IV. *Experiments on the Restoration of Paralysed Muscles by Means of Nerve Anastomosis.** Part I.—*Substitutes for the Facial Nerve.*

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[Plates 6 and 7.]

Preface.

In a memoir presented to the Académie Royale des Sciences de l'Institut on December 3, 1827, entitled "Expériences sur la Réunion des Nerfs," P. Flourens (2)† described an experiment, which is the first recorded observation on the subject of nerve crossing or the substitution of one nerve for another. He says‡:—"Je coupai, sur un coq, les deux nerfs principaux qui, du plexus brachial, vont, l'un à la face supérieure, et l'autre à la face inférieure de l'aile. . . . . Je croisai alors les bouts des nerfs divisés, en joignant le bout supérieur d'un nerf avec le bout inférieur de l'autre, et réciproquement; et je maintiens ce *croisement artificiel* par un point de suture.

"Au bout de quelques mois, l'animal avait parfaitement repris l'usage de l'extrémité de son aile, laquelle ne traînait plus, et dont il se servait pour voler tout aussi bien qu'avant l'expérience. . . . . Je mis les nerfs opérés à nu; ils étaient complètement réunis, et dans l'ordre même où je les avais placés; c'est-à-dire que le bout inférieur d'un nerf se continuait avec le bout supérieur de l'autre, et réciproquement. . . . .

"Et de plus, quand je pinçais le nerf supérieur *au-dessus du point de la réunion*, c'étaient les muscles de la face inférieure de l'aile qui se contractaient; et c'étaient, au contraire, les muscles de la face supérieure de l'aile qui se contractaient quand je pinçais le nerf inférieur, toujours *au-dessus du point de la réunion.*"

It would appear, then, that this experiment was most successful. In so far as the cross union of the two nerves was concerned, the crossing seems to have been quite efficient, judging from the description of the muscles which contracted on irritating

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† The numbers in brackets refer to the Bibliography, p. 157.

‡ *Loc. cit.*, p. 272.

the nerves. Also, apparently, co-ordinated movements were restored, seeing that the animal was able to fly as well as before the experiment.

Two other interesting experiments are also recorded by him in the same place, which consisted of crossing two nerves of different types, namely, the pneumo-gastric and the fifth cervical. He divided the former and attached its distal segment to the central segment of the latter, previously also divided. He did this in a cock and in a duck. At three months and three and a-half respectively, he divided the pneumo-gastric of the other side, but in each case the animal fell into that state of "respiration pénible et de suffocation qui accompagne toujours la section simultanée des deux nerfs pneumo-gastriques," and died on the second day after the operation. He concludes that reunion takes places between the crossed nerves in every case, and that function returns in the first case, but not where the pneumo-gastric is joined to the spinal nerve.

Various investigators subsequently approached the same subject, SCHWANN (1), STEINRÜCK, BIDDER (3), GLUGE and THIERNESSE (4, 6), and PHILIPEAUX and VULPIAN (5) taking part, their work consisting in the main in investigating the possibility of union between functionally different nerves, such as the hypoglossal with the lingual, to see if union was possible between such.

No surgical application so far had been made of these physiological facts, but in 1873, LÉTIÉVANT (7) made the following suggestion* under the name of *greffe nerveuse* :—"Un nerf vient d'éprouver une grande perte de substance; rechercher son bout inférieur, l'aviver et le suturer à un bout appartenant à un autre nerf, divisé aussi par la blessure, mais plus bas que le premier et moins important que lui."

No one took up the exact type of FLOURENS' experiment again until RAWA (9), who published his investigation in 1883 in abstract and in 1885 in full. He crossed nerves of different function, and also nerves of the same function, namely, the posterior tibial and the peroneal, crossing thus the nerves supplying the flexors and extensors of the hind leg. He concluded from his work that cross union between two motor nerves takes place with restoration of function, and that even when nerves so different as the hypoglossal and pneumo-gastric were crossed, union and efficient function could be carried on through the composite nerve.

These conclusions were combated by SCHIFF (10) and REICHERT (11), and supported and confirmed by STEFANI (12) in so far as referred to motor nerves of similar function, and this conclusion was supported also by HOWELL and HUBER (13). CUNNINGHAM (14), again, conducting his experiments on the nerves of the fore limb in dogs, came to the conclusion that, although reunion was effected, it was not one efficient to allow the function of the muscles to be carried on.

Accurate experiments in the union of the central segment of the divided pneumo-gastric to the peripheral of the divided cervical sympathetic led LANGLEY (15, 16) to the conclusion that, "when the central end of the vagus is joined to the peripheral

* *Loc. cit.*, p. 427.

end of the cervical sympathetic, the vagus is capable of acquiring an influence upon all the structures which are normally influenced by the cervical sympathetic," and he showed that, there being no pilo-motor fibres in the vagus, this function must be assumed by one class changing to another. Also from the fact that paralytic signs after the vagus had been joined to the cervical sympathetic disappeared or diminished, *i.e.*, contraction of the pupil, dilatation of the vessels of the ear, he concluded that the vagus was exercising a tonic influence in the distribution of the cervical sympathetic. From his experiments in joining the central end of the lingual to the peripheral end of the cervical sympathetic with recovery of sympathetic function, he concludes that " the vaso-dilator fibres of the lingual (chorda tympani), after becoming connected with the nerve cells of the superior cervical ganglion, become motor fibres for unstriated muscle, and, in especial, vaso-constrictor fibres for the arteries of the ear" (p. 268).

FORSSMAN (19) in 1900 published a research on the subject of Neurotropismus, in which he studied the rate of regeneration when the central segment of a divided nerve was united to its own peripheral segment and when united to that of another divided nerve, and came to the conclusion that it was the same.

My own investigations (18, 20) on this subject were published in 1899 and in 1900, and in these I considered the question of restoration of the nerve paths after division and reunion of nerves, and also the subject of restoration of function after nerve crossing in the fore limb of the dog.

BETHE (31) and LANGLEY and ANDERSON (38) followed, the latter dealing with the subject of functional union between crossed nerves of the same and of different functions, and coming to the conclusion, among others, that the " central end of an efferent fibre can make functional connection with the peripheral end of any other efferent fibre of the same class, whatever be the normal action produced by the two nerve fibres."

Within the last ten years these physiological facts have come to be more applied in surgical work, with varying success, and it appeared to me that many points from the physiological standpoint still required investigation in connection with these practical applications of the work. In the past two years I have performed about thirty experiments in dogs and monkeys, and, as these experiments fall naturally into three groups, I propose to publish them in three parts. The first will deal with the methods of cross union between a peripheral segment of a divided facial nerve with the nerves in the neighbourhood which may be chosen as substitutes for the central end of the facial; and in this part will appear a report, nearly twelve years after operation, of the case of spino-facial anastomosis which was published in the 'Philosophical Transactions' in 1901. The second part will take up experiments in the nerves of the fore limb in dogs in extension of my experimental work published in 1901. The third part will consist of experiments on the anastomosis of nerves in the brachial plexus in monkeys, the function of the roots of the plexus being also considered.

PART I.—SUBSTITUTES FOR THE FACIAL NERVE.

CONTENTS.

1. Introduction.

Substitution for the facial nerve is called for as a surgical procedure in the human subject, where from one cause or another the facial musculature has ceased to be innervated normally by the central representation of the facial nerve, and where there is no possibility of re-establishing the normal innervation. This interruption of the normal supply may be due either to a central or to a peripheral lesion, but the cases in which this form of treatment will be found suitable are, with few exceptions, those forming the latter group. Interruption of the facial nerve may take place at any point from its origin to its peripheral distribution, but the vast majority of cases in which this operation will come into consideration are those in which the damage to the nerve has taken place while the nerve is running its course within the temporal bone, in the aqueduct of Fallopius. Here the nerve is peculiarly liable to damage, and, when damaged, is less likely spontaneously to reunite than in the case of a nerve lying in soft parts, by reason of the rigidity of the walls which surround it in this situation, and which therefore offer a barrier to the expansion of the nerve at the seat of damage. As a reuniting nerve invariably produces a swelling at the seat of reunion, it follows that this, lodged within the confines of the aqueduct of Fallopius, will, in itself, produce the compression which makes functional restitution an impossibility. This, then, is one of the chief reasons why damage to the nerve in this situation is so frequently followed by abiding paralysis. The most frequent cause of damage to the nerve in the aqueduct of Fallopius is middle ear sepsis, brought about by infection conveyed through the Eustachian tube, or through a perforation in the drum. A small number of cases are due to fractures of the base of the skull involving the portion of the temporal bone traversed by the nerve, while gunshot wounds and stab wounds account for a small number of cases in which the lesion is situated on the nerve in the aqueduct of Fallopius, or after it has left the stylo-mastoid foramen. There is also a group of cases in which the lesion appears to be produced by a rheumatic cause ; and, under certain circumstances, substitution will also be available in these. In certain other cases the one side of the face will only be in part paralysed, although the lesion is situated peripherally, and this will, of course, be the case when the lesion involves only one or some of the subdivisions of the nerve, but it is also sometimes the case when the lesion is proximal to the subdivision, but involving only part of the thickness of the nerve trunk.

When, in a case of facial paralysis, it is decided that it will be imperative or desirable to intervene surgically in order to facilitate or permit recovery, it is necessary to consider what procedures may be adopted in order that the place which substitution fills may be made quite clear. Such a case, then, may be treated surgically in one of four different ways, as follows :—

(1) Restitution of the damaged facial nerve.
(2) Musculo-plastic operations.
(3) Operations devised mechanically to draw together the flaccid tissues of the cheek.
(4) Nerve anastomosis.

These methods may be considered in some detail.

(1) *Restitution of the Damaged Facial Nerve.*—This is the ideal procedure, and should be attempted when it is believed that longer delay would not be productive of a satisfactory result, and it is the method which naturally gives promise of the best result, and should be considered in all cases and carried out if feasible. Should the lesion to the nerve be situated distal to its course in the aqueduct of Fallopius, this operation will probably be more or less successful, as it will be necessary only to incise over the lesion and search for the damaged ends, remove from each the cicatricial tissue and unite them by a suture, or they may be found united by a cicatrix which may require to be cut out and the ends united, or mere liberation of the nerve from a cicatrix may be all that is required. On January 24, 1899, in the case of a man aged 20, suffering from total paralysis of the right side of the face due to a stab wound, I exposed the seat of damage 34 days after the injury. The nerve was found bound in cicatrix and was liberated. Movements commenced to reappear at the end of eight weeks, and, previous to that, the muscles were able to be thrown into contractions, when the nerve was irritated by the galvanic current applied to the seat of operation on the 25th day; although, previous to operation, the reaction of degeneration was found in the muscles on direct stimulation. At two years and four months a report was sent by the patient's doctor that the restoration of movements of the face was complete, but I have had no opportunity of confirming this by personal observation.

When, however, the lesion is in the aqueduct of Fallopius, this method has not been regarded as likely to be followed by success, as the bony surroundings of the nerve would interfere with the reunion. It would, however, appear that this conclusion, although a very probable one, is not invariably correct, for this operation has now been carried out with more or less success in several cases. KÜMMEL, in 1902, suggested in the case of damage to the nerve in the mastoid operation to expose the nerve in the aqueduct below the lesion, and to follow it centralwards and remove all the bone between the two damaged nerve ends. The first to record this as a deliberate operation appears to be STACKE, who, on March 10, 1903, published a case in which he had damaged the nerve while operating on the mastoid, recognised this at the time, and removed the obstruction between the two ends, leaving them close to each other. When published, the paralysis was clearing up. A similar procedure was done under similar circumstances by SYDENHAM (56), who used a piece of silk-worm gut laid between the two ends of the nerve in the aqueduct. He states that

the first sign of returning function was exhibited at the end of three months, when the patient showed slight movements of the ala nasi, and other facial muscles gradually came into use. Ultimately, a satisfactory recovery appears to have taken place. "The boy has now recovered his normal expression when at rest, and when his facial muscles are thrown into action it is difficult to tell that there has been any facial paralysis at all." This was a report probably nine months after operation, at which date the patient was shown at a meeting of the Stourbridge and District Medical Society.

Publication of that case induced MARSH (57) to bring forward two cases of facial paralysis in which he had adopted similar treatment, one in 1900 and one in 1908. In the former case a piece of catgut was inserted into the aqueduct through an opening in the inner wall of the tympanum, and movements began to return in six weeks, and it is stated that complete recovery resulted ultimately. In the latter, somewhat similar measures were immediately adopted on recognition of the injury, which occurred during the operation on the mastoid, and in one year and five months recovery took place in all the muscles, except those of the brow.

These cases, then, are instances of the ideal procedure, *i.e.*, primary reunion of the damaged trunk immediately after the injury, but a secondary reunion in this situation may also be possible in certain cases.

The following case occurred in my private practice, and was operated upon in one of the Glasgow nursing homes :—The patient, a girl, aged 16, had suffered from right facial paralysis since 10 months old, at which time she suffered from otitis media. For this affection an aperture had been drilled through the mastoid into the antrum at the time, but the ear had continued to discharge ever since, and the facial paralysis was unimproved. When she consulted me at 16 years of age there was the appearance of complete right facial paralysis, there being no movements due to right facial muscles possible. The eye could not be closed, but the eyeball rolled upwards on closure being attempted, the right angle of the mouth drooped and the cheek sagged. On examination, however, it was found that when the electrode was applied to the face the muscles gave responses both with galvanic and faradic currents. It was clear, therefore, that the facial nerve, although not fulfilling its function sufficiently to permit of voluntary facial movements, was nevertheless maintaining the nutrition of the facial musculature, and was therefore conducting impulses. I regarded it as probable that the nerve had either made an imperfect reunion or that it was under slight compression. Accordingly, on August 17, 1905, I performed the complete mastoid operation, and found the inner wall of the tympanum covered with a thick layer of cicatricial tissue and of granulation tissue. This was dissected away, and over the aqueduct of Fallopius a soft and yielding part was found in the wall, which on being touched with a platinum electrode with faradic current immediately produced violent contractions of the facial musculature, all the muscles of the right side of the face apparently taking part in the spasm. The nerve was

then dissected out and the external wall of the aqueduct chipped away so as freely to liberate the nerve from pressure. The nerve was then lifted out and found to have the appearance of a nerve which had been divided but reunited apparently satisfactorily. The nerve was returned to the aqueduct. Healing of the wound soon took place. For a considerable time subsequently no improvement appeared to follow this operation, but on being seen in March, 1911, it was found that the symmetry of the face at rest had been regained, there being no appearance of facial paralysis. The right side of the brow was able to be wrinkled only very slightly. The eye could be completely closed, and with some degree of firmness, but not so tightly as on the opposite side. The nares could be dilated, and at the same time the naso-labial fold was made prominent and the upper lip raised. She could raise the right cheek and show a wrinkle encircling the right angle of the mouth. The chin also moved distinctly. In attempting to whistle the lips could not make a circular aperture, but brought out the appearance of facial paralysis.

(2) *Musculo-plastic Operations.*—These operations constitute attempts to bring about improvement by a procedure on the principle of the tendon grafting operations introduced by NICOLADONI (8), but hitherto almost entirely employed in the case of paralysis in the arm or leg. GOMOIN first proposed this operation in the face, and his method is to strip up a portion of the sterno-mastoid muscle from its upper and anterior aspect and make a tunnel subcutaneously running to the angle of the mouth, along which the strip of sterno-mastoid is led, and then fixed to the angle of the mouth with traction sufficient to hold the latter tense. JANU AMZA (60) did this operation in the case of facial paralysis, but found it unsatisfactory, as the bit of sterno-mastoid merely acted as a drag on the mouth, causing a jerk of the angle at every movement of the head. He, therefore, proposes to use a bit of the masseter instead of the sterno-mastoid, to be turned forward in the same way, and to be adopted in those cases where all other methods have failed to give a result, and therefore as a last resource. GERSUNY (44) also proposes an operation consisting of a readjustment of the orbicularis oris. In these methods, therefore, it is hoped that the bit of muscle detached and turned to the face will in time commence to make movements directed to the needs of the face, independent of those which the strip of muscle formerly supplied.

(3) *Mechanical Methods.*—Attempts have been made to improve the facial appearance of those who are affected by otherwise irremediable facial paralysis by tucking up the angle of the mouth mechanically, merely supporting it in a more natural position without any attempt at restoration of movements. A most ingenious way to do this is that introduced by BUSCH, who inserted a wire subcutaneously, placed so that it passed from the zygoma to the angle of the mouth, forming a loop which was fixed tight enough slightly to overcorrect the droop of the angle of the mouth. This wire was allowed to heal in. MOMBURG (61) has published four cases of this, but found the defect of BUSCH's suggestion to be that the deformity gradually reproduced

itself owing to the wire cutting through the tissues and therefore losing its hold. To prevent this he fixed the upper end of the loop to the zygoma, causing one limb of the loop to pass outside of the zygoma and the other inside. He then experienced the defect of the lower end of the loop slipping by cutting through the tissues, and allowing the mouth again to droop, and suggests the introduction of a small piece of wire at the angle of the lip as a preliminary step, intended to be allowed to heal in and form a support for the loop subsequently to be introduced, or as a preliminary to create a dense scar at the angle of the mouth, round which to secure a firm hold for the wire.

It can, therefore, be understood that the two last described methods are not likely to lead to very satisfactory results, and could be considered as worth doing only in the event of the other methods of attaining restoration failing or being considered as impracticable.

(4) *Nerve Anastomosis.*—The foregoing has been put forward in order to show the place which nerve anastomosis takes in the treatment of facial paralysis. This consists in substituting, for the facial nerve whose continuity has been hopelessly destroyed, the function of a neighbouring nerve whose normal function is to convey impulses to other muscles. The application of this principle to paralysis of the face was first brought forward by FAURE and FURET (17) of Paris. FURET suggested the operation. FAURE writes*: "L'idée première de remédier à la paralysie due à la section du facial par l'anastomose de ce nerf avec un nerf voisin appartient à mon vieil ami, le Dr. F. FURET. Il vint un jour, au début de 1898, me demander si je ne pensais pas qu'on pût tenter de guérir la paralysie faciale en anastomosant le nerf sectionné à un nerf voisin, en particulier l'hypoglosse. Je lui répondis immédiatement que cette idée, parfaitement rationnelle, me séduisait beaucoup, mais que, *à priori*, le spinal, et en particulier sa branche trapézienne, me semblait de beaucoup préférable à l'hypoglosse, à cause de sa situation anatomique et aussi parce que, en cas d'échec, il n'y aurait pas grand mal à paralyser partiellement le trapèze, tandis que la paralysie des muscles de la langue présenterait au contraire les plus graves inconvénients. Il se rangea à mon avis."

Thus proposed, the operation was carried out by FAURE on January 23, 1898, on a man of 49 years of age, who on July 13, 1896, had destroyed the right facial nerve by a revolver shot in the ear. Complete facial paralysis resulted, and in January, 1898, the reaction of degeneration was found in the affected facial muscles. In this case, therefore, the spino-facial anastomosis was performed 18 months after the commencement of the facial paralysis, and the presence of the reaction of degeneration showed that there was no evident restoration of the divided facial nerve. The case was published at the meeting of the Congrès Français de Chirurgie in October, 1898, when therefore the patient had been operated upon nine months. At that time the condition was stated to be a failure on account of the length of time which had elapsed before the anastomosis had been made.

* BRÉAVOINE (23), p. 9.

