

On the contractility or irritability of the muscles of paralysed limbs, and their excitability by the galvanic current, in comparison with the corresponding muscles of healthy limbs / by Robert Bentley Todd.

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ON
THE CONTRACTILITY
OR
IRRITABILITY OF THE MUSCLES OF
PARALYSED LIMBS,

AND THEIR EXCITABILITY BY THE GALVANIC CURRENT,
IN COMPARISON WITH THE CORRESPONDING MUSCLES
OF HEALTHY LIMBS.

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THIS subject has already been brought under the notice of the Fellows of this Society by Dr. Marshall Hall, who has put forward his views respecting it in a paper printed in the 22nd volume of the Transactions. The statements made in that paper have been repeated by its author in the article "Irritability," in the Cyclopædia of Anatomy and Physiology, and subsequently in a volume of Essays very recently published.*

In these various writings Dr. Marshall Hall makes a distinction between the paralysis which results from lesion of the spinal cord and that produced by lesion of the brain. The distinction laid down by him may be thus expressed:—In cerebral paralysis, the irritability of the affected muscles becomes augmented: in spinal paralysis, the muscles supplied with nerves from the diseased portion of the spinal cord quickly

* See also Essay on the True Spinal Marrow, &c., 1837, p. 102.

lose their irritability; and the same effect is produced in paralysis dependent on disease of the principal muscular nerve of a limb or other segment of the body.

It must be confessed that this doctrine, so far as regards *cerebral paralysis*, is not a little startling to those who have been accustomed to admit, what experience so amply justifies, that the healthy action of a muscle is promoted by exercise within reasonable limits; and who would naturally infer that whatever restricted that exercise would be necessarily injurious to the nutrition of the muscle, and consequently to its leading vital property, namely, its irritability.

It would seem, from the perusal of Dr. M. Hall's writings upon this subject, that this doctrine suggested itself to him in reflecting on the curious fact noticed first by Fouquier, and now familiar to all physicians, namely, that during the administration of strychnine in certain cases of paralysis, the peculiar spasms which that drug is capable of exciting are first observed in the paralytic muscles. Referring to this fact, as regards the influence of strychnine, Dr. M. Hall makes the following observations:—"It will soon be seen that this view, like a former one, is far too general—far too indiscriminate; that it is not in every case of paralysis that the strychnine would first display its influence on the paralytic limbs. Meantime, however, I figured to myself the fact of the strychnine acting on the spinal marrow, and diffusing its power equally along the nerves, to the right hand and to the left, to the muscles to which they proceed respectively: and I asked myself the question—Is the difference observed in its ultimate effects on those muscles, the power being obviously the same, owing to a difference in the degree of the irritability of the muscular fibre itself? Is the irritability of that fibre actually augmented? if so, the phenomenon would be explained."

The results of experiments, instituted by Dr. Hall in order to solve this problem, confirmed his views, and led to the adoption of the opinion, that the abstraction of the influence of the brain upon a limb permitted an augmentation of

the irritability of its muscles; and this, again, gave confirmation to the hypothesis that the spinal cord was the source of muscular irritability; and that the ordinary actions of the brain served to exhaust this irritability, which, of course, would accumulate in the muscles, when the exhausting power of the brain had been withdrawn through the influence of disease.*

Feeling much dissatisfied with these views, which appeared to me to be inconsistent with many ascertained facts in the physiological history of the brain and spinal cord, I determined to repeat the experiments whenever opportunity offered, and I now venture to lay the results of my observations before the Society.

I may here state, that most of my experiments were made in hospital practice, and in presence of a large number of students, who generally attended in greater numbers when they knew that something experimental or operative was to be shown.

In the experiments the electro-dynamic machine was used, which was supplied with a single cell of Daniell's constant battery. Latterly I have employed the magneto-electric rotation machine, which does not require a battery, and which is on that account peculiarly convenient for medical purposes. It is very easy to regulate the rapidity and violence of the shocks. Only rarely have I used the galvanic battery alone; the use of this mode of developing the electric current is difficult in practice, in consequence of the trouble necessary to be taken to prepare the battery.

