Acta Physiol Scand 1983, 117: 219–226

# Muscle fibre type distribution, muscle cross-sectional area and maximal voluntary strength in humans

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SCHANTZ, P., RANDALL-FOX, E., HUTCHISON, W., TYDÉN, A. & ÅSTRAND, P.-O.: Muscle fibre type distribution, muscle cross-sectional area and maximal voluntary strength in humans. Acta Physiol Scand 1983, 117: 219–226. Received 28 June 1982. ISSN 0001-6772. Department of Physiology III, Karolinska Institutet, and Department of Radiology, Serafimerlasarettet, Stockholm, Sweden.

The relationship between maximum voluntary concentric strength, muscle fibre type distribution and muscle cross-sectional areas were examined in 23 subjects (7 female and 11 male phys. ed. students as well as 5 male bodybuilders). Maximal knee and elbow extension as well as elbow flexion torque at the angular velocities 30, 90 and 180 degrees per second was measured. Muscle biopsies were taken from vastus lateralis and m. triceps brachii. The muscle cross-sectional area of the thigh and upper arm was measured with computed tomography scanning. The maximal torque correlated strongly to the muscle cross-sectional area times an approximative measure on the lever arm (body height). Maximal tension developed per unit of muscle cross-sectional area did not correlate significantly with per cent type I fibre area and did not differ between the female and male students or bodybuilders. Neither did the relative decrease in torque with increasing contraction velocity show any significant relationship to the per cent type I fibre area. The total number of muscle fibres was estimated by dividing the muscle cross-sectional area with the mean fibre area of m. triceps brachii. The number of fibres did not seem to differ between the sexes.

*Key words:* Muscle strength, muscle fibre type distribution, muscle cross-sectional areas, female and male phys. ed. students, male bodybuilders

Several recent studies have correlated different functional capacities of the intact human skeletal muscle, such as endurance, contraction velocity and strength, to the distribution of different fibre types in the muscle. A number of these studies have indicated that the tension per cross-sectional area unit is greater for the type II (fast-twitch) fibres than for the type I (slow-twitch) fibres (e.g. Tesch & Karlsson 1978, Coyle et al. 1979). With computed tomography scanning it is now possible to determine the area of different muscle groups. In this study the maximal isokinetic torque was measured in knee and elbow extensions respectively and it was related to the active muscle cross-sectional area as well as to the fibre type distribution in the lateral head of m. quadriceps femoris and m. triceps brachii. To obtain a large range of strength and muscle cross-sectional area values, female and male physical education students as well as male bodybuilders were recruited for this study.

## METHODS

**Subjects:** 21 physical education students (10 females and 11 males) and 5 male bodybuilders (Swedish elite) participated in the study. Their average age, height and weight were 26 yrs, 1.68 m, 60 kg (females, PF); 27 yrs, 1.84 m, 75 kg (male students, PM); 28 yrs, 1.76 m, 91 kg (bodybuilders, BB) respectively.

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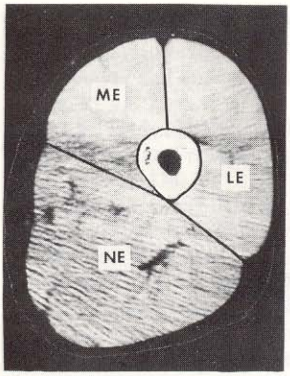


*Fig. 1.* Muscle cross-sectional image of the left thigh, obtained through computed tomography scanning. The medial extensor (ME), lateral extensor (LE) and non-extensor (NE) muscle groups as well as bone have been outlined. For further explanation see Methods.

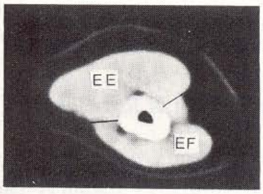


*Fig. 2.* Muscle cross-sectional image of the right upper arm obtained through computed tomography scanning. The elbow extensor (EE) and elbow flexor (EF) muscles as well as the bone have been outlined. For further explanation see Methods.

