be very conveniently carried. The necessity for smoking and varnishing paper is done away with by the use of ink, and the tracings show that the friction between the writing point and the paper is scarcely more than in other sphygmographs; and, as regards their merits as sphygmograms, the tracings speak for themselves.¹

The instrument was devised in October, 1886, and made in December of the same year. Since then repeated trials, permitted by the courtesy of the honorary medical staff and made in the

Figs. 1 and 2.—Tracings with Marey's instrument from same artery within half a minute of each other without moving the sphygmograph.

hospital here, have brought me to the belief that it may prove useful, more especially for purposes of observation, and for demonstration of the pulse phenomena of heart disease.

In conclusion I must express my obligations to Professor Fraser for his kindly encouragement, to Dr. G. L. Gulland for the drawing, and to Mr. Alexander Fraser, of Lothian Street, for many valuable suggestions, and for the successful carrying out of the mechanical part of the work.

THE DISTRIBUTION OF PARALYSIS AND ANÆSTHESIA IN INJURIES OF THE CERVICAL REGION OF THE SPINAL CORD.²

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GENTLEMEN—Having been thrown by circumstances into connection with a large number of legal investigations relating to railway accidents, and having hence been led to take a special interest in spinal injuries, I have been much impressed by the vagueness of the usually received accounts of these affections, and have endeavoured to ascertain more accurately than is commonly done the reason and the import of some of the more complex collections of symptoms which they present to us. In order to obtain reliable data, I have carefully observed a large number of serious cases which have come under my observation as Surgical Registrar in the Manchester Royal Infirmary, the staff of which hospital has kindly allowed me to use the cases which have there presented themselves. Among others, I have now watched nineteen cases of injury in the region of the cord from which arise the nerves of the brachial plexus, and I have been led to certain results which appear to me to possess both a purely scientific and a medico-legal interest.

To-day I propose to bring before you some of these results, and, in doing so, may say that the cases which I have now briefly to bring under your notice will be found reported *in extenso* in a paper which I published in *Brain* in January, 1887, and in a second communication in the same journal.

The only two points in which I shall endeavour to-day to in-

terest you are the distribution of the paralysis and of the anæsthesia observed in injuries at various levels of the brachial enlargement of the cord—that is, from the fourth cervical to the first dorsal vertebra.

First, then, as regards the paralysis, I find that with a little care it is possible to ascertain very accurately—much more accurately than is usually done—the exact extent of the paralysis produced in crushes of the cord at different levels, and also to trace the course of the ascending myelitis which frequently ensues upon such injuries by observing the way in which the muscles of the upper limb become subsequently paralysed. Such an examination has led me to assign a definite order to the spinal nuclei, if I may so call them, of the brachial enlargement—an arrangement which I have tabulated in the following manner:

Arrangement of the Muscular Nuclei of the Brachial Enlargement of the Spinal Cord.

Supra-spinatus and infra-spinatus	} 4th cervical nerve.
Teres minor (?)	
{ Biceps	} 5th cervical nerve.
{ Brachialis anticus	
{ Deltoid	
{ Supinator longus	
{ Supinator brevis (?)	} 6th cervical nerve.
Subscapularis	
Pronators	
Teres major	
Latissimus dorsi	
Pectoralis major	
{ Triceps	
{ Serratus magnus	} 7th cervical nerve.
Extensors of the wrist	
Flexors of the wrist	} 8th cervical nerve.
Interossei	
Other intrinsic muscles of the hand	} 1st dorsal nerve.

That there are certain gaps and probably some inaccuracies in this table I cannot doubt, but that in the main it will be found to hold good I am the more convinced by the fact that the results obtained tally closely with observations on the anatomy and physiology of the cord made in various other ways. Several of the muscles referred to—notably the pectoralis major—are certainly supplied from more than one level of the cord, but the nature of my inquiry permits only of recognising the chief of these levels—that is, the one from which are derived the nerve fibres supplying the functionally most powerful part of the muscle. I would further point out that, as I shall shortly explain more fully, the limbs of patients affected by the various combinations of partial paralysis acquire certain characteristic positions, so much so, that in one or two of the better marked instances it has been possible to diagnose the exact seat of the lesion by a mere glance at the attitude of the patient's limb. Time will allow of my mentioning only a few of the cases on which my conclusions are based, but these few will serve to indicate the nature of the evidence.