A little consideration will, I think, indicate that the results of the experiments need not be in any way affected by the instrument employed. The electro-dynamic apparatus is but

* "We may further deduce," says Dr. Hall, "from the facts which have been detailed, that the spinal marrow, and not the cerebrum, is the special source of the power in the nerves of exciting contraction, and of the irritability of the muscular fibre; that the cerebrum is, on the contrary, the exhauster, through its acts of volition, of the muscular irritability." *Med.-Chir. Trans.*, vol. xxii. p. 205.

a substitute for a large battery; the electricity generated in a single cell passes along a coil of wire of considerable length, and induces another current in an adjacent coil, which is itself also of great length. This current may be again augmented by placing a bar of soft iron, or, still better, a bundle of iron wires, at right angles to the coils. The battery is connected with the primary coil, and, by means of a rotatory wheel, contact may be easily made or broken: the intensity of each shock will, of course, depend on the extent of the *inductric* and *inducteous* material (to use Dr. Faraday's terms): the physiological effects, however, will be very much influenced by the rapidity with which the shocks are made to succeed each other, and this may be regulated by the rate of rotation of the wheel.

Of similar kind is that most convenient instrument the magneto-electric rotation machine. The electricity is obtained by induction from a powerful magnet, and great convenience is afforded by its being always ready for use and not needing the troublesome appendage of a battery.

In most of the experiments, the limbs to be compared were immersed by the hands, or the feet, as the case might be, each in a basin of water, which was connected with one of the wires of the galvanic apparatus. The current thus passed through both limbs at once, and both were similarly and simultaneously exposed to its influence.

I select from my case-books several cases in which I have tested the relative irritability of the paralysed and sound limbs by the methods above indicated.

Case 1.—Jane Weedon, æt. 61, hemiplegia of the right side—the paralysis of the arm is complete, that of the leg incomplete—motion only is affected in both limbs, sensibility being perfect. The attack was sudden; on getting out of bed in the morning she was seized with a violent fit of coughing, and staggered to her bed; she immediately lost her speech, retaining, however, her senses. In an hour she regained her articulation, was cupped and blistered, but seven hours afterwards lost her speech again, and with it the power of the right

arm, and that of the right leg but in a less degree. Her intellect and memory were slightly impaired.

This was a hard-working washerwoman, who had to support and bring up a large family by her own industry, her husband having been some years dead. I diagnosed the case as one of white softening, with perhaps a slight apoplectic clot or clots affecting the left hemisphere of the brain, and involving some of the fibres of the corpus striatum.

As the paralysis of motion was complete in the arm, the cerebral influence being completely cut off from that limb, the case was a fair one for applying the galvanic test to the muscles of the healthy and palsied arms.

The galvanic current was passed through the arms on the 10th May 1845, the hands being placed in basins, as already described. The electro-dynamic machine was employed—at first weak, without the bundle of wires, which is used to augment the current, the wheel being made to revolve slowly so that the shocks succeeded each other at long intervals.

By the weak current *no contraction of the muscles* was produced in the paralysed arm—slight contractions in the sound one. By the stronger current no contractions were aroused in the muscles of the paralysed arm, until the stimulus had been continued for some time, when only very slight contractions were excited, which were trifling when compared with those excited in the sound arms.

This patient remained under treatment for more than a month. She acquired much more power of her leg but none of the arm. On the 27th of July she returned to the hospital. The muscles of the right arm had wasted considerably: the palsy of that member had led to its disuse, which ought to have augmented the irritability of its muscles, if, as Dr. Hall affirms, “the constant *use* of the paralytic limb *diminishes* its irritability.” (Observations on Medicine, chap. xix. p. 118.)

The application of the electricity, however, on this occasion led to the same result as before, namely, very slight contractions of the palsied limb, and distinct and vigorous ones of the sound

limb. When the current was applied directly to the biceps muscle of each limb, that on the sound side contracted much more forcibly than the paralysed muscle.

I am glad to quote first a case in which the paralysis affected the arm; for Dr. M. Hall justly remarks, "The most unequivocal experiment is that made on the arms; because the paralytic seizure is in general most displayed in this part." (*Loc. cit.*, p. 123.)

Case 2.—This is a very similar case to the preceding one. Maryanne Twist, æt. 44, married, and had eight children. The attack was sudden, preceded by giddiness followed by paralysis of the left arm and leg, the former being completely palsied, the latter partially so. There were also paralysis of the tongue on the left side, as shown by its deviation to that side in its protrusion, and paralysis of the buccinator muscle of the cheek, which flaps somewhat in speaking.