Muscle biopsy sampling and arm measurements were only performed on a subsample of the subjects due to practical reasons or unwillingness to go through the biopsy-taking procedure. The number of subjects in each measurement has been listed in respective figures or tables. The students had participated in normal sport activities (no extreme endurance or strength training) for several years, while the bodybuilders had been training systematically on the average 7 years. Some of the bodybuilders had been using anabolic steroids. The Ethical Committee at Karolinska Institutet has granted the study.

*Torque measurements.* The torque output during maximal voluntary knee and elbow extension as well as elbow flexion was recorded with an isokinetic (constant velocity) dynamometer (Cybex II, Lumex Inc., New York). During knee extension measurements, the subject sat in an experimental chair with the left lower leg attached to the lever arm of the dynamometer. The pivot point of the lever arm was aligned with the rotation axis of the knee joint. The knee extension movement started at 90° knee angle. During elbow extension and flexion measurements, the subject sat in an experimental chair with the right upper arm resting horizontally on a table. The pivot point of the lever arm was aligned with the rotation axis of the elbow joint. The elbow flexion movement was performed with a supinated lower arm from a fully extended elbow position (0°) to a 120° flexed position. The elbow extension movement was performed with a semi-pronated lower arm from 120° flexed position to complete extension (0°). Maximal torque was recorded over the whole range of motion at the pre-set constant angular velocities of 30°, 90° and $180° \times s^{-1}$ (i.e. 0.52, 1.57 and $3.14\ \text{rad} \times s^{-1}$), respectively. Two maximal attempts were performed at each velocity. The highest values were used for analysis.

*Muscle biopsy sampling and fibre typing.* Muscle biopsies were obtained with the needle-biopsy technique (Bergström 1962) from the lateral head of the left m. quadriceps femoris (vastus lateralis, VL) at midpoint between trochanter major and the lateral articular cleft between the femur- and tibia-chondyles, and from the medial head of the right m. triceps brachii (TB) at about 8 cm above olecranon. The muscle samples were mounted in an embedding medium (Ames$^{TM}$ O.C.T. Compound), frozen in isopentane cooled in liquid nitrogen, and stored at −80°C until analysis. Serial transverse sections (10 μm) were cut with a microtome at −20°C and stained for myofibrillar ATPase to identify type I, IIA, IIB and IIC fibres (Brooke & Kaiser 1970). On the average, 730 (range 220–1 870) fibres from VL, and 490 (range 150–1 000) from TB were counted. To estimate the variation of fibre type distribution in a muscle, two consecutive biopsies were taken from each muscle in 11 subjects. With the mean percentage type I fibres of 48 % in TB, the absolute difference between two biopsies' percentage was 7.3±1.3 % (mean ± SE). The corresponding values for VL were 51 % type I fibres and 6.5±1.6 %. The number of fibres counted in each biopsy was 249±30 (mean ± SE) in TB and 482±62 in VL in this case.

*Muscle fibre area measurement.* Biopsy-sections stained for myofibrillar ATPase (preincubated at pH 4.6) were placed in a microscope, projected (magnification 600 times) and measured on a transparent measuring tablet with a grid (2.5×2.5 mm) (MOP, Kontron Messgeräte, München). Only areas without artefacts or tendency to longitudinal cuts were measured. The areas of 30–60 type I and type IIA fibres and as many type IIB and type IIC fibres as possible (0–44) were determined. The variation in mean fibre type area in two consecutively taken biopsies was determined by measuring the area of 30 type I and

Table 1. *Muscle fibre type distribution, % (mean ± SE)*

**Muscle fibre type distribution (%) in vastus lateralis and m. triceps brachii (Means and SE)**

| | Vastus lateralis | | | | Triceps brachii | | | |
|---|---|---|---|---|---|---|---|---|
| Fibre type | I | II A | II B | II C | I | II A | II B | II C |
| Phys. ed. stud. (♀), (n=7) | 52±4 | 34±4 | 12±5 | 1±1 | 51±2 | 36±3 | 10±3 | 4±1 |
| Phys. ed. stud. (♂), (n=11) | 52±4 | 35±3 | 10±2 | 3±1 | 50±3 | 41±3 | 9±2 | 1±1 |
| Bodybuilders (♂), (n=5) | 52±6 | 42±6 | 5±2 | 2±1 | | | | |