My experiments on nerve crossing were commenced in January, 1898, and by the end of that year I was convinced that these experiments had proved that recovery of voluntary co-ordinated movements was possible after the nerve crossing. Therefore, being satisfied that this was proved to be the case in dogs, I concluded that such an operation as spino-facial anastomosis would in all probability produce a restoration, complete or incomplete, of the voluntary co-ordinated movements of the face. Having, therefore, some months later seen a very bad case of facial spasm, I decided to divide the facial nerve close to the stylo-mastoid foramen, and to graft its peripheral end on to the spinal accessory nerve. This was done on May 4, 1899, so that it amounted to an operative anastomosis for facial paralysis immediately performed, and consequently stood the best chance of giving a satisfactory result in the shortest possible time. In FAURE'S case the peripheral end of the divided facial nerve was attached to the central end of the branch of the spinal accessory given off to the trapezius, the suture being end to end; but in my case the peripheral end of the divided facial nerve was attached to the entire trunk of the spinal accessory, after that trunk had been sectioned through its entire nerve substance, leaving only one side of the perineurium intact. Thus the continuity of the trunk of the spinal accessory was maintained by the suture, and the facial nerve made to arise from it as a branch. The result of that operation was a satisfactory one. The first undoubted recovery was shown at the 49th day after the operation, in the partial independent and voluntary contraction of the orbicularis palpebrarum causing semi-closure of the eye, and this was accompanied by the restoration of the conductivity of the nerve to the galvanic current, as shown by the contraction in the facial muscles when the electrode was applied near the motor point of the facial nerve, and the faradic current also gave responses in the orbicularis palpebrarum when applied directly. I desire it to be understood that this voluntary contraction was a quite independent one, unaccompanied by noticeable contractions in the distribution of the spinal accessory, and not merely an association contraction brought about by raising the shoulder. At 470 days, when the case was published, winking as a reflex movement was quite efficient, and she had the voluntary power to shut completely the eye, although not so tightly as the opposite eye. This voluntary movement was quite independent of any associated movement in the distribution of the spinal accessory, which was not observed to occur. The right side of the brow could only be very slightly wrinkled voluntarily, and slight movements were observed to be made voluntarily at the mouth and in the right cheek, but co-ordination there was practically absent. In repose there was no evidence of paralysis. At that examination it was noticed for the first time that an association movement between the spinal accessory and facial distribution could be produced by causing the former to be violently innervated, as by suddenly raising the shoulder or raising the arm, the face being then simultaneously thrown into contractions, but these association movements were only observed on discovering them accidentally during violent efforts of the right arm.

The movements taking place in the face previously described were quite independent of any of the association movements, were made quite voluntarily by the patient in a natural manner. When she was asked to close her eye, that was done without any movement of the muscles supplied by the spinal accessory, and on ordinary movement of the latter no facial twitchings were observed.

I quote this case more fully than otherwise I should have done, had it not been that the case, in so far as restoration of movements of the face independent of those of the shoulder are concerned, has been by some writers apparently misunderstood. Thus SHERREN (43) writes in 1906, "Until recently no case had been recorded in which dissociated voluntary movements were restored. In 1904, THORBURN wrote of facio-accessory anastomosis, 'this latter fact rendered these operations of comparatively slight real benefit.' Other writers who collected cases from the literature came to the same conclusion." A reference to the paper (20), in which my case was published, will show that independent voluntary dissociated movements were restored, as far as the eyelids were concerned, commencing on the 49th day and gradually improving up to the time of publication. The photographs published of the patient also demonstrated that fact. This case was published in November, 1900, and was the first case of spino-facial anastomosis in which restoration of voluntary co-ordinated dissociated movements had taken place as the result of the operative procedure.

Although the case of FAURE and FURET was the first published, and at the time supposed to have been the first case in which such a procedure had been carried out, it was found subsequently to the publication of my case that FAURE had not been the first to perform spino-facial anastomosis, but that a similar procedure had been done previously, but left unpublished, and apparently not followed by very satisfactory results. Of these, the first so far discovered was a case published in 1903 by BRONISLAS SAWICKI (28), of Warsaw, as having been performed by T. DROBNIK in 1879, but not previously published. The entire account of it is as follows:—"Sujet homme. Paralysie faciale due à la suppuration du rocher. On réunit le bout périphérique du nerf facial avec le bout central de la branche externe du spinal. D'abord, résultat nul, mais après plusieurs mois on apprit que les traits du visage étaient devenus plus symétriques." BRONISLAS SAWICKI makes the following comment upon the case:—"Le résultat n'a pas été très satisfaisant."

The fact that in Poland no further attempt appears to have been made to repeat this operation till 1901, when W. SZTEYNER* did the operation, as described by FAURE and FURET, shows that the result of the operation of DROBNIK does not appear, if known to his countrymen, to have been considered sufficient to warrant its repetition in other cases.

The other case was performed by BALLANCE (29) in 1895, but was not successful

* After SAWICKI (28).

in restoring any dissociated movements of the face at the date of its publication, namely, 1903.

About the same time as my case was published, two experimental researches appeared, the one in Italy by BARRAGO-CIARELLA (22) and the other in Germany by MANASSE (21). Both of these researches had been suggested by the publication of FAURE and FURET, started, indeed, to ascertain in the case of animals whether that operation could possibly be followed by restoration of function when performed under the most favourable circumstances for recovery, namely, immediately after the lesion which produced the paralysis. In both of these researches the authors employed dogs, and sectioned the facial nerve close to the stylo-mastoid foramen, and turned down the peripheral end and attached it to another motor nerve. Thus the long interval between lesion and attempted repair, supposed to have been the cause of failure of the operation of FAURE and FURET, was eliminated.

In the work of BARRAGO-CIARELLA three dogs were experimented with, and in two of them the nerve employed to take the place of the facial was the spinal accessory, and in the third the pneumo-gastric, in every case an end to end junction being made, *i.e.*, the normal distributions of the spinal accessory and vagus were abandoned. As far as the restoration of function is concerned, these dogs showed a considerable amount of recovery. Thus in 120 days one of the spino-facial experiments showed voluntary movements of the upper eyelid, the two eyelids being observed moving synchronously, and the affected eyelid responding by semi-closure on irritating the cornea of the normal eye. About 180 days there was practically complete recovery of movements, and only some wasting of the face remained. In another experiment the result was similar, although somewhat later in appearing. A certain amount of recovery likewise followed when the vagus was employed, commencing to show about 180 days. The result, therefore, in these three experiments appears to have been very satisfactory, but there is, in the source from which I obtained the translation of this paper into French, no mention as to whether a physiological examination of the seat of junction of the nerves had been made, in order to find if any reunion of the central stump of the facial nerve had taken place with its own peripheral end. Great precautions appear to have been taken to prevent this, and were probably successful. Thus in two the central end of the facial nerve was subjected to the action of the Paquelin's cautery, and in all the muscles were stitched over the foramen stylo-mastoideum, but it would have been desirable to have had this point definitely stated, as any proved reunion of the facial would, of course, quite vitiate any conclusions to be drawn from the experiments.

MANASSE'S experiments were likewise in dogs. He had five of them, and in all the experiment was the same, namely, a spino-facial anastomosis, but differed from those of BARRAGO-CIARELLA in that it was an end to side junction, the peripheral end of the cut facial nerve being turned down and attached to the spinal accessory undamaged, except by four fine silk stitches made to grasp not more than a quarter

of the thickness of the spinal accessory. This method of making the reunion appears to me to be worthy of being noted, as it is probable, as will be discussed later, that it had an unfavourable influence on the results.

As regards the recoveries of the facial movements, all five experiments were disappointing, as in no case was there a recovery of voluntary co-ordinated movements to any appreciable degree. In two of them there were no traces of voluntary movements, although the dogs lived 417 and 255 days respectively, while, on the other hand, in three, living respectively to 396, 398, and 334 days, there were trivial voluntary movements, in one of which, where the recovery amounted merely to slight movement of the upper lip, there was found to be a reunion of the facial nerve at the physiological examination, thus vitiating the experiment. Of the other two the slight voluntary movements appeared in the one case at 88 days and in the other at 386 days. The reappearance of faradic irritability was more regular, appearing at the following dates in days from the time of operation, namely, 132, 105, 102, 135, 88. No corneal reflex could be found in three, two of these being two of the three cases in which trivial voluntary movements had been shown. In only one case were the corneal reflex (admittedly incomplete) and trivial voluntary movements present, and in that case the latter appeared at 88 days and the former at 201 days. The animal lived 334 days, and there was no reunion of the facial nerve discovered at the examination. No mention is made of any association movements being discovered. As regards the physiological examination of the five cases, only three showed that no reunion of the facial had taken place, so that the remaining two must be rejected as being vitiated experiments. The best result which he had to report from these experiments was the disappearance of the atrophy of the affected side of the face. Referring to the imperfect results, he thinks that in time the voluntary function would have returned.

With the exception of one of BARRAGO-CIARELLA'S dogs, in which he performed vago-facial anastomosis, all the examples of substitution for the facial nerve hitherto published, whether in man as an operative measure or in animals as an experiment, had been instances of spino-facial anastomosis. It has been mentioned in one of the quotations* that FURET'S original suggestion was that the hypoglossal should be used, but that this was abandoned in favour of the spinal accessory. The hypoglossal, however, was destined to be largely used, and indeed, with some, to become the favourite nerve for this purpose.

The first actually to put hypoglosso-facial anastomosis into practice was KÖRTE (24), who, on December 8, 1902, published it at a meeting of the Freie Vereinigung der Chirurgen Berlins. The operation had been performed on December 20, 1901, in the case of a patient 38 years of age, who suffered from middle ear sepsis. At the operation the nerve was divided, and he then performed immediately a hypoglosso-

* *Vide* p. 101.

facial anastomosis, the facial nerve being cut at the stylo-mastoid foramen and turned down to the hypoglossal, to which it appears to have been attached in the way prescribed by MANASSE, *i.e.*, without section or wounding of the hypoglossal except in so far as that was done with the needle punctures in suturing the two nerves together. As a result of the interference with the hypoglossal, although so slight, there was during the first week difficulty in swallowing ("geringe Schluckbeschwerden"), and the tongue on being protruded deviated to the side of operation.

Active movements first occurred in the muscles of the left angle of the mouth 181 days after the operation, and at $11\frac{1}{2}$ months slight voluntary movements were present, although the appearance of paralysis remained. The orbicularis palpebrarum could be contracted, and the angle of the mouth raised, while the reaction of degeneration had disappeared, and the faradic irritability reappeared. There were distinct association movements between the tongue and the face, showing that some union between the two nerves had certainly been established. KÖRTE was subsequently of the opinion that the spinal accessory was preferable to the hypoglossus for this purpose.*

In May, 1903, HARVEY CUSHING (26) published a case in which the facial nerve had been destroyed in a gunshot wound. Six weeks later he performed spino-facial anastomosis, and in this case attached the whole of the central end of the divided spinal accessory to the entire peripheral segment of the facial, which he cut at a point corresponding to the stylo-mastoid foramen. The result of this operation was good. The first apparently genuine return of voluntary function occurred at 81 days, when the face was symmetrical in repose, and the orbicularis palpebrarum showed "considerable voluntary motion." Gradual progress was made, and at 287 days, the last report, it is stated that "volitional control of individual groups of muscles has returned and can be effected without association shoulder movements or contractions in the other facial muscles. Emotional expression, however, has not improved in corresponding degree, and as yet it is associated with considerable asymmetry." The associated movements were noticed by the patient himself on the 112th day, and these appear to have been very similar to the association movements discovered in my case. CUSHING says, "A violent elevation of the shoulder which would normally call the trapezius into play still contracts the entire facial group of muscles," but adds, "motions of less vigour, however, are possible without producing any accompanying contractions of the muscles of expression."

In my case, when published, I stated that the involuntary facial contractions were produced in the face when "movements are suddenly made of the upper part of the trapezius," but that "these contractions are, however, only evoked at the moment of raising the arm, and speedily pass off, although the arm is kept held up."† It is noteworthy that the association movement in CUSHING'S case occurred very similarly

* *Vide* 'Zentralbl. f. Chirurg.,' 1903, Beilage z. No. 36, p. 47.

† *Loc. cit.*, p. 155.

to those in my case, although in the former the entire spinal accessory was devoted to the face, its peripheral distribution being abandoned, while in the latter the peripheral distribution of the spinal accessory was preserved, the facial nerve being made merely a branch of the spinal accessory. CUSHING'S paper is admirably illustrated, and the description of the case is very much fuller and more precise than are those in many of the papers on this subject, and must therefore have given a very great impetus to this operation.

Other papers appearing from 1903 till 1905 include those of the BALLANCES and PURVES STEWART (29), MORESTIN,* FAURE (34) (a second case), KERN,* SZTEYNER,† HACKENBRUCH (30), GLUCK (41), FRAZIER and SPILLER (32), and NICOLL (33).

The BALLANCES and PURVES STEWART published no fewer than seven cases, five resulting from mastoid sepsis, the onset of the paralysis either preceding or following the operation. In six of the cases they did spino-facial anastomosis, and in the remaining one hypoglosso-facial anastomosis. The method recommended was practically that of MANASSE, and was therefore end to side, a small longitudinal slit being made in the spinal accessory or hypoglossal and a corresponding slit in the end of the divided facial, and four silk sutures were used to fix the parts in place. As far as their results went they do not appear to have obtained any dissociated voluntary movements, the face being moved merely as a result of endeavouring to raise the shoulder. In the first case operated on by C. A. BALLANCE in 1895 therefore no less than eight years had elapsed without any further development than that. In their case of hypoglosso-facial anastomosis, operated on on January 9, 1903, the case was published too soon for any result to have been possible. The intervals which had elapsed between the onset of the paralysis and the operative intervention in their cases were, stated in months, 6, 8, 6, $4\frac{1}{2}$, 35, 6, and 12.

The cases of FRAZIER and SPILLER and of NICOLL were hypoglosso-facial anastomosis, the latter undertaken for facial spasm, and both were published too early for a result to have had time to be attained.

The cases of MORESTIN, FAURE (2nd case), KERN, SZTEYNER, HACKENBRUCH, and GLUCK were spino-facial anastomosis. Of these FAURE'S, MORESTIN'S, and SZTEYNER'S consisted of suture of the peripheral segment of the facial to the central segment of the divided branch to the trapezius. In KERN'S case the central segment of the branch to the sterno-mastoid muscle was substituted. GLUCK followed MANASSE'S method, and HACKENBRUCH adopted a principle, new as far as the facial is concerned, of splitting the facial nerve longitudinally, allowing it to remain in its normal position, and turning up a flap consisting of two-thirds of the spinal accessory left attached centrally, and fitting the peripheral end of this flap into the slit between the fibres of the facial. In this way any reunion of the facial nerve which had already occurred was left available for the recovery of the face. Other

* After DAVIDSON (50).

† After SAWICKI (28), p. 190.

noteworthy points in HACKENBRUCH'S case are that the operation was done $7\frac{3}{4}$ years after the commencement of the paralysis, and that $4\frac{1}{2}$ months after the operation improvement began, that at 7 months movements developed in the angle of the mouth, at first associated with the shoulder movements, this association subsequently disappearing, and that when the facial nerve was exposed at the operation and stimulated contractions occurred in the face.

With reference to HACKENBRUCH'S method of performing the anastomosis, it is right to mention that a similar procedure was first proposed by FAURE and FURET,* who suggested that, should there be any possibility of spontaneous regeneration of the facial, this should not be circumvented by an operation, but the branch to the trapezius should be turned up to the intact facial, the fibres of the latter teased out, and the central end of the branch to the trapezius inserted between the teased-out fibres.

The original case of FAURE and FURET has been reported upon subsequently, and as in 1898 the appearance of paralysis was said still to be evident: In 1901, according to BRÉAVOINE, there were no dissociated voluntary movements, but the facial muscles contracted when the scapula was raised voluntarily, and the muscles reacted to the faradic current.

Since the publication of the above-mentioned cases, in the past seven years many cases of spino-facial and hypoglosso-facial anastomosis have been published, and in the large majority of the cases a recovery of some degree has been recorded. Perfect recovery does not appear to have been attained, but there is no doubt of the recovery of dissociated voluntary co-ordinated movements to a greater or lesser extent, that depending on several different conditions. In the majority of the cases associated movements have been exhibited over and above these other voluntary movements, and in a few cases all that has been got by the operation has been these associated movements of comparatively little worth to the patient.

Many of the cases have been published much too early, *i.e.*, before it was possible, under the most favourable development, to have any result, and of these further details at a later date have been supplied in some, and in others not. It is unnecessary to quote all the cases in detail. Several very excellent monographs have appeared giving full lists of published cases to date, such as that of DAVIDSON (50) in 1907.

So far as our knowledge of this subject goes, there is a division of opinion on several points. Thus some favour the spinal accessory and some the hypoglossal. The vagus and also the glosso-pharyngeal have not many advocates. There is also a difference of opinion as to whether the substitute nerve should be completely divided and attached to the divided facial end to end, or whether an end to side should be done by attaching the peripheral segment of the divided facial to the substitute nerve, or whether the substitute nerve should be divided, and its central end turned

* BRÉAVOINE (23).

up and fitted into the facial whose continuity is to be retained. Likewise there is a difference as to whether the whole of the spinal accessory should be used, or merely one of its branches, and how these are to be applied to the facial—end to end or end to side. In addition there is also the method of making the junction between the two nerves, the extent of the lesion to be produced on the substitute nerve, the suture material, and the way the sutures are applied, also the question of how long after the onset of the paralysis a result may still be expected from such procedures, and how long one must wait for spontaneous recovery to declare itself before making the intervention.

Above all this is the complicating problem of how much of the recovery in any case is due to the substituted nerve, and how much to reunion of the two ends of the facial and therefore to restoration of the normal paths. In the case of an operation in the human subject it is impossible accurately to ascertain this; and in many of the cases this possibility is not at all an unlikely one. The only way to settle this in most cases would be to expose the parts and to stimulate at the stylo-mastoid foramen and see if any facial contractions occurred. Such is possible only in experimental work, and it follows that this source of error can be eliminated only in experimental work, not in practical surgery. That it is no mere remote possibility is shown by the fact that in two out of five of MANASSE'S experiments, as mentioned above, this reunion was shown actually to have occurred. Thus, in order to settle the actual value of anastomosis for restoring the lost movements in facial paralysis, it is necessary to have recourse to experiment in animals in which exact conditions may be instituted, and, after recovery, a test made to prove whether or not these exact conditions have remained good throughout the experiment.

It was to attempt to solve some of these problems that the present research was undertaken. For the purpose monkeys and dogs were employed, and in the following section a full account is given of each experiment.

2. THE AUTHOR'S EXPERIMENTS ON SUBSTITUTION FOR THE FACIAL NERVE.

(1) *Experiments on Monkeys.*

a. *Primary Anastomosis.*

α. Experiment 1, *Primary Spino-facial Anastomosis* (*end to side*) (Plate 6, fig. 1).

On July 12, 1909, at 10 A.M., a young male *Macacus rhesus*, having been anæsthetised, the right facial nerve was exposed and irritated by a weak faradic current, causing contractions of the entire one side of the face. It was divided as close as possible to the stylo-mastoid foramen, and the latter plugged with bone. The spinal accessory, having been exposed and tested by the electrode at the lower border of the digastric muscle, was cut through transversely all but one side of the perineurium. The peripheral segment of the facial nerve was then inserted into the

gap in the spinal accessory, and retained there by a horse-hair suture. The wound was completely closed and sealed by celloidin.

On recovery from the anæsthetic, examination showed a complete right facial paralysis presenting the usual features—inability to close the eye, drooping angle of the mouth, etc. Subsequent examination from time to time revealed that the food which he lodged in the right cheek, as is customary with monkeys, had to be pushed into the mouth with his hand. On the opposite side the same was done by the power of the buccinator. Epiphora, or watering-eye, was also observed in the right eye. No defect could be detected attributable to the section of the spinal accessory.

The wound healed by first intention.

No improvement was recorded until September 8, the 58th day after the operation, although the animal was watched almost daily. It was then noticed that there was some power of closing the right palpebral fissure over and above the passive movements of the upper lid, which had been present from the first. No other facial movements could be induced. The making of sudden movements of the right arm gave no indication of association movements between the facial and the spinal accessory.

By 71 days the affected eye was beginning to show signs of contracture of the orbicularis.

By October 3 (83 days) there were no associated movements, but attacks of contraction of the right orbicularis came on from time to time. The left eye was winking independently of the right, and the right was winking on its own account quite independently of its fellow. There was over the entire right side of the face a distinct facial contraction, at times more noticeable than at other times.

By October 17 (97 days) there was power completely to close the eye, but not synchronously with the other eye. There was no epiphora. There was facial paresis about the mouth, made evident when the mouth was opened. The corneal reflex was tested. It did not act so quickly as on the left side, but it was quite distinct, and the palpebral fissure was completely closed, and remained closed for a little.

At 100 days after operation it was noticed that the eye was frequently closed synchronously with the left eye, and that when the monkey lay down both eyes could be completely closed.

On November 6 (117 days after), exciting the animal by striking him over the face with a straw caused him to fight with his arms uplifted, and during these sudden movements there appeared to be a spasmodic action in the right orbicularis palpebrarum, so as to semi-close the eye, but of a tonic character. This was probably due to association movement.