The effects of the galvanism were the same as in the previous case, as far as regards the contraction of the muscles: it is interesting to notice that, in passing the current, more pain was felt in the palsied side than in the sound one.

Case 3.—James Stallard, æt. 54, a painter, and of intemperate habits. This was hemiplegia of the left side, affecting the face, arm and leg: the arm was completely paralysed and hung lifeless by his side: the leg was only partially paralysed: the attack was sudden, without loss of consciousness, and without warning: sensation was not affected. The man had for some time before the attack been living poorly. There was no infection of lead. I viewed the case as the result of white softening of the brain.

The result of the galvanic trials were, that while contractions were excited in both arms, those of the left or paralysed arm were obviously considerably less than those of the right or sound limb.

Case 4.—Henry Angus, æt. 61. Hemiplegia of the left side, especially the arm—sensation being very much impaired; the attack sudden, and much of the same character as in the previous case.

In this case, likewise, although the galvanic current excited the muscles of both limbs, those of the sound limb were much more strongly contracted than those of the paralysed limb.

Case 5.—Edward Woof, æt. 63. Hemiplegia of left side. The arm, leg, and side of the face were completely palsied as far as regards motor power. The attack was sudden, preceded however by a noise in the head, referred to the back part, “as if an engine had been at work in it.”

The galvanism was applied to this man’s arms. The palsied limb was very little affected by it, while the sound limb was made to contract strongly.

Case 6.—Caroline Willis, æt. 25. This patient had very complete hemiplegia of the right arm and leg, and also of the face. The arm was perfectly powerless; the leg was also similarly affected but to a less degree; she dragged it after her in walking. The face was perfectly motionless on the right side, the buccinator muscle being completely paralysed; and the orbicular muscle of the eyelids was slightly affected, as the patient was unable to close the eyelids on that side completely. The muscles of the paralysed limbs were flaccid and very soft.

From the history of this case, it appeared that there was some syphilitic taint in the system. The palsy was preceded by pain in the forehead and vertex, with drowsiness, general debility, and profuse leucorrhæal discharge, for which she had been inordinately bled before her admission. After the bleeding, her drowsiness increased and her intellect seemed impaired, and she had a violent hysterical fit which lasted half an hour. From this time her mother noticed some impediment in her speech, and occasional startings of the limbs. This state lasted about three weeks, when one day she suddenly lost the use of one side without any impairment of consciousness. Both sensation and motion were affected at first, but after a few days the sensibility was restored.

I viewed the case as one of white softening of the brain, preceded by some meningeal disease which probably was syphilitic in its nature.

The report of the trial of galvanism four days after her admission into the hospital is as follows:—"The current was passed through both arms in the usual way. Contractions took place in both limbs in a very manifest way. The action of the muscles on the paralysed side was distinctly less than that of the healthy ones, especially of the biceps muscle, and the paralysed arm was not jerked out of the basin."

Case 7.—Maryanne Neale, æt. 23, exposed by her mode of living to syphilitic infection, went to bed on Wednesday morning, June 2, 1845, quite well at 2 o'clock A. M., but awoke at 7 o'clock with great pain in the head, especially over the left frontal eminence. She then perceived that she had lost the power of her right arm and leg. She was freely bled for this and afterwards blistered, and on the 6th of June was admitted into the hospital in the following condition:—complete hemiplegia of the right side, involving the muscles of the face—the arm more palsied than the leg—speech indistinct—consciousness natural—sensation unimpaired.

There could be no doubt of lesion of the left side of the brain in this case, having probably a similar origin to that in the last case.

Here again the contractions produced by the galvanic current were distinctly much less powerful in the palsied limbs than in the sound limbs.

Case 8.—George Brosby, æt. 58. This patient had complete hemiplegia of the right side, which began with symptoms of softening, at which time the palsy was imperfect; this state lasted three weeks, when he became distinctly apoplectic with stertorous breathing; he recovered from this attack with complete paralysis of both right arm and leg. The following note was made of the only trial which was made with the galvanic current:—"The galvanic current, when passed through the sound leg, caused distinct action of the muscles, and the tibialis anticus was powerfully raised; but when applied to the paralysed limb, the action of the muscles was not nearly so strong. When a pole was applied to each ham, action was induced in both limbs, that of the

sound limb being decidedly the stronger. If the current was passed along the front of the thigh, the action of the anterior muscles was induced strongly on the sound side—*very feebly on the paralysed side.*

Case 9.—John Drummond, æt. 55, a tall muscular man, has hemiplegia of the left side, affecting the face as well as the extremities. Three years and a-half ago, he suddenly became hemiplegic without any impairment of consciousness; he had but just imperfectly recovered from this palsy when he was again attacked on awaking from sleep with palsy of the same parts. The radial arteries are thick, and several spots of deposit may be felt in them. It is probable that extensive disease of the arterial system exists, and that disease of this kind in the cerebral arteries has induced a white softening of a portion of the right hemisphere of the brain.

