vital action, in their intramedullary part, having lost their neurilemma, they immediately undergo degeneration.

3. The first change is a primary degeneration of the myelin; axis cylinders and nerve cells are evidently affected later.

It seems to us that the results of our investigations suggest the possible lymphogenous origin of some nervous affections. We know that tabetiform and cranial nerve lesions in general paralysis, and even those in tabes, are not the result of nerve-cell degeneration, but are a primary affection of the myelin sheath, commencing where the neurilemma is lost. In our clinical cases, and also experimentally, we have found similar lesions starting at the same point, the result of absorption from a definite toxic focus situated outside the central nervous system, the toxins gaining access by the lymph stream. May it not be possible that the former lesions are also the result of toxins passing to the cord, medulla, and pons by the lymph stream from some external but as yet unknown focus? In support of the lymphogenous theory of infection, we have lately added two additional clinical cases, namely, one of chronic middle ear and mastoid disease in which the eighth nerve was markedly degenerated in its intramedullary portion; and another of multiple abscesses in the right trapezius in which the right eleventh nerve was attacked within the medulla.

References.
[1] *Brain*, Winter, 1904. [2] *Rev. Neurol. and Psych.*, October, 1903. [3] Ibid., January, 1906. [4] *Manuel d'Histologie Pathologique*, Cornil and Ranvier, T. 3, 1907, pp. 718 to 725.

REPORT C.

AN INVESTIGATION ON THE REGENERATION OF NERVES, WITH REGARD TO SURGICAL TREATMENT OF CERTAIN PARALYSES.

By BASIL KILVINGTON, M.S., M.D.Melb.
(From the Physiological Laboratory, Melbourne University.)

In this article some experiments will be detailed on nerve crossing in the spinal canal, and their surgical bearing discussed.

It is generally admitted that regeneration is impossible in the nerve tracts and fibres in the cord. This faculty of repair ceases at the point of entrance and exit of the nerve bundles from the cord itself, and corresponds to the place where the primitive sheath ends. The latter seems in some way to be essential for regeneration. In the case of the posterior roots useful regeneration can only take place when the lesion is distal to the posterior root ganglion. Section and suture central to this are doubtless followed by regeneration as far as the cord, but it ceases there, and the result is of no value.

In the case of the anterior root, the recovery can follow a lesion anywhere in the neural canal if the ends be brought into satisfactory apposition. There is anatomically a considerable scope for the nerve surgery within the spinal canal. It has long been recognized that injury to the cauda equina can sometimes be successfully treated by laminectomy and suture of the individual trunks, exactly as lesions of peripheral nerves can. Up to the present, I believe, nerve crossing has never been suggested within the spinal canal, and I wish to show that it is possible and has practical importance. The experiments were performed on dogs, and consisted in suturing the central ends of one of the limb nerves to the peripheral ends of the nerve supplying the rectum and bladder, with the object of innervating these structures by the higher nerve. The results were very encouraging. Before giving details of the experiments the bladder supply of the dog may be briefly given.

According to Langley and Anderson and Sherrington,[1] the nerve supply of the bladder in the dog is variable. The second and third sacral nerves always give bladder contraction sufficient to expel the contents.

The first sacral in a few cases gives bladder contraction, but not enough to cause micturition. It is very rare for the last lumbar (the seventh) to innervate the bladder, and even when it does the amount is insignificant.

The experiments were performed on three large dogs; in one the first sacral was sutured to the second and third, and in the other two the last lumbar was joined to the second and third sacral, leaving the first untouched. Preparatory to the operation a large area of the skin of the back was shaved, and cleaned with turpentine, ether, and warm perchloride solution. The single median incision was made over the vertebral spines. On each side the spinal muscles were rapidly cleared from the laminae till several of the bones were bared. The very free oozing was then arrested by firm pressure with a sponge wrung out of hot antiseptic solution. Then the laminae were chipped away with bone forceps and the nerve roots exposed in the spinal canal. The ones to be used were hooked up in their sheath with an aneurysm needle, and the dura mater was not opened. It was found that the seventh lumbar was the highest that could be sutured to the second and third sacral without any tension, and only a single thin chromic catgut suture was used. The muscles were sutured over the exposed dura to form a protection, and finally the skin. Several animals were operated on, but only three which healed by first intention were kept. The after-results produced were some awkwardness in the hind leg on the side operated upon, which partly disappeared in time. Nothing peculiar about the bladder function was noticed.

