sense of position of the little finger. There are no distinct trophic changes over the anaesthetic area, except that the skin is a little shiny over the fingers.

REMARKS.

The differential diagnosis in this case, although in the light of the conditions found at the operation it may seem to have been fairly straightforward, was not definitely settled until the patient had been some little time under observation. That there was a lesion at the level of the lower part of the cervical region of the cord with affection of the pyramidal tracts below this level was of course obvious. The further points to determine were (1) whether the disease was extramedullary or within the cord, and (2) what was its nature.

Undoubtedly the first clue to the extramedullary seat of the lesion was the discovery of the partial loss of sensation on the post-axial side of the left upper extremity, showing that the left eighth cervical and first dorsal posterior roots were definitely involved. This was supported by the distribution of the muscles affected with wasting and altered electrical reactions, which coincided with the motor supply of the corresponding anterior roots. The pain was more widely diffused, but in its chief intensity corresponded fairly to the same roots. Further confirmation of an extramedullary lesion at this level was afforded by the order of onset of the cord symptoms, that is (1) pain, (2) paraesthesiae, (3) paralysis, (4) wasting of muscles, first at the level of the lesion, and then, as pressure began to be exerted on the cord itself, the appearance of spasm, increased reflexes, and paralysis in the legs, with finally, much later in the case, some sensory loss over the trunk and legs, and affection of sphincters, as the cord gradually became more severely compressed. On the other hand, there were perhaps three features of the case which were difficult of explanation on the above hypothesis of an extramedullary lesion involving at first these roots and then pressing upon the cord.

These were the paralysis of the left shoulder muscles, the atrophic paralysis of the small muscles of the right hand, and at first sight the absence of such severe pain as would be expected from such a lesion. This last point I will refer to again later. As time went on further acquaintance with the patient made it quite clear that she had intense pain at times, which she bore bravely. Further investigation enabled the paralysis of the left shoulder and upper arm muscles to be eliminated as a direct result of the lesion, for it presented the characters of that found in long-continued disuse of the shoulder and elbow joints, and the consequent formation of adhesions about there, and it was, therefore, regarded as due to the attempt to minimize the pains by keeping the joints immobilized, and accordingly only as an indirect consequence of the lesion.

The atrophic paralysis of the small muscles of the right hand without sensory affection was never satisfactorily accounted for until the operation. It might have been taken as an evidence of an intramedullary pressure effect, for example, myelitis, or a small extravasation of blood. That no lesion of this sort occurred, however, is proved by the rapid recovery after removal of the tumour. It only appeared late in the illness, and the explanation afforded by the conditions seen at the operation was that the nerve roots on the right side at this level must have been compressed against the bone, possibly against the edges of the bony foramina. The large size of the tumour, which seemed almost too great to be accommodated in the spinal canal, would account for this, though, even if this explanation be correct, it is difficult to see how the corresponding posterior roots escaped.

The other evidences of an extramedullary tumour on the left side were, however, to my mind, so strong that I felt justified in neglecting this feature of the case, leaving it unexplained before the operation.

As to the nature of the lesion, all the above symptoms, especially the localized nature of the focal symptoms, pointed to a tumour pressing on the left eighth cervical and first dorsal roots, but she had also kyphosis and lateral curvature of the spinal column, and therefore the possibility of tuberculous disease of the bones had to be considered. This was eliminated, however, by the absence of a local deformity of the spinal column, or of local tenderness of the spines, by the characters of the cerebro-spinal fluid, by

the test for fixation of the complement for tuberculosis being negative, and by the absence of any tuberculous lesion elsewhere in the body. A syphilitic lesion was excluded also by the examination of the cerebro-spinal fluid, and a negative Wassermann reaction. There is just one other point of interest. There appears to have been no period in the case in which Brown-Séquard's syndrome was present. This syndrome is of frequent occurrence at some stage of cases in which there is either a unilateral lesion of the cord itself, or unilateral pressure upon it. In this case the affection of sensation below the lesion over the legs and abdomen appeared quite late, affected both sides equally, and was slight in degree.

The case further illustrates the fact that if it is not destroyed, or there is no pressure-myelitis, the cord is capable of recovering from an enormous amount of pressure when this is removed.