The galvanic current in this case affected both arm and leg, much less on the palsied side than on the sound one. Its influence on the arm was less even than that on the leg.

Case 10.—Mrs. L., æt. 53. This case occurred to me in private practice, and I am indebted for the opportunity of witnessing it to my friend Mr. Dunn, who is well acquainted with the present state of inquiry into the physiology and pathology of the nervous system, and takes a great interest in their progress.

The patient is a spare woman; she was found on Monday morning, the 17th May 1847, lying on the floor in her bedroom, speechless but without stertorous breathing, and not wholly unconscious—her consciousness gradually returned. I saw her four days afterwards, and found her completely hemiplegic, as to motion, on the right side—sensation unimpaired. Active reflex movements can be excited on tickling the foot, but none in the upper extremity. She yawns a great deal. There is no muscular rigidity whatever. Urine and fæces passed involuntarily. Puts her hand to the left side of the head.

The hands and afterwards the feet were placed in basins of water. I first used a Cruikshank's battery of fifty plates, but without any effect on either limb. I then had recourse to

the magneto-electric rotation machine: by this, active movements were excited in the healthy leg and arm; none in the palsied leg, very slight and feeble contractions in the palsied arm. On applying the poles directly to the palsied limbs contractions were excited, but even these were extremely feeble and partial.

This experiment was witnessed by Mr. Dunn.

On the 26th of May I repeated the experiment. The patient had acquired rather more consciousness and strength, but the palsied limbs were apparently unchanged. When the current was passed through both arms, by means of the basins, *only one or two muscles of the paralysed arm* were feebly excited, whereas the sound one was thrown into energetic action. The same results precisely were observed in the legs.

Mr. Dunn was present and assisted at this experiment likewise.

I am indebted for the next and the two following cases to my friend Dr. Babington, of Guy's Hospital, who requested Dr. Novelli, a very intelligent and competent manipulator, to apply the galvanism. Dr. Novelli has kindly furnished me with his notes of the experiments.

Case 11.—Eliz. Beaumont, æt. 33, admitted for hemiplegia of six weeks duration. The whole of the right side was paralysed. Three weeks after her admission, i. e. nine weeks after the paralytic attack, the following experiment was made:—The hands were immersed each in a separate basin of warm water, which were in turn respectively connected with the electrodes of a magneto-electric machine of feeble power. *No effect whatever was produced upon the right arm*, but the muscles of the left, i. e. the sound limb, were attacked with spasmodic quiverings and involuntary contractions. The hands were now removed and the feet substituted. A precisely similar result was obtained; the muscles of the sound leg being excited to irregular and involuntary action, *while the paralysed limb remained quiescent.*

The patient left the hospital about a fortnight afterwards unbenefited by the treatment employed. Previous to her de-

parture I repeated the experiment. The phenomena were unchanged.

The hemiplegia had been preceded by pain in the head and loss of consciousness.

Case 12.—Charles Hutchins, æt. 33, came under Dr. Babington's care on the 27th of May 1846. Three days before coming to the hospital, he had been seized with sudden pain on the left side of his head, and loss of consciousness, lasting for two hours and a half. Upon recovering from the fit, the left side of the body was found to be paralysed. I subjected this patient to the influence of voltaic electricity as above described, and it was again found that the sound arm exhibited feeble muscular contractions, *while the paralysed limb remained unaffected.*

At a *post-mortem* examination which took place, an abscess was found in the right hemisphere of the brain, involving the membranes, and extending within a few lines of the roof of the ventricle. Here, therefore, the paralysis had indubitably a cerebral origin.

Case 13.—Thomas Gardner, æt. 25, paralysis of the right arm of four months standing. In this instance, also, the paralysis was preceded by pain in the head and a fit. The same experiment was performed as in the two previous cases, and the same results were obtained.

