A STUDY
OF THE SO-CALLED
TENDON-REFLEX PHENOMENA.

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THE following paper records a series of observations on the two forms of muscular spasm known under the above designation (described first by Erb and Westphal), and which have been associated with spinal sclerosis: (1), the movement which occurs under normal conditions at the knee-joint when the patellar tendon is struck, the "patellar-tendon reflex" of Erb, the "knee phenomenon" of Westphal, which is absent in most cases of locomotor ataxy, and, (2), the movement which occurs at the ankle-joint in certain forms of disease of the spinal cord (probably lateral sclerosis) when the extensor muscle and tendon are suddenly put upon the stretch—the "Achilles-tendon reflex" of Erb, the "foot phenomenon" of Westphal.

Although the characters of each of these movements, and the mode of their production, have been made familiar to the profession in this country by the description of them by Dr. Grainger Stewart,¹ and Dr. Buzzard,² it is necessary, for the sake of clearness, to state briefly the method by which they may be obtained.

¹ "Clinical Lecture on Tendon-Reflex," 'Medical Times and Gazette,' 1878, January.

² "Lectures on Sclerosis of the Cord," 'Lancet,' 1878, July.

KNEE-REFLEX.

The knee-reflex, "patellar-tendon reflex," or "knee-phenomenon," is the contraction which may, under normal conditions, be excited in the quadriceps extensor of the knee-joint, by striking the patellar tendon a light but sharp blow, the tendon and muscles being previously put gently on the stretch. Any position will suffice which involves tension in this tendon, *i.e.*, any flexion of the knee-joint, but as the effect of the resulting contraction can be best observed by the consequent movement of the leg, a position is most convenient which leaves the leg free to move, such as sitting with the legs hanging freely, or with the leg to be tested placed across the other, or across the observer's arm, so that the knee-joint rests in a position of flexion at an angle a little greater than a right angle. This is especially convenient, because it prevents the blow on the tendon from causing an increased flexion of the leg, the swing back from which may, if the leg is hanging vertically, be mistaken for the reflex contraction.

Schültze and Fürbringer have shown that it can be obtained with great readiness by a blow on the exposed tendon of an animal. It may also sometimes be obtained by a blow upon the rectus tendon above the patella, by a blow on the muscular fibres of the rectus itself, and by an oblique downward blow on the patella, as readily as by a blow upon the patellar tendon. Each blow is followed by a single contraction, but as long as the blows are continued the contractions follow, and by making the blows succeed one another with sufficient rapidity, the contractions occur so closely that only slight relaxation takes place in the intervals, and thus a state of almost tetanic contraction is produced. The blow, if sharp, causes a peculiar sensation in the part struck, and sometimes also in the muscles of the thigh. Under pathological conditions the sensation may amount to actual pain, although the tap is light.

In order to ascertain what are the variations in this phenomenon under normal and abnormal conditions, I have,

with the kind assistance of Mr. A. E. Broster, resident medical officer at the National Hospital for the Paralysed and Epileptic, examined 300 individuals, of whom 150 were suffering from no known paralytic condition of the lower extremities. Of these some were, as far as was known, in perfectly normal health, but the majority were the subjects of simple epilepsy. The hand only was employed, the fingers being extended and the patellar tendon struck with the edge of the little finger.

Of the whole 300 cases the movement was entirely absent on this mode of testing, on both sides, in seventeen. It is possible that the use of the percussion hammer, as proposed by Westphal, might have elicited a slight reflex in some of these cases. The observations were, however, carefully made, and the results are, I think, accurate as regards the mode of testing employed. Four of the seventeen were suffering from undoubted locomotor ataxy, a fifth had atrophy of the optic nerves, and commencing ataxy was suspected. Of the remaining twelve, two were under treatment for paraplegic weakness of legs, but presented no indication of ataxy. These were :

(1.) A man, æt. 52.

(2.) A man, æt. 45; with some weakness of the legs, especially in the flexors, which had apparently been left by an attack of spinal meningitis. Sensation of the legs was normal.

The remaining ten patients were as follows :

(1.) A woman, æt. 58, who had had an attack of right hemiplegia, but had recovered so as to be able to walk five miles. The patellar reflex was absent on both sides (as in all the cases now under consideration).

(2.) A man, æt. 58, suffering from some mental disturbance and slight weakness, deafness, and considerable auditory-nerve vertigo.

(3.) A man, æt. 36, suffering from tumor cerebri, not syphilitic, of which he afterwards died. When tested he was suffering from slight weakness in the right arm, but was able to walk a long distance.

- (4.) A girl, æt. 11, suffering from chorea, a good walker.
- (5.) A man, æt. 19, suffering from epilepsy, whose legs were curved from old rickets, and who was not able to walk more than a mile.
- (6.) A man, æt. 30, suffering from epilepsy and considerable cardiac disease; able to walk about two miles.
- The remaining four cases were all young epileptics.
- (7.) A boy, æt. 7; a bad walker.
- (8.) A girl, æt. 19; a bad walker.
- (9.) A girl, æt. 22; walking power not good, about a mile.
- (10.) A girl, æt. 20; walking power not good.

Whenever the reflex was apparently absent it was tested repeatedly with great care, without the intervention of the clothes or with only a single garment.

It would thus appear that the knee reflex cannot be obtained, at least with the hand, in about four per cent. of patients suffering from disease of the nervous system who present no symptom of locomotor ataxy, and that in many of these, from sex and age, the possibility of commencing ataxy can be certainly excluded; but that, in most of them, the loss is associated with defective power of continued exertion with the legs.

In at least half the cases of nervous disease in which the knee reflex cannot be obtained with the hand the patient is not suffering from locomotor ataxy. To those who have followed recent discussion on this subject this statement will appear surprising. Hitherto, apparently, the symptom has rarely been searched for except in ataxics or in a few persons in normal condition for the sake of comparison.¹ Before considering the conditions in which it is commonly absent, the facts collected suggest several points of interest regarding the phenomenon.

¹ Since this paper was read Dr. Berger has published ('Centralbl. für Nervenheilkunde,' No. 4, 1879) the results of the examination of 1409 healthy individuals. He found that no reflex could be obtained by any method of examination in 22, or 1.56 per cent. In comparing this result with those which I have obtained, it must be remembered that most of the persons tested by me were suffering from some affection of the nervous system.

In three cases only was the reflex absent in one leg, and present, although slight, in the other. One was a woman aged 47 who had had an attack of right hemiplegia, from which she had recovered sufficiently to be able to walk several miles. The reflex was present, although slight, in the leg which had been paralysed, and was absent in the other. The second case was a woman aged 41 who had suffered in early life from chorea and subsequently from epilepsy. She had some weakness of the legs, greatest in the left, and was able to walk only one mile; the knee reflex was present though slight in the weaker leg and was absent in the other. In the third case, it was found that, on the side on which the reflex could not be obtained, there had been an old transverse fracture of the patella, and the two halves were some distance apart.

