THE TREATMENT OF FRACTURES.

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IN connexion with recent discussions on this subject, may I be permitted to state briefly the results of a considerable hospital experience of some of the commoner varieties of this class of injury, treated both by conservative and operative measures?

Attempts at reduction have habitually been made under general anaesthesia at the earliest moment possible.

In the femur, fractures of the shaft have been transverse, short oblique, or torsion (spiral) fractures. The result, by extension, etc., has been nearer perfection the more the fracture approached the transverse; in the latter the displacement is seldom marked, and the result consequently perfect in some of them. In the second class I have been astonished at the difficulty and frequent impossibility of reducing (and more so of maintaining reduction of) the longitudinal displacement by extension; this did not surprise me, however, after experiencing the extreme difficulties of doing so by open operation combined with extension in many cases with apparently little shortening; as a consequence a useful, though not perfect, limb with a varying amount of shortening has usually resulted. The large majority of these fractures have been in children.

With spiral fractures my own experiences and those of others have led me to the conclusion that never, by other than operative measures, can the fragments be placed or maintained in even approximately good position. Persistence in conservative methods has here usually led to shortening of about 1 in., often more, eversion, deformity, and pain in varying degrees for as long as I have been able to watch the patients (over several months), involving frequently in the poor the necessity for seeking a less active occupation. In one or two cases the patient has perhaps been able to hobble with a stick or crutch at the end of three or four months, and these distressing failures are not an uncommon sight in hospital practice, and possibly frequent in infirmaries. We have only to contrast a confident expectation, warranted by experience, of a perfect restoration of function with no shortening at all in ten weeks at the outside by operative measures; I will only mention a case of a spiral fracture with nearly 3 in. shortening after extension, who, after operation, was running upstairs under seven weeks later with no limp.

Little need be said about conservative treatment in Pott's fracture, for the deplorable stiffness, deformity, and inability to resume active life, which result at least for several months, if not permanently, in so many cases, have led most surgeons to consider operation the method of choice in these injuries. In fractures of the bones of the leg, if transverse, lateral displacement can sometimes be reduced by manipulation; rarely is this so with spiral fractures, especially if shortening be at all marked. To summarize, convalescence in cases operated on has taken about half the time in fractures of the femur, and in fractures of tibia and fibula about two thirds the time necessary for an inferior functional result in those treated conservatively; while aching, pain, and stiffness marked features in the convalescence of the latter class of case, is conspicuously absent throughout the whole treatment in cases operated on.

Among fractures of the humerus I need only mention the rotatory, angular, and longitudinal displacements, delayed union, and paralysis due to interference with the functions of the brachial plexus and musculo-spiral nerve, which sometimes have resulted from conservative treatment (not necessarily from neglect of treatment), and compare their imperfect or delayed functional recovery and painful convalescence, extending into months or years, with the moral certainty of complete functional recovery in six to eight weeks when operated on at once. Secondary operations, necessitated by some of the above failures, have demonstrated clearly to me the greatly increased difficulties involved in addition to a further retarded period of convalescence. The prevention of these failures is always vastly preferable to the cure. Finally, in separation of the lower epiphysis of the humerus, forcible flexion has certainly succeeded in a few cases, and those not the worst; but, with these few exceptions, the

only results which could justify our taking a pride in the patients have been attained by levering the lower fragment into position, without violence, through a posterior incision, apposition being maintained by full flexion. By this method less renewed haemorrhage and swelling is caused, and the subsequent joint movements, taking all cases, is infinitely better.

In conclusion, the risks of operation are summed up in sepsis only. I have never seen suppuration result from operative interference in fractures, while as to the disadvantages of leaving plates, screws, wires, etc., in the bone, I have come across no single instance in which any subsequent trouble has at any time necessitated the subsequent removal of them. Such an operation, if necessary, would, in any case, be the simplest procedure.

THE SCIENCE COMMITTEE

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REPORT CV.

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

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PART IV.*

IN this article the results of some experiments on the different methods of bridging over an interval between the central and peripheral ends of a nerve will be given. To this procedure the terms "nerve gapping" and "nerve bridging" have been appropriately given. The subject has received a good deal of attention, and has been occasionally practised in human surgery. I am not aware that any systematic experiments have been performed, and I do not know that any one method is used by surgeons in preference to others. The clinical experience of any single individual is too limited for any opinion to be given on the matter. Gluck¹ was one of the first to successfully perform nerve bridging. He placed a piece of a mouse's sciatic into a gap in the sciatic of a guinea-pig. Phillipeaux and Vulpien² successfully planted a piece of the lingual nerve of a dog into the hypoglossal. Ballance and Purves Stewart³ performed nerve gapping in several cases, but Sherren⁴ has rightly objected to their conclusions on the ground of the short interval filled in. The nerve length used by them was never more than $\frac{1}{2}$ inch. Albert⁵ appears to have been first to perform nerve bridging in the human subject. He used a piece of nerve from an amputated leg, and the result was not a success. Mayo Robson⁶ was the first to obtain a good result. He excised a neuroma from the median, and into the 2½-in. gap so formed he inserted a piece of the posterior tibial from an amputated leg. The various methods of gapping have been divided by Merzbacher⁶ into three groups:

- I. Auto-transplantation, where a nerve from the same animal is used.
- II. Homo-transplantation, where a nerve from another animal of the same species is used.
- III. Hetero-transplantation, where a piece of nerve from an animal of another species is used.