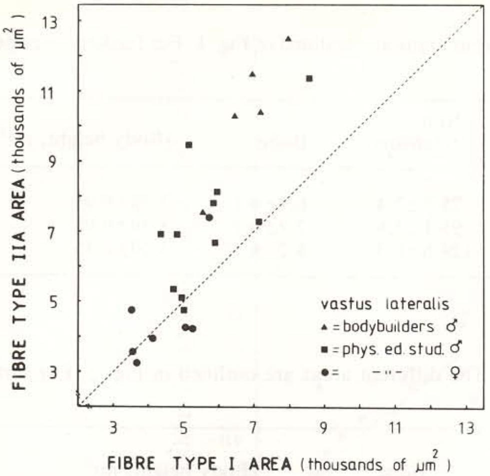


*Fig. 3.* Fibre type I area in relation to type II A area in vastus lateralis. Broken line corresponds to line of identity. Means and SE were for PF: 4 400±340 $\mu m^2$ (type I), 4 480±500 (type II A), for PM: 5 680±380 (type I) 7 240±590 (type II A) and for BB: 6 830±390 (type I) 10 400±850 (type II A).

IIA fibres respectively in 8 subjects. The mean difference was calculated to be 12% (range 0.6–53.0). The error of method in the fibre area measurment was determined by performing 3 repeated measurements of 10 fibre areas by two persons at different parts of the measuring tablet. The average standard deviation, expressed as percentage of the mean value of six measurements of 10 fibres was 2.2% (range 1.5–3.5).

*Muscle and bone cross-sectional areas* were determined from pictures obtained through computed tomography scanning of the left thigh (EMI 5005) and the right upper arm (EMI 1010). The image of the thigh was taken of an extended leg at midpoint between trochanter major and the articular cleft between the femur- and tibiachondyles. The lateral and medial part of m. quadriceps femoris, as well as the remaining thigh muscles were outlined using notches between muscle bellies and subcutaneous fat, the midpoint of the bone marrow, and the outer limits of the bone, as reference points (Fig. 1). The bone area excluding the bone marrow was also measured. The image of the upper arm was obtained on an extended arm at 60% of the distance from angulus acromialis to the lateral epichondyle of the humerus. The elbow extensor and elbow flexor muscles were outlined using notches between the muscle bellies and subcutaneous fat and the midpoint of the bone marrow as reference points (Fig. 2). The outlines were transferred onto a semitransparent paper. The bone area, except the bone marrow, was also outlined. The area was cut out and weighed. The weight/area relationship of the paper had previously been determined.

*Statistics.* Results will be presented as means and standard error of means (SE) or ranges. Only differences between female and male students as well as between male students and bodybuilders have been evaluated statistically. The differences were tested with Mann-Whitney's ranksumtest for unpaired data. When PM-values were used twice (leg-data) a level of probability less than 0.025 was considered to be significant. Otherwise, $p<0.05$, was considered significant. Determination of linear regression was performed using the method of least squares. Linear correlation coefficients are designated with r.

## RESULTS

### *Muscle fibre type distribution*

The average fibre type distribution in vastus lateralis (VL) was 52% (range 36–71) type I, 36% (23–57) type IIA, 10% (0–35) type IIB, and 2% (0–11) type IIC in the whole material (Table 1). No significant difference existed between the female (PF) and male (PM) physical education students or the bodybuilders (BB). The average fibre type distribution in m. triceps brachii (TB) was 50% (26–65) type I fibres, 39% (22–56) type IIA, 9% (0–35) type IIB and 2% (0–11) type IIC fibres. The percentage of type IIC fibres differed significantly between PF (4.4%) and PM (1.1%).