I have now adduced thirteen cases which unequivocally demonstrate that, in certain morbid states of the brain, the contractility or irritability of the muscles of the paralysed limbs is not augmented. Setting aside all comparison between the muscles of the sound and palsied limb, there can be no doubt that if the irritability of the latter were augmented, the galvanic current ought to excite them to brisk contraction.* Yet the experiments showed that in some no effect whatever was produced, and in others the effect was only slight. It may be considered, therefore, as proved that the cutting off

* In experiments with the galvanic current upon muscles, the contractions are always in the direct ratio of the intensity of the current.

of the brain's influence from a muscle does not (in every case at least) lead to the augmentation of its irritability.

There are, however, cases of hemiplegic and even of paraplegic paralysis in which the muscles respond very readily and vigorously to the galvanic stimulus, and even display a greater amount of vigour than the muscles of the healthy limbs. In these cases the muscles of the palsied limb always exhibit some degree of rigidity, and the vigour of their action in obedience to the galvanic stimulus will be proportionate to the amount of rigidity, within certain limits. It must be borne in mind, however, that this is the case generally only where the rigidity is recent, and appeared along with or very shortly after the paralytic seizure.

It is important to make a distinction between the rigidity which affects the paralytic limb early, and that which follows the paralytic seizure at a distant interval. The latter is indicative of loss of substance in the nervous centre. A patient has softening or a clot; this produces paralysis; by and by the softened brain shrinks, or the clot becomes absorbed, and the surrounding healthy brain gradually contracts around the lesion, and as it contracts it causes rigidity of the paralysed muscles. The early rigidity of the palsied muscles accompanies a state of irritation of the brain, and will disappear when that irritation is subdued. Red softening, a tumour, meningeal disease, inflammation around a clot, are all capable of producing this state of muscle. This early rigidity may be taken as indicative of an augmented innervation of the affected muscle, which is thereby kept in an excited state.

Again, there are other cases in which, while the paralysis is pretty complete, the galvanic stimulus excites equally the muscles of the sound and those of the healthy limbs. These are generally cases of apoplexy occurring in persons previously healthy and not advanced in years. The muscles are healthy and well nourished; and, after the first shock has subsided, they respond readily to the galvanic stimulus, but not more so than those of the sound limb.

I shall quote some cases in illustration of these remarks.

Case 14.—Patrick Cochrane, æt. 52. This man had enjoyed but indifferent health for some months before his admission, having suffered from irregular gout. On the 10th of November, at five in the afternoon, he suddenly experienced a creeping sensation, commencing in his head and extending to the left half of his body; he became giddy and sick, and, on attempting to rise, found that he had lost the use of his left arm and leg; the left side of the face was paralysed and the tongue protruded to the left side, and he had great difficulty of deglutition. Intellect slightly impaired.

There was slight rigidity of the muscles of both arm and leg, and these limbs also started a great deal both by day and night—a symptom most troublesome to the patient. These startings were brought on by yawning, and, on such occasions, were most conspicuous in the upper extremity.

After he had been in the hospital for ten days, during the last four or five of which the startings of the limbs were very great, the following trials were made with the galvanic apparatus.

The galvanic current was first passed from the popliteal space to the dorsum of the left (or paralysed) foot, and through the muscles of the left thigh and left calf. It was then passed, as nearly as possible, between the same points on the right or healthy side. The muscular contractions produced were most active and extensive *on the left or paralysed side*.

The current was then passed along the median nerves of the upper extremities and through their muscles. The contractions produced were clearly more powerful on the left or paralysed side than on the right.

The rigidity and startings became less in the course of a few days, and on the 7th of December it was reported that the arm was relaxed and soft, but the leg rigid so as to prevent complete extension. The galvanism excited now greater contraction in the paralysed leg than in the sound one, but less in the paralysed than in the sound arm.

The startings in the paralysed limbs ceased altogether on the 28th; he was regaining power in the leg, but the arm

had wasted, and hung quite flaccid. On the 14th of January I gave him some strychnine, in doses of one-sixteenth of a grain, three times a-day. Four days afterwards he began to feel a pricking sensation in the left foot, leg, and thigh, and the left side of his hip, followed by startings of the leg; there was no sensation referred to the arm. It was not until twelve days after this that the arm began to be affected by cramps, although he had experienced uneasy sensations at an earlier date.