This classification is not quite complete as it stands, as it does not include the use of tissue other than nerves, such as strands of catgut. It can be made complete, however, by dividing each group into transplantation with nervous and non-nervous tissue. Sherren⁷ has analysed the cases reported so far of nerve bridging. Naturally very few instances of auto-transplantation have been performed, and only two are recorded. One of these was reported too early for any recovery to have taken place, and in the other, in which a 3-in. gap in the musculo-spiral was filled in by a strand of radial, a perfect recovery followed. In the homo-transplantation group six instances are known in which pieces of nerve from amputated

* The preceding report was published in the BRITISH MEDICAL JOURNAL, 1907, vol. 1, p. 988.

legs were made use of. Only one of these was a success, but from various reasons—suppuration, the patient passing out of sight—four of the others do not admit of any conclusions being drawn. The sixth case, where 2½ in. of median was filled in by a piece of median from an amputated leg, was a failure seventeen months after.

Twenty-two cases of hetero-transplantation are known, and of these 16 are suitably reported for analysis. Out of these, 6 may be described as a success. Thus, of the auto-transplantation 100 per cent., of the homo-transplantation 50 per cent., and of the hetero-transplantation 37 per cent. were successful. It is to be noted that nerve tissue was invariably used to form the bridge, and it is unnecessary to draw attention to the fact that no great weight can be placed on the conclusions drawn from the few cases of the first and second group. The opinion formed on them is decidedly in favour of using a human nerve preferably from the same subject.

The interval to be bridged over doubtless plays an important part in the recovery of function. Sherren states that an interval of 3 in. has been successfully reunited. It is probable that the age of the animal would have an influence, and other factors, such as the particular nerve bridged over, the health of the animal, time allowed to elapse, etc., would have to be considered. It is certain that the results obtained from nerve suture are better in children than in adults. I have not attempted to solve the problem; in fact, the longest interval I have ever excised is a little over 2 in. Indeed, it does not seem capable of being accurately decided on for man, because it is very questionable if we can apply the result obtained on a certain nerve in a dog to a different or even a corresponding nerve of a human being. Before commencing any experiments on this question, it is necessary to find out an interval across which nerve regeneration cannot take place without aid. Münzer and Fischer⁸ investigated this question recently. They excised a piece of the sciatic nerve ½ in. long in puppies. The raw central and peripheral ends were fixed in position to the biceps muscle by stitches, to prevent the interval being increased by retraction of the nerves. After a time the nerves were tested electrically and examined microscopically. In 4 out of 11 cases there was absolute sensory and motor paralysis. In 3 a very feeble recovery occurred, and in 4, or about 40 per cent. of the cases, complete regeneration took place.

Forsmann's⁹ experiments seem inconclusive on this account, as he only excised 7 mm. of nerve. His opinion, based on microscopic examination, is that auto-transplantation and homo-transplantation are preferable to hetero-transplantation. In the last case it did not seem to matter whether the nerve from an animal of another species was used, or non-absorbable material such as cotton thread. In my own experiments I usually excised a piece just over 1 in. in length, and very occasionally only ½ in. In all the cases of nerve anastomosis previously reported, I examined both microscopically and by dissection for fibres growing across the gap of ½ in. to 1 in. with only negative results. Recently, however, I excised about ¾ in. of the internal popliteal, where it is in the sciatic trunk, leaving the external popliteal intact. The sheath of the sciatic nerve thus held the cut ends of the internal popliteal and prevented any retraction. On examining and stimulating after an interval of 134 days, it was found a strand had formed across the gap. This was thinner than the internal popliteal itself, but the faradic current showed that the regeneration across the gap was fairly good, though not at all perfect. On the other side of the same animal an interval of 1½ in. in the internal popliteal was bridged over with catgut, and the result was almost perfect. This case is unique in my experience, and seems to show that exceptionally power of regeneration across an interval is very vigorous. In the vast majority of cases I believe no nerve fibre can regenerate across an interval of ½ in. without some assistance in the form of a nerve bridge. I have endeavoured to avoid any possible error creeping in from such an exceptional case, by performing a series of experiments in each group, and working out the percentage of recoveries and failures.

HETERO-TRANSPLANTATION.

Under this are two subdivisions according as (a) nervous or (b) non-nervous tissue used.

Non-nervous Tissue.

As an example of non-nervous tissue, catgut which is absorbable was taken, as likely to prove as efficient as any.

Experiment 1.—A piece of nerve, ½ in. in length, was excised from the left internal popliteal, the interval being bridged over with four strands of catgut. After 134 days the condition was as follows: The central end of the internal popliteal ended in a bulb which tapered off into the bridge. This was thin and ribbon like, and much darker in colour than healthy nerve. It was slightly adherent to the adjacent external popliteal and also to the surrounding tissues, especially where the nerve joined the bridge at either end. No bulb was seen where the bridge joined the distal nerve. The nerve distal to the bridge gave a sensory response even when the internal popliteal central to the bridge was cut through. This must have been through "wound fibres." With regard to movement, electric stimulation of the internal popliteal distal to the bridge needed to be stronger than on the normal external popliteal to elicit a response. When applied to the internal popliteal central to the bridge it had to be much stronger still. Some of the results of stimulating distal internal popliteal then was partly due to "wound fibres." Result poor.