### *Muscle fibre area*

The mean fibre areas in VL were on the average 4 400±390 (PF), 6 200±460 (PM) and 8 400±530 $\mu m^2$ (BB). Individual values for the areas of fibre type I and IIA are given in Fig. 3 (for means see the

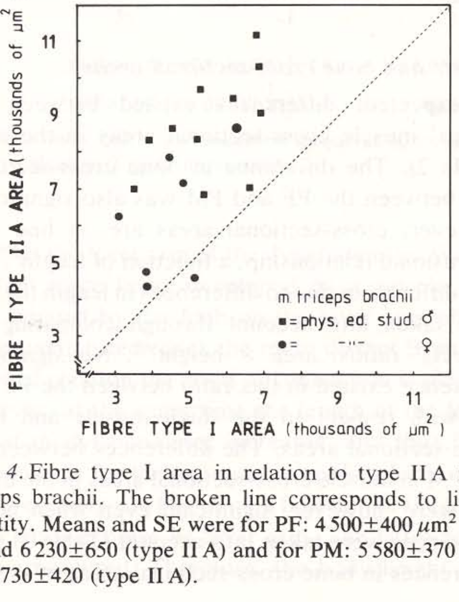
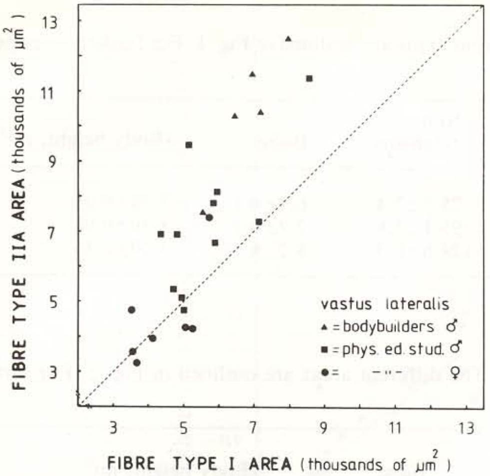


*Fig. 4.* Fibre type I area in relation to type II A in m. triceps brachii. The broken line corresponds to line of identity. Means and SE were for PF: 4 500±400 $\mu m^2$ (type I) and 6 230±650 (type II A) and for PM: 5 580±370 (type I), 8 730±420 (type II A).



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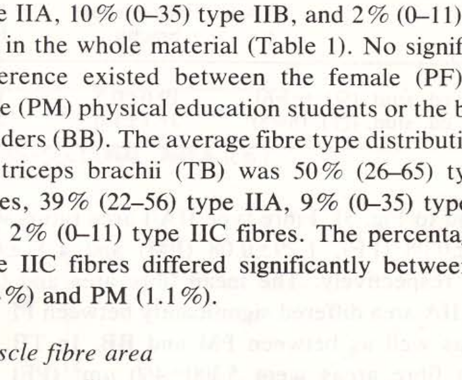

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Table 2. *Cross-sectional areas of the thigh* ($cm^2$)

Muscle and bone cross-sectional areas of the left thigh. The different areas are outlined in Fig. 1. For further description see Methods (Means and SE)

| | Medial extensors | Lateral extensors | Non extensors | Bone | (Body height, m)$^2$ |
|---|---|---|---|---|---|
| Phys. ed. stud. (♀), (n=10) | 24.1±1.4 | 42.4±1.8 | 75.3±2.4 | 6.8±0.1 | 2.79±0.05 |
| Phys. ed. stud. (♂), (n=11) | 32.9±1.0 | 55.4±2.2 | 95.1±3.8 | 7.9±0.2 | 3.39±0.08 |
| Bodybuilders (♂), (n=5) | 42.4±1.6 | 82.6±5.1 | 124.6±6.3 | 8.2±0.3 | 3.10±0.15 |

Table 3. *Cross-sectional areas of the upper arm* ($cm^2$)