Commencing then at the upper part of the region to which we have referred, I have had two cases in which there was found at the *post-mortem* examination a fracture-dislocation between the fourth and fifth cervical vertebra, with a complete crush of the cord above the level of the fifth cervical nerve roots. In both of these cases the upper limbs appeared to be completely paralysed as regards both their extrinsic and intrinsic muscles. In one of them the levator anguli scapulae and trapezius were found not to be paralysed, the former distinctly contracting when the patient took a deep breath, but both of these muscles are undoubtedly innervated from above the brachial enlargement. Unfortunately, these were among my earlier cases, and the condition of the supra- and infra-spinati muscles was not noted, but from reasons which I shall shortly give I can assign both of these muscles to the fourth cervical nerve root, and the teres minor probably accompanies them.

Passing downwards I come next to a remarkable and most instructive group of cases, most typically represented by a man who survived for twenty-six days a fracture-dislocation of the fifth cervical vertebra. Unlike the majority of these dislocations the upper vertebra—the fifth—was displaced backward, and in such a manner that the fifth cervical nerve roots, which, it will be remembered, arise above that vertebra, were uninjured, and the cord was crushed below these roots. Now, on admission, and for a considerable period thereafter, this man did not present complete paralysis of the upper limbs. The trunk and lower extremities were affected as usual in such injuries, but the arms

¹ The tracings sent are only one-third of their original length. The drawing is that of the instrument as first used. A neater model can easily be produced.

² Read in the Section of Surgery, at the Annual Meeting of the British Medical Association, held in Glasgow, August, 1888.

maintained always the position shown in the engraving which I now hand to you, and which is taken from a photograph of the patient.

Fig. 1.—Showing the position of the upper limbs in a case of complete crush of the spinal cord immediately below the fifth cervical nerve roots.—From a photograph.

You will see (Fig. 1) that there is abduction with elevation and external rotation of the humerus, flexion of the elbow and supination of the wrist; and if you consider for a moment the action of the muscles of the limb, you will notice that this is due to tonic contraction of the supra- and infra-spinati muscles with the deltoid, biceps, brachialis anticus, and supinators in presence of paralysis of the other limb muscles; and that this is so is further proved by the fact that these muscles only retained their power of contraction. This case, then, is almost the exact antithesis of the lesion met with in the so-called Erb's paralysis or in Duchenne's obstetrical paralysis, where, the fifth cervical root being torn or crushed, the muscles which in my case are paralysed, remain sound, and those which in my patient present tonic contraction are paralysed. Now, in Erb's paralysis, which, for reasons upon which we cannot now enter, is almost certainly due to rupture of the fifth cervical root, the supra- and infra-spinati muscles escape injury, whereas in Duchenne's obstetrical paralysis, which, as I have elsewhere shown, includes also the fourth root, those two muscles are paralysed. Hence, then, we must assign the spinati muscles (with possibly the *teres minor*) to the fourth root and the deltoid, biceps, brachialis anticus, and supinators to the fifth. The latter group, which I shall take the liberty of calling the "fifth root group," is, as we shall shortly see, the key to the whole position.

The above observation is, however, confirmed by other of my cases, namely:—

1. A comminuted fracture of the fifth and sixth cervical vertebrae, in which the cord was obliquely crushed in such a manner that the fifth cervical root entirely escaped injury on the left side, whereas on the right the injury extended rather higher, crushing the fifth root and that portion of the cord from which it arises. This condition is shown in this drawing (Fig. 2).

Now in this case, on the right side the upper limb was completely paralysed, whereas on the left side the muscles composing the "fifth root group" were intact, and although on the right side the upper limb was quite flaccid, on the left it had exactly the position which is represented in my first figure.