Experiment 2.—One and a half inches of the right internal popliteal were excised and the gap bridged over by four strands of catgut. After 134 days the bridge was found to be thinner and darker than the rest of the nerve, but not very adherent to the surrounding tissue. Stimulation of the internal popliteal central to the bridge showed the result practically perfect, as the minimum of current causing a contraction by the healthy external popliteal also did so with the internal popliteal. Result perfect.

Experiment 3.—One inch of internal popliteal on the left side was excised, and the gap bridged by four strands of catgut. After 130 days the bridge was a ribbon-like strand, adherent all its length to the hamstring muscles. Electric stimulation applied central to the bridge resulted in vigorous muscular contraction, though not with the minimum current effective on external popliteal. Result fairly good.

Experiment 4.—One inch of internal popliteal was excised in the right hind limb, and the gap bridged over with four strands of catgut. After 129 days the bridge was found adherent to the surrounding tissues in its whole extent. Stimulation of internal popliteal central to the bridge gave vigorous muscular response, but the minimum effective current in healthy external popliteal had no effect. Result fairly good.

In all the four cases, the catgut bridge, which varied from ½ in. to 1½ in., was of considerable use. The response to electrical stimulation was in one case perfect, in two fairly good, and in the other poor. A characteristic of this group was poor definition of the bridge from the surrounding tissues, as dissection of its whole length was generally necessary to free it.

Under hetero-transplantation also is to be included cases where a gap in the nerve of one species is filled in by means of some living tissue (not nervous) taken directly from an animal of another species. This is of no practical importance, and I have performed no experiments bearing on it. If any tissue of the lower animals were used for a human subject nervous tissue would certainly be employed. It is not possible to say, however, that a piece of nerve would be of more service than a strip of fibrous or muscle tissue without trying it on several animals.

With Nerves.

In two cases a piece of a sciatic nerve of a rabbit was used to bridge an interval in the ulnar of a dog. The ulnar nerve was exposed, and then a rabbit was killed by dislocating its neck. It was rapidly skinned and the sciatic nerve taken out, and at once sutured in position. In both cases the wounds healed perfectly.

Experiment 5.—One and a half inches were excised on the right side. After 86 days the following conditions were found:—The central end of the ulnar ended in a bulb, which was continuous with a firm nerve cord—the bridge. This joined with the distal part of the nerve, which was flabby though well defined. The bridge was a fairly distinct structure, more so than that resulting from catgut, but it had not the shiny appearance of a healthy nerve, and some dissection was necessary to isolate it. Stimulation of the ulnar distal to the bridge caused the feeble movement of the toes and paw, and a sensory response. Stimulation of the central end above the graft caused very feeble movement of the paw and toes, which was barely noticeable. Evidently most of the regenerated fibres in the distal end of the ulnar were "wound fibres"—that is, fibres which have grown in at the cut surfaces from small nerves which have been divided in the surrounding tissues. Result very poor.

Experiment 6.—One inch of the ulnar was bridged over by rabbit's sciatic. After 143 days the result was very slightly better, but still very unsatisfactory. However, it had played a small part in aiding regeneration. The naked-eye appearance

was very similar to the last case, and the bridge was not shiny or so well defined as the normal nerve. Result poor.

Experiments 7 and 8.—In these a piece of cat's nerve was used to bridge across a gap of 1 in. in a dog's internal popliteal. The same care was taken to ensure the nerve being alive at the time it was transferred as in the last experiment. The results were taken at the end of 130 days, and were fairly satisfactory as regards electrical stimulation. Though some little dissection had to be done to free it, the bridge was a very definite and mostly smooth structure. The intact external popliteal was slightly adherent to but not incorporated with it. Results fairly good.

In these experiments with nerves, the length of the bridge was 1 to 1½ in.; the electrical results were very poor in one, poor in another, and fairly good in the other two.

The bridge was a fairly definite structure, and not very adherent to surrounding tissues. It compared very favourably in this respect with catgut.

HOMO-TRANSPLANTATION.

With Nerve.

In this series I have four cases where a nerve from one dog was used to fill up a gap in that of another dog.

Experiments 9, 10, 11, and 12 were carried out on two dogs. About 1 in. of the ulnar nerve was excised on each side. The removed lengths of nerve from one dog were sutured into the gap made in the ulnar nerve of the other, and vice versa. The dogs were operated upon at the same time, and the excised nerves were at once transferred from one animal to the other. Healing of the wounds occurred by first intention. In Experiment 9 the following results were found after 115 days. On the right side the transplanted piece of nerve was flabby and not firm to the touch, but was quite distinct from, and not adherent to, the surrounding structures. At the upper end of the bridge there was a distinct bulb, and at the lower end a very small one, where the bridge joined with the central and distal end of the animal's own ulnar. The whole nerve trunk was isolated, and stimulation of the ulnar central to the bridge gave vigorous flexion of the paw. The result was very fair when compared with the adjacent and untouched median. On the left side (Experiment 10) the transplanted piece was very flabby and almost ribbon like. It was adherent to the surrounding tissues, especially the veins, though it was quite different from the irregular scar-like strand seen after the use of catgut. Like the right side, there was a large upper and a small lower bulb. Stimulation applied to the transplanted piece gave no muscular response whatever. Stimulation of the distal end of the animal's own ulnar gave rather feeble ulnar flexion of the paw, evidently due to wound fibres growing in at the lower place of suture, and not to any fibre growing down the graft. In the other dog (Experiments 11 and 12) 134 days were allowed to elapse before stimulating. On both sides the conditions found were very similar. The transplanted grafts were easily recognizable and were adherent to the branches of the basilic vein, which had to be divided to isolate them. The grafts were well-defined strands, though they had not the shiny appearance of the normal nerve. Electrical stimulation was on each side compared with the intact median; the minimum strength of current causing contraction by the median also did so when applied to the ulnar distal to the bridge. A slightly stronger current was necessary if applied central to the bridge. The explanation of this is in wound fibres growing down the distal end of the ulnar.