Physiological Examination.—On January 17, 1910 (189 days after), the animal was given chloroform, and while going under the corneal reflexes were tested. The right reflex was well marked, causing complete closure of the eye. The facial

nerves were then stimulated through the skin by the faradic current, and this caused powerful contractions of the whole of that side of the face innervated by the nerve under stimulation, and no apparent difference in the degree of contraction on the right and left side.

The seat of the anastomosis on the right side was then completely exposed, and the junction between spinal accessory and peripheral facial found. This was made easy by the discovery of the horse-hair suture. No connection with the central facial was found.

Stimulation of the exposed peripheral facial, either with faradic or continuous currents, gave vigorous contractions in the entire facial musculature of the right side, and no contractions of the opposite side of the face. The electrode was applied to the region of the stylo-mastoid foramen, and there were no contractions evoked in the face. The opposite facial was then exposed and stimulated, with the result that the contractions evoked were entirely limited to the left side of the face. The left facial was then cut. The wounds were closed and sealed with celloidin.

The result of this examination was that the left side of the face was paralysed, and control remained over the right side.

Post-mortem Examination.—On January 26, 1910, the animal died, and the *post-mortem* examination showed the peripheral segment of the facial attached to the spinal accessory at the lower border of the digastric muscle. There was no connection to be traced between the central end of the facial and the spino-facial junction, but the termination of the former could be seen swollen into a bulb, and projecting out of the stylo-mastoid foramen to the extent of about $\frac{1}{16}$ inch (Plate 6, fig. 1).

Examination of the trapezius and sterno-mastoid muscles showed them to be of apparently the same bulk on the two sides of the body.

β. Experiment 2, *Primary Hypoglosso-facial Anastomosis* (*end to side*) (Plate 6, fig. 2).

On October 9, 1909, at 10 A.M., a large male *Macacus rhesus* was anæsthetised with a mixture of chloroform and ether. The right facial nerve was cut close to the stylo-mastoid foramen after having been stimulated, showing contractions of the entire right musculature of the face. The hypoglossal nerve was exposed and stimulated, contractions of the tongue muscles being evoked. The hypoglossal was cut through transversely, except one side of the perineurium, at a position which allowed the peripheral end of the facial to be conveniently drawn to it without tension. Union was effected by a horse-hair suture. The stylo-mastoid foramen was plugged with a piece of bone.

At 5 P.M., on the same day, examination showed the right side of the face to be

paralysed, and when the animal was offered food it was seen that when he protruded his tongue there was marked deviation to the right side.

On October 10 the animal evidently suffered inconvenience owing to the paralysis of the tongue. In addition to the deviation when it was protruded, it was seen that during deglutition there was difficulty, and that during mastication the tongue rolled awkwardly in the mouth. He frequently took drinks when eating, as if to aid deglutition, and this had not been his custom previously.

By October 15 the wound was healed and the stitches were removed.

On October 17 epiphora was noticed. There was less difficulty with the tongue, deglutition and mastication apparently being easier. The corneal reflex was tested, and found on the right side to be absent as far as concerned the orbicularis, although retraction of the eyeball of course took place.

On November 10 (32 days after) there was now distinct voluntary closure of the eye, but incomplete.

By November 15 the power almost completely to close the eye was present.

Gradual further improvement took place, until the eye was undoubtedly being voluntarily closed completely. Winking, however, did not take place synchronously with the opposite eye. The progress was much the same as in the case of Experiment 1, but the spasmodic closure of the eye, which from time to time took place in that experiment, did not show itself in this case distinctly. After the first few days, feeding was not impeded by the condition of the tongue, and, on inducing movements of the tongue by giving food, it was impossible to discover any movements of the right eyelids which might suggest the presence of association movements. Up till the last the tongue continued to deviate to the right side on being protruded.

On January 16, 1910 (99 days after the operation), the animal died unexpectedly, and there was therefore no opportunity afforded for making a physiological examination.

Post-mortem Examination.—Dissection exposed the junction of the peripheral end of the cut facial joined to the hypoglossal by means of the horsehair stitch, which was found in position. The hypoglossal continued its course as normally, and its distal segment had a normal appearance, and practically the same thickness as the opposite hypoglossal. The descendens noni came off from the nerve just proximal to the point of section. The central end of the facial nerve was looked for at the stylo-mastoid foramen, but instead of it there was found projecting out of the foramen the bone plug originally inserted. It was firmly wedged here, and, on withdrawing it with some difficulty, there was no trace of a facial nerve to be seen, as the bone plug had occupied the entire lumen of the lower end of the aqueduct. There had been evidently no formation of a connection between this and the hypoglosso-facial junction, which was distant from the facial central end a considerable distance. The tongue did not present any atrophy.

b. Experiment 3.—*Secondary Spino-facial Anastomosis* (*end to end*).

On October 11, 1909, at 10.30 A.M., a small female *Macacus rhesus* was anæsthetised with a mixture of chloroform and ether. The right facial nerve was exposed and stimulated with the faradic current, thereby evoking powerful contractions on the right side of the face. It was then divided close to the stylo-mastoid foramen. The peripheral segment was ligatured close to the cut surface with a piece of horse-hair and stitched to the skin. The stylo-mastoid foramen was plugged with a piece of silver wire, thick enough to fill the entire lumen.

In the evening there was found to be complete right facial paralysis.

On October 17 examination of the corneal reflex showed no contractions of the orbicularis, but the eyeball retracted, as is usual. There was no epiphora.

On November 10 it was noted that at times there appeared to be a semi-closure of the eye, but careful inspection showed this to be different from closure produced by the orbicularis, being merely the usual passive movement.

On November 12 the animal was again anæsthetised, and the peripheral end of the facial dissected out. It did not present a wasted appearance, and on being stimulated by the faradic, and then by the galvanic, current showed no response. The peripheral segment had its end cut off, in order to open up the trunk, and it was then attached to the central end of the spinal accessory by a horse-hair suture. For this purpose the spinal accessory had been cut across at a suitable level, and the central segment turned up to meet the peripheral segment of the facial.

On November 24 (12th day) there was a semi-closure of the right eye on touching the cornea, and at times there was almost complete closure of the fissure, these movements of the lids being entirely passive.

On December 28 (46 days) the animal was closing the eye undoubtedly voluntarily, and sometimes there was spasmodic closure.

Physiological Examination.—On January 16, 1910 (65 days after the anastomosis), the animal was not looking well, and it was therefore decided to examine her condition. She was therefore anæsthetised at 3 P.M. The seat of junction was exposed, and this was evidenced by the encapsuled horse-hair suture. The junction appeared to be good. Stimulation by the galvanic current was applied, the result being distinct and strong contractions of the right side of the face, closure of the right eye, and movements of the right auricle. These results were shown when the electrodes were applied either to the distal facial segment or to the central segment of the spinal accessory, but no reunion of the spinal accessory was found. The faradic current was similarly applied, and also gave good responses. When the electrodes were brought into the position of the stylo-mastoid foramen no responses were obtained.

While under the anæsthetic the corneal reflex of the right eye was investigated, and it was found that, on touching the cornea, the orbicularis gave a good contraction,

causing immediate closure of the palpebral fissure. It was also observed that there was a tendency to contracture of the orbicularis, causing the right palpebral fissure to be somewhat smaller than the left. The same tendency to contracture was seen also over the other facial muscles on the right side.

The opposite facial was stimulated, and this produced contractions of the left side of the face, but not of the right side. It was cut. The wounds were closed and sealed with celloidin, but the animal died a few hours later.

Post-mortem Examination.—The *post-mortem* examination showed the central segment of the entire spinal accessory united to the peripheral segment of the facial, the horse-hair suture being in position. There was no evident connection between the central and peripheral segments of the spinal accessory. The stylo-mastoid foramen showed a slight amount of cicatricial tissue projecting from it for a short distance, but this could not be traced onwards to any great extent. The silver plug had disappeared from the foramen. The right sterno-mastoid appeared reduced in bulk when compared with the left.

(2) *Experiments on Dogs.*

a. *Primary Anastomosis.*

α. Experiment 4.—*Primary Spino-facial Anastomosis* (*end to side*) (Plate 6, fig. 3).

On October 7, 1909, at 10 A.M., a young fox-terrier dog was given 0·18 grm. morphia sulphate, followed by chloroform and ether inhalation. The right facial nerve was exposed and divided close to the stylo-mastoid foramen, having been first tested with the electrode, and was then anastomosed to the spinal accessory just at the lower border of the digastric, the spinal accessory having been wholly divided, and the three ends, *i.e.*, proximal spinal accessory and distal ends of spinal accessory and facial, were joined together by a horse-hair suture. The stylo-mastoid foramen was plugged with a bone plug. The spinal accessory also, before being divided, was proved by stimulation with the faradic current. Examination after the operation showed complete right-sided facial paralysis.

The wound healed *per primam.*

On November 19 (43 days after) there was no improvement apparent in the facial paralysis, and on this day the dog was tested by the electrode placed over the spino-facial junction. With a faradic current no facial contractions could be produced, although a much weaker current than that used produced good contractions on the left side of the face when the left facial was stimulated through the skin.

On December 6 (60 days) there were still no voluntary contractions. The galvanic current applied through the skin produced contractions throughout the right side of the face, when the electrode was applied over the spino-facial junction, and also the muscles contracted when directly stimulated through the skin. No contractions were obtained by the faradic current.

On January 20, 1910 (105 days), the examination proved that there was distinct voluntary control of the eyelids, the eye being voluntarily closed, and also closing on touching the cornea.

Physiological Examination.—On January 22, 1910 (107 days), the dog was given morphia sulphate 0·2 grm., followed by chloroform and ether. Faradic stimulation of the nerve trunks was first practised through the skin. When on the left side there were vigorous contractions of the left side of the face and none of the right side; when on the right side there were vigorous contractions of the right side of the face and none of the left, and there were also movements of the right shoulder.

The junction was then exposed, and the electrode applied to the stylo-mastoid foramen without producing any facial contractions. When the spinal accessory was stimulated above the junction there were contractions of the face (very vigorous, causing complete and tight closure of the eye) and movements of the shoulder.

When the distal part of the spinal accessory was stimulated there were contractions of the trapezius and sterno-mastoid only. There were no contractions produced on the right side of the face on stimulating the left facial. The left facial was cut.

On January 31, 1910 (9 days after the examination, 116 after the anastomosis), there was left facial paralysis. The wound was healed. The right eye retained its voluntary power of being closed almost completely, and the orbicularis contracted and closed the eye on irritation of the cornea. There was food lodging between the left gum and cheek, but not so on the right side.

On March 14, 1910, a photograph was taken to show almost complete power to close the right eye (Plate 6, fig. 3).

Final Physiological Examination.—On April 24, 1910, at 11 A.M. the animal was given 0·2 grm. morphia sulphate, followed by chloroform and ether, but the dog died unexpectedly. The seat of suture was at once laid open, and with the faradic current the spino-facial junction was stimulated, causing vigorous contractions of the entire musculature of the right side of the face, the eye being tightly closed. There were also contractions of the trapezius and of the sterno-mastoid. The electrode applied to the stylo-mastoid foramen gave no contractions of the face.

Post-mortem Examination.—The junction between facial and spinal accessory was well formed, and the latter had its continuity restored. The central end of the facial was seen projecting out from the foramen, giving place immediately to a few scar-like strands which were lost in the surroundings.

The trapezius and sterno-mastoid appeared to be as well developed on the one as on the other side.

β. Experiment 5.—*Primary Spino-facial Anastomosis (end to end).*

On October 22, 1909, at 10 A.M. a young Schipperke dog was anæsthetised with 0·05 grm. morphia sulphate and chloroform and ether. The right facial nerve was

divided close to the stylo-mastoid foramen, first having been tested with the faradic current. The stylo-mastoid foramen was plugged with silver, and the peripheral segment of the facial was transfixed with horse-hair. The spinal accessory was defined at the lower border of the digastric muscle, and divided sufficiently low down to give a length of proximal nerve to turn up and join the facial. The junction was effected by the horse-hair suture already passed through the facial. The wound was sealed with celloidin.

Immediately after recovery from anæsthesia it was seen that the right side of the face was completely paralysed. The wound healed by first intention.

On December 8 there appeared to be no improvement, and stimulation with the galvanic current applied through the nerve caused no response in the muscles.

On January 20, 1910 (90 days after), distinct contractions in the orbicularis and partial closure of the eye on irritating the cornea were found.

By January 31 irritation of the right cornea caused a partial reflex closure of the eye and complete winking on the left. Irritation by touching the left cornea caused closure of the left eye and no contraction of the right orbicularis.

On February 12 (113 days) there was found still to be food collecting between cheek and gums. There was almost complete closure of the eye on touching the cornea and also voluntarily.

Physiological Examination.—On February 25 (126 days) the facial nerve was exposed and stimulated with a weak faradic current, causing strong contractions of all parts of the musculature of the right side of the face. The electrode was applied to the stylo-mastoid foramen without giving any facial contractions. The left facial was exposed, stimulated, and the resulting contractions found to be limited to the left side.

The dog died on March 3.

Post-mortem Examination.—The condition of the central end of the facial nerve was examined at the stylo-mastoid foramen, and it was found that there was no appearance of a nerve trunk, but merely some scar-like tissue at the foramen. The junction of the peripheral end of the facial to the spinal accessory was marked by the horse-hair suture, and the peripheral trunk was of normal appearance, and its subdivisions in the parotid were also of normal appearance. The distal segment of the spinal accessory was found, and was seen to be joined by a large branch from the second cervical, which apparently contributed largely to the supply of the muscles. The sternal part of the sterno-mastoid was of good colour, and only a little less bulky than the opposite corresponding part. The cervical and clavicular parts of the muscle were reduced to a thin pale sheet as contrasted with the well-developed parts of the muscle of the opposite side. The trapezius superior was pale and very thin when contrasted with the left muscle, but the trapezius inferior was comparatively well developed (Plate 6, figs. 5 and 6).

γ. Experiment 6, *Primary Hypoglosso-facial Anastomosis* (*end to side*) (Plate 6, fig. 4).

On October 3, 1909, at 11.30 A.M., a young fox-terrier dog, after having had 0·2 grm. morphia sulphate, was anæsthetised with chloroform and ether. The facial nerve was exposed and irritated with the faradic current, giving normal contractions limited to the right side of the face. The hypoglossal was then exposed at the lower margin of the digastric and irritated likewise, producing contractions of the tongue. The facial was divided close to the stylo-mastoid foramen, and the latter plugged with a piece of bone. The hypoglossal was cut across, except the one side of the perineurium, and the distal segment of the facial sutured into the gap with horse-hair. The wound was closed and sealed with celloidin.

Examined in the evening the face showed right paralysis. The eye could not be closed on the cornea being irritated, but the eyeball was rolled upwards and outwards, and the nictitating membrane drawn across.

October 4. It was noticed that the tongue when protruded projected to the right side. When the animal lapped milk the tongue was seen projecting to the right, and when he ceased and raised his head milk ran out at the right side of the mouth.

On October 10 the face was as before, but there was not so much trouble with the tongue in feeding, although it still projected to the right on being protruded.

On October 15 there was no alteration. The corneal reflex was tested, but there was no contraction of the orbicularis. The wound was healed by first intention.

On November 17 (45 days after) there was a distinct power of contraction of the orbicularis palpebrarum. This was produced when the cornea was touched, shutting of both eyes being thereby caused, but in the case of the affected side the palpebral fissure could not be completely shut. The tongue was still deviating to the right during lapping of liquids.

On November 19 (47 days after) the electrical irritability of the affected musculature was tested by applying a faradic current, one electrode being over the seat of the hypoglosso-facial junction, and the other on the forepaw. Contractions of the orbicularis palpebrarum and semi-closure of the eye resulted.

On January 20, 1910 (109 days after), voluntary control of the orbicularis was quite distinct, and the eye closed almost completely on stimulation of the cornea. Movements of the nose were also exhibited.

On January 31, 1910, it was noticed that when the left cornea was touched there was immediate closure of the left eye, but not of the right, but when the right cornea was touched there was semi-closure of the right eye, and complete closure of the left eye.

On February 12 (132 days after) there was very complete closure of the eye voluntarily, and food was not accumulating between cheek and gums. The dog was photographed on March 14.

On April 30, 1910 (209 days after), the examination showed that the tongue still on protrusion deviated to the side as formerly. When the right eye was touched the reflex showed imperfectly, the eye not becoming completely closed, and the nictitating

membrane being drawn across. When the irritation of the cornea was stopped and the animal watched, it was seen that there was complete closure repeatedly taking place. This was discovered to be associated with movements of the tongue and mouth. When being fed with pieces of biscuit held out to him these movements could be well studied, as then the movements of the mouth and tongue became very vigorous, and the movements of the right orbicularis kept time and sometimes held the eye completely closed in a spasm.

On May 25, 1910 (234 days after), the association movements between tongue and face were as distinct as previously. It was noticed that in lapping liquids the rapid movements of the tongue were always accompanied by rapid winking movements of the right eyelids, and in eating the same thing occurred. The tongue still deviated to the right when protruded.

Physiological Examination.—On May 29, 1910 (238 days after), at 11.45 A.M., the dog having been given 0·15 grm. morphia sulphate and anæsthetised with chloroform and ether, a physiological examination was made. Stimulation with the faradic current through the skin, one pole being over the hypoglosso-facial junction and the other on the right forepaw, evoked powerful contractions of the right side of the face involving every part. Next the distal segment of the facial nerve was exposed, doing as little damage to the surroundings as possible, and the electrode applied to it, producing a convulsion of the right facial musculature. The electrode was next applied to the region of the stylo-mastoid foramen, but no facial contractions resulted. The distal facial segment was then traced centralwards till the trunk of the hypoglossal was reached and the latter was followed centralwards till the descendens noni was found. Stimulation of the last-named branch produced the usual contractions in the muscles of the neck. When the electrode was applied to the trunk of the hypoglossal at the origin of the descendens noni, powerful contractions of the one side of the face and of one side of the tongue resulted. Stimulation of the hypoglossal beyond the junction gave no facial contractions, but merely contractions of the right side of the tongue. Stimulation of the junction gave contractions both of the face and of the tongue. The animal was then killed.

Post-mortem Examination.—Examination after death showed the junction between the seventh and twelfth nerves to be well formed and well isolated. The hypoglossal had maintained its continuity, and its distal segment appeared to be of normal bulk. The horse-hair marked the junction. At the stylo-mastoid foramen the central bulb could be seen pouting out, but there were no continuations able to be traced from it. The plug could not be found. The tongue showed no atrophy (Plate 7, fig. 7).

δ. Experiment 7, *Primary Hypoglosso-facial Anastomosis* (*end to end*).

On October 28, 1909, at 10 A.M., a young Irish terrier dog was anæsthetised with 0·1 grm. morphia sulphate and chloroform and ether. The right facial nerve was exposed, tested with the faradic current, divided close to the stylo-mastoid foramen, and

the latter plugged with silver. The hypoglossal was exposed next, and on stimulation with a weak faradic current retraction of the tongue resulted by contraction of the muscles of the right side, or protrusion of the tongue, varying according to the point on the circumference of the nerve trunk with which the electrode made contact, *i.e.*, when touched at one point retraction occurred, and at another point protrusion took place. The hypoglossal was then completely divided and the central end turned up and sutured with horse-hair to the peripheral end of the facial. The wound was sutured and sealed with celloidin.

Examination on November 2 showed complete paralysis of the right eyelids. When the tongue was protruded it passed to the right side. The wound healed by first intention.

On December 8 (41 days after) examination with the galvanic current was made, but responses could not be obtained.

On January 20, 1910 (84 days after), it was noted that there was some evidence of contraction of the orbicularis palpebrarum.

On January 28 (92 days) there was improvement in the closure of the eye, there being voluntary power to close it, although not completely.

On January 31 (95 days) touching the right cornea caused the right eye to close to a narrow slit, and at the same time the left eye completely closed; but touching the left cornea, while causing immediate complete closure of the left eye, had no effect in the way of causing the right eye to be closed.

On February 12 (107 days) voluntary closure of the right eye was now very complete. The tongue when protruded was still markedly deviated to the right. Food was still lodging between the right cheek and gums. There was still no effect on the right orbicularis palpebrarum by stimulating the left cornea.

1*st Physiological Examination.*—On February 27 (122 days after) morphia sulphate, 0·15 grm., and chloroform and ether having been administered, the faradic current was applied through the skin over the right hypoglosso-facial junction, resulting in strong convulsions of the entire right musculature of the face. The same was produced on the left side by similar irritation of the left facial, and there were no contractions produced in the opposite side of the face.