Case 15.—Robert Morgan, æt. 25, a clerk. Three weeks before his admission he had violent pains in the head, preventing him from sleeping, accompanied with thirst and fever. These subsided and recurred, and again subsided and recurred: he was then attacked with vomiting; his speech became affected, and on the 13th of November 1845 his right arm and leg became powerless, and consciousness was much impaired.

The paralysis was complete in both extremities, but the muscles of the upper extremity presented a considerable degree of rigidity. The right fore-arm was firmly bent on the arm by the action of the biceps, and the fingers and thumb were flexed into the palm.

I had no doubt, in this case, of the existence of red softening in the left hemisphere of the brain.

On applying the galvanic current, marked contractions of the right (or paralysed) arm were produced. Very little effect was produced on the right (paralysed) leg, but there was considerable action of the left leg.

Case 16.—Eliza George, æt. 44. In this case there was hemiplegia of the right side. On awakening in the morning she was seized with dizziness, and her right leg became paralysed: three days afterwards the arm became affected. The intellect was much impaired and articulation destroyed, so that she could only utter the monosyllable "No." There was rigidity of the muscles of both limbs, especially of the upper extremity.

The effect of the application of the galvanism is thus noted: "the affected arm was more convulsed and more painful than

the sound one. The same effect was produced in the leg, but to a less degree."

In addition to these cases, I may state that, about three years ago (July 5, 1844), Dr. M. Hall did me the favour to send me a patient, in whom he stated that galvanism excited more contraction in the paralysed than in the sound limb. In this patient, a girl, *æt.* 15, there was paralysis of the right arm, with *contraction* and *rigidity* of the flexor muscles and inability to extend the fingers.

Dr. Novelli has furnished me with an account of his trial of galvanism on a case of recent paralysis of the left arm. In this case he used a trough of fifty plates. Small plates of zinc were applied at certain points of the limbs, and to one of these each wire of the battery was applied, contact being made and rapidly broken by touching one of the zinc plates with one of the wires, and immediately removing it. The result was, that no difference whatever was observable as to the degree of contraction produced in either limb—although the experiment was performed with great care, and repeated several times with the like result.

I have tested two cases of recent hemiplegia after apoplexy by the galvanic current, with the result of finding very slight difference in the contractions of the two limbs; the palsied limbs, however, exhibiting feebler contractile power than the sound ones.

Nyrten relates that he tested the muscles with galvanism in two apoplectics, who died some days after the attack; and that there was as much contraction in the paralysed as in the sound limbs.*

* I had made several experiments on this subject, and had frequently expressed my doubts of the correctness of Dr. Marshall Hall's views, before I was aware that my learned friend, Dr. Pereira, had formed similar opinions. His valuable work on *Materia Medica* is so generally in the hands of medical readers, that I need not quote the remarks which he makes on this subject. I shall only add, that he relates one case of cerebral palsy in which the paralysed muscles were less excitable to the galvanic stimulus than the healthy ones; and he states that he has "observed the same effects in many other cases."—Pereira, *Mat. Med.*, vol. ii. p. 1301.

I have thus referred to three classes of cases, in each of which the paralytic limbs respond differently to the galvanic stimulus. In the first class the stimulus produces little or no contraction; in the second it causes vigorous contractions, and even of a more lively character than those in the sound limbs; and in the third, contractions are excited of a more or less vigorous kind, but which exhibit little or no difference from those of the healthy limb.

In the first class of cases, the paralysed muscles may be more or less wasted, or they may present no difference in point of nutrition from those of the sound limb. In my tenth case there was no difference, as regards the nutrition of the muscles, between the sound and palsied limbs; yet the electric current excited scarcely any contractions in the latter.

In the second class, the paralysed muscles at first exhibit no loss of nutrition—on the contrary, they are manifestly firmer than the healthy muscles; if the palsy yields to treatment, they lose this increased firmness or rigidity and assume the natural condition; if, on the other hand, the disease obtains the mastery, the muscles waste, although in some instances they continue to maintain their rigidity.

In the third class, the muscles retain their normal condition, and will continue to do so if the patient is not slow in recovery.

In reviewing the results of the experiments in these cases, this conclusion forces itself upon me—that the effect of the galvanic stimulus upon a paralytic limb is always feeble when the nutrient condition of the muscles is low, i. e. when there has been much wasting of the muscles; but that a well-nourished state of the muscles in a paralysed limb is no index of the probable amount of contraction which the galvanic stimulus would excite in them.

