THE MEASUREMENT OF THE ELASTICITY AND VISCOSITY OF SKELETAL MUSCLE IN NORMAL AND PATHOLOGICAL CASES; A STUDY OF SO-CALLED "MUSCLE TONUS"

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Muscle "tonus" has been described, defined, and measured in a multitude of different ways.[1] Scientifically speaking, however, there is no such *single* property of a muscle as its tonus. Rather tonus is a convenient term which includes many different properties such as elasticity, viscosity, and contractility to say nothing of the many nervous processes controlling the muscle reflexes. The continued employment of the term, convenient as it is, serves to avoid the necessity of analyzing "tonus" into its various components. An experimental analysis of this sort however is exactly what is needed for a complete understanding of the phenomenon and for an intelligent and scientific classification of the various types of rigidities familiar clinically.

Muscle "tonus" is so complicated in nature that it cannot properly be measured by any *one* method. Herein lies the justification for the development of yet another method. For scientific purposes, however, more is required than merely more methods, and more than merely a simple and convenient graphic test serving to distinguish different degrees or types of rigidity. For a scientific analysis each method must measure some one clearly defined physical property of the muscle in *absolute* units. Just as surely as a muscle has length and breadth it has elasticity and viscosity, etc. which may show functional changes, and these properties must be measured quantitatively, not qualitatively, in proper physical units. It is perhaps of interest to obtain drum tracings showing changes which may be interpreted as due to an increased muscle viscosity. It is better to measure this viscosity and discover how *much* it is increased.

METHOD

The method which we have developed and used has certain practical disadvantages in matters of convenience, but, like a previous method re-

[1] Recent methods of Pollock and Davis (1932) and of Berkwitz (1932) may be mentioned in this connection in addition to methods referred to in our previous paper (Smith, Martin, Garvey, and Fenn, 1930).

ported from this laboratory (Smith, Martin, Garvey and Fenn, 1930) it does at least measure something definite in absolute units. The value of the apparatus is for research rather than for routine clinical use.

The method is a dynamic one and was developed in an effort to avoid the rather tedious calculations involved in our former method, which depended upon a mathematical analysis of the curve obtained by recording the rate of flexion of the knee in response to gravity. The general principle involved in this method is to move the leg passively to and fro, bending it at the knee at constant angular velocity, and to record on a revolving drum the force necessary to move it. The movement of the leg *at constant angular velocity* is an important feature of the apparatus because it permits us to neglect inertia. The force recorded is therefore purely one of resistance to displacement and is unaffected by acceleration or deceleration, and therefore unaffected by the mass of the leg.

The arrangement of the apparatus is shown in Figure 1. The subject lies on one side with one leg on a moving arm of the apparatus and the

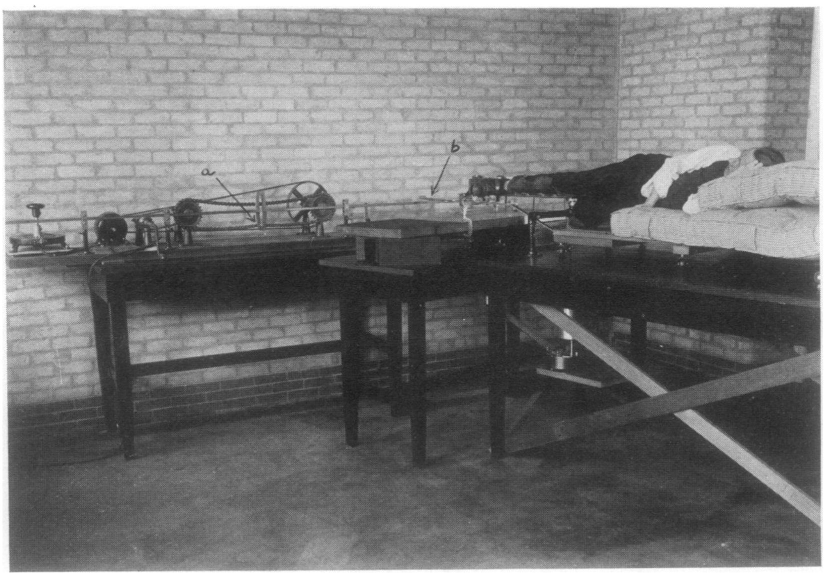

FIG. 1. GENERAL VIEW OF APPARATUS

motor moves this arm back and forth carrying the leg with it. The axis of rotation of the moving arm coincides with the axis of rotation of the knee. Tension is recorded by a principle similar to the one used in the apparatus described by Schaltenbrand (1929). The details are shown in the diagram on Figure 2, there being two arms, A_1 and A_2 pivoted about the same vertical axis, this vertical axis being made to coincide with the axis of rotation of the knee. The leg rests on A_1 which is moved back and forth by A_2 to which it is attached by springs (s). The displacement of A_1 with respect to A_2 caused by a given amount of force stretching the springs is a measure of the resistance to movement. This displacement is recorded by means of a thread attached to A_1, passing over a pulley P_1, which is fixed to A_2, and passing thence by another pulley P_2 to a lever under the table which records on a revolving drum. The string between P_2 and the lever coincides with the axis of rotation of A_1 and A_2 so that the movement

