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SOME ASPECTS OF MUSCULAR MOVEMENT: A REVIEW

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Some Aspects Of Muscular Movement: A Review

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Corrective therapists in the G.M.&S. situation are concerned primarily with the effect of human movement on muscle and, equally, with the effect of muscle on human movement—an inseparable interrelationship. While knowledge in these fields is advancing constantly, most therapists either do not have the time to devote to keeping abreast of recent developments or do not have access to the relevant research journals. It is the purpose of this paper to summarize very briefly some of the recent scientific discoveries and theories which seem to hold promise of shedding additional light on our basic understanding of muscles-movement.

Muscle Hypertrophy and Performance

Therapeutic exercise usually has two goals: the improvement of performance (strength development), and the improvement of appearance (hypertrophy). Ordinarily the basis for the development of both of these is progressive resistance exercise, but the extent to which they are related and the best means of developing them is not clear. Some year ago, Rasch and Morehouse[1] reported a correlation of only .422 between increases in muscle girth and increase in strength, and suggested that apparent increases in strength may be largely the result of learning rather than of improved muscle contractibility. Their views have since been supported by Ward and Fisk,[2] who also have concluded that hypertrophy is not necessarily correlated with an increase in strength, and that improvement in muscular performance may be due to neuromuscular learning rather than to strength increase.

It is a matter of common observation that high-repetition, low-resistance exercises, such as distance running, do not ordinarily produce hypertrophied muscles, whereas low repetition-high resistance exercises, such as weight training, do. Gordon *et al.* attribute this to the fact that repetitive exercises improve the concentration of energy liberating enzymes (sarco-plasmic proteins) and so develop muscle endurance, whereas strength exercises develop the concentration of actomyosin filaments (myofibrillar protein). They argue that from the standpoint of biochemistry, the careful investigator must differentiate between *sarcoplasmic hypertrophy*, resulting from prolonged repetitive exercises, and *actomyosin hypertrophy*, resulting from brief, forceful exercise. Further, it seems possible that endurance exercises stimulate predominantly hypertrophy of the red fibers and strength exercises affect predominantly hypertrophy of the white fibers.[3,4,5] There is also some evidence that hypertrophy of one type of fiber may be accompanied by loss of substance in the fibers of the other type. How hypertrophy is to be measured—whether by increases in muscle circumference, weight, or volume—is another and equally complex question.

Muscle Fibers

Since the study of the role of white and red fibers in the function of muscle may prove one of the keys to better understanding of muscle function and hypertrophy, this point should be examined in greater detail.

Muscle fibers may be divided into two general types: red (tonic), and pale (phasic). The relatively large amounts of myoglobin and granular material in the red fibers give them a much darker and redder appearance than is true of the pale fibers, which have few granules and very little myoglobin. Dark fibers have a smaller diameter and contain more sarcoplasm and mitochondria per unit area than do the white ones. The pigment in tonic fibers may serve as a means of storage of oxygen. These fibers depend primarily on oxidative metabolism and are adapted to sustained contraction, such as is required in maintaining posture. Phasic fibers depend primarily on glycolytic metabolism, fatigue more easily, and are better adapted to perform fast contractions. The tonic fibers are innervated by neurones with thresholds which are lower than those innervating phasic muscles. Consequently, they are usually more active. Hence, the amount of electrical activity in a muscle is in part determined by its proportion of dark fibers. Similarly, the amount of protein catabolism and synthesis is greater in tonic muscles. This suggest a direct relationship between the physiological activity of a muscle and the amount of protein metabolism.[6]

In the domestic fowl, for example, the legs, which are in continuous use, are composed largely of red fibers, whereas the wings and the breast, which are used relatively little, are composed largely of pale fibers. In contrast, wild fowl, which engage in long flights, have red fibers in both the wings and the breast. In mammals, including man, the common type of muscle is a mixed one, containing varying amounts of tonic and phasic fibers, depending on its task. Typical examples are the *soleus* and *medial gastrocnemius*, which are predominantly dark, the *tibialis anterior* and *flexor digitorum longus*, which are intermediate, and the *extensor digitorum longus* and the *semitendinosus*, which are predominantly pale. Twenty years ago, experimental findings led Bach[7] to conclude that if a red muscle is transplanted to do the work of a pale muscle, it develops characteristics typical of a pale muscle.