The order of return of reflexes is of interest:

Two weeks after operation: Sensory disturbance of legs and abdomen disappeared.

Four weeks after operation: Right abdominal reflexes returned; ankle clonus disappeared; left plantar reflex became "mixed" in character.

Six weeks after operation: Power over bladder recovered; knee-jerks still exaggerated.

Eleven weeks after operation: Double flexor plantar reflex; abdominal reflexes returned on both sides.

Another point of interest is the complete recovery from exophthalmic goitre some years previously, and that the patient was able to go through a severe operation without any return of it. Further, there was risk of being deceived by her statements as regards pain; she minimized this, but when one got to know her one learnt that she had very severe pain, but bore it bravely. Pain is a most important symptom in the diagnosis of cases of this kind, and yet its value in diagnosis is diminished by the difficulty of estimating it exactly, because patients vary so greatly in their power of endurance.

I cannot conclude without a grateful acknowledgement of what a large share in the successful result of the case was due to the very skilful manner in which the operation was performed by Mr. Hey Groves. There was no haemorrhage and no shock, and the patient recovered without any bad effects due to the operative procedures—a noteworthy fact in a woman of 55 years of age, and one to encourage explorations in doubtful cases of a similar kind. Lastly, the limitation by Mr. Groves of the operation to removal of the laminae on the left side only, whilst at the same time it afforded easy access to the seat of disease, no doubt resulted in greater subsequent stability to the spinal column, and earlier recovery of power in the back.

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

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PART V.

This article deals with secondary nerve suture, and the facts are derived from clinical and experimental studies.

The term "secondary," as opposed to primary nerve suture, is applied to cases in which the two ends of a divided nerve are not immediately united; or, at any rate, an interval of more than a few days is allowed to elapse before suture.

The condition present is a variable one. Much depends on the time interval before secondary union is performed. It is stated that two (Bowlby¹) and three (Sherren²) years seems to be the time after which we cannot expect any useful recovery in the paralysed muscles, even if secondary union of the nerves be performed.

A great deal depends on the condition of the wound with regard to sepsis or otherwise. A suppurating lesion complicating a nerve division seriously alters the prognosis for the worse. This is well exemplified by two extreme cases.

I had had very little function return after union of the median when only six months had elapsed since the original division. This particular accident was caused by

the arm being pushed through a glass window, and prolonged suppuration followed. On the contrary, I have seen a very satisfactory recovery after secondary suture performed two years after the nerve division. The case was an obstetrical paralysis where the upper and middle brachial cords were torn completely across the ends and were found apart at the time of operation.

As a matter of fact, I believe total disconnexion of the central and peripheral ends of a nerve is rarely found after some months have elapsed, unless suppuration occurred originally. Nearly always a tapering filament stretches across the interval between the two ends of the nerve, and electrical stimulation shows it to contain many functioning fibres. This was the condition actually present in the case of obstetrical paralysis just referred to. In dogs I have occasionally seen a nerve grow across an interval of 1½ in. with almost perfect function after this interval of the nerve trunk had been experimentally excised.

Considering the various pathological conditions present, I believe any explicit statement as to time or amount of recovery is impossible after secondary nerve suture. But several general facts are undoubted:

1. Recovery after secondary nerve suture is slower than after primary union.
2. Recovery follows the same lines as in primary suture, but usually falls short of complete restoration of function—sensation and motion.
3. Other things being equal, the longer the time which elapses before secondary suture is performed, the more imperfect the recovery.
4. Finally, after an uncertain time, restoration of muscle function is unlikely, though a certain amount of sensory recovery is still possible.

The following experiments were made with the object of finding whether the motor nerve cells in the spinal cord, or the muscle and motor nerve endings, were mainly concerned in this failure in regeneration.

DOG I.

In both fore limbs the median was divided and 1 in. of the nerve excised. One year and nineteen days later secondary suture was performed. (In this, as in all other cases, the bulb on the central nerve was excised before suture.) On the right side the central end of the healthy ulnar was joined to the distal degenerated median. On the left limb the central end of the previously cut median was joined to the distal end of the healthy ulnar. Excision of a considerable length of nerve prevented union between the central and distal ends of the same nerve, though at the time of secondary suture it was found that a feeble connexion had taken place between the two ends of the separated median on either side. This was not sufficient to alter any result.