Twenty-seven cases of hemiplegia from cerebral disease were examined. They were of various duration and degree of recovery: most attended as out patients and so were able to walk. The reflex was equal in the two legs in 13 of the cases, and it was unequal in 14. In the latter, without an exception, the excess of movement was on the paralysed side. The occurrence of this excess seems to bear no necessary relation to the development of the ankle clonus, which is often present in old hemiplegics. This ankle clonus was marked in several of the cases in which the knee reflex was equal on the two sides and it was absent in several cases in which the excess of movement on the paralysed side was very large.

In order to estimate the average degree of movement, apart from any weakness of the legs, the range of movement (of the foot) which could be excited by such a tap as usually develops the maximum effect, has been compared in one hundred epileptics whose walking power was reasonably good. The amount of movement was estimated by the eye, checked by an occasional measurement. Of the 100, 37 were women and 63 were men. The results are shown in the following table:

Movement in inches.		Men.		Women.		Total each degree.
$\frac{1}{2}$	...	3	...	1	...	4
1	...	22	...	6	...	28
2	...	19	...	18	...	37
3	...	14	...	11	...	25
4	...	3	...	1	...	4
5	...	2	...	—	...	2

It appears from this that in 90 per cent. of individuals possessing good walking power the range of movement is between 1 and 3 inches. The mean of the whole is just 2 inches, and about as many present a slight excess above the average movement, as present a deficiency. The reflex was entirely absent in no patient with good walking power, although in 4 it was slight, not more than half an inch. In only 6 did it exceed 3 inches.

The sexes present some differences, if it be permissible to generalise from so limited a number of cases. A larger number of men present a considerable excess and a considerable deficiency. Two fifths of the men had a reflex of under 2 inches, and only one fifth of the women. The average for men is a little below 2 inches, for women a little above 2 inches.

Much discussion has been given to the question whether the contraction is, as maintained by Erb, a true spinal reflex, or whether it is a simple effect of the blow on the tendon upon the fibres of the muscle, causing their sudden contraction, as originally maintained by Westphal. That it is a true reflex action is commonly considered to be proved by experiment on animals, since it ceases on section of the anterior crural nerve. Still stronger evidence is afforded by the fact that it is commonly absent in a disease, locomotor ataxy, in which the spinal cord is diseased, but in which the state of motor nerve and muscle is perfectly normal.

The graphic study of the movement is in entire accord with the theory of its reflex character. I show a series of tracings (Fig. 1) taken with a revolving drum, the writing pen being attached to the foot, which demonstrate that the muscular contraction occurs at such an interval after the

stimulating tap, as, according to physiological data, would be needed for the processes involved in the necessary spinal reflex action, *i.e.*, (1) the conduction of the afferent impulse to the cord, and of the efferent impulse from the cord to the muscle; (2) the process of reflex action in the cord itself; (3) the period of latent stimulation in the muscle.

(1) The length of nerve fibre to be traversed from the tendon to the cord and back again to the middle of the rectus muscle is about a meter and a half. The rate of transmission of nerve impulses in man is about 33 meters per second. For this, therefore, '045 second would be needed; (2) the shortest time needed for a simple reflex process in the centre, has been estimated at '05 second.¹ (3) The period of latent stimulation of the muscle may be taken as about the '01 second. Adding together these periods we have a total of $\cdot 045 + \cdot 05 + \cdot 01 = \cdot 105$, or a little over the $\frac{10}{100}$ ths, *i.e.*, $\frac{1}{10}$ th of a second. I have found that the interval between the tap on the tendon (*a*, fig. 1) and the movement of the foot (*c*) which indicates the commencement of the contraction, in two normal individuals, varied somewhat, but that the shortest interval is the '09 second, and the longest '15 second (fig. 1, Nos. I—IV). Generally it is the '10 or '11 second. In a case of lateral sclerosis, tracings from which are shown in the same figure, Nos. 5 and 6, the interval was always the '10 second. This correspondence between the period found to elapse and that estimated to be necessary is remarkably close, and accords perfectly with the view that the phenomenon is a spinal reflex.

But some of the tracings show another, and very interesting character; the interval between the stimulation and the movement is occupied by a slight rise (*b*) and by a fall, often more considerable than the rise. This may, at first sight, be regarded as the mechanical effect of the blow upon the leg; but a comparison of several tracings shows that this is not its explanation, for the rise is often preceded by an interval, after the blow, during which no movement occurs, an interval not exceeding '05 second. This rise and fall

¹ Exner, 'Pflüger's Archiv,' VIII, p. 526.

FIG. 1.

Tracings of knee-reflex. I—IV, tracings from two healthy individuals; V and VI, from a case of disease of the spinal cord (lateral sclerosis?); *a*, tap upon patellar tendon (not indicated in III and IV); *b*, slight (direct?) muscular contraction; *c*, commencement of reflex contraction. The tracings are all taken at the same rate; the divisions on the scale correspond to hundredths of a second,

must then be due to a slight contraction, and subsequent relaxation of the muscle. The interval is not enough for the occurrence of a spinal reflex action, and there can be little doubt that we have here the direct effect upon the muscular fibres of the blow on the tendon. The sudden slight tension upon the fibres causes a brief slight contraction, succeeded by relaxation, and followed by the strong contraction which results from the spinal reflex. Thus, although the visible movement is not the result of the mechanism to which Westphal first attributed it, that mechanism is in operation and produces an effect, not, however, appreciable by ordinary methods of observation.

I am aware that some measurements which have recently been made by Burckhardt¹ and Tschirjew,² have assigned to the interval a much shorter duration than my own observations assign—not more than .04 or .05 second. But the method of the experiments—by arranging an apparatus so that the swelling of the muscle broke an electric circuit during the rigid fixation of the foot—seems to me to be open to many fallacies from which the simpler method I have adopted is free. In spite of the brief duration they assign, both observers conclude that the phenomenon is reflex, although they admit that the time they assign is actually insufficient for the mere passage of the impulses, to and fro, along the nerves, and leaves no time at all for the reflex process in the cord. The occurrence, under some circumstances at least, of a slight muscular contraction before the more vigorous one, accounts, perhaps, for the discrepancy between these results and those I have obtained.

It should be mentioned that Burckhardt states that, in animals, the phenomenon, although arrested by section of the crural nerve, persists after division of the spinal roots and hence concludes that it is a reflex from the ganglia on the posterior roots. But this is opposed to the results of Tschirjew who found it at once arrested by section of the posterior roots

¹ G. Burckhardt, 'Ueber Sehnenreflexe,' Bern, 1877. 'Centralblatt. für die Med. Wissensch.,' 1878, 401.

² 'Archiv für Psychiatrie,' Bd. viii, 1878, No. 3.

of the sixth lumbar pair, and cannot, I think, be allowed much weight in the face of the pathological evidence of the relation of the reflex to changes in the spinal cord.

In animals it has been observed that the muscular contraction excited by the tap on the exposed tendon, sometimes occurs not only in the leg struck but also in the corresponding muscle of the other leg. I have several times observed the same thing in man, in cases in which the reflex movement is considerable, especially in cases of old hemiplegia. In some of these a simultaneous contraction in the muscles of the back was also produced, jerking the body and even the head backwards. I need not point out what strong, even conclusive evidence this extension of the reflex affords, for believing the seat of the reflex process to be in the spinal cord itself.