The hypoglosso-facial junction was exposed and stimulated with the faradic current, producing strong contractions and contortions of the right side of the face throughout its extent. Proximal to the junction, *i.e.*, in the hypoglossal nerve, the same result was obtained, and no contractions whatever in the tongue. Stimulation on the stylo-mastoid foramen with the electrode was not productive of any muscular contraction. The wound was closed and sealed with celloidin.

On March 10 it was found that the examination had not disturbed noticeably the function of the composite nerve.

On March 15 (138 days) there was found to be no accumulation of food between cheek and gums on the affected side.

2nd Physiological Examination.—On April 27, 1910 (181 days after the anastomosis), the condition having remained similar, the examination under anæsthesia was repeated with similar findings, and the dog was then killed.

Post-mortem Examination.—The facial traced centralwards from the parotid passes to the central segment of the hypoglossal, little more than the horse-hair suture marking the transition. The central end of the facial was looked for in vain, as the foramen stylo-mastoideum still remained plugged with the silver wire, which was withdrawn with some difficulty. The peripheral end of the hypoglossal was found and traced backwards, became cicatricial, and tapered to a point which was soon lost. The thickness of the peripheral segment was somewhat reduced when compared with its fellow of the opposite side, namely, about two-thirds of the thickness. The muscles of the tongue and hyoid bone examined from below, namely, mylo-hyoid, genio-glossus, baseo-glossus, genio-hyoid, were markedly atrophied on the right side, and the muscles running in the right half of the tongue itself were so much wasted that the right half of the tongue was reduced to little more than two layers of mucous membrane (Plate 7, fig. 7).

b. *Secondary Anastomosis.*

a. Experiment 8, *Secondary Spino-facial Anastomosis* (*end to end, after one month*).

On October 10, 1909, at 11.30 A.M., a four months old collie dog was anæsthetised by 0·05 grm. morphia sulphate, followed by chloroform and ether. The right facial nerve was exposed and stimulated with the faradic current, the resulting contractions being limited to the right side of the face. It was cut close to the stylo-mastoid foramen, which was then plugged with silver. The distal segment was transfixed near the cut surface with a horse-hair suture, and the suture tied tightly round the entire thickness of the nerve trunk, so as to constrict all the nerve fibres. The cut surface of the nerve trunk was then sutured to the skin, the end projecting slightly through the wound. The wound was closed, and sealed with celloidin. Next day the right side of the face was found to be in complete paralysis.

The Secondary Anastomosis.—The paralysis remained unimproved, and on November 10, 1909, anæsthesia was induced by 0·05 grm. of morphia sulphate and chloroform and ether. The old scar was incised and the peripheral end of the facial found. The end was "freshened" by removing a slice, including all cicatricial tissue. The segment was then united by horse-hair to the turned-up central segment of the spinal accessory which was previously found, proved by stimulation, and divided at a suitable level. Stimulation of the peripheral segment of the facial nerve with the faradic and galvanic currents gave no response. The wound was closed and sealed, but on November 21 it was found that union had failed, and the wound was opened up.

On January 18 (69 days after secondary anastomosis) the dog died. It had not

recovered any power over the right side of the face, and it had not been in a satisfactory condition of health for some time.

Post-mortem Examination.—The spinal accessory was found well united to the distal end of the facial, and no connections between the central and peripheral ends of the facial could be dissected out.

β. Experiment 9, *Secondary Spino-facial Anastomosis* (*end to end*, *after* 100 *days*).

On December 3, 1909, a young retriever bitch having been anæsthetised with 0·2 grm. morphia sulphate and chloroform and ether, the right facial nerve was divided close to the stylo-mastoid foramen after having been tested. The foramen was plugged with silver. The distal segment of the facial was fixed to the skin by the horse-hair suture, which at the same time transfixed the nerve and was tied round the trunk near the cut surface so as to constrict the fibres. The wound was closed, but union failed, and it had to be opened up, but was quite healed in 17 days.

Typical right-sided facial paralysis was found as soon as recovery from anæsthesia took place, and no improvement had taken place at the date of the anastomosis.

The Secondary Anastomosis.—On March 13, 1910, there having been no suggestion of recovery from the paralysis, anæsthesia was induced by 0·15 grm. morphia sulphate, chloroform, and ether. The stylo-mastoid foramen and the distal segment of the facial nerve were stimulated with the faradic and galvanic currents, and there were no movements of the eyelids or other parts of the face produced, although there appeared to be some fibrillar muscular twitches about the eyelids and nose, but not causing movements of these parts. The distal segment of the facial presented normal bulk, and tapered centrally to a point ending in scar tissue. This was removed, exposing nerve tissue. The spinal accessory was exposed, stimulated, and divided at a convenient distance, and its central segment turned up and united to the peripheral of the facial by horse-hair. The wound was then closed. It did not heal *per primam.* It was almost healed in four weeks.

No indication was given of restoration till July 15, 1910 (124 days after the anastomosis), when distinct closure of the right eye was able to be performed on irritating the cornea.

On August 2, 1910 (142 days), the palpebral fissure could not yet be completely closed.

On August 27, 1910 (167 days), closure of the eye was now made completely on the cornea being irritated, and was also made when the opposite cornea was irritated.

On October 2, 1910 (203 days after the anastomosis), there was complete voluntary closure possible, and the reflex closure of the right eye took place on touching the left cornea. Food was not accumulating between cheek and gums.

Physiological Examination.—On October 2, after administering 0·2 grm. morphia sulphate and chloroform and ether, the seat of anastomosis was exposed. The peripheral end of the facial was found and stimulated with the faradic current,

causing strong contractions of the entire facial musculature of the right side only. The region of the stylo-mastoid foramen was stimulated and no muscular contractions resulted. The animal was then killed.

Post-mortem Examination.—The dissection showed the peripheral segment of the facial united to the central segment of the spinal accessory, the horse-hair suture still remaining in place in spite of the failure of primary union, and being encapsuled just as in the case where primary union had taken place. The facial central end was seen at the foramen, and there was anatomically no evidence of any connections between it and its own peripheral segment. There appeared to be no reunion of the spinal accessory.

γ. Experiment 10, *Secondary Hypoglosso-facial Anastomosis* (*end to end, after one month*).

On October 10, 1909, at 12.30 A.M., a five months old fox-terrier dog was anæsthetised with 0·08 grm. morphia sulphate, chloroform, and ether. The right facial nerve was divided close to the stylo-mastoid foramen after being electrically tested. The foramen was plugged with silver. The peripheral end of the nerve was constricted with horse-hair and fixed to the skin. The wound was closed and sealed. The face over the right side presented facial paralysis immediately after the operation. The wound healed by first intention.

By November 11, 1909, the face presented the same paralysis which was seen immediately after the operation, no improvement having taken place.

The Secondary Anastomosis.—On November 11, 1909 (one month after), the animal had 0·08 grm. morphia sulphate, and anæsthesia was induced with chloroform and ether. The old scar was incised and the peripheral end of the facial found. When the faradic or galvanic current was applied to the stylo-mastoid foramen, or to the peripheral end of the nerve, no contractions were produced. The hypoglossal nerve having then been exposed and stimulated, it was cut across at a convenient spot, the central end was turned up and united to the peripheral end of the facial, which previously had a slice cut from its end, so as to present a freshened surface for union. Horse-hair was used. The wound was closed, but failure of union took place, and the wound had to be opened up and healed by granulation.

On January 10 (60 days after the anastomosis) the first sign of returning function occurred. When the cornea was touched there were contractions of the orbicularis to a small but distinct extent, causing partial closure of the eye, and also the left eye closed completely at the same time, but when the left cornea was irritated the right orbicularis showed no sign.

On February 12, 1910 (93 days after the anastomosis), the recovery of the orbicularis was very complete. There was complete voluntary and reflex closure of the eye, and there was closure of the right eye when the left cornea was irritated. There was

no food left lying between the right cheek and gums. No associated movements could be ascertained.

Physiological Examination.—On February 26, 1910 (107 days after anastomosis), 0·1 grm. morphia sulphate, chloroform, and ether were given, and the seat of suture exposed. The facial was found ascending from the hypoglossal. A weak faradic current applied to the facial, *i.e.*, distal to the junction, caused strong facial contractions involving the entire right side of the face only, tightly closing the eye, drawing back the pinna, and contorting the nose and lip. Stimulation on the junction caused slight contractions on the right side of the tongue and the same strong facial contractions. The electrode was next applied to the stylo-mastoid foramen without producing any muscular contractions. Finally, the opposite facial was exposed and stimulated, but no contractions of the right side were thereby produced, the contractions being limited to its own side.

Post-mortem Examination.—At the *post-mortem* examination the silver plug was found in the tissues encapsuled, having been displaced from the stylo-mastoid foramen. The central segment of the hypoglossal was found well united to the peripheral segment of the facial, the horse-hair marking the junction. The peripheral segment of the hypoglossal traced centralwards led to shreds of tissue which passed backwards, and finally were lost, none of them being traceable to the hypoglosso-facial junction. The stylo-mastoid foramen showed the central facial forming a bulbous termination projecting about $\frac{1}{16}$ inch, and terminating in some cicatricial tissue. The right side of the tongue showed wasting to a considerable extent.

4. Comparison of Results of the Various Experiments.

The series of experiments is divided into two sets, in one of which the anastomosis was performed immediately after section of the facial, and in the other of which an interval of time was allowed to elapse between section of the facial and suture of its peripheral end to the substitute nerve. Of the former group there were six experiments and of the latter four. In all the primary anastomoses the wound healed by first intention, but in the secondary anastomoses failure of primary union occurred in three. These failures of primary union were probably due to the fact that the animals, after so much confinement as occurs before the second operation takes place, are not in so healthy a condition as when first brought to the laboratory. In this respect I have found monkeys more satisfactory than dogs, as I have never seen in a monkey failure of primary union.

(1) *Primary Anastomosis Experiments Compared.*

In the group of primary anastomoses there were two monkeys and four dogs.

a. *Monkeys.*

In one of the monkeys the spinal accessory was chosen, and in the other the

3. Tabular Statement of Experimental Results.

Number of experiment.	Animal.	Nerve employed.	Lateral implantation or end to end union.	Date of first voluntary or reflex restoration.	Degree of restoration attained, and date when.	Time allowed to live in days.	Condition of junction found at examination.	Association movements observed.	Course of wound.	Interval between section and anastomosis.
					A.—Primary Anastomosis.					
1	Monkey.	Spinal accessory.	End to side.	58 days = some voluntary closure of palpebral fissure.	About 100 days after = complete voluntary closure of eyes synchronously.	198	No reunion of central facial with peripheral end. Efficient junction.	Present only during violent movements of the muscles supplied by XI, as in fighting.	*Per primam.*	None.
2	Monkey.	Hypoglossal.	End to side.	32 days = some voluntary closure of palpebral fissure.	About 90 days after = complete voluntary closure of eye.	99	No anatomical evidence of reunion of the facial, but impossible, owing to tight plugging of foramen stylo-mastoideum. Efficient reunion of hypoglossal.	None.	*Per primam.*	None.
4	Dog.	Spinal accessory.	End to side.	105 days = some voluntary closure of eye. 60 days = galv. nerve conduction. 107 days = faradic nerve conduction.	About 116 days = voluntary and reflex closure of the eye, but not complete. Power of buccinator recovered.	199	No reunion of central facial. Junction efficient.	None.	*Per primam.*	None.
5	Dog.	Spinal accessory.	End to end.	90 days = reflex closure of eye.	In 113 days voluntary and reflex closure of eye almost complete. The buccinator not recovered power = food still collecting outside gums.	132	No reunion of central facial. Junction efficient.	None.	*Per primam.*	None.
6	Dog.	Hypoglossal.	End to side.	45 days = reflex closure. 47 days found faradic irritability.	132 days = complete closure of eye and recovery of buccinator.	238	No reunion of central facial. Efficient junction.	Very marked during vigorous tongue movements.	*Per primam.*	None.
7	Dog.	Hypoglossal.	End to end.	84 days = some closure of eye.	107 days = very complete closure of eye. Buccinator still defective, but this disappeared at 138 days.	181	No reunion of central facial. No reunion of hypoglossal. Efficient junction. Great atrophy of the half tongue.	None.	*Per primam.*	None.

B.—Secondary Anastomosis.

3	Monkey.	Spinal accessory.	End to end.	46 days = some closure of eye.	65 days = good reflex closure of eye.	65	No reunion of central facial. Efficient junction.	None.	*Per primam.*	One month.
8	Dog.	Spinal accessory.	End to end.	None.	None.	69	No reunion of the central facial anatomically found.	None.	Primary union failed.	One month.
9	Dog.	Spinal accessory.	End to end.	124 days = some voluntary closure of eye.	167 days = complete closure of the eye.	203	No reunion of central facial. Efficient junction.	None.	Primary union failed.	100 days.
10	Dog.	Hypoglossal.	End to end.	60 days = some closure of eye.	93 days = complete closure of eye.	107	No reunion of central facial. Efficient junction. Slight reunion of hypoglossal and atrophy of tongue less.	None.	Primary union failed.	One month.

hypoglossal. The conditions of anastomosis were also kept as nearly similar as possible, as in both the mode of union was the same, namely, an end to side union, the facial nerve being sectioned close to the stylo-mastoid foramen, and turned downwards over the digastric muscle, which was not cut. The spinal accessory or hypoglossal was cut through transversely, so that all the actual nerve fibres were sectioned, and the peripheral end of the facial attached to the two cut ends of the substitute nerve. Thus in these two experiments the facial distribution did not have the entire substitute nerve for its supply, but had to share it with the normal distribution of that nerve.

α. *First Sign of Recovery.*—The first indication which could be seen of improvement from the facial paralysis in these animals, which were watched from day to day, was the improvement in the orbicularis palpebrarum, which showed distinct voluntary or reflex and dissociated movements permitting partial closure of the eye in the spinal accessory case at 58 days and in the hypoglossal case at 32 days. As far as could be judged, the same amount of improvement occurred at these respective dates. It is not altogether simple to judge the exact moment when the movement comes back, as there is from the first a movement in the eyelids which is probably caused by relaxation of the levator palpebræ coupled with movement of the eyeball communicated to the lid. There was, however, about these mentioned dates a distinct difference in the previously observed movements, which was due to the return of voluntary power in the orbicularis. In both cases further improvement in this respect continued, the hypoglossal case being, perhaps, a little earlier in its manifestation than the other, and the muscular independent movement of the eyelids became quite marked.

β. *The Maximum Result.*—About ninety and a hundred days respectively from the commencement of the experiment the development appeared to be about as far advanced as it ever subsequently became. The eye then could in both experiments be completely closed. The animals on lying down could shut both eyes completely and keep them shut. This was frequently observed, as it is one of the habits of the monkey to lie down while another monkey picks over its skin. During this process the eyes are often kept shut, so that this was a favourable opportunity for observing the extent of the voluntary closure. The only differences detectable were as follows:—In the spinal accessory case occasional attacks of contraction of the face came on apart from any effort of the muscles of the normal spinal accessory distribution, while these were not so much exhibited in the hypoglossal case. On the other hand, the spinal accessory experiment at 100 days frequently showed the two eyes winking synchronously, but this was not observed in the other animal, the two eyes not winking synchronously.

γ. *Paralytic Effects of Anastomosis.*—Then as to the results of paralysing the spinal accessory and the hypoglossal, the effects in the former case were not noticeable, but in the latter case were very noticeable at first, and the monkey

suffered from difficulty of swallowing and was evidently uncomfortable, rolling his tongue about in the mouth evidently ill at ease, and protruding it deviated to the affected side.

δ. *Association Movements.*—As regards manifestations of association movements, these could be produced in the spinal accessory experiment by causing the animal to fight, the action of the trapezius inducing these spasms in the face. It is possible, also, that the greater amount of contraction of the face occasionally shown in that monkey while sitting apparently at rest was due to association movements caused by putting the trapezius into action, although that could not really be determined by observation. In the hypoglosso-facial anastomosis, on the other hand, no association movements could be made out.

ε. *Duration of Experiments.*—Although the animals were allowed to live respectively 198 and 99 days, no further development took place than that recorded. Restoration of eyelid movements and improved symmetry were therefore the chief improvements, and there did not appear to be any very marked difference as regards the development of the improvements in the facial paralysis in the two cases.

ζ. *Efficiency of Anastomosis.*—With reference to the question of the efficiency of the crossing or anastomosis and freedom from reunion with the central end of the facial, this was all that could be desired, as shown in the spinal accessory experiment by the physiological examination. In the hypoglosso-facial experiment, the animal having unfortunately died before this could be ascertained, it was necessary to judge merely from *post-mortem* evidence, but fortunately in this case that evidence was as conclusive as such evidence can be, as the bone plug which had been hammered into the stylo-mastoid foramen when the anastomosis was performed was found still in place, and, indeed, tightly wedged in so as to fill the whole lumen. Therefore there could not have been any reunion of the nerve.

The eyelid movements, finally able to close the eye completely, and the improved tone of the other facial muscles constituted the entire improvement in these experiments. Probably, had the animals lived longer, further improvement would have taken place, but the observations were brought to an end by the death of one of the animals.

b. *Dogs.*

Of the four dogs operated upon, two had spino-facial anastomosis performed and two hypoglosso-facial. Of the two former, one had the spinal accessory cut through and turned up and joined end to end with the peripheral segment of the divided facial, while in the other one the union was end to side, the peripheral segment of the divided facial being turned downwards and united to the spinal accessory, the latter being divided merely to permit of the formation of a junction, but the ends retained in place, so as to allow reunion of that nerve to occur. The same difference was made in the two experiments in hypoglosso-facial anastomosis—in the one, end to end, between

the central hypoglossal and peripheral facial, and in the other, end to side, the peripheral facial being stitched into the gap made by dividing the hypoglossal.

Thus there are two points here for comparison, on the one hand between a spino-facial and a hypoglosso-facial anastomosis, and on the other hand between an end to end and an end to side.

α. *Results in Spino-facial and Hypoglosso-facial Anastomoses compared.*—In the first place, to take the question of spinal accessory or hypoglossal. The first sign of returning voluntary or reflex power in the face was in 105 and 90 days respectively in the two spino-facial experiments, and in 84 and 45 days in the two hypoglosso-facial, or an average of 97 and 64 days respectively. In one of the spino-facial dogs the nerve was found to be regenerated, as shown by the fact that the galvanic current evoked contractions in the muscles when the electrode was placed over the spino-facial junction and the nerve stimulated through the skin, this being at 60 days, but there were no voluntary movements. Somewhat earlier, namely, 47 days, the hypoglosso-facial corresponding dog, *i.e.*, the end to side, was found to be regenerated and movements were evoked in the orbicularis by the faradic current applied at the junction and the nerve likewise stimulated through the skin. Two days before that examination the movements seen were judged to be voluntary or reflex, but the electrical reaction was not tested, but the evidence of the faradic current two days later confirmed the opinion that these contractions were really the first evidence of restoration of movements actually caused by regeneration.

It is thus seen that the hypoglossal gave an earlier start, which worked out considerably earlier, taking the average.

In the further progress the more complete recovery appears in some respects to have been attained in the hypoglosso-facial experiments. Thus, in both hypoglossal experiments, complete voluntary or reflex closure of the eye was attained at 132 and 107 days respectively, while in the spinal accessory cases that function was not so completely developed up to the end of the experiments; but, although not complete, the closure of the eye was very nearly complete, and the maximum degree of recovery was recorded at 116 and 113 days respectively. The average for comparison is 119 days in the hypoglossal and 114 in the spinal accessory experiments.

As regards the other defects in the facial musculature, all, as recorded, had recovered the efficiency of the buccinator completely except in one of the spino-facial experiments, namely, the end to end.

This test is, perhaps, not very reliable, as the food is frequently found absent in this situation in dogs in which the one side of the face is certainly totally paralysed.

β. *Results in End to Side and End to End compared.*—In the two spino-facial anastomoses one was by lateral implantation and one by end to end. The course of recovery which followed in the two kinds did not very materially differ, in the former commencing at 105 days and in the latter at 90 days. Approximately the same

degree of recovery was reached in the former at 116 days and in the latter at 113 days, and although the animals lived to 198 and 132 days respectively further improvement was not seen.