Muscle and bone cross-sectional areas of the right upper arm. The different areas are outlined in Fig. 2. For further description see Methods (Means and SE)

| | M. triceps brachii | M. biceps brachii | Bone | (Body height, m)$^2$ |
|---|---|---|---|---|
| Phys. ed. stud. (♀), (n=6) | 19.0±0.7 | 14.4±0.6 | 4.3±0.3 | 2.74±0.06 |
| Phys. ed. stud. (♂), (n=8) | 31.1±1.6 | 23.5±1.2 | 6.0±0.4 | 3.41±0.10 |

legend to Fig. 3). Fibre type IIA/I area ratios were 1.02±0.08 (PF), 1.29±0.08 (PM) and 1.51±0.06 (BB) respectively. The mean fibre area and fibre type IIA area differed significantly between PF and PM as well as between PM and BB. In TB, the mean fibre areas were 5300±460 $\mu m^2$ (PF) and 7000±400 (PM). Individual values for fibre type I and IIA areas are given in Fig. 4 (for means see the legend to Fig. 4). The fibre type IIA/I area ratios were 1.42±0.14 (PF) and 1.61±0.10 (PM). The mean fibre area and type IIA area differed significantly between PF and PM.

### *Muscle and bone cross-sectional areas*

As expected, differences existed between the groups' muscle cross-sectional areas in the thigh (Table 2). The difference in bone cross-sectional area between the PF and PM was also significant. However, cross-sectional areas are, in line with dimensional relationship, a function of length$^2$. The area differences due to differences in length (height) were taken into account through comparing the subjects' ratios: area × height$^{-2}$. No significant difference existed in this ratio between the PF and PM with respect to the thigh muscle and bone cross-sectional areas. The differences between PF and PM in muscle cross-sectional areas in the upper arm were, however, significant even when height differences were taken into account (Table 3). The differences in bone cross-sectional areas of the humerus were not significant when the differences in height were taken into account.

### *The relationship between mean fibre area and muscle cross-sectional area*

The total number of fibres was estimated by dividing the muscle cross-sectional area by the mean

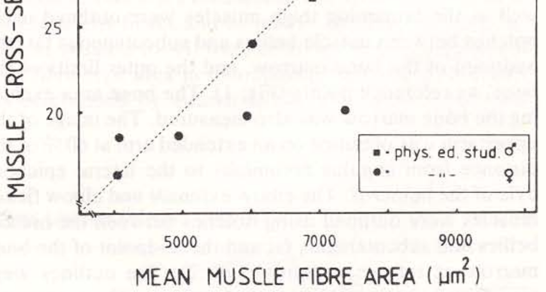

*Fig. 5.* The relationship between mean muscle fibre area and muscle cross-sectional area of m. triceps brachii. The broken line represents the slope of the same relative increment for the axis. The observations are evenly distributed around this line, indicating a rather uniform number of fibres despite great differences in muscle girth.