The stimulus which excites the reflex contraction is commonly regarded as originating from the part struck, the tendon. Tschirjew, however, asserts that it persists after division of all the nerves from the tendon. It is certainly possible that the sudden effect of the blow on the tendon upon the fibres of the quadriceps may originate the afferent impulse, but the peculiar sensation in the tendon when struck suggests that, in this case, the afferent impulse does originate in the tendon. It is probable also that the afferent impulse may originate from several localities; since an oblique downward blow on any part of the patella, a blow on the tendon above the patella, or on the muscle, will suffice to produce it.

The visible phenomenon being thus those of a spinal reflex, the integrity of the path to and from the cord, and of the reflex mechanism in the grey matter of the cord, will be necessary for its production; and damage in any one of these situations, to the sensory fibres, the motor fibres, or the grey matter, may be expected to prevent its occurrence. Facts are in perfect accord with this conclusion.

(1.) The phenomenon is absent in most cases of locomotor ataxy in which, as is well known, the region of the cord damaged is that, and may be that only, through which the

fibres of the posterior nerve roots pass, viz.—the outer portions of the posterior columns; and the absence of the reflex in this disease, is often related in a remarkable way to the degree of damage to the posterior nerve roots, as evidenced by the symptoms.

(2.) Damage to the motor nerve roots must, of necessity, interfere with the reflex; but I am not aware that any instances of its loss have yet been recorded in which the lesion was limited to this situation. In the experiments of Fürbringer the crural nerve was divided, which contains, of course, the sensory as well as the motor fibres involved.

In one case, under my own care, in which the reflex is entirely lost there is probably pressure on the nerves by meningitis; the recti, however, are completely paralysed and wasted. Sensation is normal.

(3.) Damage to that part of the anterior grey cornu of the cord, to which the quadriceps extensor is related, prevents absolutely the production of the reflex. It is usually lost—always as far as my experience has hitherto gone—in cases of atrophy of the lower extremities in which the quadriceps extensor is in any considerable degree involved, and often when its affection is slight, and this in cases in which there is not the slightest impairment of sensation. This fact has also been pointed out by Westphal. I have found it completely absent even in cases in which the quadriceps extensor retained sufficient power to maintain the complete extension of the knee when the leg was raised into the air. The reflex is lost, not only in ordinary cases of atrophy, but also in pseudo-hypertrophic paralysis, invariably in the later stages of the disease, when the quadriceps extensor is always considerably damaged.

In the diseases in which the knee reflex commonly disappears, the central change varies in distribution and exact seat in different cases, and it is not surprising, therefore, that we meet with exceptions to the rule of its absence. It is probable that instances will be met with in which it is present, under some of the conditions in which it is commonly lost, in each of the several forms of lesion. I will, however,

confine myself to some remarks on its occasional presence in the disease in which its absence has attracted most attention, viz. locomotor ataxy.

Several observers have alluded to persistence of the knee reflex in well-marked cases of locomotor ataxy. I have met with two such cases, which illustrate also the conditions to which this preservation of the knee reflex appears to be especially related, namely, the absence of evidence of damage to the posterior nerve roots. The patients were under my care at the National Hospital for the Paralysed and Epileptic. In two other cases of ataxy, in which the knee reflex was preserved, it is probable that there was combined lateral and posterior sclerosis of the cord.

CASE 1. Well-marked locomotor ataxy, of gradual onset, without any recognisable affection of sensation, without lightning pains, and with well-marked knee reflex.

William L—, æt. 43. Difficulty in walking commenced gradually at thirty-eight (in 1873), and increased so that in six months time he could not walk although he could move his legs freely as he lay in bed. Rest and a change to the sea side restored his walking power.

When seen in June, 1878, he walked unsteadily, in the most characteristic ataxic manner, raising his legs too high. He could not stand with his feet near together, and he fell down when he closed his eyes. There was no affection of his arms, ocular movements, sight, or pupils. Sensation on the legs and soles was normal to both touch, pain, and heat. The only point in which there was any doubt was as to whether he could quite accurately localise a painful impression upon one great toe. On each side there was a very well marked patellar tendon-reflex, which still (November, 1878) persists in the same degree.

CASE 2.—Symptoms of locomotor ataxy; knee-reflex present; lightning pains on standing only; no affection of sensation.

Wm. H. D—, æt. 54. At fifty-two years of age found that a small quantity of beer made him very unsteady, and soon afterwards that the unsteadiness was constant, irrespective of beer. For a year and a half the unsteadiness, slowly increasing, remained the only symptom. He then began to suffer from severe "gnawing"

pains in both legs, and subsequently from sharp momentary pains on movement, passing from the sacral region down the back of the thighs as far as the knees, "like a flash of lightning and gone again." They did not occur when he was at rest. When he came under treatment the muscular power in the legs appeared to be unimpaired, but the ataxic gait was well marked. He walked in an uncertain manner, often raising his feet too high; on turning round suddenly he almost fell. Closure of the eyes rendered standing almost, and walking quite, impossible. The knee reflex was considerable in each leg, the movement of the foot being about four inches. Not the slightest ankle clonus could be obtained. Sensation in the legs and feet, repeatedly tested by myself and others, was perfectly normal to touch, pain, and heat. The muscular sense also appeared to be normal. (Since that time his ataxic gait has increased. The gnawing pains continue, and the lightning pains occur when he is standing still, as well as when he is moving, from the hip down the back of one or the other leg. The knee reflex continues excessive, and sensation is still perfect, June, 1879.)

CASE 3.—Ataxy and weakness of legs; lightning pains in both legs, but more in one than in the other, the knee reflex lost in the leg in which the lightning pains were most intense, present in the other.

James F—, æt. 38. No history of syphilis. At thirty-three began to suffer from weakness and pains in the legs, felt in both, but far more severe in the left leg than in the right—sharp darting pains, coming for a moment and then going away, and in the left leg accompanied with a sudden involuntary movement of the leg. The pains in the right leg were of precisely the same character, but less severe. The weakness came on gradually at the same time, first, and always worse in the left leg. When seen there was a considerable amount of loss of power in the legs, more marked in the flexor muscles than in the extensor, and on the whole less in the left than in the right leg. He could stand alone on the right leg for a moment, not on the left. Over and above the weakness there was considerable unsteadiness of movement, and he was obliged to stand with his feet far apart, just as an ordinary ataxic. The electric irritability of the muscles was unchanged; there was no wasting. Sensation to touch in left leg was normal above the knee, diminished below, and lost on the sole. On the right leg it was lessened below the knee, although not so much as in the left leg, and

on the right sole a touch could just be felt. Pain was felt as such on each leg, but not at all on the left sole, moderately on the right sole. Heat was not perceived as such on either leg below the knee. The patellar reflex in the right leg was excessive, the movement of the foot being about four inches; in the left leg it was entirely absent. On faradising the skin outside the knee-joint (which in paraplegics often causes a strong reflex contraction in the flexors of the hip) the right hip was strongly flexed, the left not at all. I have no note of the existence of ankle reflex.

This may, I think, be regarded as probably a case of combined lateral and posterior sclerosis, with much greater damage to the posterior nerve roots on the left side than on the right.