2. I had a case of fracture-dislocation of the fourth and fifth vertebrae in which the cord was not at all compressed, but had hemorrhages into its central grey matter. The patient lived only a few hours, and there was no satisfactory examination, but it was noted that whereas the left upper extremity was absolutely paralysed, the right deltoid and biceps were still capable of contracting, the condition of the supinator being unnoted.

3. Other cases which I shall quote later will be found further to illustrate this paralysis below the "fifth root group" although they would not alone have so readily allowed of its identification. Also the above symptoms have been observed by other writers, but have never been fully described, nor has their significance been noticed. Thus in the *London Hospital Reports* for 1866, Mr. Jonathan Hutchinson mentions a case in which a man had partial paralysis of the right arm, but could raise the

limb although he could not grasp, and still more clearly another case of crush opposite the fifth cervical vertebra in which the arms were raised to a level with the shoulders and the forearms flexed by the biceps. Again, in the *St. Thomas's Hospital Reports* for 1870, Mr. Churchill describes a case of fracture of the fifth cervical arch with crush of the cord, where the patient had but slight power of moving the shoulders and upper arms. In the latter paper is also described a case of dislocation forwards of the sixth cervical vertebra, where there was impaired movement of the arms attributed to a desire to keep the spine immovable, the upper arms were raised to a right angle with the body, and, to quote the writer's words, "the forearms were flexed so as to relax the muscles and to support the head;" there was at the same time hyperæsthesia of the radial side of the upper limbs. Clearly this is a case of irritation of the fifth root centres, with paralysis below them.

We are, however, I believe able to go further than this, and to establish the relative positions of the nuclei in the "fifth root group." Thus returning to the case of which you have a photograph, we found that about the fifteenth day, to quote the notes, "the contraction of the deltoid muscles, which had maintained the abducted position of the arms, ceased, and the elbows fell to the sides, the elbow joints themselves remaining flexed," a condition which continued until death. From various clinical reasons, and from the *post-mortem* appearances, there can be no doubt that

Fig. 2.—Showing the condition of the spinal cord in a case where the deltoid, biceps, and supinator longus had escaped paralysis on the left side only.

during this time there was ascending myelitis, and it would thus appear that first the nuclei for the supinators, and then those for the deltoids were thereby involved, so that we arrange these nuclei as shown in the table.

Let me now briefly mention other cases illustrating and confirming these points.

1. In a case where there was no *post-mortem* examination, the patient dying a few hours after injury, the limbs were paralysed, but the arms were held abducted, with the elbows flexed, the hands lying on the epigastrium, and prone. Here the lesion had reached so high as to involve the nuclei for the supinators, leaving the deltoid and biceps.

2. In another case, which also died very early, and where, also, there was no *post-mortem* examination, all the muscles of the upper limbs were paralysed, except the flexors of the elbows. The limbs lay quietly by the sides, but, on being told to move them, the patient bent the elbows without other change. Here the destruction extended so as to include the deltoid nuclei. Between the biceps and the brachialis anticus I cannot differentiate.

3. There was a case of fracture-dislocation of the fifth cervical vertebra, in which "the left upper limb was abducted, with the

elbow flexed and the hand across the chest, the right being completely flaccid. On the left side he had the power of voluntary contraction of the biceps, supinator longus, and deltoid, but not of the other limb muscles, whereas on the right side all the muscles were paralysed. On the left side the supra-spinatus and infra-spinatus could be made to contract, on the right they could not." Hence the damage to the cord included the nuclei of the fourth root on the right side, but spared those of the fourth and fifth on the left.

4. I had another case of fracture-dislocation of the sixth cervical vertebra, with very extensive hæmorrhage into the cord, extending for some distance above the lesion. On admission, "the left upper limb was entirely paralysed and flaccid;" on the right side the shoulder was abducted, and rotated somewhat outwards, the elbow being flexed, and the wrist and fingers flaccid. In a few hours both limbs were quite paralysed, and death followed after forty hours, when the hæmorrhage in the cord was found to reach as high as the third cervical nerve roots. This hæmorrhage must have extended after admission into and beyond the nuclei for the fifth root of the right side.