In the four experiments performed the bridge measured 1 in. in each case. The response to faradism was good in three cases and an absolute failure in one. The bridge itself had not the firm feel of healthy nerve, and was at times fixed to other tissues, but not to the same extent as in the case of catgut.

With Other Tissue.

The bridging of an interval in the nerve by a piece of tissue other than the nerve from an animal of the same species is not of practical importance, and I have not any experiments to show its efficiency. In the human subject homo-transplantation has always been done with a piece of nerve from an amputated limb. It is not likely any other tissue would be used.

AUTO-TRANSPLANTATION.

In the auto-transplantation bridge, the distinction between the nervous and non-nervous tissue of the bridge is important. My experiments seem to show that a certain amount of success is to be expected from bridging with a piece of non-nervous tissue.

With Non-nervous Tissue.

I have performed six experiments on auto-transplantation with non-nervous tissue.

In Experiments 13 and 14, 1 in. of the internal popliteal was removed on both sides of the dog, and the gap filled in with a well-defined piece of fascia taken from the popliteal space of the same side. The wounds healed well, and stimulation was tried after 118 days. On both sides the result was much the same, the right being a little the better. The animal walked moderately well, though the foot tended to be flexed at the hock. A definite bulb was present at the extremity of the central end of the internal popliteal. This was followed by a well-defined graft, only slightly blended with the surrounding tissues. The adjacent external popliteal was easily separable from it. Stimulation of the internal popliteal distal to the bridge resulted in movement and sensory manifestations. Stimulation of the internal popliteal central to the bridge with a weak current resulted in vigorous muscular contraction. The result was not obtained with the minimum efficient stimulus for a healthy nerve. Result fairly good.

Experiment 15.—On the right side 2 in. of the internal popliteal were excised and the gap filled in by a thick strand of muscle taken from the biceps of that side. After 134 days it was found that the bridge had effected no useful result. The bridge had contracted adhesions all the way down, and its muscle nature was apparent to the naked eye. Stimulation central to the bridge resulted in contraction of the graft itself but caused no movement in the foot. Result failure.

Experiment 16.—On the right side 1 in. of the internal popliteal was excised and a gap bridged over with a piece of fascia, fat, and muscle from the popliteal region. After 130 days the bridge was thin, ribbon-like, and adherent to the hamstring muscles. Stimulation of the internal popliteal applied central to the bridge resulted in vigorous muscular contraction. The minimum effective stimulus applied to a healthy nerve was not sufficient to produce any response in the bridged internal popliteal. Result fairly good.

Experiment 17.—On the left side 1½ in. of the internal popliteal were excised and the gap filled in with fat, muscle, and a thin strip of biceps. After 129 days the bridge was a thick mass very adherent to surrounding tissue, but still retaining some muscle tissue, as it contracted by stimulating the internal popliteal. Stimulation of the internal popliteal central to the graft gave a vigorous contraction, but it was less sensitive than on the opposite side, where catgut had been used, and much less sensitive than the untouched external popliteal. Result fair.

Experiment 18.—An inch and a half of internal popliteal were excised and the gap filled in by a strand taken from the biceps. After 126 days the bridge was thin, of reddish colour, and adherent to the surrounding tissues. Stimulation applied to the internal popliteal central to the graft gave a vigorous contraction, but it was much less sensitive than the healthy external popliteal. No contraction of the bridge itself occurred, the muscle tissue having apparently disappeared. Result fair.

In the six experiments made the length of the bridge varied from 1 to 2 in. In three cases where the length of the graft was 1 in., the response to electrical stimulation was fairly good. In two, where the interval was 1½ in., the result was less sensitive and could only be called fair. In the case where 2 in. were bridged over by this means, the result was an absolute failure. In nearly every instance the bridge was not defined from the surrounding tissues, and at times the muscle tissue persisted.

By Another Nerve from the Same Animal.

This is a very important group, as the experiments on it have an important surgical bearing. It is possible to cut a nerve in two places and suture the intervening piece, which practically becomes a nerve bridge, in position with successful result. I have performed this successfully in at least five instances in connexion with another research. The sciatic nerve was cut just below the sciatic notch, and again in the upper part of the popliteal space. The intervening piece, which measured about 2 in., was not lifted out of its bed, and was at once stitched in position by single chromicized catgut sutures. After between 80 and 100 days complete recovery of sensation and motion had occurred.

It is also possible to remove a piece of a nerve and suture it in the reverse position, so that its central end is joined with the peripheral end of the nerve, and vice versa, with success. Bethe¹⁰ reports this as having been done, though at the time of my experiment I was unaware of it. I have only performed this once, in a case where ¾ in. of the ulnar nerve was excised and sutured in the orientated position. After 116 days there was very good sensory and motor recovery.