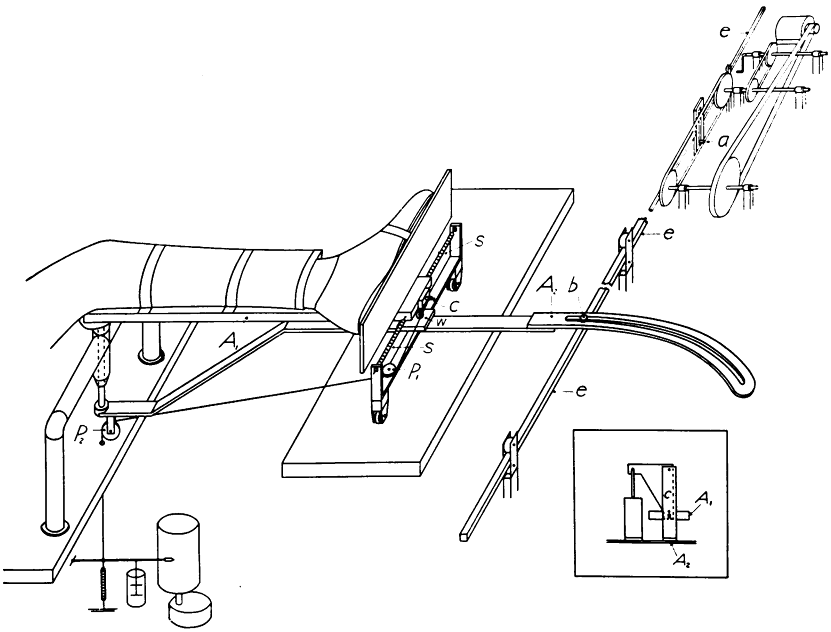

FIG. 2. DIAGRAM OF APPARATUS

Not drawn strictly to scale. The motor and chain in the upper right corner is much diminished in size. The inset shows details of the dash pot which is fastened to A_2 just to the right of the pin c where the thread over pulley P_1 is fastened. Rapid horizontal movements of A_1 and the leg in relation to A_2 are translated into vertical movements of the piston in the dash pot by means of a right-angled lever.

of these arms, without any real displacement of A_1 with respect to A_2, causes no movement of the lever. In order to support the weight of the leg, A_2 is provided with two wheels which run on a galvanized iron surface of the table with negligible friction (see Fig. 1). Likewise there is a wheel between A_1 and A_2 to reduce friction when the weight of the leg is bearing down on A_1. The force for moving the leg is applied to A_2, the lower arm, by a toggle b, which runs in a slot on A_2. b is carried backward and forward with constant linear velocity by the motor and the slot in A_2 is so designed that a linear movement of the toggle b results in movement of A_2

at constant angular velocity. The total excursion of b is 90 cm. and that of A_1 and A_2 and of the leg itself is 63°. The method by which the toggle b is made to move with a constant linear velocity is shown in Figure 1. The heavy chain passes over two sprockets which are driven by a 1/4 horse power D.C. motor. The chain carries at one point a toggle a which engages with a slot in the bar c, which in turn carries the toggle b. (The bar c is shown in three sections in Figure 2. It is actually one steel bar 12 feet long and 1/2 inch square.) Thus at constant speed of rotation of the motor the toggle a on the chain moves with constant linear velocity and therefore also the toggle b. There is a considerable amount of vibration set up when this apparatus is running and this is damped out by two oil dash pots, one to damp movements between A_1 and A_2 and one directly on the recording lever. These effectively eliminate oscillations of high frequency but do not interfere with the slower changes due to the pull of the muscles.