And now let us go a little further. J. E. C. was admitted to the infirmary with an injury afterwards found to consist of a partial dislocation of the fifth cervical vertebra, with some compression of the cord and hæmorrhage into its substance, but with no injury to nerve roots. I cannot now take time to give in detail the various symptoms observed during the twenty-nine days for which he survived, but must state briefly that:

1. When first seen, the intrinsic muscles of the hands and the flexors of the wrist were completely paralysed; none of the other muscles of the upper limbs had entirely lost their functions, but those of the "fifth root group" were distinctly the most powerful. That the cord was only partially destroyed was proved by the fact that the lower part of the body was not absolutely anæsthetic.

2. On the second day the extensors of the wrist were completely paralysed.

3. Between this and the fourth day the pectoralis major, latissimus dorsi, teres major, and pronators ceased to act.

4. After this the subscapularis and the muscles of the "fifth root group" alone remained to the patient. His limbs then lay close to his side with the elbows flexed. It will be observed that the retention of the "tonus" of the subscapularis modifies in an important direction the attitude shown in Fig. 1 by preventing the abduction and outward rotation of the humerus.

5. On the sixth day we could no longer distinguish any contractions of the subscapularis or supinator longus. After this the limbs still usually lay by the sides, owing, doubtless, to already commencing paralysis of the deltoid; but at times, especially in sleep, the patient would abduct the arms.

6. About the twelfth day he ceased to be able to abduct the humerus, and the biceps was beginning to fail.

7. On the fourteenth day the limbs were absolutely paralysed.

From this case we are able to trace the ascending lesion, picking off in succession the various nuclei; and, reading the lesson conveyed in reverse order, it will be found to confirm my table to the extent that it fixes for us, from above downwards: (1) biceps; (2) deltoid; (3) supinators and subscapularis; (4) pronators, teres major, latissimus dorsi, and pectoralis major; (5) extensors of the wrist; (6) flexors of the wrist and intrinsic muscles of the hand. The most important omissions are the triceps and serratus magnus, as to which no information is yielded.

The next case is one in which was found a dislocation forwards of the last cervical vertebra, with a crush of the cord at the seat of injury and subsequent ascending myelitis, life lasting for thirty-one days. On admission we found the upper limbs lying "across the chest, with the elbows close to the sides, and flexed," as shown in Fig. 3. "On both sides the flexors of the wrist and fingers were completely paralysed; on the right side the extensors were also paralysed, but on the left they retained very slight power. The triceps, pectoralis major, and serratus magnus, could be felt to contract on both sides, but only very feebly so. The deltoid, biceps, and supinator longus were more powerful than any of the other muscles of the upper limb, but were also weak."

On the twenty-second day almost all the muscles of the right limb were paralysed; but the patient could still rotate the humerus outwards, the supra- and infra-spinati being felt to contract, and could feebly flex the elbow; but neither the biceps nor the supinator longus could be felt to contract, and he had lost

all power over the deltoid. On the left side there was obvious contraction of the spinati, deltoid, and biceps, and he had feeble power of supination and pronation. Here, then, we find the lesion at first causing complete paralysis only as high as the flexors of the wrist on the left and the extensors also on the right side, and at the end of three weeks all muscles below the flexors of the elbow are paralysed on the right side, and these are very feeble, whereas on the left side the fourth and fifth root groups and the subscapularis and pronators retain a little power.

The application to the table is obvious, and there is some indication that the serratus magnus, triceps, and pectoralis major are about equally affected, and should, therefore, be placed near together. The position of the pectoralis major being already defined indicates that of the other two muscles. The sketch shows how the action of the subscapularis and pectoralis major modifies the attitude characteristic of the "fifth root group" by preventing abduction and external rotation of the humerus.