A little reflection upon this conclusion suggests that, in all probability, the state of the muscles has essentially little to do with the phenomena excited by the galvanic stimulus; else, in every instance the state of the muscle and the effect of the galvanism ought to correspond.

To explain the phenomena we must look to the state of the *nerves* of the paralytic limb. An analysis of the cases shows that a direct relation exists between the degree of development of the *nervous force* in the nerves of the affected limb and the effect of the galvanic stimulus.

In the first class of cases the nervous force is depressed in the nerves of the paralytic limb; in the second class it is exalted; and in the third class it retains its normal development.

Every one who has experience in physiological experiments upon the nerves and muscles, knows that the application of the galvanic stimulus directly to the muscle itself is much less effective in exciting it to contract, than the application of it to the nerve by which the muscle is supplied. When we observe how general and consentaneous is the action of the muscles in the upper or lower extremities, when the galvanic current is passed through them, each limb being immersed in a basin of water according to the method described in the experiments, it is impossible not to conclude that it is upon the nerves that the galvanic stimulus acts under these circumstances, and that the contractions of the muscles are the result of its influence upon the nerves. In corroboration of this view, let the poles of the electric apparatus be applied to the muscles themselves, and the contractions excited are comparatively feeble; but let them be applied in the course of some of the principal nerves of the limb, as the median or the sciatic, and a marked increase in the number and vigour of the contractions will be produced.

This view acquires further support from the following experiment. Let the posterior extremities of a frog be separated from the trunk at the dorsal region of the spine, and then let them be skinned. If the feet be immersed each in a cup or glass of water, and a weak current passed through the limbs, both will be equally affected: let now a piece be cut out of the sciatic nerve in one thigh,* and immediately the contrac-

* Very conclusive evidence in favour of this view is derived from Matteucci's experiments, which show that, after a time, *the direction* of the current exerts an important influence upon the contractions. This in-

tions in that limb will be manifestly less than those in the uninjured limb.

We must look then to the state of the nerve to explain the different effect of the electric current upon the muscles. When the nerve is in a state of irritation, or, in other words, when the nervous force in it is in a *plus* condition, so to speak, the galvanic stimulus will take great effect; on the other hand, when the nervous force is depressed, or in a *minus* condition, the galvanic current takes little or no effect.

Galvanism may, therefore, sometimes serve as a test to distinguish between an irritant and a depressing lesion of the brain. In using this test, however, the practitioner will do well to bear in mind, that an irritant disease of the brain is not necessarily inflammatory, but that, on the contrary, inflammation of the brain is very frequently most depressing in its effects. A spiculum of bone or a meningeal tumour may be irritant in its effects, but not inflammatory; whilst a patch of red softening, which is distinctly inflammatory, will often produce great depression, both local and general.

These views suggest what appears to me to be the true explanation of the remarkable tendency of strychnine to affect paralytic limbs first. It will scarcely be doubted, now-a-days, that a medicine which exercises such potent influence upon the body, when given in so minute doses as one-eighth or one-fourth of a grain, must do so through the blood. This material, being taken up into the blood, circulates with that fluid wherever it flows, to all parts of the cerebro-spinal centre, equally on both sides, if the circulation on both sides be in equilibrium. But if there be any lesion on one side of the brain, which from the morbid irritation, or for purposes of repair, attracts a larger quantity of blood to or around it than that which flows to the corresponding part on the opposite side, then a greater amount of the strychnine will be accumulated there, and that part will become the seat of irritation

fluence is clearly exerted through the nerve, for in applying galvanism to a muscle, it is of no consequence in what direction the current may pass.

by that drug. This irritation will, in conformity with the known law of cerebral action, be communicated to the muscles of the opposite or paralysed side, and consequently the muscles of that side will first exhibit the peculiar effects of strychnine.*

In a few rare cases, strychnine does not affect the paralysed limbs first. In these cases the lesion in the brain is doubtless of such a nature that the blood is attracted to the brain-substance around it in less quantity, than to the corresponding parts of the opposite side.