The following case is probably also of the same character:

CASE 4.—James L—, æt. 27; never quite well since rheumatic fever, at 25. Three months before being first seen he found that he could not walk well. When seen he could only walk a mile with difficulty. He stood unsteadily, with the legs far apart, but could just balance himself with the feet close together and his eyes shut. His gait was unsteady; the feet brought down too suddenly, and the unsteadiness was increased by closure of the eyes. The walk was precisely like that of a moderate degree of ataxy. Sensibility in the legs and feet to heat, touch, and pain was perfect. The knee reflex was excessive in each leg. Ankle clonus slight, but "front-tap contraction" (see p. 292) very marked. No sharp pains, but dull, "numb-like" pains in both legs.

In another case which has come under my notice, a woman, with symptoms of spinal sclerosis, weakness of legs, with unsteadiness of gait in excess of the weakness, and slight impairment of sensation, the knee reflex was present when she was first examined, but, three months later, had entirely disappeared. I had not an opportunity of ascertaining whether its disappearance coincided with any increase in the loss of sensation.

These cases show, I think, that the preservation of the reflex in simple locomotor ataxy coincides with such a slight degree of damage to the fibres of the posterior nerve roots as does

not involve appreciable loss of sensation. It does not follow that the fibres which convey sensation from the limb are the same as those which convey the impression from the tendon. This latter may have a somewhat different course, and suffer when the damage is extensive, and escape in some cases in which it is slight, while other cases, in which the loss of the reflex has preceded other symptoms of ataxy, seem to suggest that the position of the fibres from the tendon is one in which the posterior sclerosis is apt to commence.

Another indication of damage to the posterior nerve roots is the occurrence of lightning pains which, as Westphal and Buzzard have shown, commonly coincides with absent reflex. But the second and third cases I have recorded show that, in some conditions, the reflex may persist after lightning pains have occurred for some time. In the second case, however, they only occurred when the patient was standing or moving. In Case 3 the lightning pains, although present in both legs, and occurring at all times, had been most intense in the leg in which the patellar tendon reflex was lost.

ANKLE CLONUS.

The ankle clonus, or ankle reflex, is the clonic spasm which can be obtained at the ankle-joint in certain cases of weakness of the legs. To obtain it, it is necessary merely to make a sudden dorsal flexion of the foot. It is obtained most readily when the knee-joint is nearly but not quite extended. If, then, the hand be placed against the ball of the foot, and the ankle-joint flexed by a sudden pressure of the hand, so as to make the Achilles tendon tense, there follows, apparently instantly, a brief contraction of the gastrocnemius, sufficient to move the foot and hand a little in the direction of extension, and this ceasing, the pressure of the hand being kept up, another similar contraction follows, and so on as long as the pressure of the hand is maintained. When the hand is removed, the contractions cease, immediately, or after two or three weaker contractions. If the foot be passively extended, so as to relax

completely the Achilles tendon, the contractions instantly cease.

It is not necessary that the passive flexion should be made by pressure of the hand on the sole. The clonus may be produced equally well by grasping the extremity of the os calcis and pulling the heel down.

If the passive flexion be made gently and gradually a considerable tension may be put on the tendon without exciting the movement. If, however, the Achilles tendon or the gastrocnemius muscle be then tapped, a contraction instantly occurs, followed by others, the pressure of the hand being maintained.

The phenomenon occurs commonly in those diseases of the spinal cord in which there is reason to believe that there is sclerosis of the lateral white columns, either primary or secondary to disease of the cord higher up, or secondary to a lesion in the brain. It is thus frequently met with in both hemiplegia and paraplegia. Its occurrence in both legs in cases of hemiplegia has been noted, and I have confirmed this observation, having found it in one case even more marked in the sound leg than in that on the hemiplegic side.

With a revolving drum, I have taken tracings of this movement in ten cases, the number of tracings being in all about forty. The writing lever was fixed to the side of the foot. These tracings show certain characters which deserve description.

1. The regularity of the movement, apparent to simple observation, is still more strikingly seen in its record (Fig. 2). The series of curves traced are almost as regular as those of a tuning fork. They are, however, liable to slight variations, both in different individuals and in the same individual at different times.

The average number of contractions per second is nearly six, the variations being, in the whole series of cases, between five and seven per second. This applies to the frequency of the contractions when they are set up. The first one or two may be at a longer interval. The average duration of each movement, and the interval between them from the

commencement of one contraction of the gastrocnemius to the commencement of the next, is sixteen hundredths ($\cdot 16$) of a second, the shortest being thirteen ($\cdot 13$), and the longest twenty hundredths ($\cdot 20$) of a second. The average length may thus be roughly put at one sixth of a second. The facts from which these estimates are made are contained in the following table.

Measurement of the Frequency of Movement in the cases of Ankle Clonus.

Case.	Disease.	Number per second.		
		Minimum.	Maximum.	Average.
1	Primary (lateral ?) sclerosis . . .	6	7.3	6.8
2	" " " . . .	6.5	8	6.8
3	" " " . . .	5	5.8	5.4
4	" " " . . .	5.1	6.3	5.7
5	Descending sclerosis ; caries of spine . . .	6.3	7.5	6.9
6	" syphilitic growth in cord . . .	6.15	6.3	6.2
7	" hemiplegia . . .	7	7	7
8	" " " . . .	5.2	5.8	5.3
9	" ? " . . .	5	5.8	5.4
Average		...	...	6.17

It is not easy to adjust the apparatus to the foot so as to obtain the regular curve which the lever actually describes, but from an examination of the most successful tracings it appears that the rise of the lever is more sudden than its fall, but the curve at the top renders the commencement of the fall very nearly midway between the commencement of two successive contractions ; one contraction ceasing on an average about one tenth of a second before the commencement of the next.

The actual amount of muscular contraction, *i.e.*, the extent of movement, varies in different cases. It was several times estimated by making the distance of the writing pen from the malleolus (corresponding to the fulcrum) a multiple of the distance from the insertion of the tendo Achillis to the malleolus. The contraction was found to vary from 1.5

millimeter to 3 millimeters, giving a movement at the tip of the great toe of 1 to 2 centimeters.

FIG. 2.

Tracings of the ankle clonus. I, primary spinal (? lateral) sclerosis; II and III, lateral sclerosis after hemiplegia. The tracings read from right to left. The divisions of the scale are tenths of a second.

During the intervals of contraction, the relaxation of the muscle is not complete. This is shown by the following tracing (fig. 3) which represents the commencement of the contraction started by a tap upon the tense tendon. The straight line was traced by the writing lever during the maintenance of the tension by gentle pressure. The tap caused a slight rise and backward movement of the lever, followed by a sudden strong contraction of the muscle, shown by the ascent, first vertical and then curved. The descent which follows the cessation of contraction does not fall so low as the line from which the lever started, the descent (relaxation) being interrupted by another rise (con-

traction). It is to be noted, further, that the line joining the lowest portions of the curves rises for a time, indicating that the degree of residual contraction increases. In this case the degree of residual contraction was at first 1.5 mm. and gradually increased to 3 mm.

FIG. 3.