In the case of the hypoglosso-facial experiments also one was end to side and one end to end, and as regards recovery the former began at 45 days and attained the power of complete closure of the eye at 132 days, while the latter began later, namely, at 84 days, but made more rapid progress, as he was able to close the eye completely at 107 days. It is thus seen that, in dogs, of the four primary anastomoses the best results were got with the hypoglossal. Of the two experiments with that nerve, the end to end method produced the most rapid result, power to close the eye completely being attained earlier than with end to side, although recovery was slower to commence. The ultimate results were very similar in both hypoglossal experiments so far as concerns restoration of power to close the eye.

γ. *The Paralysis in the Distribution of the Substitute.*—In the dogs in which spino-facial anastomosis had been done it was difficult, indeed, to detect any defect in movements or attitude which could be attributed to the loss of function of the spinal accessory. In one or two it appeared after a time that very slight wasting could be detected over the region of the trapezius, but it was so slight that it could not be detected in most of the animals. In none could any other defect be found.

It was quite the contrary in the cases of hypoglosso-facial anastomosis, for in every one of these there was a marked paralysis of the one half of the tongue, and this produced the following features: On protruding the tongue during lapping of milk or in licking the lips the tongue was deviated to the side of the lesion. In addition there was marked interference with the power of swallowing, the animal spilling the milk out of the mouth in a way which must have been due entirely to the lesion in the hypoglossal, as it was never observed in those cases in which the spinal accessory was employed, and therefore was not due to the paralysis of the face. It must, however, be added that the distress during deglutition was a passing occurrence, disappearing entirely in a few days, apparently when the animal got accustomed to the alteration in the motion of the tongue, and this was not an indication of reunion of the hypoglossal, as it equally disappeared when, as in the end to end case, the entire hypoglossal had been devoted to the face and the tongue left to be permanently unsupplied on that side. It was otherwise with the deviation of the tongue to the side, as this remained until the nerve was regenerated and the muscles built up, and even then, as far as the observations went, the animals did not altogether get over the tendency for the tongue to deviate to the side of the lesion.

In addition to these defects in its movements the tongue was also found to undergo hemiatrophy. This, of course, was of gradual formation, and was arrested and repaired in the experiment in which the facial had been laterally implanted into the hypoglossal, but in that in which reunion was prevented marked atrophy of the tongue remained, and at the time of the death of the animal had become so extreme

that the tongue on the right side was reduced to little more than mucous membrane (Plate 7, fig. 7).

δ. *Association Movements.*—In the four dogs association movements were carefully watched for, and many attempts made to elicit them, but only in the case of one out of the four were they able to be found, and that was in the hypoglosso-facial anastomosis by lateral implantation. Nothing resembling association movements could be got when the spinal accessory had been used or where the entire hypoglossal had been devoted to the face. In the case in which they were observed they were most strikingly exhibited. Apparently every movement of the tongue of sufficient vigour produced a wink, but it could not be determined that the converse also applied. In order to demonstrate these movements it was necessary only to show the dog some food, when on commencing to lick his lips the eye on the affected side began to wink synchronously with the lingual movements, and also when the animal was given milk the vigorous movements of the tongue were accompanied by synchronous movements of the face.

ε. *Efficiency of the "Crossing."*—At the *post-mortem* examinations all four experiments were found efficient, it being proved that no reunion of the facial nerve had taken place.

c. *Comparison of Monkeys and Dogs.*—Comparing the various dates in the case of the experiments in monkeys and in those of dogs, it may be seen that, in a general way, they correspond. Thus, in both monkeys and dogs, the improvement commenced earlier when the hypoglossal was used. Complete voluntary and reflex closure of the eye was not possible before 90 and 100 days in the monkeys, and in one of the dogs this was attained in 107 days, and in the other in 132 days.

On the other hand, the comparative results, as far as concerns association movements, were contradictory. Thus, in the monkeys, none could be found in the hypoglosso-facial experiment during movements of the tongue, but in the spino-facial anastomosis they could be brought out by inducing the animal to make forcible shoulder movements. The contrary was found in the dogs, in so far that the only case showing these movements was the one of lateral implantation of the facial into the hypoglossal.

(2) *Secondary Anastomosis Experiments Compared.*

In this group were one monkey and three dogs.

a. *Monkey.*

In the monkey, the interval which was allowed to elapse from the time of section of the facial till the substitution was effected was one month, and the substitute employed was the spinal accessory, which was sectioned, and its central segment attached to the peripheral of the facial end to end, the distribution of the spinal accessory being thus left unsupplied. This animal lived only for 65 days after the secondary

anastomosis, and consequently was not available for development of the recovery so long as in the previous experiments, but at that time there was undoubted reflex closure of the eye by contraction of the orbicularis on irritating the cornea, and the animal was able to close the eye for a considerable time preceding the examination. It was somewhat difficult to determine in this animal the exact time when the reflex began, but there was undoubted ability partially to close the eye voluntarily at the 46th day.

From other points of view that experiment was satisfactory. Thus, no new paralytic effects were noticeable after section of the spinal accessory. No association movements developed, and the physiological examination showed that the facial had not reunited.

b. *Dogs.*

Three experiments on secondary anastomosis were made on dogs. The interval allowed to elapse between the production of the facial paralysis and the substitution for its recovery was in two one month, and in one 100 days. Of the two in which one month was allowed to elapse, one experiment was incomplete, showing no recovery at 69 days after the anastomosis, when the dog died. The other was more complete. In it the hypoglossal was used as the substitute, and was united end to end with the facial, the peripheral segment of the hypoglossal being left unattached.

The first sign of recovery was made out to be on the 60th day, when there were distinct contractions of the orbicularis on touching the cornea, and at 93 days there was very complete voluntary and reflex closure of the eye by orbicularis contractions.

There was distinct atrophy of one half of the tongue, which, however, was not so extreme as in a former case of the same type, and the explanation of this was found at the examination, as slight lingual contractions were produced on stimulating the central segment of the hypoglossal. Although these contractions were trivial, yet they showed that some reunion of the hypoglossal had occurred, and this resulted in a partial building up of the muscle substance in the tongue. The purity in other respects of this experiment was proved by the physiological examination, showing that there was no reunion of the facial. No association movements were discoverable.

In the experiment in which 100 days were allowed to elapse before performing the anastomosis the animal lived for 203 days after the anastomosis, and therefore long enough to give time for a very full recovery. In this case the central segment of the spinal accessory was united to the peripheral segment of the facial end to end, and there was no sign of recovery till 124 days, when distinct contractions of the orbicularis were produced on the cornea being irritated. At 167 days complete closure of the eye was made on irritating the cornea. There was no ascertainable defect as the result of sectioning the spinal accessory, and no association movements could be detected.

(3) *Primary Anastomosis Compared with Secondary Anastomosis.*

a. *Monkeys.*

On comparing the recovery in the case of secondary anastomosis in the monkey with those in which immediate substitution was performed, it is seen that there was no delay in the recovery as far as this experiment goes, as the result of waiting one month before making the anastomosis. The earliest reappearance of motor function was probably at 46 days as contrasted with 58 and 32 in the two primary experiments.

b. *Dogs.*

In the experiment where one month was allowed to elapse, it is seen on comparing the corresponding primary anastomosis experiments that the course of recovery is very similar. It began in the secondary anastomosis at 60 days, as compared with 45 and 84 days for the two primary hypoglossal anastomoses, and became fairly complete in 93 days as compared with 132 and 107 days. As far as this experiment goes, it would appear then that the interval of one month does not add to the length of time before the recovery begins after the substitution. This also confirms the observation in the monkey in which secondary anastomosis was performed.

In the dog in which 100 days elapsed the time was longer, namely, 124 days before the recovery was found to have commenced, and 167 days before complete closure of the eye was possible. This is much longer than in any of the experiments in which primary anastomosis or secondary anastomosis after one month was done, and suggests therefore that the longer interval was the cause of the delay. Unfortunately there is the complicating factor of the wound, which in this case did not heal *per primam*, which may have itself led to delay, but the same accident also happened in the dog which made so good a recovery in the time of a normal primary anastomosis, although a month had been allowed to elapse between the onset of the paralysis and the anastomosis being performed.

5. General Considerations.

(1) *Signs of Facial Paralysis in Monkey and Dog.*

In the case of the monkey the effects of cutting the facial nerve close to the stylo-mastoid foramen, in so far as they are visible, are as follows:—The entire cheek appears to droop, carrying downwards the angle of the mouth. The orbicularis palpebrarum no longer fulfils its function, and when the animal is observed to wink only the unaffected eye is closed, while the affected eye remains patent. On touching the cornea of the affected eye the lids come together somewhat, but exhibit no muscular contraction, and the eyeball is sometimes rolled upwards. The eyebrow is incapable of being elevated. On account of the paralysis of the orbicularis, epiphora, or overflowing of tears, is sometimes seen. There is on the

affected side absence of all active facial movements, those which are observed being merely passive due to traction by neighbouring muscles. Thus, when the animal makes grimaces the unaffected side pulls on the affected side, drawing it over towards the unaffected side and causing a very evident asymmetry. Food lodging between the cheek and gums is of course not a sign of paralysis in the monkey, in which animal this is a normal situation for the storage of food, which is then bit by bit squeezed in between the teeth, masticated, and swallowed. When the buccinator is paralysed the animals have been seen to help the food lodged here out of the cavity by applying the hand to the outside of the cheek.

In the dog the same lesion also is productive of complete one-sided facial paralysis, the visible features of which are as follow:—The most striking thing is the loss of voluntary or reflex contractions of the orbicularis palpebrarum. The animal is observed winking with the unaffected eye, while the affected one remains open. It is seen, however, that the nictitating membrane continues to perform its function, being swept over the cornea in a direction upwards and outwards. On touching the cornea great attempts are made by the animal to close the eye, and the lids appear to come towards each other to a certain extent, but without producing any puckering of the skin or other evidence of contractions of the orbicularis. When the unaffected eye is touched on the cornea the effect is instantaneous closure of the lids, the muscle showing its contractions by puckering the skin, but there is no evidence of this contraction in the movements of the lids which occur on the affected side under identical corneal irritation. At the same time that the lids fall slightly together, the nictitating membrane is strongly drawn across the eye and the eyeball is rotated upwards and is retracted as a whole. These passive movements of the eyelids, which are seen here as in the monkey, are also exhibited in man in facial paralysis. They have been formerly described by me (20), and the explanation of them given that they are probably due to relaxation of the levator palpebræ, coupled with movements of the eyeball communicated to the lids. Cushing (26) also gives a similar explanation. I believe them to be largely produced by the muscular retraction of the eyeball, which thus allows the palpebral fissure to become smaller, just as protrusion of the eyeball, as in exophthalmus, causes an enlarged palpebral fissure. These movements, thus, are no evidence of returning function, which, indeed, they may be mistaken for if a proper examination is not made of the animal immediately after the section of the nerve. They are really entirely passive. Epiphora is also observed in the dog, but it is not a constant sign.

This lack of movements of the eyelids is in the dog the best marked feature of facial paralysis, as all the others are liable to be difficult to detect. Thus the general appearance of the dog's face very often shows very little asymmetry, and, indeed, it is never well marked. At most an eversion of the lower lip may be seen near the angle of the mouth, but this depends on the breed of the dog, the normal degree of laxity about the face influencing this very much. Movements of the nares are

absent on the affected side, but are not easy to study. The ear also, in some animals, appears to be little altered in position by the section of the nerve, although, of course, its independent movements are not possible, but in other animals it falls back as if retracted. This again depends on the breed of the dog and how the ear is normally held. Then there is loss of power of the buccinator, which permits food to lodge between the cheek and the gums, but this test of facial paralysis is not very satisfactory, as in many animals affected with unrelieved facial paralysis, such as those awaiting a secondary anastomosis, no food can be found in this position at any time. Thus it is seen that in the case of the dog the most reliable thing to study in waiting for improvement of voluntary function is the orbicularis palpebrarum.

(2) *Signs of Recovery from Facial Paralysis in Monkey and Dog.*

In the case of the monkey recovery from facial paralysis begins by the reappearance of independent movements of the eylids and a disappearance of the drooping of the angle of the mouth. The recovery of the orbicularis palpebrarum must be very carefully judged, on account of the difficulty of discriminating between early independent movements of the eyelids and the passive movements which have all along been in evidence. In order to determine the matter, the animal must be taken to a good light, and irritation of the cornea applied by touching it gently with a straw, or something of the kind, and observing the movements resulting. This is best brought out when the animal is partially under the influence of chloroform, when all voluntary efforts are abolished, and merely the corneal reflex remains. The test then gives most reliable results.

As regards voluntary closure of the eye, this is best observed when the animal lies down to allow another monkey to pick over its skin, as is their habit. Then the eyes are frequently kept closed for a considerable time, and the capacity voluntarily to close the eye can then be judged. At first the affected eye does not close synchronously with the normal eye in winking, but it can be observed that the normal eye is winking, while the affected one is kept open. Then the affected one can be seen giving some winks independently of the other. A further advance in recovery is attained when synchronous winking becomes possible. Also in testing the degree of recovery it is useful to irritate one cornea and see if merely the corresponding orbicularis contracts, or whether both are thereby thrown into action.

Other parts of the face also show recovery. The most usual recovery, and one which occurs along with the recovery of the orbicularis, is that of the tone of the musculature in general, so that the appearance of facial paralysis becomes less striking. Likewise this is accentuated by the occasional appearance of a slight contracture affecting the formerly paralysed musculature.

I have not in my experiments observed recovery to proceed to perfection. The application of electrical testing to monkeys presents some difficulty, and is often

impossible unless the animal is under an anæsthetic. The ordinary methods of electrical investigation can then be applied.

In the case of dogs, the most important point in studying restoration of voluntary or reflex function is again the orbicularis palpebrarum. Previous to the recovery of the voluntary function, the muscles should be stimulated through the nerve, and this gives the indication when to expect recovery. When the galvanic current throws the muscles into contraction on applying it to the nerve near the seat of the anastomosis, this of course indicates resumption of conductivity in the peripheral segment of the facial, but at first voluntary function will not be possible. This comes later, and when present it will be found that the muscles can then be thrown into contraction by the faradic current applied to the motor point of the nerve. The converse, however, is not true. Thus faradic irritability of the nerve may be restored, and yet no voluntary function be apparent, even after long periods. Direct stimulation of the muscles by the galvanic current is useful in order to ascertain whether these are still giving responses in cases in which the nerve has not been reunited or anastomosed, and thus cause given for progressive destruction of the muscles. Return of *direct* faradic irritability will always be also accompanied by return of *indirect* faradic irritability through the nerve, but need not imply that the muscles which are thus thrown into contractions must also be able to be used in voluntary or reflex movements. In my experience the converse is not the case, as, if voluntary movements can be made, then the faradic irritability direct and indirect must always be present also. It is necessary to bear these characteristics in mind, as they explain many apparently anomalous results of nerve anastomosis performed after long periods of paralysis, and some of these points have been contradicted within recent years.

In the dog the most pronounced defect, namely, loss of ability to close the eye, is naturally the one which must be watched for indications of restoration, and it is as difficult here to detect early steps in the restoration as in the monkey. Naturally the way to study this is by causing gentle irritation of the cornea, and finding if the eyelids exhibit movements within themselves. This is sometimes determined by lifting the upper eyelid off from contact with the cornea and then applying the irritation. The contraction of the orbicularis then sometimes is distinctly seen when it would be otherwise difficult to be sure of its presence. The voluntary function may be brought out by approaching the hand suddenly to the dog's face, this at once causing winking in the normal eye, and ultimately in the affected one as recovery progresses. Blowing on the face was employed by MANASSE, and is a good means of causing facial movements. In order to ascertain if the animal is able to keep the eye shut for any length of time, this is best done by introducing into the eye an irritating material; which, if there is the power present, always is successful in causing that power to be exercised to the full. In this way photographs showing the recovery of power to close the eye may be secured (Plate 6, figs. 3 and 4).

As already mentioned, the buccinator is very unreliable as a test of recovery, as the accumulation of food outside the gums does not always take place where the muscle is completely paralysed. Other paralytic features also and the general paralytic appearance are not altogether constant.

(3) *Mode of Forming the Anastomosis.*

The exact mode by which the substitute is attached to the facial nerve has varied with different authors. In the first place, the two nerves may be cut across and the central segment of the substitute and the peripheral segment of the facial joined end to end by suture, the central end of the facial and the peripheral end of the substitute being left without any union. In the second place, the one nerve may have its continuity maintained, and the other nerve completely divided and one of its segments applied to the side of that nerve, this being an end to side junction.

In the first case, where an end to end union is formed, the mode of suture may be, firstly, by a single suture passed through the entire nerve trunk near the cut surface and tied, so as to bring the two ends gently into apposition, as practised in all my experiments in which end to end union was performed. Secondly, several sutures may be inserted round the nerve, grasping only the perineurium, as employed by CUSHING (26). Thirdly, as performed by BARRAGO-CIARELLA (22), following HUETER, the needle is made to enter the side of the nerve near the cut surface, traverse the substance nearly to the middle of the trunk, and then emerge at the cut surface to enter then the cut surface of the other nerve segment at its centre and emerge at the side of the segment near the cut surface. The same is done on the opposite side, and thus the two ends are fixed by two sutures.

It appears to me that the purely perineurial suture is difficult to apply, and will therefore cause so much manipulation of the nerve ends that more harm will be done than by a single suture traversing once the entire thickness of the nerve. Likewise, in dealing with nerves of such tenuity as those found in the monkey, it would be a very difficult if not impossible task to apply two or several stitches grasping merely a part of the nerve trunk. The defect in the method of a single transfixing suture is that if the nerve ends are transfixed too far off from the cut surfaces, and the suture tied too tightly, the result is that the ends are not brought into contact, but the two sides are brought into contact instead, and one half of the thickness of each constricted by the suture. The remedy is to have the suture transfixing the nerve at a not too great distance from the cut surface, and to tie the suture lightly.

As regards the other two ends of the two nerves concerned in an end to end anastomosis, namely, the central end of the facial and the peripheral end of the substitute, these are left ununited. As far as concerns the central end of the facial in an experiment such as those here recorded, this will be considered subsequently

(p. 147). The peripheral end of the substitute in this form of anastomosis must be left unjoined to its own central end, as the latter is wholly devoted to the facial. This is the defect of the end to end method, as it means that the distribution of the substitute nerve must become atrophied and useless, and it will be necessary to enquire fully how far this is going to inconvenience the individual on whom such a procedure may be contemplated for the relief of facial paralysis. Proposals for the obviation of this defect have been put forward, namely, to join the peripheral end of the substitute nerve to the central end of another neighbouring nerve of minor importance. It was also suggested, in the case of the hypoglossal, to insert the peripheral end of the hypoglossal into the opposite hypoglossal, but this, it must be remembered, would involve a temporary total paralysis of the tongue, and in the event of failure instead of a temporary paralysis there might be a permanent one. A more suitable nerve for that purpose would be the glosso-pharyngeal, or spinal accessory, if such a procedure become necessary.

In the case of end to side junctions one of two principles may be followed. That which has been followed in the great majority of published cases, and which has been followed in my end to side experiments, is to section the facial close to the stylo-mastoid foramen and turn the peripheral segment downwards till its cut edge comes into contact with the trunk of the chosen substitute, and by one or another method make junction, so that in this way the substitute becomes a nerve supplying not only its previous distribution, but also that of the facial nerve, and the facial nerve comes off from the trunk of the substitute like a branch.

The only advantage of this method over the end to end is that the distribution of the substitute is preserved from destruction, but it will be necessary to consider whether there are no associated disadvantages, and if so whether these are greater or less than the destruction of the distribution of the substitute.

Before going into these points it may be better to examine the different modes of making the end to side union. In my case published in 1900 (20), being the first published case of end to side union in man, the method employed was to cut across the entire trunk of the spinal accessory at a suitable level, with the exception of one side of the perineurium, the cut being therefore designed to sever all the nerve fibres in the trunk. The suture was passed through the peripheral end of the facial and through both central and peripheral ends of the spinal accessory and tied, so that all three ends were brought together in one suture. In these experiments I have always followed this method in performing end to side anastomosis. In working with such fine nerves as those of the monkey it facilitates matters, and saves much trauma, to pass the needle with the suture through the nerves before cutting them.