The cases where the piece of one nerve has been transferred to the gap in another have been of two kinds. The nerve which has been bridged over has always been a mixed one, while the nerve graft has been taken in some cases from a mixed, and in other instances from a purely afferent, trunk.

Experiments 20 and 21.—Three quarters of an inch of the ulnar nerve was excised on the right side, and the piece put in the median of the left side. The piece of median excised from the left was used as a gap for the ulnar on the right side. After 130 days the condition was as follows: On the right side the bridge inserted in the ulnar was rather thicker than the rest of the nerve. Some little difficulty was experienced in separating it from the basilic vein and its branches, though not so much as in the homo-transplantations. It was not adherent to the median nerve. Stimulation of the ulnar central to the graft produced contraction of the muscles with as weak a current as was efficient in the intact median. Result perfect. On the left side the same anatomical condition was present, but the stimulation result was not quite as sensitive as on the right side. Result good.

In three cases a gap of 1 in. in a mixed nerve was bridged over by strands of a purely efferent trunk—the radial. The double strand was used in two because the combined size about equalled that of the nerve trunk to be bridged over.

Experiment 22.—Two strands of radial were used to bridge over an interval of 1 in. in the median. After 103 days the nerve bridge was about the same thickness as the median itself, and was hardly adherent to the surrounding tissues at all. It was smooth and polished like a healthy nerve, but the two strands could not be distinguished by the naked eye. Compared with the adjacent uninjured ulnar the result was perfect.

Experiments 23 and 24.—On the right side 1 in. of the posterior interosseous was bridged over by the same length of radial from that side. On the left side 1 in. of the ulnar was bridged by two lengths of radial from that side. After 136 days the naked eye appearance was very similar to the former case, and the electrical response was perfect.

Experiment 25.—In the left hind leg 2 in. of internal popliteal were excised, and the gap filled in by the same length of internal popliteal from the right side. After 134 days the bridge was very like a healthy nerve, being firm, glistening, and non-adherent to surrounding tissue. A very weak current applied to the internal popliteal central to the graft resulted in a vigorous flexion of the toes and contraction of the calf muscles. Compared with the normal external popliteal, however, the minimal current was not effective. Result good.

Experiment 26.—On the right leg 1½ in. of internal popliteal were excised and the gap filled in by a piece of the opposite internal popliteal placed in the reverse (orientated) position. After 126 days the bridge was very like healthy nerve, being shiny, round, firm, and non-adherent to the surrounding tissue. The minimum of electric stimulation for a healthy nerve caused movement when applied to the internal popliteal central to the graft. Result perfect. On the opposite side 1½ in. were bridged over by a piece of the animal's own muscle. The sensitiveness to electrical stimulation was very much superior on the side where the nerve had been used as a bridge. During life the animal was made to walk on the hind legs, and there could be no doubt that functionally the nerve bridge gave the much more satisfactory result.

SUMMARY.

Seven of these experiments were done; the length of the bridge varied from ¾ in. to 2 in. In five out of these the response to electrical stimulation was perfect, and in the remaining two nearly so. It did not seem to make any difference whether the corresponding nerve from the opposite side was used, or whether the nerve bridge was sutured in the reversed position, or even if a purely afferent nerve was used to bridge over a mixed one. The appearance of the nerve bridge was very like that of a healthy nerve except that it was not so firm to the touch. It was shiny, and not at all incorporated with any of the adjacent tissues, being a definite and separate structure.

CONCLUSIONS FROM THESE EXPERIMENTS.

I have rejected all cases where suppuration occurred, and these are not included in this paper. The outstanding feature is the immeasurable superiority of the nerve from the same animal in bridging over a nerve defect. The tests applied were (a) function of the muscles, (b) sensitiveness to faradic stimulation applied directly to the nerve above the bridge, (c) distinctness of the bridge from the neighbouring tissues, (d) microscopical appearance.

(a) It is not easy to compare differences in muscular power in animals, but as far as this could be done it was in favour of the cases of nerve auto-transplantation. In two dogs a similar length of the corresponding internal popliteal was excised in the hind legs. On one side nerve, and on the other tissue, auto-transplantation was employed. By watching the animals jumping and getting them to walk on their hind legs a good comparison could be made. This was markedly in favour of the nerve bridge.

(b) The test of electrical stimulation requires no comment.

(c) The distinctness of the bridge from other tissues is of importance. Where the bridge blends more or less completely with the adjacent structure, many of the nerve fibres will wander out of it and not reach the distal end of the nerve at all. If there be the least scar tissue—as is often the case—in the operation area, it will surround and blend with the adherent nerve bridge, and the effect will be disastrous. On the other hand, where the bridge is a distinct structure, there is not much opportunity for the down-growing nerve fibres to wander astray. Catgut seems to give the least defined bridge. The surprisingly good electrical results in my cases with catgut are probably explained by the absence of any scar tissue. A few cuts with a sharp knife opens up an intermuscular space with scarcely any injury to the neighbouring structures. The nerve is then exposed, a length excised, and catgut sutures passed through both cut ends, leaving a length of the catgut between them as a bridge. The resulting scar tissue is insignificant. When the retractors are taken out the muscles fall together, obliterating the space. Such a favourable condition is not found in most cases where nerve bridging is necessary in surgery.