Lastly, J. S. sustained a fracture of the anterior and upper part of the first dorsal vertebra, with displacement forwards of the last cervical, and subsequent ascending myelitis. Life remained for ten days. To relate the sequence of events as briefly as possible:—

1. At first there was paralysis only of the intrinsic muscles of the hand, the interossei, and possibly the extensor communis digitorum.

2. At first, also, the flexors of the wrist were distinctly feebler than the extensors.

3. On the third day both flexors and extensors of the wrist were paralysed.

Fig. 3.—Showing the position of the upper limbs and the distribution of anæsthesia in a case of crush of the spinal cord, in which hæmorrhage had extended partially into the territory of the sixth cervical nerve root.—From a sketch.

4. On the sixth day the triceps and pectoralis major were paralysed, and he ceased to rotate the wrist.

5. The latissimus dorsi failed on the seventh day.

6. The teres major and subscapularis had at that time become very feeble, and external rotation with abduction of the humerus was noticed.

7. The "fifth root group" remained until the end.

Thus, then, this very complete case, which I regret to have had to describe so briefly, coincides with our arrangement, except in so far as the rotators of the wrist are concerned, and it warrants us in provisionally arranging the teres major, latissimus dorsi, pectoralis major, and triceps in the order there given, this group not having been hitherto differentiated.

I had wished next to discuss the arrangement of the anæsthesia, but fear that time will not permit. Briefly, I may say that all my cases bear out most clearly the conclusions so ably presented by Dr. Ross in a paper in *Brain* for January, 1888, on "The Segmental Distribution of Sensory Disorders;" that is, the outer parts of the limb are supplied by the higher roots, the inner by the lower in continuous order. Thus I find that the fifth root usually supplies the outer side of the limb down to about the styloid process of the radius; the first dorsal extends to the styloid process of the ulna, and the other nerves divide the intermediate region. By noting the limits of the anæsthesia we are able to confirm the position of the lesion.

And now let me bring before you a few more complicated cases of injury in this region, which will serve to show how the already

acquired knowledge enables us to define clearly the seat of any given lesion.

R. M. was admitted with an obvious dislocation of the fifth cervical vertebra to the right, the neck being clearly bent over. He had on both sides the symptoms of a partial destruction of the cord below the fifth cervical roots, the lower limbs and trunk being almost but not quite paralysed. For reasons which I cannot now give in detail I was able to demonstrate that the cord was more injured on the right than on the left side. But the fifth root had entirely escaped injury on the right side, so that sensation was perfect on the outer side of the right limb, and the "fifth root group" had escaped paralysis. On the left side, on the other hand, the "fifth root group" was entirely paralysed; and the outer side of the limb was absolutely anæsthetic, whereas the remainder of it was only partially so. By means of extension we reduced the dislocation, and the left elbow, which had before been straight, then became flexed, showing that in some way we had relieved the left fifth root. Still the patient showed on the right side an intact fifth root, with partial destruction below it; on the left side partial paralysis below the fifth root, but more complete paralysis of that root itself. The attitude is shown in this figure (Fig. 4), which demonstrates very well the different

Fig. 4.—Showing the position of the limbs in a case in which the fifth cervical nerve root was injured on the left but not on the right side.—From a photograph.

position of the two limbs. In this case the diagnosis which seemed most probable is indicated by this diagram (Fig. 5), showing dislocation of the fifth cervical vertebra to the right, crushing of the cord below the fifth roots more marked on the right side, entire escape of the right fifth root, but over-stretching or partial tearing of the left fifth root, which would be partially relieved by reduction. The man gradually recovered, and can now (after eighteen months) do some light work. He has a good deal of atrophy of the upper limbs, and on the right side the "reaction of degeneration" in all muscles but those of the "fifth root group;" on the left side there is no such reaction in any muscles.

