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The relationship between the mean muscle fibre area and the muscle cross-sectional area of the thigh in subjects with large differences in thigh girth

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A salient feature of skeletal muscle is its ability to increase in girth in response to heavy resistance training or overload. Both the training-induced increase in muscle girth and the increase with normal growth after early infancy, have usually been regarded to be due to hypertrophy of a constant number of muscle fibres. Muscle overloading through tenotomy might however lead to an increase in muscle cross-sectional area due to hypertrophy of an increased number of fibres due to fibre division (e.g. Vaughan & Goldspink 1979) or new fibre production (Salleo et al. 1980). That the latter also might be a conceivable mechanism for increases in muscle girth in humans is supported by MacDougall et al. (1980), who found that the fibre area of bodybuilders was not greater than those of controls. However, no quantification of muscle girth was performed in that study. In order to further investigate this matter, we have combined computed tomography with muscle biopsy—histochemical technique and measured muscle cross-sectional area as well as fibre area in trained subjects with large differences in thigh muscle girth.

Subjects. 7 female and 11 male physical education students as well as 5 male bodybuilders (Swedish elite) volunteered to participate in this study. The means for their age, weight, and height were 29 years, 61 kg, 1.67 m, (female); 27, 75, 1.84 (male students); 28, 91, 1.76 (bodybuilders), respectively. The students had performed normal athletics (no extreme endurance or strength training) for several years, while the bodybuilders had been training systematically on the average for 7 years. The bodybuilders trained the thigh extensor muscles on the average 3 times per week. The training consisted mainly of two movements: 1) knee flexion-extension from a standing position with a weightbar on the shoulders and 2) the so-called "leg-extension" movement in a sitting position. The number of sets and repetitions per set were for the knee flexion-extension movement on the average 6 and 7, respectively, and for the "leg extension" movement 4 and 11, respectively. The weights were chosen so that the exertion should be maximal at the last repetition per set.

Muscle cross-sectional area measurements were performed on pictures obtained through computed tomography scanning (EMI 5005) of the left thigh at the midpoint between trochanter major and the articular cleft between the femur- and tibiachondyles. The lateral part of m. quadriceps femoris, which mainly consists of vastus lateralis, was 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 outlines were transferred onto a semitransparent paper. The area was cut and weighed. The weight/area relationship of the paper had previously been determined.

Muscle fibre sampling and staining. Muscle biopsies were obtained from the lateral head of m. quadriceps femoris (vastus lateralis) at the same level as the tomography pictures were taken. Serial sections of the biopsies were stained for myofibrillar ATPase (Brooke & Kaiser 1970) to identify type I, IIA, IIB and intermediate (IB, IIC) fibres. On the average 760 (range 220–1860) fibres were counted.

Muscle fibre area measurements. Biopsy-sections stained for myofibrillar ATPase (preincubated at pH 4.6) were placed in a microscope and projected (magnification 600 times) on a transparent measuring tablet with a grid (2.5×2.5 mm). The cell membranes were traced with a pen. Based on magnetostrictive principle, the x- and y-coordinates passed by the pen were entered into a microproces-

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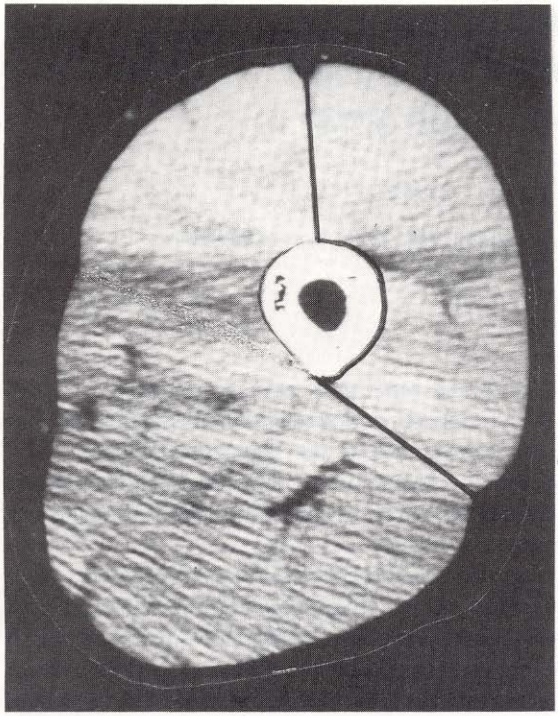

Fig. 1. An example of a cross-sectional image of the left thigh. The lateral part of m. quadriceps femoris was outlined (upper-right part of the picture). For further explanation see text.

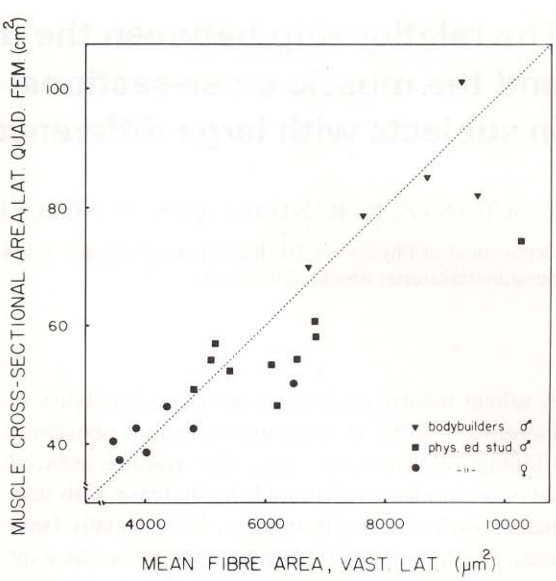

Fig. 2. The relationship between the mean muscle fibre area in vastus lateralis and the muscle cross-sectional area of the lateral part of m. quadriceps femoris.

sor and converted into area values (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 intermediate fibres as possible (0–44) were determined. The mean fibre area was calculated according to the formula: 1/100 (type I area × % type I + type IIA area × % type IIA + type IIB area × % type IIB + intermediate type area × % intermediate type). The number of fibres in the lateral part of m. quadriceps femoris was estimated by dividing the muscle cross-sectional area by the mean fibre area.