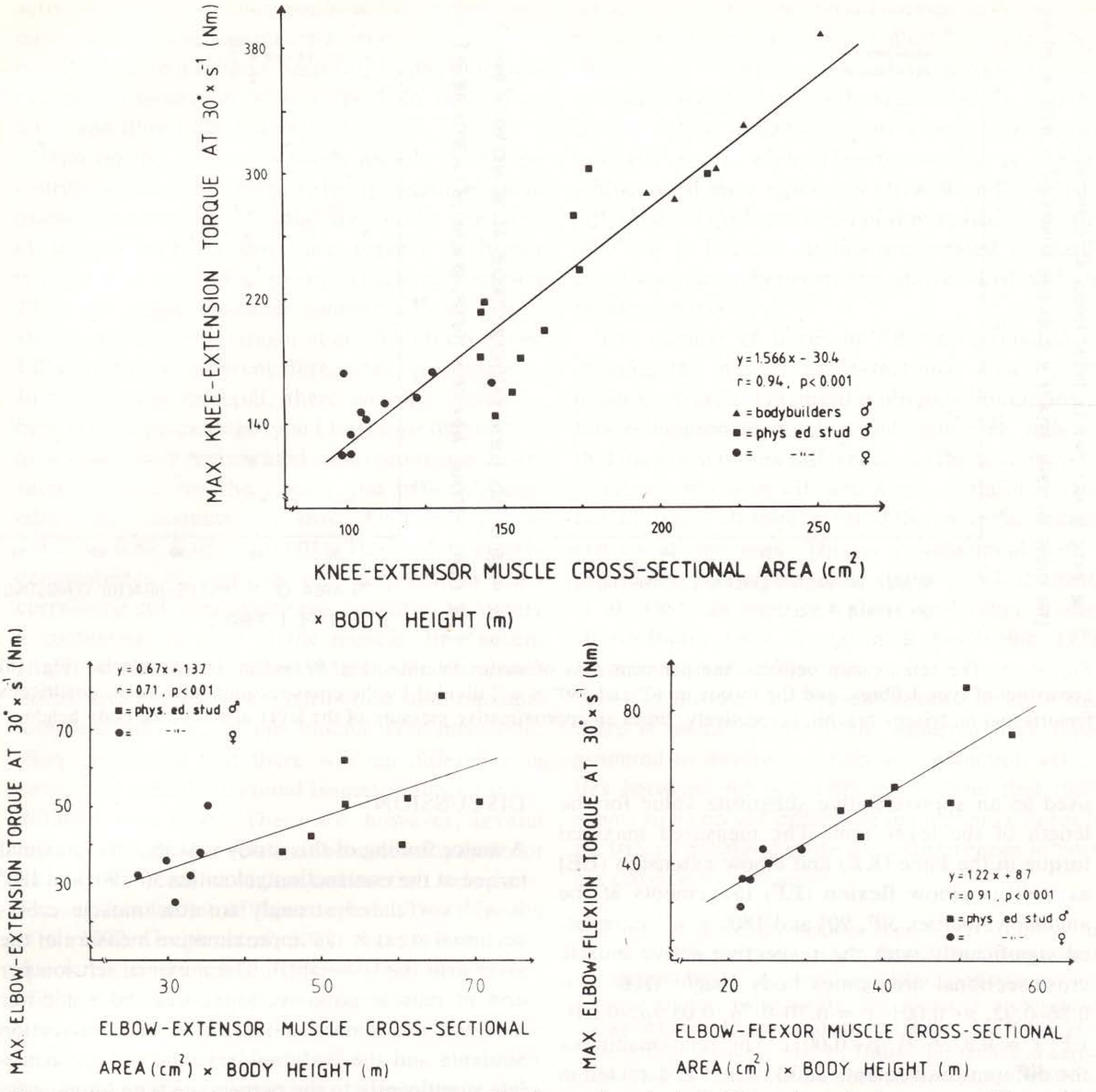

*Fig. 6–8.* The relationship between muscle cross-sectional area times body height and maximal torque at 30° × $s^{-1}$ in the knee- (Fig. 6) and elbow- (Fig. 7) extension as well as the elbow-flexion (Fig. 8) movements.

fibre area of the TB. No significant difference existed between PF (mean $3.67\times10^5$, range $2.72\times10^5$–$4.55\times10^5$) and PM (mean $4.34\times10^5$, range $3.64\times10^5$–$6.00\times10^5$) (Fig. 5). A similar finding was noted with respect to the lateral extensor muscle group of the thigh as reported previously (Schantz et al. 1981).

### *Maximal torque*

The torque measured by the isokinetic dynamometer is a product of the applied force times the length of the lever arm of the dynamometer. With a constant force being developed by a muscle, the force applied by the limb on the lever arm of the dynamometer decreases the more distant from the centre of rotation the point of connection is placed. However, at the same time the length of the lever arm of th dynamometer increases, and thus fully compensates for the decrease in applied force. The measured torque is therefore a function of the force of the muscle times its lever arm. The latter could not be measured. Therefore, the body height was