Manasse (21), in his five experiments published in 1900, did end to side anastomosis, and the method which he employed was totally different from that which I had employed. All Barrago-Ciarella's experiments had been end to end unions. Manasse's end to side method, as described by himself, is as follows:—

"Ich bin bei meinen Versuchen in der Weise vorgangen das ich nach Durchschneidung des N. facialis beim Austritte aus dem Foramen Stylomastoideum seine Aeste an den Stamm des N. accessorius ohne seitliche Anfrischung desselben mittelst paraneurotischer und neurotischer Nähte (gewöhnlich 4 feinste Seidennähte) anheftete. Dabei wurde der N. accessorius etwa in $\frac{1}{4}$ seiner Dicke durch die Nähte mitgefasst."* He objects to removal of substance by lateral freshening, as this removes nerve bundles, "die—nach der theoretischen Anschauung—zur erfolgreichen Vereinigung mit der Schnittfläche der Facialisäste nothwendig waren."

A number of those who published cases operated upon subsequent to the appearance of MANASSE'S paper copied his method of making the junction with but slight modification. Thus in all the cases published by the BALLANCES (29) in 1903, and in that by KÖRTE (24) in 1903, and in that by GLUCK (41) in 1905, and also others, this was the method followed. In the series of MANASSE, as already mentioned, the results, from the point of view of the restoration of voluntary movements, were most disappointing, and quite inferior to those of BARRAGO-CIARELLA. The same may be said of the cases published by the BALANCES, KÖRTE, and GLUCK. The first named write of their cases: "So far in our series of facio-accessory cases we have not observed any independent movement of the face, unassociated with that of the trapezius and sterno-mastoid, although in several cases a minimal innervation of the trapezius is sufficient to cause facial contractions."† Of seven cases published, six were operated upon subsequent to MANASSE'S work being published, and in three of these, cases in which the paralysis had existed only for 8, 6, and $4\frac{1}{2}$ months respectively, a considerable time had elapsed since the operation was performed when they were published, namely, 17, 14, and 14 months respectively, and that without any recovery of independent movements in the face. Also in KÖRTE'S case, in which an immediate anastomosis was done, the result appears to have commenced very late. Thus, at 111 days after the operation, there was "zum ersten Male Spuren von Rückkehr activer Beweglichkeit in den Muskeln des linken Mundwinkels." After four years the eye could not be closed, according to a report by BERNHARDT (46) in 1906.‡ Also in the case of GLUCK, although operated upon so late as five years after the onset of the paralysis, faradic irritability and association movements in the face were present one year after operation. In this case, reported at five years after the operation by BERNHARDT, the patient was not able to close the eye.

It would appear, then, that the results in these cases were most unsatisfactory from the clinical point of view. On the contrary, in the case published by me in 1900 a very complete voluntary and dissociated closure of the eyelids was restored. At that time it was reported,§ "Winking is perfectly efficient, ... she can shut

* MANNASSE, *loc. cit.*, p. 816.

† *Loc. cit.*, p. 1011.

‡ *Loc. cit.*, p. 486.

§ *Loc. cit.*, p. 155.

the eye completely, although not so tightly as in the case of the sound eye." In this case, however, the end to side anastomosis was effected by means of complete section of all the nerve fibres of the spinal accessory. A similar development was recorded in the case of CUSHING (26), and that being an end to end union, all the nerve fibres were there, of course, sectioned. In MANASSE'S method the only means of cutting nerve fibres in the spinal accessory is the passage of the sutures through the trunk of the nerve, which grasp, according to the directions, about a quarter of the nerve trunk, and, as four sutures are used, this represents four passages of the needle. Only a very few of the nerve fibres must be divided in this way, and, in consequence, there must be a most inefficient union established between the spinal accessory and the facial. Of the nerve fibres passing down the trunk of the spinal accessory, those which remain unwounded after the needles have been passed cannot participate in the junction which will be established with the facial, and it follows that the fewer fibres which are divided in the spinal accessory the fewer will be the number available to make junction with the peripheral segment of the facial, and consequently the anastomosis will be less efficient. On the other hand, the greater the number of fibres of the spinal accessory which are sectioned the greater will be the number which will be available for junction with the facial, and the greater the efficiency of the anastomosis. In this respect the most efficient anastomosis must be the end to end union, and of all methods of end to side union, that must be the most efficient in which complete section of all the nerve fibres of the spinal accessory occurs. These are the theoretical considerations on which complete section is founded, and, judging from the clinical results of anastomoses performed by MANASSE'S method, or modifications of the same, these theoretical considerations are confirmed by clinical evidence.

Other modifications of the anastomosis suture have been recommended. Thus LAFITE-DUPONT (49), who prefers the hypoglossal as the substitute, wishing to preserve the continuity of that nerve and its function from the very first, with the object of saving the paralysis of the tongue, splits the hypoglossal longitudinally, and having divided the facial close to the stylo-mastoid foramen passes two stitches through the peripheral segment of the facial, separates the two halves of the split hypoglossal, inserts the peripheral facial segment between them, and ties the two sutures round the one half of the hypoglossal nerve.

Another method, which takes into consideration the central segment of the facial, was suggested by FAURE* for the branch to the trapezius, and has been put into practice, first by HACKENBRUCH (30), and subsequently by PETERSEN and by VÖLKER in their cases reported by DAVIDSON (50). This is a principle which would not be admissible in experimental work, but is a valuable one in surgery, and consists in leaving the facial nerve in a position to benefit from any present or future connection with its own central end. Commencing near the entrance of the spinal accessory into the sterno-mastoid, that nerve was half cut through, and split upwards

* After BRÉAVOINE (23).

sufficiently to allow the liberated half to be turned upwards still attached by its central end to the spinal accessory. It was brought up to the facial nerve, and inserted into a slit made in the facial longitudinally, where it was fixed by three catgut stitches. For reasons already stated, I should suggest that, if this principle is adopted, the entire nerve-fibres of the facial ought to be sectioned, and the graft from the spinal accessory fixed in one junction with the two ends of the facial, in order that an efficient junction should take place. It is true that in a case in which partial recovery of the facial had taken place already, this would bring about a return of the total paralysis, to avoid which was doubtless the object which PETERSEN and VÖLKER had in view in preserving the integrity of the facial nerve-fibres, but I submit that it is only by going back to the state of paralysis by complete section of the nerve that an efficient anastomosis can be hoped for. Modifications of this method might be suggested, such as turning up flaps from both spinal accessory and hypoglossal.

(4) *Material Used for Sutures.*

As regards the material used for making the sutural junction, some of the authors have employed silk and some chromicised catgut, etc. I found some difficulty, while dealing with nerves of monkeys, to get a catgut sufficiently fine to pass through a nerve such as the spinal accessory without producing much damage, which is apt to destroy the result. I therefore made use of horse-hair for suture, and have since been satisfied with this material for nerve suture, and have even employed it in the human subject. Its great advantages are that it is easily sterilised by boiling in water; that it is thin and smooth, consequently passing through the nerve with least damage to the latter; and, important from the experimental point of view, that it is not absorbable. The last-named character is of great benefit, for when the physiological examination is being made the presence of the horse-hair at once discloses the seat of anastomosis, and this facilitates re-exposure of the nerve for examination. It is always found encapsuled in the position in which it was left.

(5) *Association Movements.*

These, which I first described as being present in addition to the independent movements of the face, were brought out in my case only during violent innervation of the spinal accessory. It might have been thought that these movements were the result of maintaining the peripheral segment of the substitute nerve in continuity with its own central segment, but in the case which was published by CUSHING (26) in 1903, the peripheral segment of the spinal accessory was abandoned, union being an end to end one, and yet, despite this fact of retaining the entire spinal accessory for the face, the association movements were certainly quite as pronounced as in the case published by me.

The cases of anastomosis which have been published from time to time show great

variation in these association movements. Thus some have had these alone developed, and practically no independent movement of the face (KÖRTE, BALLANCE, GLUCK). In others they have been present in addition to the independent movements of the face, and discovered only when looked for, and never causing the individual any inconvenience from their presence, while in others they appear to have been absent altogether (*vide* Addendum, p. 153). In the series of experiments detailed here they have certainly not been in evidence except in two cases.

(6) *Choice of a Substitute Nerve.*

There are several conditions which a nerve which it is proposed to substitute for the facial must fulfil before it can be used for this purpose, and several other features which must be taken into consideration. The chief of these are as follow :—

(a) *Proximity to the Facial.*—The nerve must lie sufficiently close to the facial to be easily attached to it, or to permit the cut facial to be easily united to it. The nerves which lie sufficiently close to the facial and which might be selected for anastomosis are the spinal accessory, the hypoglossal, the glosso-pharyngeal, and the pneumo-gastric, all of them cranial nerves. There are also some branches of cervical nerves which might be useful to anastomose to the peripheral segment of the substitute nerve in the event of an end to end being the form of anastomosis effected, leaving the substitute's peripheral segment unattached.

The pneumo-gastric was first used by BARRAGO-CIARELLA (22) in one of his experiments on dogs. The glosso-pharyngeal was stated by BALLANCE (29) to have been first suggested by SCHAEFER. The spinal accessory was first used by DROBNICK, according to SAWICKI (28), and first published by FAURE (17). The hypoglossal was first used by KÖRTE (24), although first suggested by FURET, according to FAURE, quoted by BRÉAVOINE (23).*

From the anatomical point of view it is possible to make use of any of these, but the most easily accessible are the spinal accessory and the hypoglossal.

(b) *Nature of the End-organs normally Innervated by the Substitute.*—The end-organs which the substitute normally innervates should correspond to the end-organs of the facial as nearly as possible. In so far as correspondence of the end-organs of two nerves which have been "crossed" is concerned, this has been a matter which has been subjected to investigation long since. Even FLOURENS (2), who was the first to investigate cross union of nerves, came to the conclusion that if there is not a sufficient correspondence in the nature of the peripheral organs supplied by the two crossed nerves recovery of function after the crossing does not take place. Thus he joined in two animals the central segment of the fifth cervical nerve with the peripheral segment of the cut vagus without finding any ultimate recovery of function in the distribution of the pneumo-gastric. BIDDER (3) and GLUGE and

* *Loc. cit.*, p. 9.

THIERNESSE (4, 6) experimented by crossing the lingual and hypoglossal nerves, but found no recovery of function as a result of this union, and concluded that a functional reunion between sensory and motor nerves was unlikely.

On theoretical grounds, as well as on the results of experiment, the nerve chosen as a substitute for the facial should be one supplying, like the facial, voluntary muscle, and this alone if possible. In the case of the pneumo-gastric the peripheral organs differ largely from those of the facial, and in the case of the glosso-pharyngeal part of the fibres conveyed are taste fibres for the posterior part of the tongue and other sensory afferent fibres. On the other hand the spinal accessory and the hypoglossal are nerves concerned almost entirely with the supply of voluntary muscles, and in this respect resemble the facial nerve more than any other within the requisite distance of the facial.

(c) *Relation between the Central Representation of the Substitute and that of the Facial.*—It is perhaps desirable on theoretical grounds that the central representation of the nerve should lie in as close proximity to the central representation of the facial as possible. It is known that the central representation of the hypoglossal is more closely placed to that of the facial than is that of the spinal accessory. As regards the cortical representations on the præcentral gyrus of the tongue and of the muscles moving the shoulder and neck and of the face, the last named is situated in somewhat closer proximity to the tongue representation. Likewise the nuclear origin of the spinal accessory is further removed from that of the facial than is that of the hypoglossal. Also it is well known that there is an association between the nuclei of the seventh and twelfth nerves in so far that when the facial paralysis is of central origin the brow muscles and the orbicularis oris escape, being really innervated by the nucleus of the twelfth. It has been held, therefore, on theoretical grounds, that the hypoglossal is preferable to the spinal accessory, as in the first place the association paths between the cortical representations of the facial and hypoglossal nerves would be shorter than those between the facial and spinal accessory representations, and in the second place because these two nerves have a normal association so great that some of the nerve fibres passing to the one are derived from the nucleus of the other.

As regards the association paths connecting the two cortical representations, namely, of the facial nerve and of the substitute nerve, I do not think that these are necessarily of great importance. After union of the peripheral segment of the facial nerve to the central segment of, say, the hypoglossal, and recovery of function of the face and loss of function of the one half of the tongue, the recovery might be said to be due to one of two new conditions in the cortex. First, the facial area might continue to function, would originate impulses there, and these, passing by association paths to the cortical area of the hypoglossal, would originate impulses there which would descend to the hypoglossal nucleus, and thence by the central segment of the hypoglossal, and from that to the peripheral segment of the facial, and thus reach the

facial muscles. Second, the facial area would not be restored to activity, but would remain quiescent as before the anastomosis was performed, and the hypoglossal area would take up the function which formerly was performed by the facial area, impulses started in it reaching the face instead of the tongue. Then, of course, there is the question of the afferent impulses from the muscles of the face, and how they come into relationship with the substitute's cortical representation so as to start there the impulses for facial movements.

The same thing would apply when an end to side junction was made with the hypoglossal, except that the hypoglossal area would send impulses both to the face and to the tongue along separate paths, running together in the central hypoglossal segment and parting at the junction. But in any case association paths must be called into function in the restoration which results from anastomosis, for the hypoglossal area is not in a position to originate impulses to be discharged to the facial muscles so as to cause co-ordinated movements, until it has received afferent impulses, and as these may ascend through paths other than those normal for the hypoglossal, namely, along the fifth, there must be a development in that case of association paths to the hypoglossal area to conduct these to the new area, so that impulses may be originated in such a way as to cause co-ordinated movements such as closure of the eye.

With reference to the first aspect of this question, namely, whether the old facial area continues or does not continue to function, I hold that my experiments, published in 1901, have given a clear indication of this. In these experiments on the crossing of the flexor and extensor supply in the forelimb of dogs it was found at the physiological examination that the position of the two areas, namely, those of the flexion and extension of the forepaw—usually clearly separate in the dog—had become reversed on the side affected by the crossing, and further evidence on this subject will be given in the second part of this research. The evidence, therefore, in such a case as facial anastomosis points to the old facial centre remaining quiescent, the representation of the substitute actually taking up the function of the facial representation.

(d) *The New Paralyses Resulting from the Anastomoses, and the Extent of the Association Movements when Present.*—As to the peripheral organs supplied by the substitute nerve, and the possible or intentional loss of these to the individual, this must be made a careful consideration. In the case of spino-facial anastomosis, it is the sterno-mastoid and the upper part of the trapezius (Plate 6, figs. 5, 6) which are affected, and these are not entirely affected, as they are in part also supplied by cervical nerves. In the case of the hypoglossal the entire musculature of one half of the tongue is supplied (Plate 7, fig. 7). Granting that the descending hypoglossal nerve remains attached to the central segment, and that therefore the muscles which that branch supplies are left unaffected by the operation, there are the following muscles in man which must necessarily be affected if the union is

made in an efficient way by section of the whole of the nerve fibres, namely, thyro-hyoid muscle, hyo-glossus, genio-hyoid, genio-hyo-glossus, stylo-glossus, and intrinsic muscles of the tongue.

Of these the thyro-hyoid muscle is really supplied from the first and second cervical nerves, as it is to that source that the small twig which comes off for its supply is traceable back. Also the genio-hyoid really receives its supply from the loop between the first and second cervical nerves, so that the only muscles remaining to be supplied through the hypoglossal nucleus are the intrinsic muscles of the tongue, the stylo-glossus, the genio-hyo-glossus, and the hyo-glossus. Thus a considerable part of the hypoglossal is really made up of contributions from the cervical cord.

Thus the result of an end to end anastomosis using the spinal accessory is partially to affect with flaccid paralysis the upper part of the trapezius and the sterno-mastoid muscles, and the apparent consequences in man of this operation appear to be limited to a slight droop of the shoulder on the affected side. The individual himself feels no inconvenience, but his friends remark the depression of the shoulder, which can be in great part hidden by a suitable pad placed over the shoulder.

In the case of an end to end anastomosis using the hypoglossal, the result is a flaccid paralysis of one-half of the tongue. This produces some distress at first, owing to the alteration in the act of mastication and swallowing which it produces, but this distress appears to pass off quickly. Perhaps also the swelling of the affected side of the tongue, due to the section of the vaso-constrictors in the hypoglossal, adds to the preliminary distress which is experienced. It also produces the deviation to the side of the anastomosis of the tongue on protrusion. It produces, likewise, marked wasting of the tongue, which is reduced by and by to little more than mucous membrane on the side of the lesion (Plate 7, fig. 7), and is bound to be a serious defect in so important an organ as the tongue.

Of course, in the case of an end to side anastomosis, the continuity of the substitute nerve being restored, these defects, both in the case of the spinal accessory and in that of the hypoglossal, are merely temporary, unless some accident should happen, such as sepsis, which might destroy the result by preventing efficient union of the nerve. Then, instead of a temporary, there would be a permanent paralysis added to that of the face previously alone present.

As far as association movements are concerned, it appears that they are not always demonstrable. Theoretically it might be argued that they would not be found when an end to end anastomosis was performed, but only when an end to side was done, so that the normal distribution of the substitute retained its normal nerve supply—weakened, perhaps, but still controlled by the same nerve, which, however, has now given over to the face part of its function. The one nerve therefore being obliged to supply both distributions, it is not surprising that when violent innervation of one area is intended, the other area is unintentionally also innervated. Experience

has, however, shown that it is not only in end to side anastomosis, but also in end to end, that the association movements are exhibited. These must be regarded as a defect in the procedure when they are present, and the question comes to be whether they are more objectionable or troublesome when the hypoglossal is used or when the spinal accessory is the nerve employed. In the spino-facial experiment in the monkey in which they were seen they were only obtained during the most forcible shoulder movements, as in fighting, and ordinarily did not come into consideration. This was exactly the experience which I had with my case of spino-facial anastomosis published in 1900, as then they were not discovered until one day a violent movement of the shoulder was made, when they became evident. They never at any time produced the least inconvenience to the patient, and were never in ordinary movements observed. In one of the dogs, however, in which hypoglosso-facial anastomosis was done they were always in evidence with the movements of the tongue, and, as the tongue is frequently in vigorous movement, the conditions here exist for producing these movements of the face during such movements of the tongue as occur in eating, etc. The same may occur in man after hypoglosso-facial anastomosis. Thus TAYLOR and CLARK (42) record a case of WEIR'S in which, when the patient swallowed, this act "was accompanied by a slight grimace of the right side of the face."

From this point of view, therefore, less inconvenience is to be expected when the spinal accessory is used than when the hypoglossal is taken as the substitute, as the ordinary movements of the shoulder are less likely to evoke the facial contractions than are the ordinary movements of the tongue.

(e) *Comparison of Results with Different Nerves as Substitutes.*—As regards the results obtained in the experiments, it would appear that when the hypoglossal was used a somewhat earlier start was made with the reappearance of voluntary or reflex contraction of the orbicularis. In the case of the monkeys, the end result was practically the same in the two types, but in the case of the dogs the hypoglossal cases were further on when the observations ceased, but the end results were not very markedly different (Plate 6, figs. 3, 4).

Conclusions drawn from the recoveries in the published cases of operative anastomosis in man are very unreliable, for the conditions are so inexact, and so incapable of being controlled by subsequent examination. Thus some of the recovery might have been due to a reunion of the facial. Likewise many of the cases were useless by the inefficient way in which the anastomosis had been made, and occurring at a time when this operative procedure was, so to speak, on its trial, gave rise to very erroneous conclusions regarding the worth of the procedure, such as the cases of KÖRTE, BALLANCE, and GLUCK. Thus BERNHARDT came to the conclusion that the procedure had little practical worth. There has also been the complicating feature of the very various periods which had elapsed between the onset of the paralysis and the performance of the anastomosis, so that the muscles to be re-innervated were in

different stages of degeneration. Also in some the facial nerve was partially united and the tonus of the facial muscles kept up all the time. A careful study of the published cases of the two kinds shows that many of them have been published much too soon and that further details are wanting, and, of the comparative few which were fully reported, and which were satisfactory in result, there does not appear to be any marked difference in their development. But, for the reason stated, it would be very difficult or, indeed, impossible to draw very reliable conclusions from these cases, these matters requiring to be settled by experimental research.

(f) *Conclusions as to Choice of Substitute Nerve.*—It is thus concluded that of the nerves which offer themselves for attachment to the facial there are two, namely, spinal accessory and hypoglossal, which so correspond in the nature of their peripheral organs as to be preferable to the glosso-pharyngeal or pneumo-gastric. Of these two, while the research has indicated a slight advantage in favour of the hypoglossal as regards the return of voluntary function, there are other considerations which require to be taken into account in coming to a decision as to which of the two nerves ought to be employed in surgery. Had the results presented a marked discrepancy, then the recovery of voluntary function in the face might have outweighed all other considerations, but such a marked discrepancy in the restoration of voluntary function did not occur.