In order to identify the nerves, the following points were observed. A line joining the two posterior superior iliac spines crosses the point where the second sacral pierces the dura. The first sacral was very much larger than the second and third, and the last lumbar is nearly as big as the first sacral. The key to the position lies in identifying the second sacral, and counting the roots upwards and downwards.

The following are the details of the experiments:

Dog 1.—Operated on June 29th, 1906. The central end of both roots of the first sacral nerve were fixed to the distal end of both roots of the second and third sacral on the left side. The first sacral was cut out of the intervetebral foramen, and the second and third where they come out of the cord. There was no chance of the two ends of the same nerve joining in any way.

October 15th, 1906. The spinal canal was again opened up, and the nerves isolated. There is always considerable difficulty in this, as the outer surface of the dura is roughened and adherent to the surrounding structures at the time of the second operation. Faradic stimulation of the first sacral nerve caused no sensory reflexes as the posterior root had been divided central to the ganglion. Stimulation of the first sacral produced strong movement of the tail and contraction of the pelvic diaphragm, and usually started bladder contraction with expulsion of contents. A cannula tied in the bladder and connected with a manometer showed a rise in the intravesical pressure. It seemed as if the contraction of the pelvic floor started the bladder reflex rather than caused the bladder contraction directly. This was not quite certain, however, but the practical results were the same in either case. Stimulation of the first sacral on the right side produced none of these effects.

Dog 2.—Operated on August 20th, 1906. The anterior root of the seventh lumbar was joined to both roots of the second and third sacral nerves on the left side; in the latter case both roots were used, because they were so small that it was impossible to separate anterior from posterior without causing much damage. An endeavour to do this in one animal spoiled the operation.

February 12th, 1907 (176 days after). Stimulation was performed, after cutting the spinal cord across at the level of the sixth lumbar nerve. The faradic current on the seventh nerve produced: (*a*) A vigorous contraction of the muscles of the pelvic floor; (*b*) vigorous contraction of the sphincter ani, and after ceasing the stimulation, extrusion of faeces; (*c*) expulsion of some of the bladder contents through the urethra in a jet (the organ having been previously filled with fluid), though no definite and visible contraction of the bladder or rectal wall was noticed. These organs were exposed by making a large incision in the abdominal wall. As a control, the seventh lumbar of the opposite side was stimulated and produced no contraction of the pelvic floor, sphincter ani, or expulsion of bladder contents. On the sound side stimulation of the second and third sacral produced exactly the effects of the seventh lumbar on the opposite side, but here, too, there was no contraction of the bladder or rectal walls detectable by the eye alone.

Dog 3.—Operated on October 18th, 1906. Both roots of the last lumbar nerve on the left side were fixed to the two roots of the second and third sacral nerves. The posterior root of the lumbar was cut distal to the ganglion, and the second and third sacral central to this. There were thus two ganglia in connexion with the posterior roots connected with the regenerating second and third sacrals. The first sacral was left untouched.

February 28th, 1907 (123 days after). Stimulation was performed. On the left side the faradic current, when applied to

the seventh lumbar nerve (which was detached from the cord), resulted in (1) vigorous contraction of the perineal muscles and sphincter ani; (2) slight expulsion of bladder contents; (3) movement of the leg normally produced by stimulation of the second and third sacral roots. In this case, too, no visible contraction of the bladder wall was observed. As a control the second and third sacral roots of the untouched side were stimulated, and identical, though somewhat more forcible, movements resulted. No bladder movements were visible. The seventh lumbar of the opposite side, as well as the first sacral roots on both sides, caused only leg movements without the slightest contraction of the perineal muscles. Curiously, in none of the three dogs have I been able to get satisfactory and forcible bladder contraction, even by a current applied to the untouched sacral roots. I attribute this to the low state of the animal, resulting from the laminectomy and pulling on the cord and nerve roots. In addition, a large abdominal incision has to be made and the viscus pulled into the wound to be observed. This always starts the reflex and results in emptying the organ, and it has to be filled by means of a cannula passed through a small hole in the bladder wall. But it has been conclusively shown that the last lumbar, when joined to the second and third sacral roots, can produce all the effects that these latter give on the untouched side.

The Surgical Possibilities of Intraspinal Nerve Crossing.