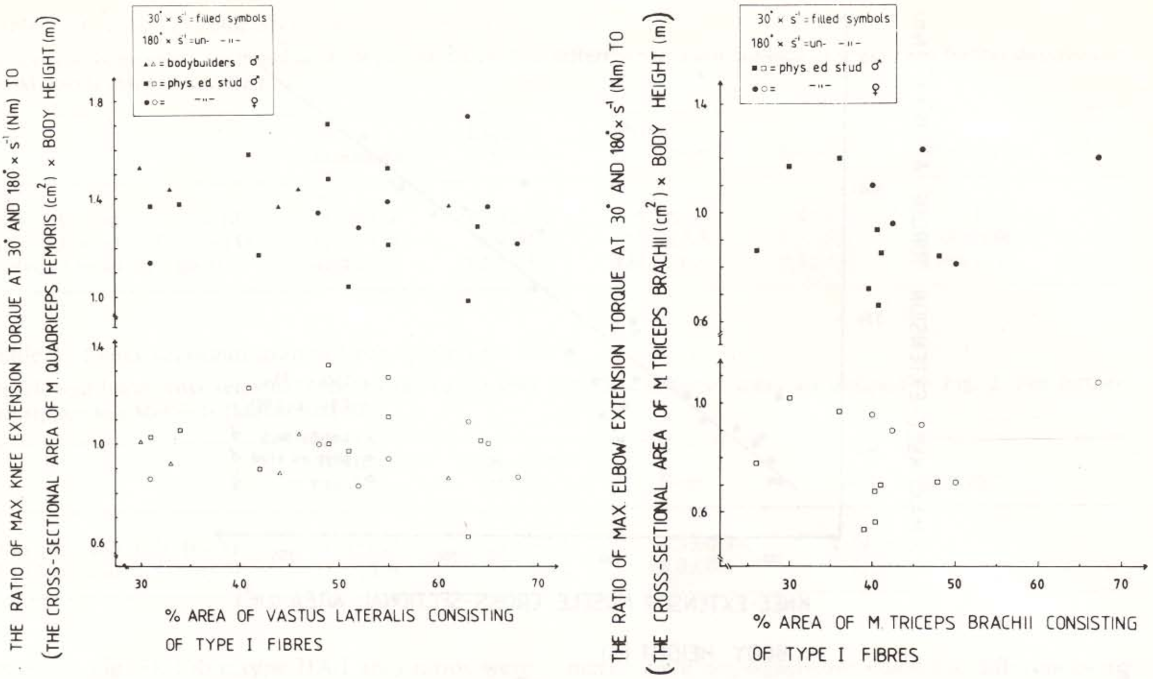

*Fig. 9–10.* The relationship between the per cent area of vastus lateralis (Fig. 9) and m. triceps brachii (Fig. 10) consisting of type I fibres, and the torque at 30° and 180° × $s^{-1}$ divided by the cross-sectional area of m. quadriceps femoris and m. triceps brachii, respectively, times an approximative measure of the lever arm, i.e. the body height.

used as an approximative substitute value for the length of the lever arm. The measured maximal torque in the knee (KE) and elbow extension (EE) as well as elbow flexion (EF) movements at the angular velocities 30°, 90° and 180° × $s^{-1}$ correlated significantly with the respective active muscle cross-sectional area times body height (KE: r = 0.86–0.92, $p<0.001$: r = 0.70–0.76, $0.05>p>0.001$; EF: r = 0.87–0.91, $p<0.001$). The relationship for the different movements at 30° × $s^{-1}$ is depicted in Fig. 6–8.

The ratios obtained through dividing the maximal torque by the muscle cross-sectional area times body height, did not differ between the PF, PM or BB in any movement, thus indicating that the groups were able to produce equal force per area unit of muscle cross-section. These ratios did not correlate to the percentage area consisting of type I fibres in respective muscle. (Fig. 9–10).

### *Force-velocity relationship*

From Fig. 9 and 10 it is evident that the relative decrease in torque between 30° and 180° × $s^{-1}$ in the KE- and EE-movements was not related to the fibre type area distribution.

## DISCUSSION

A major finding of this study was that the maximal torque at the contraction velocities 30°, 90° and 180° × $s^{-1}$ correlated strongly to: (the muscle cross-sectional area) × (an approximative measure of the lever arm (body height)). The maximal tension per unit of muscle cross-sectional area did not differ between the female and male physical education students and the bodybuilders, and did not correlate significantly to the percentage type I area, covering a range from 30 to 70% of the total muscle area. Neither did the relative decrease in maximal torque between 30 and 90 or 180 degrees × $s^{-1}$ show any significant relationship to the percentage of type I area.