Ankle clonus set up by a tap on the tendo Achillis during passive dorsal flexion of the foot. The initial contraction of the gastrocnemius is seen to occur almost instantly, to be greater in degree and in duration than the contractions which succeed. The lowest subsequent descent does not fall so low as the line indicating the position of the foot before the tap, *i. e.* the relaxation is incomplete. The tracing reads from right to left. The divisions on the scale indicate tenths of a second.

This peculiar clonic spasm, which is so common in the gastrocnemius has not, I believe, been described in any other muscle. On several occasions, however, when it has been well-marked in the calf, I have succeeded in obtaining it with almost equal readiness in the plantar muscles of the great toe, the abductor and flexor brevis pollicis. These muscles are inserted into the base of the first phalanx of the great toe, and to obtain the movement it is only necessary to fix the foot with one hand in a position of extension (*i. e.* plantar flexion) so as to prevent the occurrence of the gastrocnemius reflex, which would obscure the other, and then to make a sudden passive extension of the first phalanx of the toe. The resulting movement is quite similar in

its characters to that of the ankle-joint. This is shown by the tracing of it (fig. 4) which I have obtained by fastening the writing lever to the great toe only.

In most cases the movement ceases after five or six contractions as it does also, in slight cases, at the ankle-joint. At other times, and by careful manipulation, a long series of contractions may be obtained. One of the tracings shows a series of eighteen. The time of this toe clonus is almost the same as that of the ankle clonus. One tracing (not figured) shows the identity of time in the toe clonus and in the ankle clonus which was taken at the same time, from the same patient, a girl suffering from a primary (lateral ?) sclerosis of the cord. The frequency of the toe clonus in this case was,

FIG. 4.

Toe clonus; contractions in abductor pollicis on passive extension of great toe in a case of spinal (lateral ?) sclerosis. The tracing reads from right to left. The divisions on the scale indicate tenths of a second.

maximum 6.15, minimum 6, mean 6.1. The mean of the ankle clonus being 6.8 contractions per second.

In several cases presenting the symptoms usually ascribed to lateral sclerosis of the cord, I have succeeded in obtaining a lateral ankle clonus by grasping the foot with the hand and pressing it laterally. In most of these cases the clonic spasm was evidently in, and confined to, the peronei, and could only be obtained when the foot was pressed inwards. In one case, however, it could be obtained in either the peronei or the tibialis posticus according as the foot was pressed inwards or outwards. The time appeared to be the same as that of the ordinary ankle clonus, and of the toe clonus.

In two cases in which the patellar tendon reflex was very marked, the contraction produced in the extensor of the knee was very often followed by others, in uniform succession, continuing for a considerable time; a knee clonus, resembling the ankle clonus in regularity. It differed from the ankle clonus, however, in the much longer interval between each contraction. In one case tracings were taken, and fig. 5 shows the characters of this movement, only two and a half contractions occurring per second. In each case it had the same slow time. Its probable significance and origin will be considered presently.

FIG. 5.

Knee-clonus — clonic contractions in the quadriceps extensor femoris in a case of advanced disease of the spinal cord (spastic paraplegia). To be read from right to left. The extent of movement gradually increasing; its frequency is seen to be about half that of the ankle clonus.

To return to the ordinary ankle clonus.

Two theories have been proposed regarding the nature of this phenomenon, analogous to those which have been suggested in explanation of the knee reflex. The one, that of Erb, regards each contraction as a reflex from the spinal

cord, the excitant being the stimulation of nerves in the tendo Achillis by the sudden tension, alone or combined with a tap which may act by increasing the tension previously gently applied. The stimulation is constantly repeated by the maintained passive flexion, whenever the muscle relaxes. On the other hand Westphal has suggested that the tension must affect directly the muscular fibres of the extensors of the ankle, in which the contraction occurs, and that this excites them to immediate contraction, so that the phenomenon is not really reflex. A third explanation may however, be proposed viz., that the phenomenon is really reflex but that the stimulus originates, not in the tendon but in the muscle, by the irritation of its afferent nerves by the sudden tension on its muscular fibres. There are thus two points to be considered, first, is the spasm produced by a stimulation of the tendon or of the muscle? and secondly, if the latter, is the effect direct or reflex?

In the first place the spasm cannot be excited by any stimulus applied to the tendon which does not increase the tension. It may perhaps be doubted whether this is true of the gentle tap which, when the tendon is made tense, excites the contraction of the muscle. But that even this gentle tap produces its effect by causing an increase of tension is shown by the following fact. If the tendon be gently made tense, in the manner already described, a tap on the side of the tendon will produce the muscular contraction almost as readily as one upon the posterior aspect. But if the movement of the tendon be prevented by placing the tips of two or three fingers against the opposite edge, the tap produces no effect. Take the fingers away, and the same tap at once causes the contraction of the muscle. Moreover, no other means of stimulation of the tendon, if they do not increase its tension, will excite the spasm. The tendon is sensitive to a pinch, as anyone may ascertain by making the experiment on himself; but pinching the tense tendon does not excite the contraction. This is the more worthy of special notice, because, in the patients who present the ankle clonus, a pinch of the tendon does commonly excite a very marked reflex

spasm, but this is similar in character to that which results from a cutaneous stimulation, and in it the flexors predominate. This will be considered more fully presently. But any stimulus which increases the tension in the tendon, must increase the tension in the muscle also; and thus no stimulus is effective, applied to the tendon, which does not act also upon the muscle. No fact can be adduced in favour of the view that the stimulus originates in the tendon which is not equally in favour of its origin in the muscle.

But when gentle passive dorsal flexion is made, a tap upon the muscle will excite the contraction as readily as a tap upon the tendon. Now a tap on the muscle will cause a much slighter increase in the tension of the tendon than a tap on the tendon itself; and so this fact is in favour of the view that the stimulus originates in the muscle. But it is not conclusive, for it cannot be denied that the tap may increase, although very slightly, the tension in the tendon.

Additional light is, however, thrown on this question by an examination of the second point. What evidence is there regarding the reflex nature of the phenomenon? The first fact is that the clonus (obtained in this manner) occurs only in cases in which there is the strongest reason to believe that there is an organic change in the cord, and a change which causes an exaltation of the knee reflex, which, as we have seen, must be regarded as of spinal origin. But this fact, the constant relation of the ankle clonus to spinal disease, is not evidence of its spinal origin, because it is quite conceivable that disease of the cord, by the withdrawal or the exaltation of a central influence, may leave the muscle in a condition to respond, in an abnormal manner, to direct stimuli. We see the muscular fibres in progressive muscular atrophy quiver unduly when struck, but we do not regard their quivering as therefore a spinal reflex. Other evidence on the question has therefore to be sought.

Does any stimulus applied at a distance from the muscle and tendon excite the peculiar spasm? I have found one stimulus which does, at first sight, appear to fulfil this condition, and which is in itself a phenomenon of considerable

interest and practical importance. If, when the ankle is gently flexed in the manner described, so that no spasm occurs, the tibialis anticus or adjacent muscle be gently tapped, there occurs, not a contraction in the muscle tapped, but a contraction in the gastrocnemius, causing a slight extension movement at the ankle, not followed by others, but a single isolated contraction. That this is not the result of any increased tension of the tendon, such as might result from the tap tending to increase the flexion of the ankle-joint, is shown by the circumstance that a similar and even stronger tap upon the adjacent tibia produces usually no effect.* This phenomenon, which may be termed the "front-tap contraction" may generally be obtained in the cases in which the ankle clonus is present.