The experiments described show that the bladder, and presumably the rectum, can be innervated by other of the spinal nerves than those which normally supply them. In fracture-dislocation of the spine much of the trouble and most of the danger result from the paralysis of the bladder. The well-known retention, overflow, cystitis, and ascending infection up to the kidneys, usually cause the death of the sufferer. In cases which do survive, the bladder and rectum empty periodically without the patient's knowledge. If it were possible to innervate the pelvic viscera in such cases by nerves above the spinal lesion, bringing them again under voluntary control, many deaths would be prevented, much inconvenience and misery would be relieved. I believe that this can be done in some instances by surgical intervention. In man there are two bladder centres, one sending impulses through the lumbar roots, and the other by the second and third, and possibly the fourth, sacral. The exact function of the upper of these is not quite understood. Sherrington[2] states that stimulation of the lumbar nerve produces a bilateral contraction which does not overcome the sphincter, and does not produce micturition.

Stimulation of the sacral roots produces a strong contraction which is unilateral, and results in expulsion of contents. There is a general consensus of opinion that the sacral nerves are the more important, and they are the ones which should be used in performing nerve anastomosis. It is most important to innervate the pelvic floor in addition, because the bladder muscle itself is not directly under the control of the will. Micturition is a reflex act started by a voluntary contraction of the abdominal and perineal muscles, and, when once started, is very difficult to inhibit. If the reflex be intact, and the pelvic and perineal muscles brought under sensory and motor connexion with the brain, the viscera would be under satisfactory contol, as this appears to be all that obtains naturally.

In the human subject fracture-dislocation of the spine occurs commonly in two situations, the cervical and the dorso-lumbar regions. The latter is the one in which nerve anastomosis offers some help. The operation does not seem feasible in the cervical lesion. It is important to know how far direct suture of the nerve roots is possible in the spinal canal. In the dog the last lumbar root was the highest that could be sutured without the least tension to the second and third sacrals. It might have been possible, by dividing the sixth lumbar far out in the intervertebral foramen, to have obtained sufficient length, but this complication of the operation was unnecessary to establish the principle aimed at. It is a very important point in making use of this operation in man, because it determines the level of the spinal lesion in which it is applicable. In the human subject a considerably higher root can fortunately be utilized. In man the spinal cord ceases usually at the lower border of the first or upper border of the second lumbar vertebra, and a large number of the lower nerve roots arise very close together, and have a long intraspinal course. I have made a number of dissections in the human subject to determine this point. After opening the spinal dura mater it was found that the second and third sacral roots could be joined to the first lumbar root if the latter be divided as low as possible—that is, where it is piercing the tube of dura mater. There are several disadvantages, however, in using this intradural method, which exclude its use. The most important objection is that the ganglion of the posterior root lies outside the dura in the intervertebral foramina, and if the nerve be divided central to this, no regeneration of sensory fibres is possible, and the operation would therefore lose a great deal of its utility.

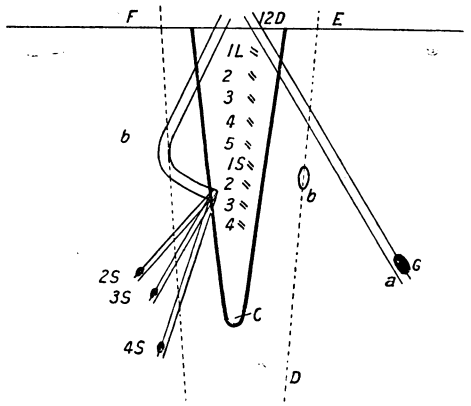
Another fault of the intradural operation is that the upper root with which we intend to innervate the pelvic structures can be obtained much longer by cutting it from the intervertebral foramen; or, in other words, a higher one can be used. I have found by several trials that it is possible to get the twelfth, or even the eleventh, dorsal roots in their fibrous sheath, and cut distal to the ganglion to come in apposition with the highest parts of the second, third, and fourth sacrals where these are arising from the cord. It would even be possible to get the tenth dorsal to do this if the intervertebral foramen were opened up, and the anterior and posterior primary divisions followed for a short distance.