Measurements of records

A typical record obtained with this apparatus is shown in Figure 3. The large spikes represent the points where the direction of motion is reversed. These spikes are of no significance, their height depending merely upon the speed of movement and the inertia of A_1 and the leg. Between

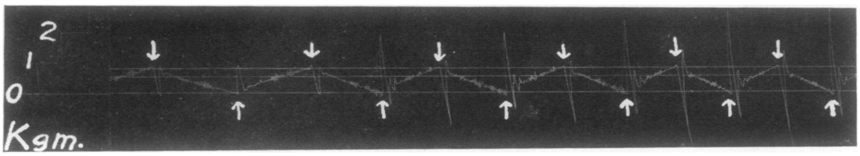

FIG. 3. TYPICAL RECORD SHOWING CALIBRATION

Points where tonus is measured are indicated by arrows. Horizontal lines were drawn arbitrarily by spinning drum after record was taken. Reduced to 3/5 original size.

the spikes, the record indicates the total resistance to movement offered by the muscles, the joint, and any frictional forces in the apparatus. At the points marked by arrows measurements are made of the vertical distance above or below the horizontal base line. Deflections at these points represent the resisting forces at the end of the flexor and extensor movements respectively. The base line can be drawn representing zero tension but in practice we have found the position of this line slightly variable and have therefore drawn any base line arbitrarily merely for purposes of measurement and have utilized only the *sum of the flexor and extensor resistances,* i.e. the vertical distances on the record between two successive points indicated by arrows.

Routine measurement of the resistance to movement in the leg of a patient consists of a preliminary record at a very slow speed, then a series of periods of four or five to and fro movements each, at increasing speeds, and finally a repetition of the same observations at decreasing speeds, ending up with a very slow movement. The speed is varied by the resistance in the motor circuit, but for very slow speeds it is necessary to turn the shaft by hand using a handle and crank provided for this purpose.

Figure 4 shows some complete sample records. *C* is a typical record from a normal subject. The large excursions, representing merely the over-shoot of the instrument when the direction is reversed, are naturally higher at high speeds. They appear likewise in the record *A* obtained with an artificial leg consisting merely of a weight tied to the apparatus. This record with an artificial leg differs however in showing practically zero deflections between and just previous to the large spikes, these being the points which are measured. Records *D* and *E,* Figure 4, are taken from subjects classified clinically as spastic (Parkinson's) and record *B,* from a case of muscular atrophy which was clinically flaccid.

After taking these records they are measured as described and the average values of deflections above and below the arbitrary base line obtained in successive movements at each velocity are determined and added together so that figures are obtained for the sum of the average flexor and extensor resistances at a series of different velocities. These deflections are calibrated in terms of kilograms on the original record (as in Figure 3) so that deflections in centimeters can be expressed in kilograms. These values are multiplied by the distances from the point on the apparatus where the calibrating force was applied to the axis of rotation, a distance of 60 cm. so that the results are finally expressed in terms of kilogram-centimeters of torque. These values are plotted against the angular velocity of movement in radians per second. Graphs representing average values of this sort are shown in Figure 5. As the velocity of movement increases the resisting force also increases, usually in a more or less linear fashion. It is noteworthy, however, that if these curves be extrapolated backwards they do not pass through the origin but intercept the *X* axis at a point which represents the force exerted at zero speeds of movement. It is, in fact, usual that a leg simply resting on the apparatus exerts some slight force either in the flexor or the extensor direction. This resting force may be regarded as a measure of the elasticity of the leg. The slope of the line, representing the increase of force for a given increase of velocity of movement, may be taken as a measure of the viscosity of the leg. The meaning of these forces may be stated more explicitly as follows:

Let the leg be assumed to be an elastic body which is at rest and exerts no external tension at some intermediate position. Let it have a coefficient of elasticity K and a coefficient of viscosity μ. If displaced a distance s_1 to the " flexor " end of the range the flexor muscles are stretched and an elastic force Ks_1 is exerted. Likewise an elastic force Ks_2 is exerted at the " extensor " end of the range. Since our measurements were all made at the ends of the range,