(d) I hope to furnish a description of the microscopic examinations of the bridges in another paper. From the small number already examined, it seems that in nerve auto-transplantation the bridge has the structure of the normal nerve. Fibres are arranged in large groups in funiculi, and there is a definite fibrous sheath binding them all together. In all the other cases the nerve fibres are arranged in groups of about half a dozen, scattered all through the bridge, apparently lying in the lymph spaces between the tissue element of the bridge itself. These statements are at present based on the examination of only four specimens.

With every test, then, nerve auto-transplantation comes first. It is not easy to allot the second place, however. With a nerve defect in a previously uninjured area, such as would be present after the removal of a small nerve tumour, catgut would be fairly efficient. If more or less scar tissue were present, as would be the case after loss of part of the nerve from injury, a bridge of nerve from an amputated leg, or failing that a nerve from a dog (which is firmer than that of most animals), would be the better. If nerve tissue be used there is more chance of a definite and separate structure resulting.

It is merely necessary to mention the nerve-flap operation described by Létievant¹¹ for bridging over a gap. It was apparently suggested by a similar method of treating a tendon defect. It comes under the head of nerve auto-transplantation and would probably be of some service, though from its nature the result could only be very imperfect. It should scarcely ever be necessary.

It should be mentioned that nothing like the successful results obtained in my experiments would be found where the nerve defect is of some standing. The proportion of cases where nerve bridging is a primary operation is surprising. Out of 20 cases in the human subject reported by Peterson,¹² 8 were done at once; 2 others were performed two and four days after the injury, and a third one at eleven weeks. The first 2 of these are practically primary operations, so that it is only in 50 per cent. of the cases that secondary nerve suture with bridging is to be performed.

NERVE BRIDGING IN SURGERY.

These experiments confirm the conclusion reached by Sherren from an analysis of the few reported cases of nerve bridging in man. Curiously enough a bridge from a purely afferent nerve trunk seems to form just as efficient a connexion as a mixed one for the regeneration of motor fibres. This seems to justify the conclusion that though sensory and motor nerve fibres differ in their size and function, these depend more on their central and peripheral connexions than upon their structural difference. Nerves play the part of telegraph wires between different stations, and it is the connexions they form which decides the use they are to be put to. A piece of isolated nerve can have its position reversed without any ill-effect.

At first sight nerve auto-transplantation appears only of academic interest. It would seem foolish to sacrifice a healthy nerve for the sake of an injured one. This has, however, been done on one occasion. Dean¹³ bridged over an interval in the musculo-spiral nerve by a piece from

the radial; but, of course, here the radial being a branch was useless unless the musculo-spiral were conducting. There is one purely afferent nerve in the body that I think could be sacrificed for the chance of improving a more important, especially a motor, trunk. The one I refer to is the internal saphenous of the leg. Practically no disability would be caused by its division. A narrow area of anaesthesia along the inner side of the leg and foot would result, but this would diminish and doubtless disappear in time owing to the overlapping of adjacent sensory areas. A long length of it is available, and one or more thicknesses could be used. For instance, a gap in the ulnar would require at least three widths of internal saphenous stitched side by side. The sciatic would need many more, and probably the width of the bridge would be insufficient unless both internal saphenae were utilized. The experiments in auto-transplantation suggest that some unsensational nerve like this should be extensively used in bridging.

It is only in very extensive nerve injuries, such as total lesions of the brachial plexus, that other methods would have to be considered. In Erb's brachial (obstetrical) paralysis the nerve trunks can usually be brought into apposition after excising the scar of the original tear, that is, when it is extra-vertebral. In the adult form, such as not uncommonly occurs after dislocation of the shoulder, the cords of the brachial plexus for a considerable distance are reduced to firm fibrous non-conducting bars adherent to the surrounding structures. The internal saphenous would be quite inadequate to fill such an extensive gap. Probably the median of the paralysed arm could be made use of. If it be excised from just below where the interosseous trunk is given off, to the wrist, a comparatively unimportant part is lost. Beyond paralysis of the thenar muscles very little ultimate disability is caused by loss of this part of the median. It is only necessary to call attention to the hopelessness of total brachial paralysis, and the fact that many sufferers have submitted to amputation of the limb, to justify a dangerous and difficult operation. My only case of nerve bridging in the human subject was of this nature. A boy of 17 had total paralysis of the arm owing to a tree falling on his shoulder nine weeks previously. The clavicle was evidently pushed violently back, squeezing the plexus against the first rib. At the operation a scar involving about 1 in. in length of the whole plexus was removed. It was necessary to divide the clavicle to do this, and the bone was afterwards wired. With the arms well abducted the upper and middle trunks of the plexus could be brought into apposition, but a gap of about $\frac{1}{2}$ in. separated the lower trunk. Just previously to this I had had several successful cases of tissue auto-transplantation, and I used a piece of the boy's sterno-mastoid to span the interval. There is no recovery yet, after four months, but this can hardly be expected. This case exemplifies the fact that the duration of nerve defects can be diminished in many cases by placing the limb in a position to relax the particular nerve. It should be kept like this for about four weeks till nerve union has occurred.