Bajusz has reported that during denervation atrophy, white fibers decrease in size earlier than do red fibers. However, if muscles are immobilized in plaster casts, both fibers atrophy at the same rate. From these observations, he concluded that white fibers display a greater dependence on neuromuscular integrity than do red ones.[8] A contrary view has been expressed by Carrow *et al.* When they forced rats to exercise, they found that red fibers showed a relatively greater increase in size than did white ones, from which they concluded that during physical activity, red fibers are more dependent on the neural mechanism than are white fibers.[9] This difference in opinion cannot be reconciled at this time, but both views confirm Bajusz's theory that "the quality, extent, and significance of nerve impulses are not the same for the two basic types of muscle fibers."[8]

Myoglobin

The myoglobin in muscles is believed to store O_2 and to supply it when needed to support aerobic metabolism. Astrand *et al.* suggest that "oxygen bound to the myoglobin plays an important role in the supply of oxygen to the working muscles in the initial stage of work."[10] It is now accepted generally that the amount of myoglobin in muscles increases with training. Thus, Pattengale and Holloszy[11] observed that after 12 weeks of training in running, rats showed a myoglobin content in the *quadriceps* which was approximately 75 per cent higher than in the controls. The concentration in the abdominal muscles remained unchanged, indicating that the increase was a local factor, limited to the working muscles.

Mitochondria

The mitochondria appears to exist primarily to furnish ATP (the substance necessary for contraction) to the myofibrils. They have the power to oxidize sugar, pyruvic acid and other substances and to use the energy thus produced for the synthesis of protein and other purposes as well as the contraction of muscle fibers. These, too, can be increased by training. Gollnick and King[12] reported that rats trained to swim had nearly twice as many mitochondria per unit of skeletal muscle as did the unexercised controls. Thus, exercise alters the composition of the muscle in a way favorable to improved aerobic and anaerobic performance.

Protein

Since something over 80 per cent of the dry weight of muscle is protein, a great deal of attention has been given to the role of protein in the production of muscular hypertrophy. In normal muscle there is a continual degradation of protein. Hypertrophy of skeletal muscle as a result of increased work is accompanied by increased incorporation of amino acids into proteins, but the amount of growth is proportional only to the protein synthesis over and above that required to offset the degradative process. Although the synthesis of soluble and myofibrillar proteins during hypertrophy appears to be proportionate to their presence in non-growing muscle, the difference in degradative rates may mean that there are differences in their concentrations in muscle. This may account for earlier reports that exercised muscles have a higher content of myofibrillar proteins than do those of unexercised controls.[13]

It is now accepted generally that the basic phenomenon in muscle contraction is the sliding of the I bands, as postulated by Huxley. There is, however, a good deal of question as to whether this is the whole story. At least six proteins have been identified in muscle: actin, myosin, tropomyosin, metin, troponin, and actinin. About 55 per cent of the total protein of myofibrils is accounted for by the A filaments, about 36 per cent by the I filaments, and about six per cent by the Z discs. Electron microscopic studies indicate that during muscle contraction there is a migration of protein from the A bands into the I bands and eventually into the contraction bands surrounding the Z disc. The mechanism of this protein migration is unknown.[14]

Facts such as these do much to justify the almost obsessive fascination with protein on the part of body builders and even many athletes. Unfortunately, controlled attempts to improve muscular performance and hypertrophy by the means of adding a protein supplement to the diet have proved fruitless.[15,16] Apparently, the problem is not susceptible to such a simple solution. Even though diet and environment are similar, the concentration of amino acids in the blood may differ widely from one individual to another. Whether a heavy dietary protein intake affects the free amino acid pool remains a matter of controversy.[17]

Summary

1. The correlation between increases in strength and increases in hypertrophy is low.

2. Improvement in muscular performance following training may be due to motor learning.

3. The careful investigator must differentiate between sarcoplasmic hypertrophy and actomyosin hypertrophy.

4. Muscles are composed of red and of pale fibers. Each of these may be affected differently by a given exercise and/or neuromuscular integrity.

