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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