What, then, is the condition of the irritability or contractility of the muscles of the paralysed as contrasted with those of the sound limb? Certainly it is not augmented. It is in exact proportion to the nutrition of the muscles. Matteucci's extensive and carefully conducted experiments have quite settled the much-vexed question respecting the *vis insita*. He has shown that the nutritive changes of muscle develop a galvanic current, which passes from the interior to the surface of the muscle, and that muscular contraction causes what may, with the highest probability, be regarded

* There are many pathological facts which show that a poison in the blood is apt to be attracted largely to any part to which there may be a great flow of blood from any previous cause. Four years ago I attended a lady in small-pox; she had in one groin a large congenital nævoid patch, and was much alarmed to find that this spot had an extraordinary accumulation of pustules upon it. A very similar case is related in Dr. Wm. Budd's paper in the 25th volume of the Society's Transactions, p. 129. Ollivier justly remarks, that it is not the motor power only which is affected by strychnine, but also sensibility; that paralytic limbs are frequently rendered painful by strychnine, and even before the motor power becomes affected. In the fourteenth case referred to in this paper, this effect of strychnine is recorded; and I believe this to be the most common way in which this drug begins to show its effects. Many physicians write and speak of this poison as if it had a peculiar and specific influence on the spinal cord, *to the exclusion* of other parts of the cerebro-spinal centres. This view I believe to be incorrect, and that the influence of strychnine pervades the whole cerebro-spinal system; it by no means follows that, because this drug *appears* to act upon the spinal cord first, it acts *exclusively* upon that organ.

as an electric discharge, which can excite the nervous force in the nerve of a frog's leg,—and that these phenomena are in the direct ratio of the nutritive actions of the muscle,—they fail when the changes of nutrition are slow and imperfect or vitiated, and they are distinct and easily demonstrable when the muscles are well nourished. And when we take into account the beautiful and complicated structure of muscle, which modern research has so well developed,—when, likewise, we remember its complex and peculiar chemical constitution, it is impossible to refer the force which muscles can develop to any other source than its own tissue and the chemical and physical changes of which it is the seat. The two tissues, muscle and nerve, and the forces which they respectively develop, are, no doubt, nearly allied, and probably so far mutually dependent, that the imperfect nutrition of either would exert an unfavourable influence upon the other.

It is in vain to find any distinction between cerebral and spinal palsy, upon any difference that may exist between the paralysed and healthy muscles as to their excitability by galvanism. The very same states of muscle and of nerve exist in spinal palsies as in cerebral. There is this difference, however; that as in spinal palsy the nerves are more nearly related to the seat of lesion, sometimes, indeed, implanted in it, they participate more directly and, therefore, more completely in the effects of the lesion than in cerebral palsy; and when these effects are depressing, the nervous force is more completely depressed, or when they are irritant, the nervous force is more exalted, in spinal than in cerebral palsies. In a case of intra-spinal disease, which occurred about twelve months ago in King's College Hospital, the lower extremities were in a state of continued tonic contraction more intense than I had ever seen them in tetanus. These muscles responded readily and very forcibly to the galvanic stimulus. Yet the influence of the will was completely withdrawn from them, and the paralysis of voluntary motion and of sensation was complete. Muscular rigidity to a less degree is by no means uncommon in spinal palsy.

Furthermore, it may be stated that strychnine is as apt to affect the paralytic limbs where the lesion is spinal as where it is cerebral.

In conclusion, I will sum up the results of the preceding observations in the following propositions :—

1. The contractility or irritability of the muscles of paralysed limbs bears a direct relation to their state of nutrition.

2. The excitability of the paralysed muscles to galvanism varies with the condition of their nerves, more than with that of the muscles themselves.

3. In the majority of cases of cerebral palsy, the contractility or irritability of the paralysed muscles is less than those of the sound side, simply because their nutrition is impaired by want of exercise.

4. No diagnostic mark, to distinguish between cerebral and spinal palsy, can be based on any difference in the irritability of the paralysed muscles ; for the muscles in spinal paralysis exhibit the same states as those in cerebral paralysis.

5. The tendency of strychnine to affect the paralytic limbs before the healthy ones, is attributable to its being attracted in greater quantity to the seat of lesion in the brain than to the corresponding part on the other side.

6. The manner in which the muscles of a paralysed limb respond to the galvanic stimulus, assists us in forming an opinion as to the state of its nerves ; if they respond feebly or not at all, the nerves are in a depressed state : if they respond vigorously, more so than the healthy muscle, the nerves are in a state of irritation.

[*From Transactions of the Medico-Chirurgical Society, Vol. xxx.*]