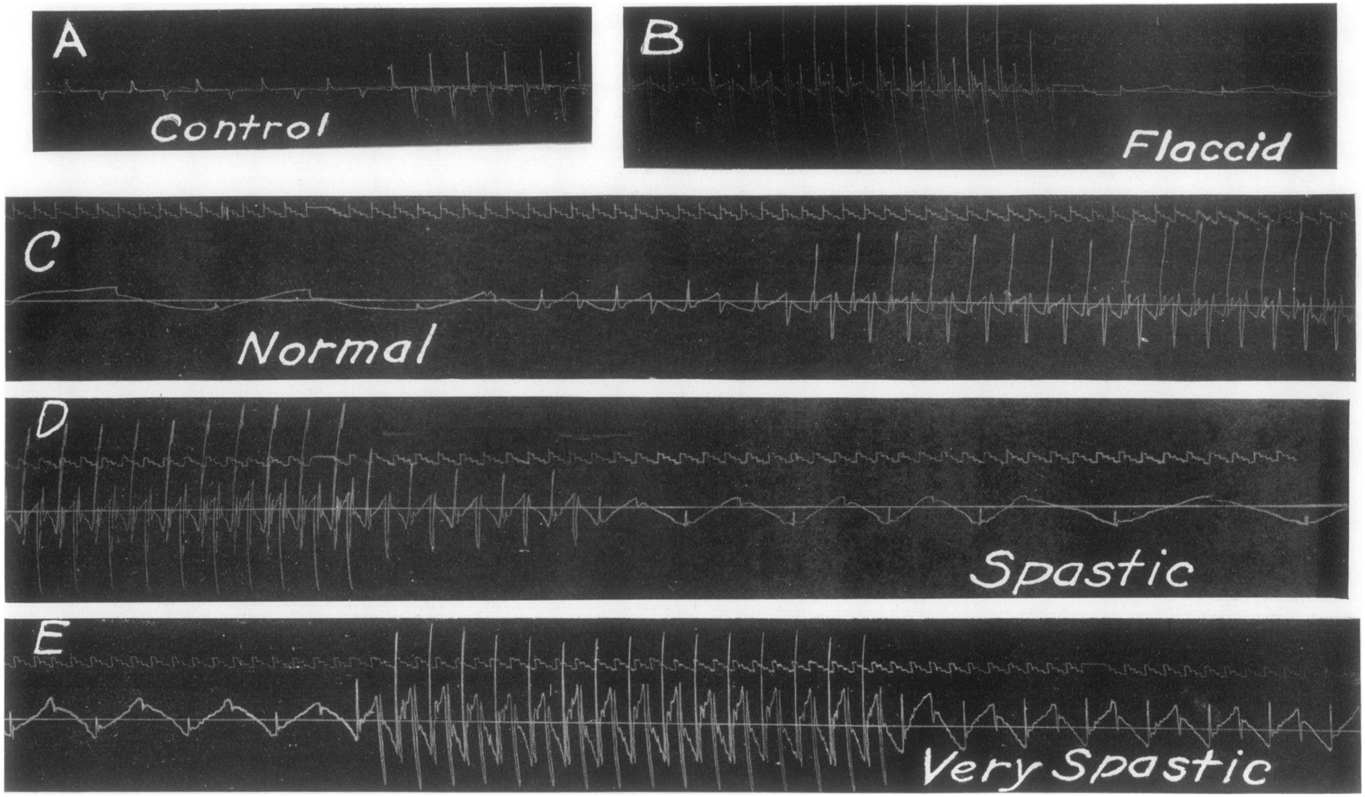

FIG. 4. SAMPLE RECORDS AT VARYING SPEEDS

A, control—no leg; *B*, muscular atrophy; *C*, normal; *D* and *E*, Parkinson's syndrome. Time in 1 second intervals. Reduced to ¾ original size.

the resting force, or force at zero velocity (obtained by extrapolation of graphs in Fig. 4), is $Ks_1 + Ks_2$, or $2\ Ks$, if $s_1 = s_2$. The force ($2\ Ks$) is therefore proportional to the coefficient of elasticity of the leg. From this value the coefficient of elasticity of the muscles themselves could be obtained by dividing $2\ Ks$ by 2 and by the average displacement, s, of the individual muscles and reducing to unit length and cross section area. For this purpose it would have to be assumed that the extensor muscles exert no force in the flexor position and vice versa. When the leg is moving with a velocity ds/dt there is an additional force measured equal to $\mu\ ds/dt$. The force which we have actually measured is 2

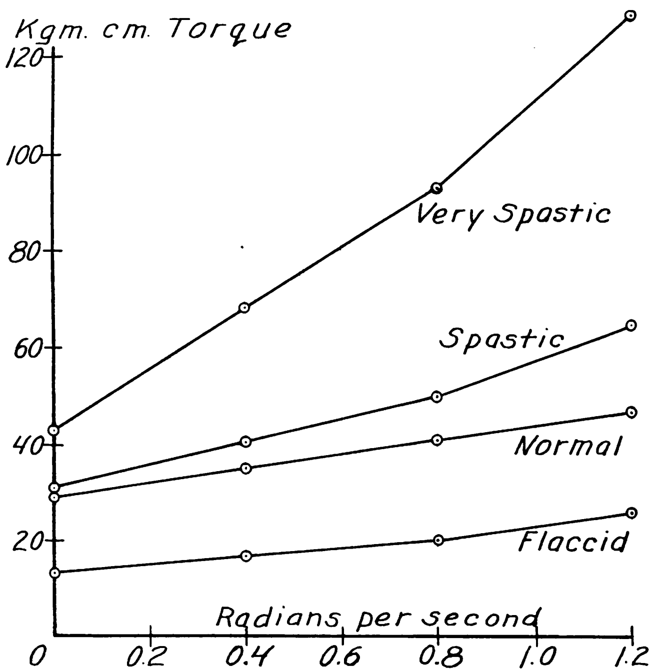

FIG. 5. AVERAGE VALUES FROM TABLE I

The resisting torque is plotted as ordinates against the angular velocity of movement of the leg at the knee in radians per second. The upper graph was taken from a patient showing Parkinson's syndrome.