Another man had a fall upon his hands, followed by coldness, weakness, and spastic symptoms in the lower limbs and a peculiar spasm of the upper limbs, which lasted for about a fortnight. During this period he says the limbs were held close to the sides with the elbows flexed, the hands in front of the chest and the wrists and fingers partially flexed. I saw him two months after the accident; he had then spastic symptoms in the lower limbs, hyperæsthesia of the dorsal divisions of the sixth and seventh cervical nerves, no sensory affection of the limbs. There was some weakness of the muscles of the upper limbs, most marked in the flexors of the wrist. Fifteen months later he had lost all his sensory symptoms, but had obvious wasting of both triceps muscles; and an electric examination showed a varying degree of activity in the muscles tested. The best was the biceps, then came the flexors of the wrist, then its extensors, and the worst was the triceps. Here I should diagnose a small central hæmorrhage about the nuclei for the triceps and extensors of the wrist. From this we get in the early stage paralysis of these nuclei, and spasm of those above and below, and you will see that spasm of the pectoralis major, latissimus dorsi, teres major, and biceps will produce the position occupied by the arms and forearms, and spasm of the flexors of the wrists and fingers that occupied by the hands. Later on we find partial paralysis of the triceps and extensors of the wrist, and, to a less extent, of the flexors of the wrist, so that there may have been slight extension downwards. The hyperæsthesia corresponds to this localisation.

Another man fell upon his back, and developed immediately paralysis of both triceps muscles, with weakness of the extensors and flexors of the wrist; the flexors of the wrist were more

powerful on the right than on the left side, but abduction of the humerus was weakened on the right side. There were no sensory symptoms, and recovery was soon complete. Diagnosis: a small central hæmorrhage about the triceps nuclei, extending down to those for the extensors and flexors of the wrist, but a little lower on the left than on the right side, so that the left flexors were the weaker, and on the right side extending up so as partially to weaken the adductors of the humerus, the pectoralis major, latissimus dorsi, teres major, and subscapularis. Again this coincides with the table.

Again, J. B. sustained a spinal injury causing paralysis, partial anæsthesia, etc., of the lower part of the body, contraction of both pupils, especially of the right, marked feebleness of the flexors of the wrist and fingers but no other paralysis of the upper limbs (the intrinsic muscles of the hand were not noted). Diagnosis: A hæmorrhage in the lower part of the brachial enlargement, rather larger on the right side, affecting the nuclei for the flexors of the wrist and fingers and the descending fibres of the cord. Death ensued in forty-eight hours, and at the *post-mortem* examination we found this hæmorrhage exactly as predicted in the lowest cervical and upper dorsal regions. It occupied the central canal, was about an inch and a half long, and on the right side extended very slightly into the anterior cornu.

Fig. 5.—Diagram of the supposed nature of the injury in the case represented by Fig. 4.

W. H. received an injury to the spine, causing complete paralysis of the left arm and leg, almost complete paralysis of the right leg, and paralysis of the right arm, except the rhomboids, supra- and infra-spinati, biceps, deltoid, and supinators, which were unaffected. The left pupil was more contracted than the right; anæsthesia was more marked on the right side of the body. Diagnosis: Hæmorrhage into the spinal cord, more extensive on the left side, and sparing the "fifth root nuclei" of the right side. About a week later these nuclei were also paralysed by myelitic changes. Partial recovery then followed, the right limb regaining more power than the left.

I have thus run over a few out of a large number of cases of injury in the region of the brachial enlargement of the cord, and hope that I have been able to show you that in all cases, however complex the symptoms may appear, we are able, by means of a careful consideration of the distribution of the paralysis and anæsthesia to obtain a definite diagnosis. In this way many of the cases usually described as "concussion" of the cord may, I believe, be much more accurately diagnosed. Of a total of about 350 railway accidents of all kinds and 50 spinal injuries due to various causes which have come under my observation, I have never yet seen an instance in which spinal symptoms were present where I could not definitely postulate some gross injury—fracture, hæmatomyelia, meningeal hæmorrhage, myelitis, meningitis, or sprain with pressure upon certain nerve roots, without requiring to fall back upon the unknown "molecular" changes supposed to constitute concussion, and hence I am strongly led to believe that such observation will enable us to detect many cases of imposture, in which symptoms are irreconcilable with any definitely localisable lesion.

THE Birmingham Hospital Sunday collection amounts to £4,455 13s. 4d.