In the first place the nature of the new paralysis produced in the two cases proclaims at once in favour of the spinal accessory, even although the paralysis is merely temporary, and all the more so if the paralysis is to be permanent, either in the case of an end to end suture or in the case of failure of the suture, which is always possible, although improbable. Likewise in the event of development of association movements, these, as has been shown, are much less objectionable when the spinal accessory has been used. Should an end to end suture require to be made, abandoning the peripheral end of the substitute, then the hypoglossal is quite excluded as a nerve of choice, as the hemiatrophy of the tongue would be an unjustifiable defect to inflict on the patient, and would be too dear a price to pay for the restoration of the face.

(7) *Continuity of the Facial to be Retained in Certain Cases.*

In the case of a patient affected with facial paralysis, that paralysis is not infrequently found to be partial only, or if total the muscles may be found to be responding to the faradic current, and in any case, at six months no one could take up the position that the possibility of restoration through the normal path was excluded, except in very unusual circumstances, such as occurred in the case of CUSHING, where a large destruction of the nerve was found in a gunshot wound. In consequence of this there is grave objection to cutting the facial nerve at the stylo-mastoid foramen and turning it downwards to meet the hypoglossal or spinal accessory, thus doing away with any

possibility of any reunion in the facial of those fibres which had been restored, and which had been again severed in cutting the trunk close to the stylo-mastoid foramen. Therefore the better procedure is to cut the facial nerve across near the stylo-mastoid foramen, severing all the nerve substance, and leaving only one side of the perineurium, to cut across the spinal accessory at a convenient level, and to turn the central segment upwards to meet the cut facial trunk, into the gap in which it is stitched by one suture, taking it and the two ends of the facial in one grasp. Instead of the entire trunk of the spinal accessory being taken, one-half of the thickness only may be taken, following HACKENBRUCH, VÖLKER, and PETERSEN, or a flap might be taken from both the spinal accessory and the hypoglossal, so as not to paralyse permanently either nerve and yet to take to the facial the equivalent of an entire nerve. This union should not be made as VÖLKER and PETERSEN did; for these surgeons merely made a longitudinal slit in the facial. A more efficient union would be made if the facial is cut across as already explained.

In the case of an experiment to test the restoration of the face apart from the innervation of the facial the central end must be prevented from reuniting. This is not easily done. In two out of MANASSE'S five dogs such a reunion took place. In the case of a nerve which has been severed with much trauma, as by a kick or by tearing, it is well known that reunion is not so probable as in the case of a clean division of a nerve by a knife. In such a case the nerve ends may be lying in contact without reunion having taken place by nerve substance (Plate 7, fig. 8). Probably, therefore, if a central end is bruised much this will hinder the preliminary steps which take place in reunion and delay or frustrate the entire process. I have not found in any case reunion of the facial nerve after inserting into the stylo-mastoid foramen a plug of silver or bone which is intended to remain in permanently, but which frequently was found to have dropped out. However, the bruising of the nerve which it produced was apparently enough in every case to prevent reunion.

(8) *The Maximum Result, and Comparison of Results with that of a Control Experiment.*

I have not yet seen a case or experiment in which the facial nerve has been substituted for, in which perfect recovery has taken place. But I have also not seen a case in which the facial nerve has been sectioned and reunited, in which perfect recovery has taken place. I have seen many cases in which there has been facial paralysis consequent upon compression of the nerve by exudation after the mastoid operation, and in which perfect recovery has occurred after very varying intervals, but in these cases no severance of the nerve fibres has ever taken place. A sufficiently large number of cases has not yet come under my observation to enable me to form a definite judgment as to whether the recovery which takes place in the face is as good or less good when a substitute is attached to the facial, as when a reunion is made between

the two facial ends, but I am inclined to the belief that the results are not widely different.

In the case of a control experiment in a dog in which the facial nerve was divided close to the stylo-mastoid foramen and accurately reunited, the suture being passed and in place before the severance was effected, there does not appear to have been a development in any way different from that in which the conditions of substitution were observed. Unfortunately this animal died suddenly while under the influence of chloroform for an electrical examination. This took place 59 days after the section and suture of the facial nerve, and at that time there had been no appearance of recovery of facial movements on the paralysed side, either voluntary or reflex. But the nerve had reunited and regenerated, as was shown by muscular responses on applying the galvanic current to the facial nerve near the ear on the 44th day. There was no faradic irritability in the muscles of the face at the 59th day, either when the electrode was applied to the facial nerve or to the muscles directly. One of the hypoglosso-facial anastomoses showed a return of reflex movements at 45 days, so that evidently, as far as the date of commencing recovery is concerned, this does not take place earlier when an accurate reunion of the divided facial is performed. The wound in this control experiment healed by first intention.

This is also confirmed by former experimental results published by me (20), in which crossing was effected between the forelimb nerves which supply respectively the flexor and extensor muscles. A control experiment was made in which the identical nerves were divided and reunited each to each as accurately as possible. No better result was got and no quicker recovery. It is interesting, therefore, to find the same result in this series of experiments indicated, at any rate for the date of commencing restoration, but unfortunately not completed on account of the death of the animal.

In the cases which have been reported during the past 10 years the results have been very irregular. Some authors shortly report a result as practically perfect, but it would have been more satisfactory had these reports contained more details in order to allow a definite judgment to be made. In my cases the restorations are not perfect. The eyelid movements are practically perfect, as they enable the eye to be tightly closed without any action of the shoulder muscles, but the other muscles are less perfect. There is no appearance of asymmetry of the face, the muscles evidently having a good tonus (Plate 7, fig. 13). In the case which was published in 1900, the mouth can now be filled with air under tension, the lips being efficient to prevent its escape, and there is no accumulation of food between cheeks and gums after eating. The angle of the mouth can be moved and the lips puckered up as in whistling without any very marked asymmetry (Plate 7, figs. 10 and 12). The brow is defective in movements, showing very slight wrinkling when the patient raises the eyebrows. A slight smile can be made with trivial asymmetry

(Plate 7, fig. 11), but any extreme emotional movement at once proclaims the defect.

This corresponds to the course of the recovery obtained in the experiments. In most the eyelids had practically complete restoration of their movements, and in the dogs little else was necessary to remove the evident signs of facial paralysis. In the monkeys also the eyelid movements were the most outstanding recovery, but the appearance of facial paralysis disappeared when the face was at rest, apparently from improved tonus.

(9) *When and by what Method to Operate in Man.*

In the event of facial paralysis in man, the question of performing this operation comes up when it is thought that no recovery is taking place, or is likely to take place, in the facial nerve, and in coming to a decision there are two points of view from which the matter must be considered :—

(a) Is efficient reunion of the damaged facial nerve possible ?

(b) If the paralysis has lasted for any considerable period of time, are the muscles still in a position to benefit from having their nerves again brought under the influence of the central nervous system ?

The first question is one which, although it may always have been considered, appears not always to have been correctly answered. A study of some of the published cases will bring this out. When the nerve is exposed for the anastomosis it ought invariably to be stimulated by a weak galvanic current, and should contraction be found in any of the facial muscles, then the central end of the nerve cannot be regarded as quite useless, and it may be very useful. Thus, at six months after the onset of the facial paralysis, there may have been no evident recovery in the face, but the nerve might well be found to be conducting impulses, and in that event this must be due to a reunion with its own central end. Again, there is a phenomenon described by the Ballances and Purves Stewart (29) which is of great interest, as showing the state of the facial nerve at the time of exposure for operation. They say : " Another point of interest is that if the paralysed muscles have already developed contracture, to however slight a degree, they at once become flaccid again ; in fact, in several cases where clinically the muscles before operation appeared to be flaccid, this flaccidity seemed to become actually exaggerated, a condition for which we do not offer any explanation, except that possibly in such cases the nerves, though completely disconnected from the brain, do in some way, by virtue of the regeneration that has taken place in them, exert an influence on the muscles " ; and again, " the facial muscles during operation (see Cases V and VI), in which the patient was completely anæsthetised, though unresponsive to the strongest faradic shocks applied through the skin, nevertheless reacted when the peripheral end of the divided facial nerve was stimulated directly. This is possibly a clinical evidence of peripheral regeneration." The explanation of these phenomena which

appears to me to be the correct one is that, in the cases in which they were shown, the two ends of the facial nerves had reunited, at least to a certain extent. This was indicated by the fact that there was contracture present in some, that there was muscular tonus present in some, as shown by the increase in flaccidity on the nerve being divided, and that at the operation the application of an electric stimulus to the peripheral end of the facial produced contractions in the muscles.

Care must therefore be taken that the surgical intervention does not take place too early, while there is still a chance of reunion occurring, and that it does not take place while the process of spontaneous recovery is actually in progress, as otherwise many cases might be operated upon unnecessarily, and with a result inferior to that which might have been attained by the spontaneous recovery. The time through which one ought to wait has been variously answered. Some think three to six months reasonable, but this will depend on our knowledge of the causes of the paralysis, and on the result of our search for signs of spontaneous recovery. If it is known that the facial nerve is hopelessly destroyed, then it may be right to proceed to anastomosis at once, and by the method of section of the nerve at the stylo-mastoid foramen, and turning down the peripheral segment and inserting the same into the spinal accessory, or turning up the central segment of the spinal accessory and performing an end to end suture between the two nerves. It will not cause any delay in the result, however, to put off the operation for at least a month, and possibly longer, as the experiments show, and this may be a most valuable option, as in the case of an open wound in which the nerve has become destroyed, where it would be most important to get this healed before proceeding to exposure of the nerves.

If, however, it is hoped that there is a possibility of reunion, this ought to be given a fair chance of exhibiting itself, and here again the cause of the paralysis is most important, for if, for example, where due to middle ear sepsis, it has been present before the operation, the paralysis may clear up as a result of the operative removal of the disease in the mastoid, the nerve soon regaining its conductivity (HAMMOND, 27).

If, on the other hand, the paralysis comes on, not immediately, but a short time after the operation for mastoid sepsis, such a paralysis, as a rule, clears up by itself, and, as it is not due to nerve section, but to compression by exudation finding its way into the aqueduct of Fallopius, where it presses on the nerve, such cases usually recover perfectly.

If, on the other hand, the paralysis develops during the operation by division of the facial accidentally or by crushing it in the aqueduct, the muscles of the face twitching at the time, and the patient recovering from the anæsthesia with a profound paralysis, then an attempt ought to be made to restore the nerve in the aqueduct in the way already noticed. When the paralysis is due to mastoid disease, or to the operation for it, it is those cases in which the paralysis was present before operation, and those cases in which it is produced at the operation, which will yield

the cases ultimately suitable for operation by anastomosis. After six months, in these cases, without the appearance of any definite improvement, an operation ought certainly to be undertaken, and, when the facial nerve is exposed at the stylo-mastoid foramen, it ought in all cases to be stimulated with the galvanic current. Should any indication be shown of reunion by the contraction of the facial muscles on stimulation of the facial trunk, then the spinal accessory ought to be turned upwards or a flap from the same, and attached to the facial, after complete division of all the nerve fibres of the facial, but the two ends of the facial united in one suture with the spinal accessory as already described. Should the facial nerve show no indication of reunion, then the sectioned nerve may be turned downwards and attached end to side to the spinal accessory, or an end to end with the spinal accessory may be performed.

Muscle contraction on stimulation of a detached peripheral segment is always a proof of at least partial reunion of the segment with the centres, as a completely detached peripheral segment gives on stimulation no response in the muscle. BALLANCE'S view, that an autogenetic regeneration of the peripheral segment, although that segment is still unconnected to the centres, gives at the same time an influence on the muscles causing tonus, and conducting impulses started by electrical stimuli to the muscles which thereby contract, is in my opinion untenable. This may therefore be taken as a clear indication at the operation which procedure to adopt, so as not to lose any influence of the facial for restoration of the face, should that reunion be indicated.

The second question which will require to be considered is whether or not the time during which paralysis has lasted will preclude a recovery after anastomosis has been done. The literature shows several records of old-standing cases of paralysis which have been dealt with by anastomosis.

In the original case published by FAURE (17) 18 months elapsed, and when published at nine months no improvement had taken place, and subsequent reports up till five and a-half years still showed no improvement of a striking kind. MORESTIN,* however, also published a case of the same standing in which the result was quite different. There was no improvement for three months, but after eight months the face became symmetrical in repose, and in one year there was a restoration of voluntary movements independent of those of the shoulder. The operation was done by FAURE'S method.

Other cases have been published in which the paralysis had lasted much longer, and in which restoration took place in an apparently incredibly short space of time. Thus BARDENHEUER (36) has published two cases, in both of which he used an end to end anastomosis with the hypoglossal. In one of these no less than 16 years had elapsed since the onset of the paralysis, and yet in both cases a very rapid and very satisfactory result appears to have been reached. There is, however, one peculiarity

* Quoted by DAVIDSON (50).

in this case which explains the apparent anomaly, and that is that at the operation it was found that conductivity was present in the facial nerve when it was tested with the electrode. The same thing was noticed in the case of HACKENBRUCH, in which the paralysis had lasted for seven and three-quarter years, and began to clear up four and a-half months after the operation, as already noticed in an earlier part of this paper (p. 108).

In other cases operated on, after long intervals, there appears to have been little in the way of result, and probably the fact of the facial nerve having reunited to a certain extent, and thus keeping up the nutrition of the muscles or part of them, accounts for the recovery in such cases as those of BARDENHEUER. It is not yet definitely determined what length of time the muscles may be cut off from the influence of the central nervous system and yet be reparable, but if it is found at the operation that they are wholly unresponsive to direct galvanic stimulation the prospects are not good. Examination of electrical reactions through the skin with negative result is not conclusive proof that reactions are absent. It is necessary to puncture the skin to permit a platinum electrode to reach the muscle substance directly.

6. GENERAL CONCLUSIONS.

If now the conclusions from the facts ascertained in this research may be shortly reviewed, they are as follows :—

1. In any case of facial paralysis due to division or compression of the facial nerve, the best procedure, should spontaneous recovery fail or be deemed impossible, is to attempt restoration of the damaged nerve.

2. Should efficient restoration of the nerve be impossible, or be deemed impossible, anastomosis with the spinal accessory or hypoglossal holds out most favourable prospects of recovery, given that the facial muscles are still recoverable from the point of view of duration of complete severance from the nutritive influence of the central nervous system.

3. Of the two substitutes, spinal accessary and hypoglossal, when the latter is used the restoration appears to commence sooner, but there does not seem to be a great difference in the ultimate result of the two substitutions, as far as the recovery of the face is concerned.

4. Of the new paralysis produced as a result of cutting the substitute nerve, that which is produced when the spinal accessory is cut is much less objectionable than that produced when the hypoglossal is cut, and when the paralysis is to be left as a permanent defect, namely, when the peripheral segment of the substitute nerve is to be left unattached, the hypoglossal paralysis is not justifiable.

5. When in consequence of the anastomosis association movements are present in addition to voluntary co-ordinated and dissociated movements, these associated movements give no trouble, and are not noticeable with ordinary movements when

the spinal accessory has been used, but if present may be most objectionable and noticeable with ordinary movements when the hypoglossal has been used.

6. As regards the interval during which the paralysis has lasted before anastomosis has been performed, there appears to be no difference in the date of commencing recovery and ultimate result, whether anastomosis immediately follows section of the facial, or whether one month's interval at least is allowed to elapse before the anastomosis is performed after the facial has been cut.

7. The only way to make an efficient union between two nerves is completely to cut across all the nerve fibres in both nerves; methods such as MANASSE'S, designed to maintain the integrity of the nerve fibres, give inefficient unions.

8. In the course of recovery of independent voluntary co-ordinated movements, the orbicularis palpebrarum is first to exhibit recovery, and usually is the muscle which recovers best, and in no case has a perfect recovery in the movements of the face been proved to take place.

9. Reunion of the facial nerve is to be preferred to restoration by means of an anastomosis, as the latter involves interference with the distribution of another nerve, and association movements are sometimes troublesome.

10. The distribution of the facial nerve is, in dogs and monkeys, limited to its own side of the face, and recoveries cannot therefore be attributed to a supply from the opposite facial.

11. The distal segment of the divided facial, except for a short period immediately following division, on being irritated gives no response in the muscles if no connections at a subsequent date have been made with the centres, either through its own central segment or by some other path; and, conversely, the occurrence of muscular responses on irritating the peripheral segment is proof that such connections have been established.

ADDENDUM.

(1) REPORT NEARLY TWELVE YEARS AFTER OPERATION OF CASE OF SPINO-FACIAL ANASTOMOSIS, PUBLISHED IN 'PHIL. TRANS.' IN 1901.

(a) *Résumé of History of the Case.*

In this case the right facial nerve in a woman, aged 46, was divided on May 1, 1899, for the relief of severe facial spasm, and for the cure of the resulting facial paralysis spino-facial end to side anastomosis was at the same time performed. Recovery commenced on the 49th day by some action in the orbicularis palpebrarum, and steadily advanced. In about one year and a quarter she could voluntarily close the eye completely. The right side of the brow could be wrinkled only very slightly, and only inco-ordinated movements could be made with cheek and mouth. In attempting to blow, the aperture of the mouth could not be made circular. All these movements were independent of those of the shoulder, and it was only at the end of the year and

a quarter that association movements were discovered to be present when she suddenly elevated the shoulder, but these movements speedily passed off, although the arm was kept held up. At 23 months further progress was made.

(b) *Condition at Present Time.*

a. Examination of Electrical Reactions.

Faradic Current.—The electrode, with a current from the secondary coil, applied to the motor points alternately on the two sides gave the following comparative results for minimal contractions, as indicated by the position of the secondary coil, as follow:—

Facial nerve, Right	90 mm.
,, Left	95 ,,

All the facial muscles of the side were thrown into contraction. The motor point on the left side which gave contractions with the minimal current was just behind the lowest point of attachment of the ear; on the right side it was about $1\frac{1}{2}$ cm. below that point. Stimulation at the latter point gave pure facial contractions, without contractions of the sterno-mastoid or trapezius either felt or seen.

Direct stimulation of the muscles—

Frontalis, Right	103 mm.
,, Left	103 ,,
Orbicularis palpebrarum, Right	102 ,,
,, ,, Left	105 ,,
Muscles moving angle of mouth, Right . .	91 ,,
,, ,, Left . . .	96 ,,
Muscles of chin, Right	97 ,,
,, Left	100 ,,

Galvanic Current.—Minimal contractions at 5 MA. These were identical on the two sides, and the polar reactions were normal KCC > ACC.

It is thus seen, as far as electrical responses are concerned, the face has recovered perfectly.

The Spinal Accessory Distribution.—Electrode with faradic from secondary coil applied to the motor points gave the following results for minimal contractions:—

Spinal accessory in posterior triangle of neck—

Right . . .	85 mm.	Left	90 mm.

Direct stimulation of upper part of trapezius—

Right . . .	80 mm.	Left	83 mm.

Spinal accessory in front of the sterno-mastoid—

Right . . .	83 mm.	Left	87 mm.

β. Examination of Movements.

With the face in repose there is no sign of facial paralysis (Plate 7, fig. 13).

The shoulder is at normal level, and there is no atrophy of the upper part of the trapezius or of the sterno-mastoid of the left side. Turning the head, so as to put the right sterno-mastoid into action, produces no association movement in the face, but causing strong innervation of the sterno-mastoid by causing forcible action of it against much resistance produces a very slight muscular action on the angle of the mouth, but the eyelids or other parts are in no way affected.

Raising the shoulder, when done with moderate force, produces practically no sign in the face (Plate 7, fig. 9), but forcible and sudden elevation against resistance produces association movement of the face, affecting the eyelids, the brow, and the angle of the mouth—in fact, all the muscles, but these are only maintained while the resistance is kept up, and pass off, although the shoulder is kept elevated.

The following is the condition as to voluntary co-ordinated movements independent of the association movements.

The Brow.—This is the most defective part, and only very slight control over the frontalis and corrugator can be made so as very slightly to wrinkle the brow.

The Eyelids.—These are able to be brought together completely so as to shut the eye completely, and, indeed, with some degree of tightness. The winking is present synchronously with that of the other eye.