$Ks + 2\mu\ ds/dt$. The slope of the graphs of Figure 4 is therefore equal to 2μ or twice the coefficient of viscosity. Lacking a knowledge of the true displacement, s, of the individual muscles we have not tried to calculate the coefficient of elasticity of the muscles themselves but we simply refer to the observed resting force as the elasticity *of the leg*. We shall show later, however, how an approximate calculation can be made of the value of μ for the muscles themselves. Treating the leg as a mere physical object this is a true coefficient of viscosity but it must be remembered that it includes " reflex viscosity " or the force developed as a result of proprioceptive reflexes initiated by the movement of the leg.

NORMAL AND PATHOLOGICAL CASES

We have measured in all the elasticity and viscosity of 19 normal legs, 46 flaccid legs, and 29 spastic legs (as classified clinically), and some others unclassified. Separate graphs for each of these legs, similar to those in Figure 5, have been plotted and figures obtained by graphical interpolation for the kilogram-centimeters of torque at 0.4, 0.8, and 1.2 radians per second. The difference between the values at 0.4 and 0.8 has been subtracted from the value at 0.4 in every case in order to obtain the force exerted at zero velocity (elasticity), this being in effect the backward extrapolation of the curve. The average values so obtained as recorded in Table I, and plotted in Figure 5, are 13, 29, and 31, respectively, for the flaccid, normal, and spastic legs. Likewise the average values for the slope of the curve between 0.4 and 0.8 and between 0.8 and 1.2 radians per second are also recorded in Table I. Here also the more spastic legs generally show the higher value, as would be expected.

TABLE I

Summary of torques measured in kilogram centimeters

	Number of cases	Torque at zero velocity	Increase in torque	
			Between 0.4–0.8 radians/second	Between 0.8–1.2 radians/second
Flaccid	46	13	3.6	5.7
Normal	19	29	6.0	5.5
Spastic	29	31	9.5	14.4

It is a point of some interest that this method does not invariably reveal abnormally high elasticity or viscosity in a leg which is classified clinically as spastic. Thus a group of 17 patients was studied. Nine of these exhibited symptoms of Parkinson's syndrome, and eight cases manifested spasticity due to a pyramidal tract lesion. Thus 34 legs were measured. An arbitrary scale was chosen so that they could be classified on the basis of the measurements as non-spastic, spastic, or markedly spastic. Likewise the same legs were classified on the basis of the clinical report in similar groups. The results may be summarized as follows:

Spastic clinically and by test	17
Spastic clinically, not spastic by test	14
Markedly spastic clinically, not spastic by test	6
Spastic by test, not spastic clinically	1

The result shows that 14 out of 31 clinically spastic cases do not appear to be so by this method of measurement. The largest percentage of failures to confirm the clinical impression of stiffness occurred in the group with pyramidal tract signs where only one out of seven clinically spastic legs appeared abnormally resistant on the apparatus. Of 17 Parkinsonian legs which were rigid clinically, six failed to show any abnormality in the records as far as the viscosity was concerned but of these six cases, four showed abnormally high elasticity. Most of the spastic cases which the apparatus completely failed to detect were therefore due to pyramidal rather than extra-pyramidal lesions.

It may be suggested that the pyramidal spasticity is more directly or more completely dependent upon the stretch reflexes for its manifestation and that these stretch reflexes are not always elicited by our apparatus for the following two reasons: (1) There is a certain threshold speed of movement required for the development of a stretch reflex which is the basis of the pyramidal spasticity. This threshold is attained in the clinical test when the leg is moved by hand but is not attained in the laboratory examination. The threshold may be higher in pyramidal than in extra-pyramidal lesions. (2) The spasticity felt clinically may be in the form of an isolated stretch reflex which develops at a certain point in the excursion of the limb but is absent at the end of the excursion where measurements are made with our apparatus.

It is possible to offer another suggestion in partial explanation of these results. The psychological factor is an important one in measurements of this sort as Berkwitz (1932) has emphasized and the position of the subject in our apparatus is not always conducive to complete relaxation in all persons. This may account in part for wide variations in normal cases which thus overlap the spastic range and interfere with clean-cut distinctions. Further, considerable allowance must be made for subjective error in the rough clinical classifications.

