THE STIFFNESS OF SPASTIC MUSCLE*

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This study stemmed from an attempt to find out whether simple physical manoeuvres have any measurable effect on the spastic state as such in small children with diplegia. Muscle tone is difficult to define except in crude clinical terms, but for the purposes of the present paper it can be defined simply as that resistance which is felt by the examiner's hand on passively extending a muscle. It was recognized clearly by early workers with the electromyogram (Weddell, Feinstein, and Pattle, 1944) that in both normal muscle at rest and in spastic muscle at rest there is no electrical activity, though in the case of the latter during stretching the electrical response is excessive, hypersynchronous, and subject to widespread irradiation. Hoefer and Putnam (1940), Lindsley, Schreiner, and Magoun (1949) and later Hoefer (1952) confirmed this, and indeed much of this early work served merely to demonstrate that the electromyogram alone can contribute little to our knowledge of states of muscular hypertonus. Combined with differential procaine block of the gamma efferents the technique has proved more rewarding (Rushworth, 1960). Weddell et al. (1944), however, made it clear that muscle tone is not merely a matter of the stretch reflex but must in part be due to the viscous and elastic properties of the muscles and tendons. A ballistic method for the measurement of the elastic property of skeletal muscle in situ in man was developed by Simonson, Snowden, Keys, and Brozek (1949) but has not proved of clinical value. There has been a tendency to regard "muscle tone" and "postural tone" as synonymous, but this is confusing, as there is tone in a normally innervated muscle which is not maintaining posture. Postural tone is a state of activity required to maintain a posture against gravity and is found, for example, in the long cervical muscles or the temporalis muscle as rhythmic motor unit activity with a frequency of 7 to 10 a second, instantly abolished by bringing the antagonists into action; while in the muscles of the back and legs it is found as occasional injections of activity into agonist and antagonist alternately to restore the body to a state of balance which is principally maintained by bones, tendons, and ligaments. Except in paraplegia in flexion the resting muscle of a spastic limb, if supported, is electrically silent, and yet its tone is high in comparison with normal or denervated muscle and becomes immediately higher on stretching. The purely mechanical component of muscle tone is present at rest and in movement, and both hypertonus and hypertonus are associated with a quantitative alteration in the physical property of the muscle. The neurogenic component of muscle tone is absent at rest, and is a complex state of hyperreactivity of the phasic and tonic stretch reflexes; and what determines the nature of the hypertonus appears to be the behaviour of the tonic part of the stretch reflex, and the timing of the lengthening reaction once stretching has begun. From the neurological point of view the spastic state comprises a number of phenomena which can be listed as follows: (a) low threshold of the stretch reflex, (b) increased reflexogenic area, (c) augmentation of the response, (d) irradiation of the response, (e) hypersynchrony of motor unit discharges, (f) desynchronization of the lengthening reaction, (g) contraction in agonist and antagonist, and finally (h) a particular distribution in the antigraft muscles. Not all of these are susceptible to measurement. Measurement of the threshold is too difficult for clinical purposes. The strength of a tendon jerk can be measured, provided the stimulus is of constant force; the technique of Buller and Dornhorst (1957) can be used with adult subjects but is too difficult to apply to young children. Hypersynchrony of motor units cannot be measured. The irradiation of the response to stretch can be mapped out but not measured. The response to a relatively slow stretch, i.e., of a speed not sufficient to elicit a tendon jerk is, however, more measurable. But the intact muscle spindle system is so designed that it will adjust itself continuously to increase in length or...
tension of the muscle. The activity of such a system can only be measured by pitting against it another servocontrolled system which will provide either constant force throughout the movement, while the velocity is recorded, or constant velocity throughout a movement irrespective of resistance, in which case the force required is measured. Servocontrolled myotonometers have been constructed by Spiegel, Wycis, Baird, Rovner, and Thur (1956), but the apparatus is costly, involves fixation of the limb and the cooperation of the subject, and is quite inapplicable to children. But the normal adult nervous system is of course servocontrolled and it can maintain a constant posture, or provide constant velocity against a changing resistance with surprising accuracy; and this fact, which is merely an expression of manual skill, is the basis of the method devised by Tardieu and his co-workers (Tardieu, Rondot, Mensch, Dalloz, Monfraix, and Tabary, 1957; Rondot, Dalloz, and Tardieu, 1958) for use with children, and of the simpler and more limited method described in this paper. Tardieu applied his method to the manual extension of the biceps at constant velocity, the force being measured by means of a strain-gauge through which is fed an A.C. signal, while the angular velocity of the elbow joint is recorded by a potentiometer giving a D.C. signal. He demonstrated that above a certain critical velocity of extension, which is the hallmark of spasticity, the resistance is directly related to the velocity of stretch. He also demonstrated a decrescendo tension in the isometric state at the end of the stretch which is clinically imperceptible; he termed this the “curve of decontraction” and implied that it is due to afterdischarge. This decline in tension in the isometric state after stretch can be recorded quickly and easily in the calf muscles using simple apparatus and only manual fixation of the knee, and the method can be employed in children under the age of 4, an age at which one can be clinically certain that no fibrous contracture is present. The principle is to apply an approximately constant stimulus in the form of dorsiflexion of the foot from its resting position to the right angle within a period of one second. This thrust was originally delivered through scales of the spring-balance type, registering either 0-10 or 0-20 pounds (Fig. 1). The operator sits in such a position that he can see neither the dial of the scales nor the clock; his task is to dorsiflex the foot and then keep it at a predetermined angle by eye for the next 30 seconds, during which time an electrically driven camera records the readings on the two dials and checks against the protractor that the angle of dorsiflexion is in fact constant. At the end of 30 seconds the foot is allowed to return to its original position for a 30-second period of similar length, and then the procedure is repeated. Any number of recordings can be made at 30-second intervals. After development of the film all the readings for tension and time are plotted in a tension-time curve. An electrical transducer devised later proved somewhat less accurate than the spring balance, but had the advantage that the signal could be recorded simultaneously with the integrated electromyogram of the calf muscles (Fig. 2). The result by either method is a series of exponential curves (Fig. 3), the peak occurring at the moment the foot reaches the right angle and stretching ceases. Even if the procedure is repeated at intervals of half an hour the shape and height of the curves are unchanged and it can be demonstrated that the tonic neck reflexes have no influence on

