1984; Heyward et al. 1986). The high correlations between muscle CSA and muscle strength confirms earlier reports (Maughan et al. 1983; Maughan and Nimmo 1984; Ryushi et al. 1988) and suggests that the greater absolute strength of men is primarily the result of their larger muscles. Moreover, when strength was expressed relative to lean body mass, strength for the men was also significantly greater in both limbs, but the difference was more pronounced in the arms. This differs somewhat from previous studies which have found no gender difference in leg strength relative to lean body mass (Wilmore 1974; Levine et al. 1984) and suggests the possibility of quanlitative differences in male and female muscle tissue. This is not supported, however, by our finding, and that of previous studies (Komi and Karlsson 1978; Maughan et al. 1983; Sale et al. 1987), of similar strength to CSA ratios for both sexes (Fig. 3A–C).

The greater gender difference in upper body strength relative to lean body mass may be the result of differences in lean body mass distribution between the sexes. Although it has traditionally been believed that women have a smaller proportion of their lean body tissue distributed in the upper body, a previous study by Warren et al. (1990) found the arm to leg fat-free volume ratio to be similar in men and women. In contrast, Heyward et al. (1986) found no gender difference in upper or lower body strength when the relative distribution of lean body mass was controlled for. This suggests that differences in muscle distribution contribute to the greater gender difference in upper body strength expressed per kilogram lean body mass. In the present study, the ratio of elbow flexor CSA to knee extensor CSA was 25% for women and 30% for men, indicating that, in females, a smaller proportion of their lean tissue is distributed in the upper body.

Our data indicate that the proportion of intramuscular non-contractile tissue was approximately 3.5% greater in biceps brachii and about 3.8% greater in vastus lateralis in the women, but this difference was statistically significant only for the vastus lateralis. This is consistent with previous findings (Prince et al. 1977; Sale et al. 1987) and may reflect larger amounts of intramuscular fat or connective tissue in female muscle. Since such tissues do not contribute to force production, such a gender difference could theoretically be expected to affect estimates of specific tension. Our finding of no gender difference in this parameter, however, indicated that such differences have only a minor effect.

In contrast to the finding of the present study (Fig. 6), previous studies of female biceps have found the type I fibers to be larger than (Brooke and Engel 1969), or of similar area to, the type II fibers (Sale et al. 1987; Alway et al. 1989). This may be due, in part, to the fact that many of the female subjects in the present study had previous experience in sports such as softball, ice hockey and tennis and some prior exposure to resistance training, which is known to result in a relatively greater hypertrophy of type II fibers (MacDougall et al. 1980). The men had significantly larger type I muscle fibers in the biceps than the women (Fig. 6C), but despite an almost twofold difference in type II fiber size, this difference did not achieve statistical significance (Fig. 6D). In the present study, it is difficult to determine the extent to which the larger muscle fibers of the males can be at-

tributed to true biological differences in circulating androgenic/anabolic factors or to differences in previous physical activity patterns. Although an attempt was made to select subjects of both sexes representing a wide range in physical activity involvement, on average the women were probably slightly more active than the men. In thus appears that the larger fibers of the men may represent a true innate difference.

Consistent with previous reports, in the men, type II fibers were larger than type I fibers in vastus lateralis (Brooke and Engel 1969; Schantz et al. 1983; Ryushi et al. 1988), but in contrast to a number of earlier reports of larger type I fibers than type II fibers in vastus lateralis of women (Brooke and Engel 1969; Nygaard 1981), no significant difference was found between the two fiber types. Again, type II fibers in the women in the present study may have been affected by previous physical activity patterns. Also consistent with previous reports, the type II fibers of the vastus lateralis were significantly larger in the men (Schantz et al. 1983; Ryushi et al. 1988) compared to women (Fig. 6D).

Our finding of a similar percent fiber type in the biceps brachii of both sexes confirms previous reports for this muscle (Sale et al. 1987; Alway et al. 1989). The higher proportion of type II fibers in vastus lateralis of the men confirms a previous study by Simoneau and Bouchard (1989) but is inconsistent with studies which have found no gender difference (Prince et al. 1977; Nygaard 1981) or a higher proportion of type I fibers in men (Komi and Karlsson 1978), and probably reflects differences in subject sampling rather than a true genetic difference.