Summing up our facts, so far, we find (1) it is possible to satisfactorily innervate the pelvic structures by means of a nerve arising higher up from the spinal cord; (2) that the eleventh or twelfth, or possibly even the tenth dorsal nerve, can, in man, be sutured directly to the second, third, and fourth sacral nerves. One could even use a higher nerve still by bridging over the gap by means of a nerve graft. This would be preferably obtained from the patient himself (auto-transplantation). A gap of 3 in. has been successfully bridged over in this way in the case of peripheral nerves. I would suggest a piece of the internal popliteal be selected for this, as it supplies muscles already paralysed, and has a comparatively small skin distribution. Direct end-to-end suture, where possible, is much to be preferred, as nerve bridging adds another element of complexity and is a possible source of failure. In an ordinary total transverse injury of the spinal cord in the dorso-lumbar region the lesion is usually just below the point where the twelfth dorsal nerve arises.

The main objections to the operation which is advocated are its severity and the possibility of leaving the patient in a worse state than he originally was. It is certainly true that a laminectomy with subsequent isolation, division, and suture of nerve roots, entails a good deal of shock. On the other hand, the patient's condition when left is extremely pitiable. A large proportion die in a few months of septic bladder and kidney trouble. Even if life be preserved, their condition with no control over bladder or rectum is a miserable one, and any chance of improving it would be eagerly consented to by the patient. With regard to the second objection, it should be noted that the only extension of the paralysis would be of one, or at the most two, dorsal nerves on one side, which is of not much consequence. Where the bladder centre is intact and working automatically, I should only advise crossing on one side. The untouched nerves on the opposite side would be still sufficient to innervate the organ, even if the nerve crossing were unsuccessful, and to connect the bladder with its spinal centre. In cases where this is destroyed by the injury, crossing should be done on both sides. The operation was tried recently by Mr. Bird and myself on a case, but we failed mainly through errors in technique, which we think could be avoided in the future. It is of sufficient interest to be briefly recorded. A man, aged 40, had six years previously fallen from a tree on to his head. On recovering consciousness it was found he had complete paralysis of both legs. He had survived the bladder trouble, and that organ with the rectum emptied periodically without his knowledge. When we saw him there was an obvious deformity of the vertebrae. The lesion extended as high as the twelfth dorsal on one side and the eleventh on the other side, these being the last nerves intact. The operation was unfortunately divided into two stages. At the first several laminae were removed, and the dural sheath exposed. It was found that three vertebrae were displaced and partly rotated, causing compression and destruction of a considerable length of the cord. The second operation was performed ten days later. It was found almost impossible to identify the structures, owing to the formation of recent scar tissue

where the previous dissection had been made. At the seat of the lesion the cord had disappeared, and the dural sheath was greatly thickened, its lumen being practically obliterated. The sheath was opened below, but it was impossible to pass a fine probe through the part where the dura had been damaged. It was felt that to persevere and perform nerve suture in the midst of this scar tissue would only have been to court disaster, and the identification of the nerve roots would have been most difficult. The operation was abandoned, but we both thought that it might have been performed if everything had been done at the first sitting.

The technique had been worked out previously on the dead subject, and can be understood by reference to the diagram. The twelfth dorsal was to be cut as far from the cord as possible in the intervertebral foramen (at *a*), and



F E, Level of lesion; 12 D, twelfth dorsal nerve; C, cord; D, dural sheath; G, posterior root ganglion.

brought through a slit in the dura distal to the lesion (at *b*). The nerves here have a firm fibrous sheath derived from the spinal membranes, and are easily handled. This part of the dura was then to be opened in the mid line, the twelfth dorsal pulled through as far as possible, and fixed to the anterior and posterior roots of the second, third, and fourth sacral, which were to be cut free from the cord as long as possible, as shown on the left side of the drawing. The median incision in the dura was to be closed with fine catgut, and one suture where the twelfth dorsal was put through the dural sheath. This would prevent any tension being put on the actual nerve junction.

The identification of individual nerve roots is a matter of difficulty, as they lie very close together. The easiest way of doing this is by applying a very weak interrupted electric current by means of sterilized electrodes, and noting the resulting contraction. This is an easier method than following definite landmarks for the individual nerves, for their level is variable. I have used this method during the operation on cases of brachial palsy and found it most helpful.