Here then we have a contraction in the calf muscles similar to that which initiates the clonus, and produced under similar conditions, but by a stimulus applied at a distance from muscle and tendon. It appears at first sight to be an unmistakeable reflex action. Regarding it as such, I took, to ascertain its characters, several tracings by the same means which the other tracings were taken, but with a rapid movement of the drum so as to measure accurately the interval between the stimulus and the contraction. Two of these tracings are now shown (fig. 6). The tap, it will be seen, is very distinctly indicated in the brief rise of the lever (*a*), and the contraction of the gastrocnemius by the fall (*c*), which commences a little time after the movement from the tap has ceased. It will be seen, however, that the interval from the commencement of the tap to the contraction, is, in the one case, only $\cdot 04$ and in the other $\cdot 05$ second, while the interval between the middle of the rise occasioned by the tap is only $\cdot 03$ and $\cdot 04$ second respectively. This is, according to received facts, insufficient for the occurrence of a spinal reflex. The mere passage of the impulse to and from the cord would occupy a longer time, about the $\cdot 06$ of a second, and as before stated, physiological facts suggest that nearly as much

* In rare cases, in which the irritability is very great, a tap on the tibia will produce the contraction.

time ($\cdot 05$ sec.) would be needed for the simplest reflex process in the centre. The corresponding interval in the case of the knee reflex, in which there is a shorter distance of nerve fibre to be traversed, has been seen to occupy double the period in question.

FIG. 6.

Tracings of front-tap contraction, *i.e.* the contraction in the gastrocnemius excited by a tap on the tibialis anticus during passive dorsal flexion (lateral flexion?). The interval between the commencement of the rise (*a*), indicating the tap, and the descent (*c*), due to the contraction of the gastrocnemius, is in the upper tracing $\cdot 05$, and in the lower one $\cdot 04$ second. The divisions of the scale indicate hundredths of a second.

This fact seems entirely to dispose of the hypothesis that the contraction can be a reflex from the spinal cord. If not a reflex, how does the tap produce it? If the fingers of the other hand be placed upon the middle of the calf, when the tap is made, during the dorsal flexion of the foot, a distinct vibration will be perceived, when the tap is upon the muscles in front of the leg, which is absent when the tap is made upon the tibia. This vibration must be transmitted through the muscles and the intermuscular septum; and it seems probable that this vibration may so disturb the equilibrium of the tense fibres of the gastrocnemius and soleus as to excite them to contraction, by direct stimulation.

I have also measured, in two cases of spastic paraplegia the interval between a tap on the gastrocnemius itself and the resulting contraction of the muscle, and also the interval between the tap on the Achilles tendon, and the contraction it excites. If the passive flexion of the foot and tap are gentle, each of these stimuli will excite a single contraction. If the flexion and tap is forcible, this single contraction is followed by others in the ordinary clonus.

In the case of the tap on the muscle (fig. 7) the interval was in the one patient $\cdot 025$ of a second; in the other case it was $\cdot 045$ of a second. In the case of the tap on the Achilles tendon (fig. 8) the intervals in the one patient with con-

FIG. 7.

Contraction (c) in gastrocnemius excited by tap (a) on the muscle. I and II, case of slight lateral sclerosis; III and IV, case of advanced ditto.

FIG. 8.

Contraction (c) in calf muscles excited by a tap (a) upon the Achilles tendon during passive dorsal flexion of the foot. I and II, case of considerable lateral sclerosis; III and IV, case of slight ditto.

siderable cord disease varied from $\cdot 035$ to $\cdot 04$ of a second; in the other patient, with slighter disease, the interval was $\cdot 04$ second. Thus in the case of the tap on the tendon, just

as conspicuously as in the tap on the front of the leg, the interval before the contraction is insufficient for the occurrence of a reflex process.

But, whatever is the mechanism through which the single contraction is excited by the tap on the Achilles tendon, is certainly the mechanism by which the ankle clonus is excited.

If the theory of a spinal reflex is thus untenable, the theory of stimulation of the tendon, of course, at once falls to the ground. It is hardly necessary, therefore, to point out, that by the tap on the front of the leg the clonus is excited by a mechanism which, however it acts, does not affect the tendon.

The conclusion thus seems to me a necessary one, that the clonic contractions are the result, not of reflex but of direct stimulation of the muscle by the sudden tension or vibration. But this does not exclude all reflex influence in the production of the phenomena. We have to explain not merely the origin of the clonic contractions, but also the origin of the extreme muscular irritability which renders the muscle abnormally sensitive to local stimulation. This irritability is developed by passive flexion of the ankle joint, and ceases as soon as the flexion ceases. That is to say, it coincides with tension of the muscular fibres. The tension may be conceived as affecting their irritability directly, but I think that the phenomena accord best with the hypothesis that the effect of the tension in increasing the muscular irritability is reflex. That such tension is capable of developing a strong afferent impression from the muscle to the nerve centres is shown by an experience which probably has been that of most of us. After a severe attack of cramp in the calf, the muscle is left in a condition of painful sensitiveness. As long as the ankle joint is not flexed beyond a right angle, little discomfort is occasioned by its movements; even a pretty strong contraction of the calf muscles, pointing the toes downwards, occasions little uneasiness. But if the ankle joint is flexed passively, even a little beyond a right angle, the tension on the fibres of the gastrocnemius

occasions acute pain. Moreover, the attempt to obtain the ankle clonus by sudden passive flexion of the foot, occasions a distinctly painful sensation in the calf muscles. It is probable that the centripetal stimulus, which under these circumstances is painful, always occurs during the tension of the fibres, although we are not conscious of it under normal circumstances, unless it is long continued; and that when the reflex irritability of the spinal cord is increased, as in lateral sclerosis, the afferent impression develops in the muscles an extreme degree of readiness to contract on the slightest local disturbance of equilibrium, whether by a direct tap or a sudden increase in tension.

This explanation harmonises entirely with the phenomena to be observed when the development of the ankle clonus, on sudden dorsal flexion of the foot, is followed in its details by taking a tracing such as I now show (fig. 9.) In this, the

FIG. 9.

Gradual development of ankle clonus (x x x) on sudden dorsal flexion of ankle (*). The contractions of the clonus are indicated by the downward movement of the pen. Rapid rate of movement of recording drum. (Reduced to $\frac{1}{2}$.)

first horizontal line is traced by the foot before the passive dorsal flexion was commenced. The latter is indicated by the sudden rise. The first contraction of the gastrocnemius is so slight as merely to flatten and slightly depress the curved line, the second is more marked, and the third more marked still. Thus the irritability of the tense fibres is not instantly developed in full degree by the tension, but is

developed gradually, not reaching its full degree until nearly a third of a second after the application of the tension. If the whole were of local production—the irritability as well as the intermitting stimulation—the first clonic contraction should be as great, or greater, in degree, than any of the others, since no stimulation will be as great as that which occurs on the sudden change from complete relaxation to tension. So, too, if the whole of the phenomena were reflex, the first contraction should be as great as any of the others, although delayed until such a time as is required for reflex action. The gradual development of the clonus—which may also be readily seen on simple observation—can only be understood on the explanation now given of a reflex irritability and a local stimulation. If the tension have been previously placed on the muscle, and the reflex irritability thus previously developed, the first contraction from local stimulation is as great as those which succeed, even greater in the case of tap upon the muscle, as in fig. 3.