The validity of the present findings depends to a great extent on how representative two biopsy samples from the vastus lateralis (VL) and m. triceps brachii (TB), respectively, are for m. quadriceps femoris and m. triceps brachii.

Since the fibre type distribution in different muscles within an individual are strongly correlated (Saltin et al. 1977, Häggmark & Torstensson 1979, Fugl-Meyer et al. 1982), and the other heads of the active muscle-group are mainly active in the same movements, these samples are probably rather representative on a relative basis for the physiological muscle cross-section with respect to both fibre areas and fibre type distribution.

Data on the relation between muscle fibre type distribution and the force-velocity relationship in humans are somewhat conflicting. On the sole basis of muscle biopsies there are reports of higher (Clarkson et al. 1980), lower (Tesch & Karlsson 1978) and equal maximal isometric force (Thorstensson et al. 1976, Gregor et al. 1979) for the type I fibres and the different fibre types, respectively. In the present material, there was a covariation between the percentage type I fibres, or the relative area which they represented, and the muscle cross-sectional area for the female and male physical education students' vastus lateralis ($r = -0.77 - -0.87$, $0.05 > p > 0.001$). This finding clearly demonstrates the risks for misinterpretation when correlating different functional capacities to merely a qualitative measure of the muscle. In a recent study by Nygaard et al. (1981) muscle cross-sectional area, fibre type distribution and maximal muscle force of m. biceps brachii were measured. They concluded that there was no difference in developed specific maximal isometric force for the different fibre types. There are, however, several reports on a greater relative force development for the type II fibres at higher contraction velocities. The results of some of those reports (Thorstensson et al. 1977, Gregor et al. 1979) may, however, be due to the non-homogenity in training background of the subjects forming the groups with predominance of either fibre type (endurance and sprinting or jumping athletes, respectively), since it recently has been shown that resistance training at a given velocity may increase the strength selectively at that velocity (Caiozzo et al. 1980, Coyle & Feiring 1980). The results of Coyle et al. (1979) indicated a fibre type dependent force-velocity curve at high velocities. This might be due to the fact that the subjects with a greater proportion of fast twitch muscle area may have developed peak torque earlier and at joint angles closer to the optimal for torque development, due to the shorter contraction times for the type II fibres. However, there are still two studies (Thorstensson et al. 1976, Nygaard et al. 1981) which, on the basis of the information they provided concerning the subjects and methods, can not be criticized using the criteria above. Both studies indicated that the type II fibres may produce relatively greater force at higher velocities. Nygaard et al. (1981) studied elbow flexion in eight subjects and found large differences in relative torque output already at slow contraction velocities, ($60° \times s^{-1}$), while Thorstensson et al. (1976), who studied knee extension strength, only noted a difference at the most rapid of the studied velocities ($180° \times s^{-1}$). Further studies are needed to clarify the discrepancy between the above cited and the present results.

The number of fibres in TB was estimated by dividing the muscle cross-sectional area by the mean fibre area. Having the obvious limitations of this estimation in mind, it did, however, indicate that there are no sex differences in the total number of muscle fibres in TB, and a rather uniform number of fibres despite great differences in muscle cross-sectional area. This is in agreement with a previous report on the same subjects' VL (Schantz et al. 1981) as well as with several other studies (Barin-Baum 1963, Vaughan & Goldspink 1979, Häggmark et al. 1978).

In conclusion, the present results indicate that there is no difference in the different fibre types potential to develop tension at contraction velocities between 30° and $180° \times s^{-1}$, and that there seems to be no sex difference in number of fibres in m. triceps brachii despite great differences in muscle cross-sectional areas.

The authors gratefully acknowledge Ms U. Siltberg for excellent secretarial assistance, Drs G. Westberg and H. Arvidsson, Depts. of Radiology, Serafimerlasarettet and Södersjukhuset, respectively, for generous provision of computed tomography scanning facilities, Dr B. Jonsson for statitical assitance and B. Hillner for technical assistance. This investigation has been supported financially by the Research Council of the Swedish Sports Federation and the Coca-Cola Export Corporation, Sweden.

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