After 238 days it was found that the regeneration was much more perfect on the right than the left side. The test used was the sensitiveness in response to small faradic stimuli applied directly to the isolated nerve above the junction.

Conclusion.—In secondary suture (one year and nineteen days after the nerve division and after 238 days allowed for regeneration) the result is better when the distal nerve is the one degenerated for some time, and the central nerve a healthy one, than when the opposite conditions obtain.

DOG II.

Primary Operation (April 2nd, 1908).—Right side 1 in. of ulnar excised and on left side 1 in. of median.

Secondary Operation (October 8th, 1908—188 days).—Right side: Central healthy median was sutured to distal degenerated ulnar. Left side: The central end of the previously divided median was sutured to the distal end of the healthy ulnar.

Stimulation performed November 23rd, 1909—that is, one year and forty-six days after the secondary suture. Good regeneration had occurred in both legs. The sensitiveness was greater on the right side when tested with the faradic current applied directly to the nerves. This confirms conclusion in Dog I.

DOG III.

Primary Operation (April 21st, 1909).—Right side: Fore limb median nerve divided, and both ends fixed in rubber tubing to prevent wound fibres growing in the distal trunk. Left side same.

Secondary Operation (December 6th, 1909—229 days later).—Right side: Central end of previously divided median was sutured to distal end of freshly cut ulnar. Suture area was wrapped round with Cargile membrane. Left side: Central end of freshly cut ulnar was sutured to distal end of previously divided and degenerated median, Cargile membrane being again used to isolate the suture area.

Stimulation performed October 4th, 1910 (302 days later). On both sides the nerves about the suture level were fairly adherent for some distance to the surrounding structures, and were very difficult to separate from the vein and artery. Regeneration

was very efficient, and was better on the left side where the central nerve was the healthy one.

DOG IV.

Primary Operation (May 6th, 1909).—Right: Fore limb median nerve divided and both ends fixed in rubber tubing. Left side same.

Secondary Operation (December 3rd, 1909—311 days later).—Same as Dog 3, but no Cargile membrane used.

Stimulation (September 23rd, 1910—294 days later) gave same results as Dog 3.

SUMMARY OF RESULTS.

In four series of experiments secondary nerve suture was performed at an interval varying from 188 to 384 days after the primary division. Two experiments were made on each animal. On one fore limb the central end of the nerve sutured was a healthy one (that is, just divided before the stitching), and the distal end the nerve which had degenerated for the varying periods of time. On the opposite side the central nerve was the nerve divided some considerable time previously, and the distal one joined to it was the freshly cut trunk.

The object of performing these reversed experiments on the same animal was accurately to contrast the two conditions. Thus the time element and the individual factor were identical in the two groups.

At the time of secondary suture it was found that several changes had taken place. Unless special means were taken to prevent it, the distal degenerated nerve was appreciably innervated by wound fibres; so much so that faradic stimulation to the nerve invariably gave a definite though feeble appropriate response.

In one case, even where rubber tubing was used, some wound fibres found their way to the distal trunk. In every instance of ununited nerve division wound fibre innervation plays a prominent part unless sepsis has occurred. In this case the resulting scar tissue interferes with these wound fibres.

In my opinion this explains the influence of sepsis in the original wound in preventing recovery after secondary nerve suture.

The distal degenerated nerve in the experiment was flabby, red in colour, and more or less adherent to surrounding tissues. In two cases a very feeble but still functional strand of nerve tissue had grown across the interval of 1 in. between central and distal ends of the nerve. This shows the vigorous power of nerve regeneration with aseptic conditions. The period allowed for regeneration after the secondary suture varied from 238 to 411 days. Many different conditions were found, which presumably occur in man where secondary suture is performed.* These include variation in size of the bulb where suturing was performed, adhesion to other tissues, etc. It is interesting to note that the cases in which Cargile membrane was used differed, if anything, for the worse in this respect. It is important to observe that whatever variety of condition was present one feature was constant. When the central end of an old divided nerve was sutured to the distal end of a recently divided nerve, the resulting regeneration was not so good as when the reverse condition obtained.