The difference which we believe exists between pyramidal and extra-pyramidal spasticity is in agreement with the conclusion of Pollock and Davis (1929, 1932) who state that "muscles intoned by labyrinthine tonic reflexes show marked internal friction of so-called viscosity whereas the muscle intoned by muscle proprioceptors show an elastic type of curve." Schaltenbrand (1929) has also observed a difference between pyramidal and extra-pyramidal rigidity which would seem to indicate a greater dependence of the former upon stretch reflexes for he found that the rigidity persisted after the movement stopped in Parkinsonian muscles but not in muscles with spastic paralysis.

These results provide us with some information about the nature of the spasticity which is observed clinically. In some measure this is a static spasticity (elasticity) but in general the spasticity is only present when one attempts to measure it, that is, it is purely a dynamic spasticity (viscosity) which is developed to an abnormal degree by moving the leg. This spasticity becomes therefore to a considerable degree a matter of stretch reflexes. To progress further in the investigation of the subject it would be desirable to be able to measure the threshold stimulus for these stretch reflexes or for a knee jerk. Apparently in some spastic patients the threshold is sufficiently high so that no stimulus takes place at the velocities which we could attain in our apparatus. These legs appeared to be completely normal as far as could be determined from graphic records, yet when tested in the usual clinical manner by simply bending the knee with the hand at considerably higher velocities, definite indications of spasticity could be obtained. The hand is more sensitive than the apparatus in this respect; at least it can test the muscle at higher velocities of movement and can pick out the particular range and conditions which will best elicit a spastic response. In our previous study of this subject we found similar indications that clinical spasticity is a matter of stretch reflexes, for we found that the spastic leg did not fall smoothly but rather in jerks, so that the rate of fall could be well imitated by applying a tap to the patellar tendon while the leg was falling. This appeared also in Parkinsonian legs which are therefore not uninfluenced by reflexes.

The inability of this method to detect spasticity in certain legs does not mean that it cannot detect small differences in tension but rather that the legs were not spastic under the conditions of the measurement—at least the spasticity was no greater than in the most resistant of normal legs. There is in fact little doubt that a systematic investigation of two legs with our apparatus can reveal differences between them which cannot be detected by hand. Thus one case of hemichorea was examined on five successive occasions and in four of these tests higher forces were measured on the affected side due either to higher elasticity or higher viscosity on that side. Another similar case was examined three times in two of which the affected side showed the greater resistance while the third trial showed no difference between the two legs. None of these differences could be detected with certainty by the hand.

The records of Figure 6 were taken from a patient who readily went into a tetany on overbreathing. Records *1*, *2*, *3*, and *4* were taken at intervals during a period of hyperventilation. In *4* the tetanus was very marked and the resistance finally became so great that the motor was unable to move the leg at all. The spikes indicating the sudden reversal of direction are scarcely visible at all on account of the extreme spasticity.

Normal viscosity

Figures in Table I for the slope of the curves representing torque plotted against velocity are of interest from the point of view of the coefficient of viscosity of normal muscle. By coefficient of viscosity we understand the force necessary to maintain a unit increase in velocity of movement, i.e., dF/dV, where F represents the force in grams per cm.^{2} cross section and V is the velocity of shortening in cm. shortening per cm. length of muscle per second. It is possible to calculate from the figures of Table I a coefficient of viscosity expressed in these units for comparison with similar figures obtained in other ways.

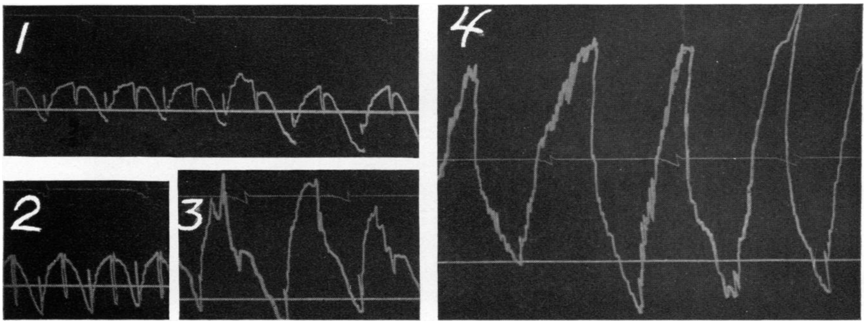

FIG. 6. FOUR SUCCESSIVE RECORDS AT CONSTANT SPEED FROM A PATIENT DURING OVERBREATHING WHICH BEGAN JUST BEFORE THE FIRST RECORD WAS TAKEN.

The speed of the motor moving the leg was decreased somewhat in Number 4 because of the great resistance against which it had to work. Time in 5 second intervals. Reduced to ¾ original size.