FIG. 1

FIG. 2.—Spastic diplegia: calf muscle. Integrated E.M.G. (top trace), E.M.G. of calf muscle (second trace), and transducer signal (middle trace) during isometric stretch for 30 seconds after dorsiflexion of the foot.
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The stiffness of spastic muscle has been studied in a number of ways. One of the most useful methods is to measure the tension in the calf muscle while it is stretched and then released. This can be done by applying a constant force to the muscle using a spring balance, and measuring the resulting force-displacement curve. The stiffness of the muscle can then be calculated from the curve, and compared with that of normal muscle.

The stiffness of the calf muscle is normally higher than that of normal muscle, and it increases with the degree of spasticity. This is due to the increased resistance of the muscle fibers to stretching, which is caused by the hypertonicity of the muscle fibers. The stiffness of the muscle is also affected by the length of the muscle fibers, with shorter fibers being stiffer than longer fibers.

The stiffness of the muscle can be measured in both the intact and denervated state. In the intact state, the stiffness is due to the tension in the muscle fibers, while in the denervated state, the stiffness is due to the passive tension in the muscle fibers.

It is important to note that the stiffness of the muscle is not a constant, but varies with the length of the muscle fibers. The stiffness is also affected by the temperature of the muscle, with higher temperatures leading to higher stiffness.

The stiffness of the muscle is an important factor in the treatment of spasticity, as it affects the force required to move the muscle.

[References]

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Fig. 3.—Spastic diplegia: calf muscle. Five consecutive tension-time curves recorded at 30-second intervals.

Fig. 4.—Tension-time curves for one normal adult and two normal children aged 4 and 3 respectively.

Fig. 5.—Spastic diplegia. Tension-time curves, one being disturbed by an extensor thrust caused by coughing.

Fig. 6.—Spastic diplegia. Tension-time curves before (continuous lines) and after (interrupted lines) a period of standing with support. The latter curves are disturbed by extensor thrusts caused by coughing.

Fig. 7.—Spastic diplegia. Relation between the height of the peak and the velocity of dorsiflexion of the foot.

Fig. 8.—Spastic diplegia. Tension-time curve during isometric stretch lasting nine minutes (heavy line). The integrated E.M.G. of the calf muscles is shaded, and the integrated E.M.G. of the anterior tibial group is shown by the dotted line. The curves are disturbed by one involuntary extensor thrust.
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Fig. 9.—Normal adult. Comparison of the curves in the normal right calf (hollow circles) with that of the left calf paralysed by intraneural procaine injection (solid circles). Acute denervation has no effect on the height or shape of the curve.

Fig. 10.—Motor neuron disease. The "curve" of a completely denervated calf muscle is flat.

Fig. 11.—Normal adult. Curve before (thick line) and after standing on tiptoes to the point of exhaustion (upper two lines) showing that the tension-time curve can be raised by exertion.

Fig. 12.—Spastic diplegia. Four consecutive tests before (continuous lines) and after (interrupted lines) a period of passive general flexion of trunk and lower limbs for 18 minutes, showing the reduction of "tone".

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Fig. 13—Spastic diplegia. Integrated E.M.G. records from calf. Top trace: resting record over a period of 30 seconds; time base 0.5 second. Middle trace: integrated E.M.G. during 30-second period of isometric stretch before period of "treatment". Bottom trace: integrated E.M.G. during 30-second stretch after a period of 15 minutes passive dorsiflexion of the foot, showing the diminution of the tonic stretch reflex.
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Fig. 14.—Spastic diplegia, the same case as Fig. 13.
Column A: tension-time curves (open circles) and integrated E.M.G. units (solid areas) for three consecutive tests before a period of 15 minutes' passive dorsiflexion of the foot. Column B: the same after the period of passive dorsiflexion of the foot, showing the reduction of "tone" and of the E.M.G. response during isometric stretch.

been shown, in the normal at least, that the actual height and shape of the curve is not affected by acute denervation, it would seem probable that the change in the electromyographic activity of a spastic muscle which has been subjected to prolonged extension is secondary to a change in the rheological property of the muscle itself. One visualizes a postural muscle, therefore, as a kind of adjustable viscoelastic springboard, modifiable by prolonged stretching or vigorous activity, the resilience of which is governed, not immediately but over a period of time, by reflex postural activity.

Summary

A simple method of measuring "tone" in the calf muscle of children with spastic diplegia is described. In the isometric state after a stretch, the decline in tension in the muscle follows an exponential curve. The height of the peak of the curve is proportional to the velocity of the initial stretch; although the curve is uniform in shape, electromyographic activity is associated only with its first part, and reasons are advanced for the hypothesis that the actual height and shape of the curve are not directly related to stretch reflex. Prolonged stretching modifies the height of the curve for about 10 minutes, and also indirectly modifies the stretch reflex obtainable from the muscle.

REFERENCES


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