Reflex contractions of the orbicularis are quite normal on touching the cornea. Touching the left eye produces vigorous closure of the left eye and less vigorous closure of the right eye. Touching the right cornea causes closure of the right eye and vigorous closure of the left eye.

The left eye can be kept shut and the right open, but not *vice versâ*. She states, however, that she never had the power before her paralysis began to do this.

There is no epiphora, and foreign bodies never get into the affected eye more frequently than into the other eye.

The Mouth.—There is the voluntary power to make a circular aperture with the lips, as in whistling or blowing (Plate 7, figs. 10, 12), although close inspection reveals some evidence of paresis.

The mouth can be voluntarily distended by air under pressure, and the lips are able to prevent it escaping. When the air is forced to escape by lateral compression of the distended cheeks, it is between the right sides of the lips that the escape first takes place, showing the presence of weakness.

Labials are perfectly pronounced. She can protrude the lips. The lower lip protrusion is practically perfect, but the upper shows some right-sided weakness.

The Buccinator.—There is never any lodgment of food between cheeks and gums.

The Chin.—The movements are excellent. The lower lip on the right side can be elevated or depressed.

Smiling (Plate 7, fig. 11).—There is slight smiling possible without more than slight indications of weakness, but extreme emotional movement brings out the weakness more distinctly; but during laughing of this description there is distinct elevation of the right angle of the mouth.

The most extreme voluntary movements of the face—those, namely, of the eyelids and of the chin—when made as forcibly as possible, produce no association movements in the spinal accessory distribution. Such has never been observed at any time.

(2) A Case of Facial Paralysis of Three Years' Duration, in which Recovery commenced Three Years Subsequent to the Anastomosis.

The patient, a girl, when two and a-half months old began to be troubled with left otitis media. Shortly afterwards a glandular swelling appeared in the upper part of the left side of the neck and suppurated. When she was six months old the facial paralysis began. Five months later the mastoid operation was performed, but that was not followed by any improvement in the paralysis. Two and a-half years later, when the paralysis was of three years' duration, I saw her for the first time. There was then typical left complete facial paralysis. The eye was unable to be closed, but rolled upwards on attempts at closure being made. The cheek was flaccid and hanging, drawn to the opposite side with the movements of the normal side. There was an extensive scar in the upper part of the neck, due to the suppurating gland. An electrical examination could not be made until an anæsthetic was administered.

The operation was performed on April 25, 1907, when the child was $3\frac{1}{2}$ years old. It was found that the facial gave no responses in the muscles when stimulated by a galvanic or faradic current. Very trivial responses alone were obtained by direct galvanic stimulation. The spinal accessory was found to have been interrupted by the suppurative process in the neck, at least as regards its conductivity, which was lost. Its proximal segment was dissected out, and after the facial had been cut at the foramen stylo-mastoideum, its peripheral segment was turned down and attached with catgut to the spinal accessory, which had to be identified from its anatomical position in the absence of the responses.

There were no indications of any improvement till May, 1910, *i.e.*, three years after the operation. At that time the eyelids commenced to show power to come together more than the mere passive movements permitted, and some muscular movements of the lower part of the face could be made.

In March, 1911, nearly four years after, the eye could be voluntarily closed almost completely (Plate 7, fig. 16), and when asleep the eye was completely closed. The conjunctiva was quite normal, not being irritated by entrance of particles, as the winking was efficient. In repose there was no sign of facial paralysis (Plate 7, fig. 15).

The chin had developed muscular movements, and the mouth could be distended

with air under pressure, the power of closure of the lips being efficient to prevent its escape until the cheeks were suddenly compressed, when the air escaped with a report. There were no association movements able to be elicited on forcibly raising the shoulder against resistance, and there had never been any to be found on examination. There was distinct atrophy of the left sterno-mastoid and upper part of the trapezius, but that of course was present before operation. An electrical examination of the condition of the facial muscles could not be satisfactorily obtained without an anæsthetic.

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EXPLANATION OF PLATES.

PLATE 6.

Fig. 1.—Experiment 1. *Macacus rhesus*, showing spino-facial anastomosis (end to side union). *Post-mortem* appearance of the anastomosed nerves. The peripheral segment of the facial is seen ascending from the junction with the spinal accessory to enter the parotid. Below the parotid is seen the digastric muscle, from the lower border of which the spinal accessory descends to enter the sterno-mastoid. The bifurcation into its two branches is seen and at the junction the horse-hair suture can be distinguished. The central segment of the facial can be seen projecting from the stylo-mastoid foramen. The animal lived 198 days after the anastomosis had been performed. The nerves were painted white, in order to render them prominent in the photograph.

Fig. 2.—Experiment 2. *Macacus rhesus*, showing hypoglosso-facial anastomosis (end to side union). *Post-mortem* appearance of the anastomosed nerves. The peripheral segment of the facial is seen arising from the hypoglossal and ascending, dividing into branches and entering the parotid. The hypoglossal is seen passing horizontally, and from its inferior border the descending hypoglossal nerve is evident. A small piece of the spinal accessory is visible between sterno-mastoid and digastric just behind the point at which the hypoglossal becomes visible. The white spot at the

upper border of the digastric represents the end of the piece of bone plugging the stylo-mastoid foramen. The animal lived 99 days after the anastomosis.

Fig. 3.—Experiment 4. Fox terrier on which spino-facial anastomosis (end to side) was performed on the right side 158 days before the photograph was taken. Shows power to shut almost completely the right eye. In this, as in Fig. 4, the animal was induced to keep the eye shut till the photograph was taken by placing an irritating substance on the cornea. The left eye remains open owing to the paralysis of the left side of the face due to section of the left facial 51 days before the photograph was taken.

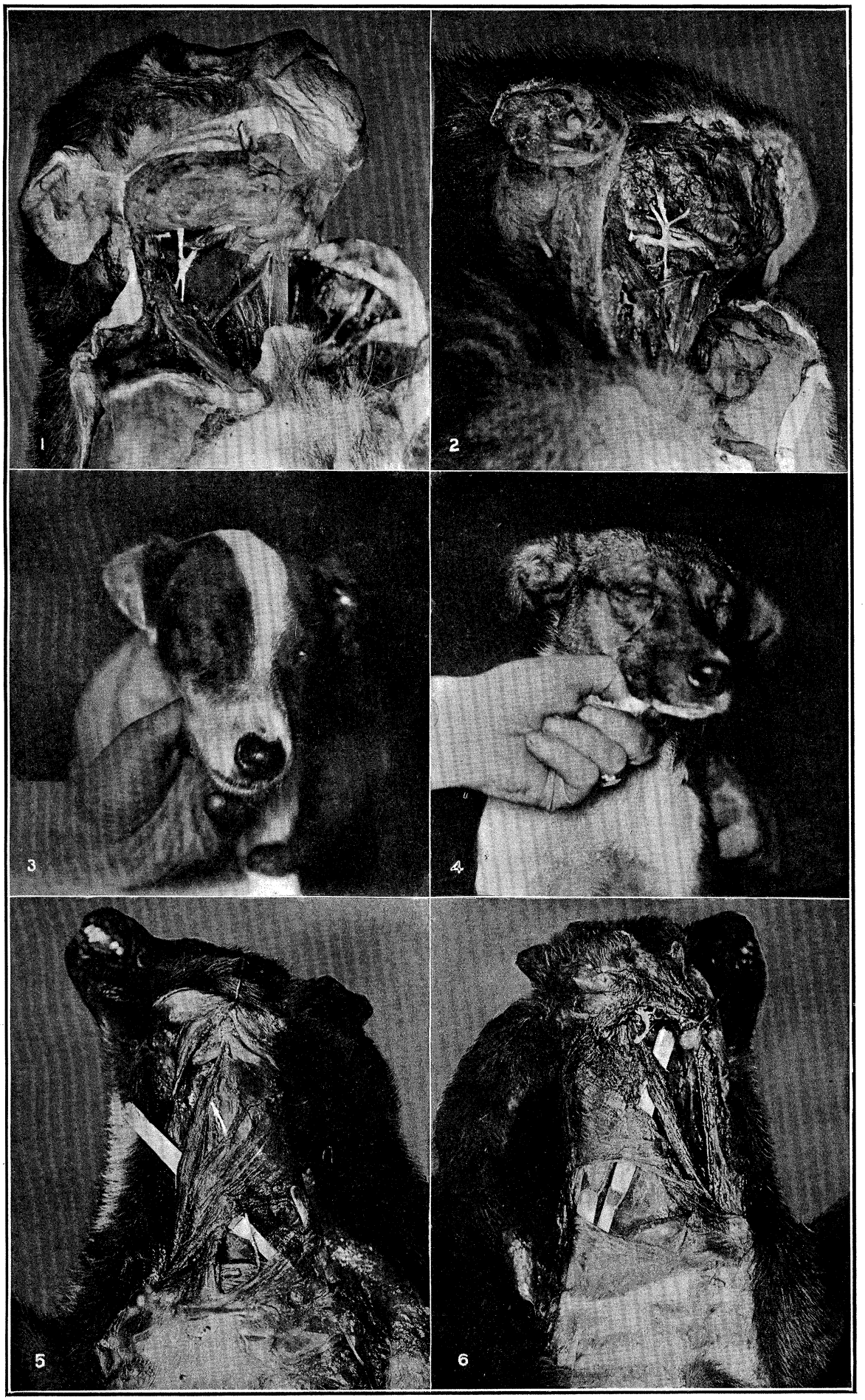
Fig. 4.—Experiment 6. Fox terrier on which hypoglosso-facial anastomosis (end to side) was performed on the right side 162 days previous to taking this photograph. Shows power to shut the right eye completely. It is seen that both eyes are kept shut, and that although the irritating material was introduced only into the right eye.

Figs. 5 and 6.—Experiment 5. Schipperke dog in which spino-facial anastomosis (end to end) was performed on the right side. The animal lived 132 days after performance of the anastomosis. Shows the *post-mortem* appearance of atrophy produced by this type of anastomosis. Fig. 5 shows the normal sterno-mastoid and trapezius held up on scalpels for comparison with the same muscles, similarly held up, in fig. 6, the atrophied condition being evident in the latter. In fig. 6 the anastomosis between the turned up central segment of the spinal accessory and the peripheral segment of the facial is visible.

Plate 7.

Fig. 7.—Experiments 6 and 7. Tongues removed *post mortem* from the dogs in these experiments. A piece of white thread is laid along the median raphe of each. In the upper of the two tongues there was hypoglosso-facial anastomosis (end to side) performed 238 days previous to the death of the animal; in the lower of the two tongues hypoglosso-facial anastomosis (end to end) was performed 181 days previous to the death of the animal. The difference between the two is seen in the right half of each tongue, which has been restored practically to the normal where the restoration of the hypoglossal was secured by the end to side method of anastomosis, but where the restoration of the hypoglossal was prevented by the end to end method, as in the lower of the two tongues, it has left its right half completely atrophied, as shown.

Fig. 8.—Longitudinal section of an un-united nerve (circumflex) which was severed by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a kick, and therefore with much traumatic injury, eight months previous to the excision of the damaged piece of nerve. The central and peripheral ends are seen to be un-united and they are joined together with connective tissue. Shows that reunion has not occurred, although the two ends were in close approximation, and indicates that the infliction of bruising at the end of a cut nerve will probably hinder reunion. (Zeiss a, proj. oc. 2. ×12.)

Fig. 9.—Case of spino-facial anastomosis twelve years after operation. Published in the 'Philosophical Transactions' in 1901. Shows that the arm and shoulder can be continuously held up without producing more than a trivial association movement affecting the naso-labial fold, and not affecting the eye.

Fig. 10.—Ditto. Shows voluntary power to close the right eye and to pucker the lips, as in whistling.

Fig. 11.—Ditto. Shows the condition of the face in smiling, there being some deficiency of control over the right angle of the mouth.

Fig. 12.—Ditto. Shows whistling and eyes kept open at the same time.

Fig. 13.—Ditto. Shows the condition of the face in repose, there being absence of all indication of defect.

Fig. 14.—Case of facial paralysis of the left side of the face of three years' duration in a girl aged $3\frac{1}{2}$ years, due to otitis media. Shows enlarged palpebral fissure and flaccid cheek.

Fig. 15.—The same patient as shown in fig. 14, but four years after a spino-facial anastomosis (end to end) had been performed. Shows the symmetry of the face in repose.

Fig. 16.—The same patient as in fig. 15. Shows the voluntary power to close the left eye almost completely. There was no trace of association movements able to be elicited in this patient.

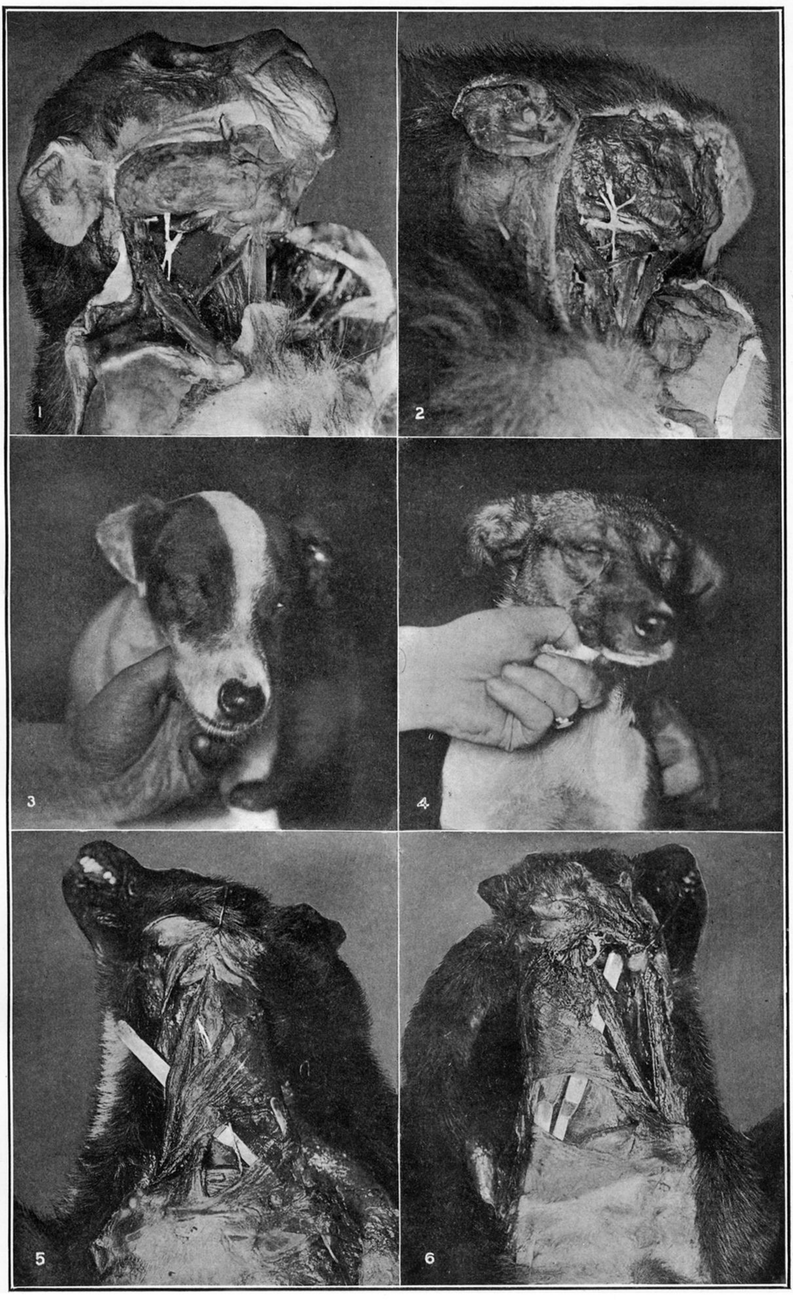

PLATE 6.

Fig. 1.—Experiment 1. *Macacus rhesus*, showing spino-facial anastomosis (end to side union). *Post-mortem* appearance of the anastomosed nerves. The peripheral segment of the facial is seen ascending from the junction with the spinal accessory to enter the parotid. Below the parotid is seen the digastric muscle, from the lower border of which the spinal accessory descends to enter the sterno-mastoid. The bifurcation into its two branches is seen and at the junction the horse-hair suture can be distinguished. The central segment of the facial can be seen projecting from the stylo-mastoid foramen. The animal lived 198 days after the anastomosis had been performed. The nerves were painted white, in order to render them prominent in the photograph.

Fig. 2.—Experiment 2. *Macacus rhesus*, showing hypoglosso-facial anastomosis (end to side union). *Post-mortem* appearance of the anastomosed nerves. The peripheral segment of the facial is seen arising from the hypoglossal and ascending, dividing into branches and entering the parotid. The hypoglossal is seen passing horizontally, and from its inferior border the descending hypoglossal nerve is evident. A small piece of the spinal accessory is visible between sterno-mastoid and digastric just behind the point at which the hypoglossal becomes visible. The white spot at the upper border of the digastric represents the end of the piece of bone plugging the stylo-mastoid foramen. The animal lived 99 days after the anastomosis.

Fig. 3.—Experiment 4. Fox terrier on which spino-facial anastomosis (end to side) was performed on the right side 158 days before the photograph was taken. Shows power to shut almost completely the right eye. In this, as in Fig. 4, the animal was induced to keep the eye shut till the photograph was taken by placing an irritating substance on the cornea. The left eye remains open owing to the paralysis of the left side of the face due to section of the left facial 51 days before the photograph was taken.

Fig. 4.—Experiment 6. Fox terrier on which hypoglosso-facial anastomosis (end to side) was performed on the right side 162 days previous to taking this photograph. Shows power to shut the right eye completely. It is seen that both eyes are kept shut, and that although the irritating material was introduced only into the right eye.

Figs. 5 and 6.—Experiment 5. Schipperke dog in which spino-facial anastomosis (end to end) was performed on the right side. The animal lived 132 days after performance of the anastomosis. Shows the *post-mortem* appearance of atrophy produced by this type of anastomosis. Fig. 5 shows the normal sterno-mastoid and trapezius held up on scalpels for comparison with the same muscles, similarly held up, in fig. 6, the atrophied condition being evident in the latter. In fig. 6 the anastomosis between the turned up central segment of the spinal accessory and the peripheral segment of the facial is visible.

PLATE 7.

Fig. 7.—Experiments 6 and 7. Tongues removed *post mortem* from the dogs in these experiments. A piece of white thread is laid along the median raphe of each. In the upper of the two tongues there was hypoglosso-facial anastomosis (end to side) performed 238 days previous to the death of the animal; in the lower of the two tongues hypoglosso-facial anastomosis (end to end) was performed 181 days previous to the death of the animal. The difference between the two is seen in the right half of each tongue, which has been restored practically to the normal where the restoration of the hypoglossal was secured by the end to side method of anastomosis, but where the restoration of the hypoglossal was prevented by the end to end method, as in the lower of the two tongues, it has left its right half completely atrophied, as shown.

Fig. 8.—Longitudinal section of an un-united nerve (circumflex) which was severed by a kick, and therefore with much traumatic injury, eight months previous to the excision of the damaged piece of nerve. The central and peripheral ends are seen to be un-united and they are joined together with connective tissue. Shows that reunion has not occurred, although the two ends were in close approximation, and indicates that the infliction of bruising at the end of a cut nerve will probably hinder reunion. (Zeiss a, proj. oc. 2. ×12.)

Fig. 9.—Case of spino-facial anastomosis twelve years after operation. Published in the 'Philosophical Transactions' in 1901. Shows that the arm and shoulder can be continuously held up without producing more than a trivial association movement affecting the naso-labial fold, and not affecting the eye.

Fig. 10.—Ditto. Shows voluntary power to close the right eye and to pucker the lips, as in whistling.

Fig. 11.—Ditto. Shows the condition of the face in smiling, there being some deficiency of control over the right angle of the mouth.

Fig. 12.—Ditto. Shows whistling and eyes kept open at the same time.

Fig. 13.—Ditto. Shows the condition of the face in repose, there being absence of all indication of defect.

Fig. 14.—Case of facial paralysis of the left side of the face of three years' duration in a girl aged $3\frac{1}{2}$ years, due to otitis media. Shows enlarged palpebral fissure and flaccid cheek.

Fig. 15.—The same patient as shown in fig. 14, but four years after a spino-facial anastomosis (end to end) had been performed. Shows the symmetry of the face in repose.

Fig. 16.—The same patient as in fig. 15. Shows the voluntary power to close the left eye almost completely. There was no trace of association movements able to be elicited in this patient.