In secondary nerve bridging the fact that the bulb on the proximal end of the nerve has to be removed adds to the nerve interval. A bulbous swelling constantly appears on the divided proximal ends within a month after the injury. It consists of fine tortuous nerve fibres lying among fibrous tissue. When it has been in existence any time it is probable that no efficient regeneration will occur from these fibres, and it must be totally removed. This is another argument, if any were needed, for primary operations.

The Time for Performing Nerve Bridging.

It is in about 50 per cent. of cases only that secondary nerve bridging is necessary. In subjects where a length of nerve has been destroyed by an injury or by a burn it will usually be impossible to perform primary nerve bridging. The lacerated and often dirt-ingrained tissues do not heal readily, and it is inadvisable to try any nerve operation while suppuration is going on. The earliest time at which anything can be done will be when the granulating area has healed. It is usually stated that after about two years it is hopeless to expect any motor recovery in a divided nerve. At the end of this time the muscle fibres, or the nerve

cells, have degenerated beyond redemption. There appear to be certain factors that sometimes prevent this result, especially the growth of wound fibre from the damaged tissues into the distal end of the divided nerve. This was well exemplified in a case of Erb's¹⁴ palsy under my care. The boy was 6 years of age, and a definite lesion of the fifth and sixth nerve of the brachial plexus was found. He had never had the least use of his dorsal-scapular muscles. At the time of operating it was seen that a large scar mass shut off the suprascapular nerve from the central end of the plexus. Stimulation of this nerve beyond the scar resulted in feeble outward rotation at the shoulder-joint, though centrally to the scar it produced no effect. I have recently had a case in a girl of 13 showing exactly the same condition. That wound fibres can prevent a certain amount of muscular atrophy was also shown conclusively in one of my dogs. One inch of the ulnar nerve was excised and filled in by two strands of radial from the same side. Mild sepsis resulted from the operation. After 103 days electrical stimulation of the ulnar above the bridge resulted in no contraction of the muscles, while if applied below the graft it caused feeble muscular movement. The nerve graft itself consisted of dense scar tissue. In this the only source of the nerve fibres growing down the distal part of the ulnar was from nerve twigs to the tissues divided at the operation. A most conclusive proof of the presence of wound fibres preventing total degeneration of the nerve and muscle was seen in another dog. In this case the central end of the radial was sutured to the distal end of the posterior interosseus. A large piece of the central posterior interosseus and distal radial nerves were excised.

After 82 days, stimulation of the central end of the radial gave no motor response, while when applied to the interosseus joined to it fairly vigorous extension of the paw resulted. As there are no motor fibres in the radial, and the central end of the interosseus had effected no connexion with its distal end (as proved by stimulation) there was no other source of the motor fibres. Instances like these lead me to believe that we can assign no time-limit beyond which the regeneration of the motor fibres is impossible. Doubtless in many, perhaps in the majority of cases, the wound fibres which so to speak keep up the nutrition of a divided nerve are too few to be of any real service. But it is impossible to tell which are the cases which can be benefited unless the study of the electrical reactions may in future be found to do so.

Probably, too, there will be more wound fibres where fairly extensive damage has been done to the tissues near the nerve trunk. In nerve lesions where the sheath has not been damaged, such as is seen in infantile paralysis, wound fibres can play no part. These considerations seem to justify attempting secondary nerve suture, and also nerve bridging for an almost indefinite time after the injury.

The length of nerve which can be bridged over successfully seems uncertain. When the interval appears to be too great the paralysed nerve should either be fixed in a notch of a neighbouring trunk or a flap of the healthy nerve separated for a short distance and then attached to the affected trunk, if anatomical conditions permit of this being done.¹⁵ If there is any doubt as to which method should be used, it is open to attempt nerve bridging, and if this be a failure, to try nerve anastomosis later on. It must be admitted that the time wasted by an unsuccessful nerve bridging would make subsequent nerve anastomosis less satisfactory.

Finally a word might be said as to the inadvisability of performing nerve bridging in the midst of old scar tissue. I have seen two cases where it was attempted to bridge over the median by nerve hetero-transplantation after an extensive laceration of the forearm destroying part of the nerve. The results were an absolute failure. To open up a region and insert a nerve graft in the relentless grip of scar tissue is to court failure. The only way in these conditions is to free the central and peripheral end of the nerve and carry them to an adjacent intermuscular space where scar tissue is absent, and then perform bridging or anastomosis. Such an alteration of the position of the nerve will almost certainly increase the distance to be bridged over, but this is unavoidable.

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

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REPORT CVI.

INVESTIGATION OF THE BUNDLE OF HIS IN RABBITS' EXCISED HEARTS PERFUSED WITH LOCKE'S FLUID.*

By L. N. HESKETH BIGGS, M.D., EDIN.

ONCE the rabbit's heart has settled down to its work after excision—say in three-quarters of an hour to an hour—it is remarkable how much cutting about it will stand without marked disturbance. On several occasions all the right side of the heart was removed; on another both ventricles were removed, leaving only the septum; and on yet another the septum and the right side of the heart were cut away, leaving the left ventricle hanging by a strip about 5 mm. wide; and still in all these cases the tissues continued giving very good contractions, considering how little fluid could possibly have reached them after such extensive section of vessels.