5. The concentration of myoglobin in a muscle may be increased by exercise.

6. The number of mitochondria per unit of skeletal muscle may be increased by training.

7. Skeletal muscle is predominantly protein, but experimental attempts to increase the muscle mass by means of dietary supplementation have been unavailing.

References

1. Rasch, P. J. and Morehouse, L. E., Effect of Static and Dynamic Exercises on Muscular Strength and Hypertrophy. *J. Appl. Physiol.,* 11:29, 1957.
2. Ward, J. and Fisk, G. H., The Difference in Response of the Quadriceps and the Biceps Brachii Muscles to Isometric and Isotonic Exercise. *Arch. Phys. Med. Rehab.,* 45:614, 1964.
3. Gordon, E. E., Kowalski, K. and Biesel, W. R., Adaptation of Muscle to Various Exercises. *J.A.M.A.,* 199:103, 1967.
4. ———, Changes in Rat Fiber with Forceful Exercises. *Arch. Phys. Med.,* 48:577, 1967.
5. ———, Protein Changes in Quadriceps Muscle of Rat with Repetitive Exercises. *Arch. Phys. Med.,* 48: 296, 1967.
6. Goldberg, A. L., Protein Synthesis in Tonic and Phasic Skeletal Muscles. *Nature,* 216:1219, 1967.
7. Bach, L. M. N., Conversion of Red Muscle to Pale Muscle. *Proc. Soc. Exp. Biol. Med.,* 67:268, 1948.
8. Bajusz, E., Red Skeletal Muscle Fibers: Relative Independence of Neural Control. *Science,* 145:938, 1964.
9. Carron, R. E., Brown, R. E. and Van Huss, W. D., Fiber Sizes and Capillary to Fiber Ratios in Skeletal Muscle of Exercised Rats. *Anat. Rec.,* 159:33, 1967.
10. Astrand, I., Astrand, P. O., Christensen, E. H. and Hedman, R., Myohemoglobin as an Oxygen Store in Man. *Acta. Physiol. Scand.,* 48:454, 1960.
11. Pattengale, P. K. and Holloszy, J. O., Augmentation of Skeletal Muscle Myoglobin by a Program of Treadmill Running. *Am. J. Physiol.,* 213:783, 1967.
12. Gollnick, P. D. and King, D. W., Effect of Exercise and Training on Mitochondria of Rat Skeletal Muscle, *Am. J. Physiol.,* 16:1502, 1969.
13. Goldberg, A. L., Protein Synthesis During Work-Induced Growth of Skeletal Muscle. *J. Cell. Biol.,* 36:653, 1968.
14. Vajda, E., Guba, F. and Harsanyi, V., Protein Distribution in Myofibrils of Different Sarcomere Length. *Acta Biochem. et Biophys. Acad. Sci. Hung.,* 2:317, 1967.
15. Rasch, P. J., Hamby, J. W. and Burns, H. J., Effect of Protein Dietary Supplementation on the Physical Performance of Marine Corps Officer Candidates. NMFRL Report, 19, No. 6, March 1969.
16. Rasch, P. J. and Pierson, W. R., Effect of a Protein Dietary Supplement in Muscular Strength and Hypertrophy. *Am. J. Clin. Nutr.,* 11:530, 1962.
17. Feigen, R. D., Klainer, A. S. and Beisel, W. R., Circadian Periodicity of Blood Amino Acids in Adult Men. *Nature,* 215:512, 1967.

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13. ABSTRACT

The current literature was reviewed and the most recent developments in our understanding of muscle hypertrophy and performance, muscle fibers, myoglobin, mitochondria, and protein are summarized, (U)

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