The nerves supplying the bladder also cause priapism when stimulated, and this is the easiest result to go by. Contraction of the pelvic floor and perineal muscles is readily appreciated. If nerve crossing be attempted, it would be best to operate as soon after the injury as possible, that is when the original shock and the acute symptoms following had subsided. Postponement only gives time for septic troubles to arise, and in any case it will be some months before any recovery takes place. If the level of the injury be lower down than the twelfth dorsal, the procedure becomes easier. Provided the lumbar roots be intact and in connexion with the brain, it might be feasible to anastomose some of the sacrals into a gap made in the higher nerves. It is even within the bounds of possibility that with several of the lumbar nerves we might produce sufficient power to enable the patient to walk again in a feeble manner. At any rate, enough has been said to show that nerve crossing within the spinal canal may open up a new field in surgery, and, though necessarily a severe operation, is worthy of trial.

My best thanks are due to Professor Osborne, Dr. Mathison, and Mr. Bird for their valuable assistance.

The expenses of this research were partly defrayed by a grant from the British Medical Association.

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MEMORANDA:

MEDICAL, SURGICAL, OBSTETRICAL.

THE THIRD FACTOR IN THE ETIOLOGY OF BLACKWATER FEVER.

OF the many good articles in that new volume (Part II, vol. ii) of *Allbutt's System of Medicine* which is devoted to diseases of tropical countries there is none which will be read with greater interest than that by Dr. J. W. W. Stephens on blackwater fever, which disease in the Duars and Terai tea-planting districts of India has recently had considerable attention drawn to it.

I confess to having been strongly opposed to the theory which ascribed blackwater fever to malaria, assisted by quinine. It is difficult, however, to resist the facts and closely reasoned arguments used by Dr. Stephens in the article just mentioned, but while one may agree with Dr. Stephens that intense malaria *plus* quinine can and does induce haemoglobinuria, still the fact remains that, in the districts where both intense malaria and blackwater cases are found, there are many bad cases of malaria which are treated successfully by quinine in which no such untoward symptom as blackwater occurs. Hence, while admitting the two factors, namely, malarial attacks of greater and lesser frequency and quinine, not necessarily in large doses, still I think that the real clue to the etiology of this disease may lie in Plehn's suggestion that a kidney lesion is one of the essential factors. On this view we have three factors, namely, malaria infection, use of quinine, and a lesion of the kidneys.

This, it seems to me, might explain the scattered incidence of the disease in the same district, where intense malarial fevers are common, the use of quinine universal, but the third factor, a diseased kidney (we can understand), will only rarely be present also. In this way the state of the kidneys acquires a prognostic significance equal to that which it has in the prognosis of cholera attacks, and possibly it may be found that, in regions where bad malarial fevers abound and also blackwater fever, it would be wise before administering quinine to make an examination chemically and microscopically of the urine, and to avoid using this drug where the microscope gives evidence of a kidney lesion. The exact nature of the kidney lesion which (on this hypothesis) joins in precipitating an attack of haemoglobinuria would therefore be a subject for further inquiry.

W. J. BUCHANAN, M.D., D.P.H., Major, I.M.S.,
Calcutta. Editor, *Indian Medical Gazette*.

A CASE OF COMPLICATED STRABISMUS.

THE patient in the following case, a girl aged 15, asked me in June, 1906, to do something to improve the defect in her appearance caused by the following condition: In addition to an unsightly left internal strabismus of 24° there was well marked lateral nystagmus which only ceased on extreme abduction to the left, and sight in this eye was extremely defective as the lens had been removed in infancy for congenital cataract. Fixation was possible, but could not be maintained for any length of time. The right eye was highly myopic (— 7D., with astigmatism of 4D.). Movement was perfect. The patient being anxious for treatment, the question arose as to which eye it would be the best to operate on. As fixation was possible with the left eye, and the nystagmus became so much lessened on abduction to the left, it was hoped that an extensive advancement of the external rectus of the left eye would be productive of parallelism, and at the same time lessen the nystagmus. It was also considered that an operation on the right eye would leave her practically blind whilst the right was recovering from the operation, and any mishap to the eye would be a most serious state of matters. Lastly, the myopia present in the right showed that it was not completely healthy. All these points led one to attempt the rectification by operation on the left eye.

The left external rectus was advanced, and it was found necessary to divide completely the internal, leaving the eyes exactly parallel at the completion of the operation and for some days after. Unfortunately, within a few weeks the left eye returned to its old position of convergence, only 4 degrees having been removed by the operation, though a marked lessening of the nystagmus was gained. No fault in the