Cutting any of the ultimate branches of the A-V bundle makes no discernible difference. I have divided both the descending and the anterior divisions of the left branch of the A-V bundle, as it emerges through the inter-ventricular septum, but noticed absolutely no change at all except a distinct, though temporary, lengthening of the As-Vs interval. Similarly I cut through the left division before its branches (so far as is as yet known), but obtained no result, though I cut almost through the entire thickness of the septum. I also tried dividing the right division, first of all in its ramifications and then closer and closer to its origin, but all was of no avail, the ventricles continuing to respond to the auricular impulses undisturbed.

In one experiment I carefully separated the right from the left ventricle, and placed a pin with lever attached in the tip of each ventricle, and tried to block one side without the other, but found that the most careful sections of the left and right branches separately produced no block of its half, and, as in every other experiment, finally one snip with the scissors penetrating the entire thickness of the septum blocked both ventricles simultaneously.

This seems to entirely contradict the usual view that the fibres of the A-V bundle do not fuse with those of the septum in its upper part, but continue enclosed in a sheath a long way down the septum, uniting only in the lower third, as otherwise it would have been possible, by dividing all the main branches, to produce the same effect as by section of the A-V bundle itself, either before it reaches the pars membranacea septi or just before its division into right and left. This I never found it possible to do; for, unless the bundle was divided just as high up as one could go without injuring the cusp of the aortic valve—that is to say, just about its division—one might cut the whole septum across and cut it out, and yet get only a very partial heart-block.

A few of the hearts used had abnormally-developed membranous part of the septum, and in these the A-V bundle seemed to pursue an abnormal course or to divide prematurely, or else its anatomical relations are masked; for division at the spot usually successful produces no heart-block, and it is not till the division is performed high up on the interauricular septum, while the fibres of the bundle are in the auricular cavity, that heart-block is established. Great care has to be exercised in doing this, as frequently the aortic valves begin to leak seriously, and thus render the experiment almost useless.

One may even in such a case carefully dissect away as far as one is able every scrap of muscular tissue from the pars membranacea and the root of the aorta and yet get only a very partial condition of heart-block. I have one heart preserved in alcohol in which this was done, and yet a block was not produced.

It seems as though there were some other path of conduction which can only be divided by an incision at or before the bifurcation of the A-V bundle.

I found further that so long as a minute part of the A-V bundle was left undivided, although section appeared at first to have produced complete block, yet recovery would almost invariably take place to normal rhythm. This might take a considerable time, as though the amount of stimulus that could pass through the small uninjured part of the bundle was insufficient to stimulate the ventricles to contract until their inherent rhythmicity had increased to such a degree that the stimulus plus their increased irritability became effectual. I do not believe that this was in any way to be attributed to an injurious compression of the fibres of the A-V bundle still uncut during the attempted section.

I was unable to find that any part of the A-V bundle supplied any definite part of either ventricle. In one or two experiments it did seem as though one ventricle was more affected than the other, and on one or two occasions as though part of a ventricle was not contracting properly, but it was practically impossible to be certain of the point, and different onlookers of experience gave quite different opinions as to the result obtained.

Thus I infer that so long as a small part of the thickness of the A-V bundle is still intact every part of the ventricles will respond to the auricular stimuli, and that this may be due to the extreme reticulation of the fibres and their tendency to fuse with one another, so that every bundle of muscle fibres may be said to have a universal distribution. Moreover, apart from actual compression, such as Erlanger used, any part of the A-V bundle uncut and uninjured is capable of performing almost the entire function of the whole bundle, and the whole bundle must be cut across or damaged by compression for even a partial state of heart-block to remain for any length of time. For sometimes in these experiments cut after cut was carefully given to the bundle without any sign of heart-block except a lengthening, usually only temporary, of the As-Vs interval, till finally a touch with the edge of a knife, which could not have cut more than a small fraction of a millimetre, has produced total heart-block. Probably the left and right branches of the A-V bundle are not confined in their distribution to their own side of the heart, but supply both ventricles, for it looks as though auricular impulses were always capable, when one of the two primary branches was divided, of reaching both ventricles simultaneously through, presumably, the other uninjured branch.

The details of the procedure adopted for dividing the A-V bundle do not seem to call for mention, except to state that an incision of 2 mm. was ample to produce block in a rabbit's heart. The incision was made at the upper edge of the muscular part of the septum, and ran slightly downwards and backwards. The anterior end of the incision should reach to the line drawn down the centre of the aorta as the heart hangs from the cannula.

As a rule the first cut at the A-V bundle would appear to have produced complete block, with total cessation of the ventricles for a period varying from several seconds to many minutes, but often after a period of independence of the ventricles, auricular extrasystoles would appear in response to the ventricular contractions, and then a gradual recovery take place through 4-1, 3-1, and 2-1 rhythms to the normal, but with a slightly lengthened As-Vs interval, at any rate for a time. A small further cut would then produce dissociation, sometimes absolute and sometimes with auricular extrasystoles following ventricular contractions, but with no vestige of conduction in the normal direction. In these latter cases the Vs-As interval was usually about half the normal As-Vs interval, but varied from half to the same length as the As-Vs interval.

The normal As-Vs interval averages about $\frac{1}{4}$ of the cardiac cycle, or between $\frac{1}{8}$ and $\frac{1}{10}$ of a second. Incising the ventricles generally produced a temporary shortening of the interval, as one would expect as the result of the

* A short extract from the latter half of an M.D. thesis, submitted in April, 1907, which was awarded a gold medal, and towards the experimental expenses of which a grant was made by the British Medical Association.