In several cases I have observed the sudden flexion of the foot to cause, not merely the ankle clonus, but also a reflex contraction of the flexors of the hip, which distinctly *succeeds* the first contraction in the calf muscles.

In the cases in which the ankle reflex is present, there is often also an excess of reflex action in the limbs, which is excited by a painful sensory impression. The form of this reflex action in relation to the action of the gastrocnemius is very instructive. If, for instance, the skin of the leg be pinched, there results, in many cases, a general reflex spasm of the limb, a tracing of which is shown in fig. 10. Below the knee, this does not fall primarily upon the gastrocnemius, but upon the flexors of the ankle joint in the front of the leg. By the strong spasm in these muscles the ankle joint is strongly flexed (*a a*), the foot being brought up, and commonly inverted from the strong action of the tibialis anticus. But this puts the gastrocnemius in a state of tension, and excites in it clonic contractions just as when the hand is pressed against the sole. These occur even while the contraction of the flexors is proceeding (*b b*), but are more

marked when the spasm is subsiding (*c c*), and when it is over they also cease, unless the hand be applied to the sole of the foot during the flexor spasm, when the clonic contractions of the gastrocnemius persist in the ordinary form after the flexor spasm is over, as in the figure (*d d*). This con-

FIG. 10.

Effect of cutaneous stimulation, as pinch (*x*), in causing reflex spasm of limb, flexor spasm predominating and causing strong flexion of the ankle-joint (*a, a*), interrupted (at *b, b*) by clonic spasm in extensors of ankle, which is more marked (*c, c*) as the flexor spasm subsides and continues (passive dorsal flexion being maintained) as the ankle clonus (*d, d*) when the flexor spasm is over. Before the peripheral stimulation the hand was gently pressed against the sole, and slight ankle clonus occurred, indicated by the waves in the initial line, although not visible to the eye.

stitutes a paroxysm of the one form of so-called spinal epilepsy, of the most typical form to which the term can be applied. The clonic spasm in the gastrocnemius, excited by, and super-added to, the general spasm, predominating in the flexors, constitutes the chief part of the clonic phenomena of the paroxysm, and being most distinct during the subsidence of

the tonic (flexor) spasm, gives to the phenomenon its resemblance to an epileptic convulsion, which was pointed out by Brown-Séquard, a resemblance which is thus wholly superficial.

It is always this form of spasm which is excited by *pinching* the tendo Achillis; but I may remark that careful observation may be necessary to distinguish this fact, since the clonic spasm in the gastrocnemius begins, as is seen in the tracing, during the rise of the flexor spasm, and it may begin so soon after the commencement of the latter, that it may easily be mistaken for a primary effect. The flexion of the foot is always, as in the spasm shown in the tracing, the initial event.

What, then, is the explanation of the knee clonus (p. 289) which is set up, during passive extension of the patellar tendon and extensor muscle, by a tap on the tendon? The contractions, as fig. 5 shows, succeed one another at a much longer interval than the contractions of the ankle clonus. This is in proportion to the longer interval which elapses between the stimulus and the contraction, in the case of the ordinary patellar reflex, than in the single contraction of the extensor of the ankle. The proportion between the frequency of the ankle clonus and the frequency of the knee clonus is nearly as 4 to 10: and the proportion between the interval which intervenes between a tap on the Achilles tendon, and the contraction of the gastrocnemius, is to the interval between the tap on the patellar tendon and the contraction of the thigh muscles also as 4 to 10. It has been seen that the difference of interval in the case of the isolated contractions affords ground for the conclusion that the mechanism of the two is different. The same conclusion is suggested by the corresponding difference in time in the two forms of clonus, viz. that the several contractions of the knee clonus are of true reflex origin. The sudden tension of the quadriceps by the weight of the extended leg on the fibres, after the cessation of one contraction, probably constitutes the afferent stimulus for the next. It will be remembered that the single contraction may be excited by a blow on the tendon above the patella, and even by a blow on the muscle,

as well as by a blow on the tendon below the patella. It seems probable, therefore, that the individual contractions in the quadriceps owe their origin to the mechanism which develops the irritability to local stimulation in the calf muscles.

Should the objection suggest itself, that the difference in time between the knee and ankle clonus is due only to the larger size of the muscles which move the knee, I would point out that the difference in size between the calf muscles and the plantar toe muscles is incomparably greater than that between the calf and the thigh muscles, and yet the ankle clonus and the toe clonus have practically the same time.

In the case of the ankle and toe clonus the conclusion is, that the passive extension leads to a reflex irritability, a hair-trigger susceptibility to local influences, an incipient contraction, excited to developed contraction with extreme readiness, and that this irritability is at its maximum immediately after the cessation of a previous contraction. It is, I think, an interesting and significant fact that, in these two sets of muscles, those which extend the ankle and flex the first phalanx of the great toe, the sequence of passive extension and tonic contraction is being constantly developed under ordinary circumstances in the act of walking. In each step, after the leg is put forward on to the ground, first the ankle joint is flexed by the anterior tibial muscles, and then, when the calf muscles have thus been made tense, they pass into a state of tonic contraction, by which the heel is raised, and simultaneously the great toe muscles (previously extended by the flexion of the toe) also contract, as the foot rests on the ball and great toe and the body is impelled forwards. This sequence of tension (which has been seen to be attended with an afferent impression) and tonic contraction is frequently repeated—with persons who lead active lives not less than fifty thousand times every day—and the development of a reflex mechanism between the afferent and sequential efferent impulses, will be almost a necessary

result. It is this reflex effect which is assumed to be so excessive in lateral sclerosis of the cord as to permit the local development of the ankle clonus. I have never been able to obtain the ankle clonus in a child who had never walked, although such children not rarely exhibit a form of paraplegia similar to that in which, in older persons, the phenomenon occurs. It may be supposed that the act of learning to walk opens up the reflex path between tension and contraction of the calf muscles. We are able thus to understand why the ankle clonus, although of local excitation, occurs in cases in which the reflex action, as shown by the knee reflex, is in excess.

The phenomenon which I have described as the "front-tap contraction" is, I think, of considerable practical value. It is an exceedingly delicate test of the reflex irritability in the calf muscles, and may be obtained when their irritability is insufficient to permit the development of the clonus. I have found it in cases before the clonus could be obtained, and in cases which improved after the clonus had ceased to be obtainable in the ordinary way. When once it can be produced, if there is no ankle clonus, there is always a great excess of the knee reflex. It is occasionally, though not usually, to be obtained in apparently healthy individuals, and so is, alone, of less absolute value than the ankle clonus. In those who present it, however, although the power of the legs may be good, there is always an excessive knee reflex.