Results and discussion. The relationship between the mean fibre area and the muscle cross-sectional area is presented in Fig. 2. The broken line in the figure, represents the slope on which all observations would lie if all individuals had the same number of fibres, and thus the area of the fibres would exclusively determine the muscle cross-sectional area. The observations in the present study are evenly distributed around this line, indicating a rather uniform number of fibres in different individuals. This is in line with earlier findings in humans (Häggmark et al. 1978) as well as in animals (e.g. Gollnick et al. 1981), although the results on animals might be due to inbreeding.

It may be questioned whether the "mean fibre area", estimated on basis of a biopsy sample from vastus lateralis, is representative for the whole lateral muscle cross-sectional area, which besides vastus lateralis also contains vastus intermedius. Due to constant fibre type area (Polgar et al. 1973) and only slight variation in fibre type distribution within vastus lateralis (Johnson et al. 1973), the estimated mean fibre area is probably quite close to the true mean for vastus lateralis. It is reasonable to assume that there is a rather constant relationship between the fibre area of vastus lateralis and vastus intermedius since they are active in the same movement. Also the degree of contraction of the muscle biopsy is most likely to be the same in different individuals. Therefore the usefulness of the estimated mean fibre area lies in giving individual values that can be compared with other individuals rather than giving the mean fibre area in absolute terms. This is even more valid with respect to the estimated total number of fibres, since the fibres in vastus lateralis do not run perpendicular to the obtained muscle cross-sectional image.

The estimated number of fibres was about the same in the female ($\bar{m}=1.00\times10^6$, range $0.78\times10^6-1.17\times10^6$) and male students ($\bar{m}=0.92\times10^6$, range $0.72\times10^6-1.10\times10^6$) as well as in the bodybuilders ($\bar{m}=1.00\times10^6$, range $0.86\times10^6-1.09\times10^6$). The equality between the sexes with regard to number of fibres is consistent with earlier findings both in animals (Vaughan & Goldspink 1979) and humans (Nygaard et al. 1979). The lack of difference in number of fibres between the students and the bodybuilders indicates that the differences in muscle cross-sectional area of the thigh between the groups most likely may be explained exclusively by hypertrophy of the bodybuilders' muscle fibres. This does not, however, rule out the possibility that fibre division or new muscle fibre production might occur in connection with heavy resistance training of other muscle groups, as suggested by MacDougall et al. (1980), who studied m. triceps brachii. On the other hand, a prerequisite for fibre division or new fibre production in response to heavy resistance training may be that more extensive or different training is undertaken than that performed by the subjects in this study. This may be the case in the study by MacDougall et al. (1980), as they reported a higher incidence of structural abnormalities such as central nuclei and atrophied fibres in the bodybuilders than in the controls. In the present study, no structural abnormalities were seen in any subjects from light microscope inspection of the myosin ATPase staining.

Due to methodological limitations it is not possible to judge if the variation in estimated number of fibres ($0.72\times10^6-1.17\times10^6$) is representative for the actual variation. However, if the calculated magnitude of variation is correct, which is supported by a recent direct count of the fibres in some leg muscles from rats with 20-fold difference in size (Gollnick et al. 1981), and hyperplasia does not occur, the number of fibres in the muscle will be an obvious limiting factor for attaining greater muscle girth.

In conclusion, the fibre number in the lateral part of m. quadriceps femoris seems to be rather uniform in trained subjects with large differences in muscle cross-sectional area. Thus great muscle cross-sectional area may be explained by great mean fibre area.

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REFERENCES

BROOKE, M. & KAISER, K. 1970. Three "myosin ATPase" systems: The nature of their pH lability and sulfhydryl dependence. J Histochem Cytochem 18: 670–672.

GOLLNICK, P., TIMSON, B., MOORE, R. & RIEDY, M. 1981. Muscular enlargement and number of fibers in skeletal muscles of rats. J Appl Physiol 50: 936–943.

HÄGGMARK, T., JANSSON, E. & SVANE, B. 1978. Cross-sectional area of the thigh muscle in man measured by computed tomography. Scand J Clin Lab Invest 38: 355–360.

JOHNSON, M., POLGAR, J., WEIGHTMAN, D. & APPLETON, D. 1973. Data on the distribution of fibre types in thirty-six human muscles. An autopsy study. J Neurol Sci 18: 111–129.

MACDOUGALL, J., SALE, D., SUTTON, J., ELDER, G. & MOROZ, J. 1980. Muscle ultrastructural characteristics of elite powerlifters and bodybuilders. Med Sci Sports 2: 131.

NYGAARD, E., NIELSEN, H. & SALTIN, B. 1979. Number of muscle fibers in human muscle—determined in vivo. Acta Physiol Scand, Suppl. 473, p. 37.

POLGAR, J., JOHNSON, M., WEIGHTMAN, D. & APPLETON, D. 1973. Data on fibre size in thirty-six human muscles. An autopsy study. J Neurol Sci 19: 307–318.

SALLEO, A., ANASTASI, G., LA SPADA, G., FALZEA, G. & DENARO, M. 1980. New muscle fiber production during compensatory hypertrophy. Med Sci Sports 4: 268–273.

VAUGHAN, H. & GOLDSPINK, G. 1979. Fibre number and fiber size in a surgically overloaded muscle. J Anat 129: 293–303.