The failure of the percent type II fiber area of the biceps to correlate with any of the strength/CSA ratios of the elbow flexors suggests that the specific tension of the type I and type II fibers does not differ. This is in agreement with previous findings (Schantz et al. 1983; Maughan and Nimmo 1984). Similarly, we interpret the positive correlation which was detected between the percent type II fiber area in the vastus lateralis and the knee extensor strength/CSA ratio when strength was expressed as a 1RM as simply reflecting the high correlation between muscle strength and CSA (since type II fibers are larger than type I fibers in this muscle), rather than differences in specific tension between the two fiber types (Schantz et al. 1983).

One of the major findings of this study was the lack of a significant difference between the sexes as to biceps fiber number (Fig. 7). This differs from previous studies using this technique (MacDougall et al. 1983; Sale et al. 1987), but agrees with the finding of Alway et al. (1989), who examined male and female bodybuilders and indicate that the greater CSA of male muscle is primarily the result of larger fibers rather than greater fiber number. This suggestion is supported by the existence of a significant positive correlation between mean fiber area and biceps CSA (Fig. 8A) and the lack of a correlation between fiber number and biceps CSA (Fig. 8B).

The finding that no significant gender difference exists in the muscle area to fiber area ratio in the vastus lateralis (Fig. 9A) agrees with that of Schantz et al. (1981) and again indicates that it is the greater mean fiber area in male vastus lateralis which is responsible for the greater muscle CSA. Similarly, this is supported by the significant positive correlation between vastus lateralis mean fiber area and vastus lateralis CSA (Fig. 9B), and the lack of a correlation between vastus lateralis muscle area to fiber area ratio and vastus lateralis CSA (Fig. 10B).

Our data failed to find a significant gender difference in the number of motor units in the biceps brachii and vastus medialis or motor unit size in the biceps brachii. In addition, no significant gender difference was found in MUA for either the elbow flexors or the knee extensors. This finding is in agreement with that of a previous investigation (Belanger and McComas 1981) and indicates that men are no better able to maximally activate their available motor units than women.

Our finding of greater relative muscular endurance in women for elbow flexion at 60% 1RM has also been noted by Maughan et al. (1986). These authors reported a significant gender difference at loads corresponding to 50, 60 and 70% 1RM, but not at 80 or 90% 1RM. Such differences in muscular endurance at relatively low, but not at high, proportions of maximum strength may be the result of differences in blood flow due to mechanical compression or occlusion in the contracting muscles. Although both sexes exercised at the same relative intensity, the absolute load was greater for the male subjects. Since occlusion of flow is dependent upon the muscle mass involved and the absolute force generated (Mitchell et al. 1980), one would expect a greater restriction of blood flow in the men. At very high proportions of maximum strength, a gender difference would not be detected, since complete occlusion would apparently exist in both groups (Mitchell et al. 1980).

An alternative explanation for a gender difference in muscular endurance may relate to the work of de Haan et al. (1988), who reported that differences in muscle dimensions (i.e. muscle mass) between the sexes may be responsible for the gender difference in muscular endurance. These authors argue that if two muscles have similar CSA, the longer muscle will have a higher energy utilization at the same %MVC because it has a greater number of sarcomeres in series which will utilize energy but not enhance the force generated by the muscle (de Haan et al. 1988). Therefore, the metabolic cost of the exercise is dependent on muscle mass rather than muscle CSA alone. We found that the difference in muscular endurance was greatest in the elbow flexors, the muscle group which displayed the greatest difference in size.

In summary, in a population of men and women of similar body mass, men were stronger in the muscles of both the upper and lower limbs, both in absolute units and when expressed in units relative to lean body mass. This gender difference was most pronounced in the muscles of the upper limbs. Since the groups did not differ significantly according to the number of muscle fibers, the number of motor units, the ability to activate motor units or strength per CSA of muscle, the greater strength of the men is due primarily to the larger fibers. The greater difference in upper compared to lower limb

strength is apparently attributable to the fact that women tend to have a lower proportion of their lean tissue distributed in the upper body. It is difficult to determine the extent to which the larger fibers in men represent a true biological difference rather than a difference in physical activity, but our data suggest that it is largely an innate gender difference.

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