It has been remarked that, as a rule, if the ankle clonus can be obtained, the knee reflex is excessive. In such cases the disease is above the lumbar enlargement or in the lateral columns, and leaves both reflex processes unimpaired. But since the knee reflex occurs through nerves which arise higher up the cord than those through which the reflex irritability of the gastrocnemius is developed, it is conceivable that a local lesion in the upper part of the lumbar enlargement might abolish the knee reflex, and yet lead to the development of the ankle clonus. This combination was, in fact, presented by the following instructive case:

CASE 5.—John W—, æt. 44, came under my care at the National

Hospital for the Paralysed and Epileptic, November 11th, 1878. Weakness in the legs, chiefly in the left, commenced nine months before, and in a few weeks had reached such a degree that he could not move the legs at all. Power was slowly recovered, until his state on admission was reached; then he could only just stand with assistance. After a few weeks' treatment he had recovered so much power that he could walk half a mile. His condition then was as follows: Arms normal. When lying he could move the legs freely at all joints, but the left with less power than the right. The left quadriceps extensor was thinner than the right, and its irritability to faradisation was lower; it required two centimeters more of the secondary coil of Stöhrer's larger battery than the right, while it contracted to two cells of the voltaic battery less than the right. There was a similar difference between the two glutei. The flexors of the knee and all the muscles below the knee were equal in nutrition and irritability on the two sides. Sensation in the right leg was normal. In the left leg in front of the thigh and in the part supplied by the ilio-inguinal nerve a touch was felt at once. On the front and outer part of the thigh, in the part supplied by the anterior crural, middle cutaneous, and external cutaneous, neither a touch nor prick could be felt. Sensation was good on the outer part of the leg below the knee, in the part supplied by the external popliteal (sacral plexus), but not in the inner part (supplied by the internal saphenous of the lumbar plexus), until near the ankle. On the foot, back of leg, and back of thigh, the parts supplied by the sciatic, it was normal. There was also a little diminution of sensation over the whole of the left gluteal region supplied by the small sciatic. Cutaneous reflex from the sole of the foot was very marked. In the left leg typical ankle clonus could be obtained; in the right foot no clonus, but a single contraction, with the foot in passive dorsal flexion, on striking either the Achilles tendon or the front of the leg. Patellar tendon-reflex well marked on the right side; absent, absolutely, on the left.

There was thus diminished sensibility in the parts supplied by the external cutaneous (2nd lumbar nerve) and middle cutaneous and anterior crural (2nd, 3rd, and 4th lumbar), and gluteal region (supplied above by the 2nd lumbar, and below by branches from the small sciatic, which is almost certainly derived by the lumbar sacral cord from the 4th lumbar nerves). There was diminished irritability and some wasting in the quadriceps extensor femoris, supplied by the

anterior crural (2nd, 3rd, and 4th lumbar) and the gluteus maximus (small sciatic, probably from 4th lumbar), while there was no impairment of sensibility or wasting in any part supplied by the great sciatic, into which the 5th lumbar and sacral nerves go. There is thus strong reason to believe that there was a lesion, perhaps due to pressure from syphilitic disease, of the left side of the cord, and to a much slighter extent of the right side in this region. It had arrested the knee reflex, but the unaffected portion beneath had undergone the same increase in reflex activity which the whole lumbar enlargement presents in disease of the dorsal region.

In the cases in which the ankle clonus can be obtained, there is often a considerable amount of general muscular spasm in the legs, excited by sensory impressions or by attempts at voluntary movement. When this general spasm is considerable, the condition is that which has been designated "spastic paraplegia," "spasmodic tabes dorsalis," &c. When the spasmodic action becomes great, the ankle clonus often can no longer be obtained. The attempt to elicit it produces general tonic spasm in the limbs. I have, in several cases, observed the gradual cessation of the ankle clonus as the spastic state became developed. In some cases it could still be obtained at periods when the spasm was slight. It is probable that the reflex tonic irritability in the gastrocnemius, which permits the ankle clonus, is part of the same reflex action which in greater degree, or so to speak, storm-like action, leads to the tonic spasm in which the local stimulation cannot produce its effect.

The question suggests itself—if the reflex mechanism by which the ankle clonus can be developed by local stimulation is a normal phenomenon, excessive in lateral sclerosis, would not the ankle clonus also be obtainable, in slighter degree, under normal conditions? I have found that the ankle clonus is to be obtained in many, probably in most, individuals under normal circumstances. It cannot, indeed, be produced by passive dorsal flexion of the foot, but it may be obtained in another method. The ankle clonus in

spinal sclerosis may be produced very readily by making the patient sit on the edge of a seat with the knee flexed at a little more than a right angle, so that the foot rests on the ball, and the heel does not quite touch the ground. This posture evidently involves tension of the gastrocnemius. If then the top of the knee be tapped, the tension on the gastrocnemius is suddenly increased, and the ankle clonus is set up. The occurrence of the movement on this posture has been remarked by Dr. Buzzard, and was indeed observed long before the ankle clonus excited systematic attention. If a normal individual assumes this posture, a tap on the knee does not set up the movement; but if the movement is initiated by a voluntary effort, it will go on, often increasing in degree, without the slightest voluntary action, as long as the posture is maintained. A tracing from such a movement (fig. 11), obtained by attaching the writing lever to the

FIG. 11.

Normal ankle clonus from a healthy individual.

knee, has the same characters as that in spinal sclerosis. It is as regular, and occurs in just the same time. I show four tracings obtained from the first four individuals whom I examined—two strong robust hospital porters, the resident medical officer at the hospital, and myself. The time varied a little in the several instances, but within the limits of variation presented by the ankle clonus. In one case the number of contractions per second was 7, in the second 6, in each of the others 6.2 per second. How uniform the movement is, is shown by the fact that in one individual two observations gave respectively in equal periods of 9 seconds, 63 and 64 contractions, and in another, two ob-

servations on the one leg gave 56 and 57 in the same period and in the other leg 56 contractions.

These facts suggest that a reflex relation between muscular tension and contraction may play an important part in the mechanism by which often-repeated movements are co-ordinated. This reflex is excessive in lateral sclerosis of the cord. It is probably lost in posterior sclerosis, locomotor ataxy. The allied knee reflex is lost, and I have found that the normal ankle clonus cannot be produced, nor any voluntary movement resembling it.

The phenomena of muscular inco-ordination in this disease may be in part due (as Tschirjew also has suggested) to the loss of this reflex between tension and tonic contraction. In such respect the condition of the ataxic will resemble that of the infant who has never walked, and it has often been remarked how similar is the unsteadiness of the one to that of the other.

Within the last few days Mr. Romanes has communicated to the Royal Society observations which prove that, in the Medusæ, rhythmical movements result from a *continuous* nervous stimulation, the alternate exhaustion and return of muscular irritability determining the rhythmical character of the movement. The theory of the ankle clonus, which the observations, above recorded, suggest, is also that of a continuous nervous stimulation, but the rhythmical movement occurs as a consequence of the continuous central stimulation, and the continuous local stimulation of passive tension. The muscular contraction excited is transient, and the local stimulus only affecting the fibres when they are not contracting, the contraction, as it were, interrupts the stimulus, and renders the continuous influence an intermitting stimulation. The phenomenon thus indicates another method by which rhythmical action may be the effect of a continuous influence.