To do this it is necessary to know the cross section area of all the muscles which are stretched when the knee is bent. These comprise the quadriceps group, the hamstring group, and the gastrocnemius. Only a rough estimate can be obtained of the average normal cross section of these muscles. We have attempted to estimate it from cross section diagrams of the leg, such as those given by Braune and Fischer (1889, Table II). The total cross section area of the diagram was measured by a planimeter and also the cross section area of the particular muscles concerned. Knowing what fraction of the total cross section area is represented by a given muscle it is simple to calculate this fraction in absolute units from the circumference of an "average" normal leg. In this way we have found that the cross section of the quadriceps represents 34.6 per cent of the total cross section of the leg, the hamstrings, 19.3 per cent, and the gastrocnemius 15.9 per cent. The first two are measured at the upper third of the thigh and the gastrocnemius at the calf. Thus the cross section areas may be estimated roughly at 790, 440, and 172 $cm.^2$ respectively or a total of 1400 $cm.^2$. From Table I the increase in torque between velocity 0.4 and 1.2 radians per second for normal muscles is 11.5 kgm. cm. If the lever arm of the muscles concerned be estimated at 3.8 cm. (Fischer, 1927), then the force on the muscle tendons is 3020 grams or 2.15 grams per sq. cm. This force is concerned with a velocity of rotation of the leg of 0.8 radians per second, which with a radius of 3.8 cm. means a rate of stretching of the muscles of $0.8 \times 3.8 = 3.04$ cm. per second. If the muscle length be estimated at 40 cm., this means a velocity of shortening of 0.076 cm. per cm. muscle length per second. The coefficient of viscosity is therefore 2.15/0.076 which equals 28.3. This figure may be compared with considerably larger figures obtained by Bouckaert, Capellen and de Blende (1930), of 1120 by an extensometer method, 1005 by the Levin-Wyman method. Similar values may be calculated from the data of Hill (1922) on work performed by human arm muscles in shortening at different speeds.

From Hill's data, Fenn, Brody, and Petrilli (1931, *see* their Table III) calculated the per cent loss of tension for an increase in the angular velocity of movement of 1 radian per second, and give also Hill's value for the maximum work, W_0 (in kgm. M.), which was performed. To calculate the coefficient of viscosity in the above units it is necessary to determine the force on the muscle corresponding to this maximum work, and to express the angular velocity in terms of cm. shortening per cm. of muscle. The work was performed by pulling a distance of 60 cm. so that $W_0/60$ is equal to the force on the hand at a distance of 34 cm. approximately from the elbow. If the lever arm of the muscles be taken as 2.88 cm. and the cross section of the flexor muscles be estimated as 29 per cent of the total cross section of the arm or about 218 sq. cm., then the force on the muscles is equal to $W_0/0.6 \times 34/2.88 \times 1000/218 = 90\ W_0$ gm. per cm.^{2} If the lever arm of the muscles is 2.88 cm. and the length of the muscle be estimated at 20 cm. then an angular velocity of 1 radian per second represents a shortening of 2.88/20 cm. per cm. length of muscle per second. If the values 43.5 K/W_0 (per cent loss of tension for an increase of 1 radian per second in angular velocity) as given by Fenn, Brody, and Petrilli be multiplied by 20/2 88, we have the per cent loss of tension for 1 cm. per second increase in velocity. Multiplying by 90 W_0 we have the coefficient of viscosity. Thus if W_0 equals 14 kgm. the coefficient of viscosity is $14 \times 90 \times 11.5 \times 20/2.88$ which is equal to 1010. Other values similarly calculated from the same data are 738 and 637. These values compare very well with those of Bouckaert, Capellen and de Blende, and also with others which we have obtained on stimulated frog muscle.

The value of 28 from our muscle tonus measurements is very much lower than similar coefficients of viscosity calculated from Hill's data (637 to 1010) and the difference is greater than the inaccuracies of the estimations. It is perhaps accounted for by the fact that in passively flexing a leg, the flexor muscles assist the movement by their own elasticity while the extensor muscles retard it and we are measuring really the difference between the flexor and extensor pulls. These relatively feeble elastic forces of resting muscles are of no importance in Hill's experiments with contracting arm muscles.

It is also of interest to compare the figures obtained in Table I for the resistance of normal muscles to stretching at different velocities with corresponding figures which may be derived from the data of Smith, Martin, Garvey and Fenn (1930) who measured muscle tensions from a record of the speed with which the lower leg falls from the horizontal position when suddenly released. In their Figure 6, subject number 2 (normal), graphs are given for the velocity of fall of the leg and for the resisting force at different times during the fall. From measurements on these curves, simultaneous values for velocity and force may be obtained and these are plotted in Figure 7 for times 0.1, 0.2, and 0.3 second after the moment of release of the leg. This gives a smooth graph through the origin showing that the force increases as the velocity increases. Three other points at low velocities are indicated by crosses on this curve. These were derived from the data of Table I. The torque at velocities 0, 0.4, 0.8, and 1.2 radians per second for normal muscles was divided by 3.8 cm., the estimated lever arm of the muscle, to obtain the force in kilograms on the muscle itself. The value at zero velocity was substracted to get the force due to movement only. On the assumption that half of this force was measured during flexion and the other half during extension, the figures have been divided by two to give the tension in the extensor muscles at these three velocities. It is striking that the results obtained by these two utterly different methods should fall on the same smooth curve. The validity of the comparison depends upon the assumption that the dimensions of the legs