In other words, from the point of view of regeneration, an unremedied nerve division produces more serious changes in the central end (with the nerve cell) than in the distal end (with the muscle fibre and motor end organ).

The appearance in the nerve trunk is the reverse of this. Beyond the bulb at the divided face of the nerve there is little visible change in the central stump. The distal divided trunk is always thinner than normal, more or less adherent to tissues, flabby to the touch, and reddish in colour. The microscope shows marked alterations (Wallerian degeneration) in the distal nerve and none in the central.

From these facts it is legitimate to conclude that the motor nerve cell is more damaged by ununited division of the nerve trunk than the isolated neuro-muscular apparatus.

In other words, when secondary suture is delayed too long and regeneration is not effected, it is not due to degeneration of the muscle or to loss of chemiotactic attraction in the peripheral stump for the sprouting nerve fibres from the central nerve.

* Several animals in which suppuration occurred at the primary or secondary operation were discarded.

CONCLUSIONS.

1. The condition found after the non-union of a cut nerve trunk is very variable.

2. These varying conditions render any definite statement as to time limit to secondary suture difficult, if not impossible. I have had successful cases of secondary nerve suture in the human subject after many (six) years of non-union.

3. Where regeneration after secondary nerve suture has not taken place, the main cause (apart from local conditions at the suture area, such as sepsis) is lack of regenerating power in the nerve cell.

4. When all factors have been taken into consideration and it is concluded that restoration of function after secondary nerve suture is unlikely, there is still another surgical procedure open. This is the suture of recently divided central nerve fibres to the distal trunk of the degenerated nerve—that is, by nerve anastomosis to an adjacent healthy nerve.

My best thanks are due to Professor Osborne for many suggestions, and to Mr. Jona, who assisted me at most of the experiments.

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PNEUMOCOCCAL MENINGITIS.

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THE causes of acute inflammation, with purulent lymph exudation, of the pia arachnoid are various forms of pus-producing micro-organisms, and not infrequently more than one kind of organism is found in the same case. The *Meningococcus intracellularis* of Weichselbaum usually suggests itself in the first instance, especially when cases of cerebro-spinal meningitis are known to be in the neighbourhood, though the claims of the pneumococcus for recognition as a common cause are well known to pathologists. The impression that this organism is a more common cause of acute meningitis than is generally supposed, and that involvement of the cerebral membranes is a more frequent complication of fatal cases of pneumonia than is commonly believed, must be my excuse for publishing the following cases. For the notes of the third case I am indebted to Dr. J. W. Smith of Ryton, who has kindly given me permission to use them:

CASE I.

James S., aged 15, a factory storekeeper, was in good health until February 1st, 1911, on which day he was struck on the head by a heavy iron bolt which fell 12 ft. He was not rendered unconscious, but it produced giddiness and headache. He was able to attend to his work next day, and little was thought of the injury until three days later, when he fell in a fit whilst at work. He was unconscious for upwards of two hours, and on recovering complained of pain in the right side of the chest and severe headache.

He was admitted into the Royal Victoria Infirmary on February 5th, when it was noticed that he was drowsy, had a temperature of 101°, a pulse of 95, and that his face twitched. Next day he was restless and delirious and complained constantly of severe headache, chiefly frontal. There was photophobia and slight nystagmoid movements and the pupils were dilated, but there was no ocular paresis. There was slight rigidity of the muscles of the neck, but no retraction of the head. The skin of the trunk and legs was hyperaesthetic. The knee-jerk was normal and the plantar reflex flexor. There was no optic neuritis.

On the third day of the illness the breathing became accelerated and a hyper-resonant note was detected over the left lung. This was, however, soon replaced by dullness, and harsh breathing by tubular, so that it was evident by the fourth day at least that the illness was pneumonia complicated by nervous symptoms. Lumbar puncture on the third day led to the withdrawal of clear fluid free of organisms at increased pressure.

There was little change in the symptoms until the sixth day, when the respirations and temperature rose, the former to 62, and the latter to nearly 104°. Indeed, for a day or two the signs of meningitis became less evident, and the case assumed in a more pronounced form the aspect of a very bad case of croupous pneumonia. On the seventh day the nervous symptoms

resembled the delirium of enteric at the end of the third week: the patient was wakeful, muttered constantly to himself, and occasionally uttered loud shouts. He rapidly sank and died on the eighth day.