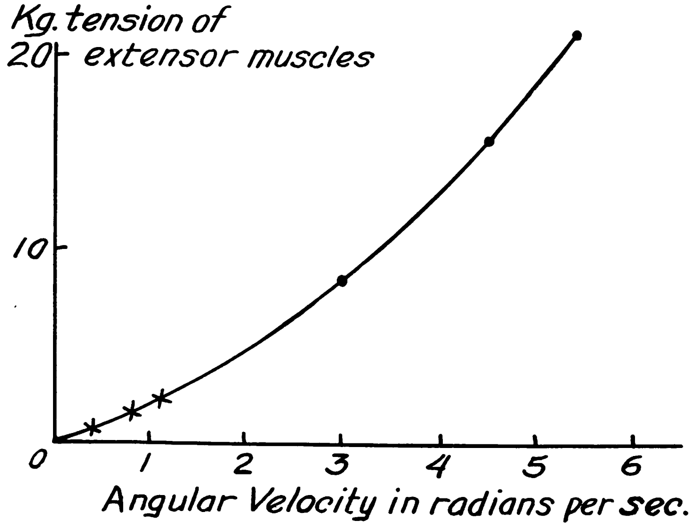

FIG. 7. RESISTANCE OF THE NORMAL LEG TO PASSIVE MOVEMENT (ORDINATES) PLOTTED AGAINST THE ANGULAR VELOCITY OF MOVEMENT (ABSCISSAE)

Dots are from the data of Smith, Martin, Garvey, and Fenn and crosses from data of Figure 5. The tensions have not been reduced to unit cross section areas.

in the two sets of data were approximately equal. One other complicating factor has been neglected, i.e. the length of the muscle, which has varied at the different points chosen. The graph nevertheless represents the best data now available on the resistance offered by human muscles to passive stretch at different velocities. Further data are necessary under more uniform conditions before conclusions can be drawn but the data as they stand indicate that the force increases approximately as the 1.26th power of the velocity of stretching, i.e. the curve is concave upwards. The same tendency is shown by the graphs of Figure 5.

DISCUSSION

We have described in this paper an apparatus with which we have been able to measure in absolute units the resistance to movement at the knee joint at different velocities of rotation in both directions. Measurements have been made in both normal and pathological cases. The results show the variations of force as a function of velocity. Thus both a static and a dynamic measure of "tonus" is found, for the force at zero velocity is static and is proportional to the coefficient of elasticity of the leg. The increase of force with increase of velocity is a dynamic measure of "tonus" or is more properly defined as the coefficient of viscosity of the leg. This figure has been calculated and provides an adequate description of the behavior of the leg in the apparatus.

We do not believe that the apparatus described is ideal for the purpose. It has served, however, to measure the resistance to movement independently of inertia and as a function of velocity and the magnitude of this resistance is of physiological interest. On the clinical side the results serve to emphasize the importance of speed of movement in eliciting a spastic response. The reflex nature of spasticity is thus indicated. It appears that if we could explore the whole range of movement of the knee at different velocities we might expect to find some individuals in whom stiffness would only manifest itself above certain velocities and perhaps at certain knee angles.

SUMMARY

1. An apparatus is described which alternately flexes and extends the leg at the knee at constant angular velocities and records simultaneously the necessary torque which is applied to the leg for this purpose.

2. The force so recorded is not zero at zero velocity and this residuum is a static measure of muscle "tonus" and is found to be large in clinically spastic subjects. It is equivalent to a measure of the elasticity of the muscles.

3. The force (F) increases more or less linearly with increase in velocity of movement (V) and this rate of increase of F (dF/dV) is a kinetic measure of the muscle "tonus" and serves for a calculation of the coefficient of viscosity of the leg. The average value for normal legs is 28 grams per $cm.^2$ of muscle cross section for a velocity of stretch of 1 cm. per cm. muscle length per second.

4. Some legs classified clinically as spastic give normal values when tested by this apparatus. This occurs chiefly in patients with pyramidal rather than in those with extra-pyramidal lesions, and it appears to be due to the slow speeds of movement which are attained by the apparatus which are not adequate to reach the threshold for the stretch reflexes responsible for the spasticity observed clinically.

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