The urine was free from albumen throughout the illness, and there was no vomiting.

Post-mortem Examination.

Body poorly nourished. Rigor mortis general. No signs of injury to scalp or skull. The heart showed nothing abnormal worthy of note.

The pleural cavities contained small quantities of turbid fluid. Evidence of recent pleurisy over surface of left lung, both lobes of which were consolidated. The right lung was intensely congested, and the lower lobe contained patches of bronchopneumonia.

The spleen was soft and acutely congested. The liver and kidneys were in an advanced state of cloudy swelling.

Examination of the brain showed general leptomeningitis, best marked over the vertex, where there was a deposit of greenish fibrinous lymph. The exudate was also well marked over the base, especially on the under surface of the frontal and temporal lobes and over the pons, medulla, and cerebellum. Films from the cerebro-spinal fluid showed typical pneumococci.

CASE II.

James B., aged 38, cartman, was admitted into the Royal Victoria Infirmary in a semi-conscious condition on January 27th, 1911.

The history of the case was very indefinite. The friend who brought him to hospital stated that he had been found in a lodging-house that morning in a state of delirium, and had only been ill a few hours, having fallen in a fit, which was apparently the commencement of the illness.

The cheeks were flushed and the pulse and respirations quick. There were temporary intervals of consciousness, when his speech was slurred and slow and he appeared to have some difficulty in articulating. The temperature was 103.4°, the pulse 114, and the respirations 28. There was no paralysis. The tongue was furred and dry. The patient was restless and delirious and was with difficulty kept in bed. There was nothing definite to be detected in the chest. The reflexes were normal.

On the morning following his admission he became very violent and excited, and this was followed by a period of collapse, in which the pulse became weak and rapid (130), and a few hours later paresis of the right side of the face and right arm and left eye were noticed. The temperature was 103°, and the respirations 44.

As the day advanced he picked at the bedclothes and became more and more drowsy. The urine had to be drawn off, and was found to contain albumen and sugar. Then ptosis of the left eyelid appeared and the paralysis extended to the right leg with anaesthesia, on which the plantar reflex was extensor. The next development was paralysis of the left side of the face, motor and sensory.

A lumbar puncture was made, and turbid fluid flowed under marked pressure. It contained flakes of lymph, was highly albuminous, and did not reduce Fehling's solution. Pneumococci, streptococci, and lymphocytes were in abundance. A blood count showed no leucocytosis. The optic discs were normal.

He passed rapidly into a state of profound coma, and died on the morning of the fourth day.

Post-mortem Examination.

The body was well nourished. Rigor mortis present. Post-mortem lividity marked.

Brain.—Extensive suppurative leptomeningitis. The exudate extended to the vertex and over the base (temporal lobes, pons, and cerebellum). It was best marked over the right hemisphere. It passed down the spinal canal and affected chiefly the cervical and dorsal regions (back and front). A considerable quantity of turbid fluid escaped from the base of the brain and spinal canal. Stained films showed numbers of pneumococci.

Lungs.—Acute inflammatory changes in bronchi and extensive patches of bronchopneumonia on both sides.

Heart.—Muscle soft and flabby. Recent vegetations on both segments of the mitral valve indicating infective endocarditis.

There was cloudy swelling of the liver and kidneys and the spleen was acutely congested.

CASE III.

J. T., a man aged 42, was taken suddenly ill on January 23rd, 1911, with intense headache, vomiting, aching in the back and limbs, and general febrile symptoms (temperature 103°, pulse 132). On the third day delirium, and on the fourth twitchings of the legs and arms, with rigidity of the muscles of the back of the neck and coma were observed. Next day there was general rigidity with opisthotonos; the knee reflex was active and the plantar response extensor, and the pupils were widely dilated. He died on the sixth day of the illness.

Post-mortem Examination.

The lungs were congested and oedematous at the bases, but there was no pronounced consolidation. The heart was normal.

The soft membranes of the brain were covered by a greenish purulent exudate, which passed down the spinal canal. A bacteriological examination of the exudate demonstrated pneumococci.