a pad, because there is a tendency to sinking backwards of the divided bones at that level.

In several cases in which I have found the curvature in the leg bones producing the genu valgum combined with an antero-posterior curve of the tibia producing the ordinary deformity of bow legs I have had to deal with such a combination of deformity by a double osteotomy—the removal of a wedge from the upper end of the tibia for the correction of the genu valgum, and removal of a wedge from the lower part of the bone for the correction of the antero-posterior curve (in this position of course with the base of the wedge anteriorly).

REFERENCES.

- ¹ BRITISH MEDICAL JOURNAL, 1897, i, p. 1347. ² *Ibid.*, 1898, i, p. 1347.
³ *Ibid.*, 1902, i, p. 529.

Lectures

ON

THE SYMPATHETIC INNERVATION
OF STRIATED MUSCLE.*

BY

THE LATE JOHN IRVINE HUNTER, M.D., CH.M.,
CHALLIS PROFESSOR OF ANATOMY IN THE UNIVERSITY OF SYDNEY.

LECTURE III.—PART I.

THE PRACTICAL APPLICATIONS.

THE INCONSISTENT RESULTS OBTAINED BY OTHER
INVESTIGATORS.

In the second lecture attention was called to the evidence in support of the view that the two kinds of striated muscle fibres perform different functions. Only those innervated by the somatic medullated nerves are actively contractile and under the direct control of the will. The slender fibres innervated by the sympathetic non-medullated nerves are not contractile (although their length is passively altered by the activity of the contractile fibres alongside them): their function is to establish plastic tone, to support and maintain the more active and easily exhausted contractile fibres and relieve them of much of the work that would otherwise induce the rapid onset of fatigue.

When the grey rami of the sympathetic distributed to skeletal muscle are stimulated the muscles supplied show no sign of shortening (Bayliss¹⁸). But, of course, this is to be expected if the sympathetic innervation is responsible for plastic tone of skeletal muscle. The result of appropriate stimulation would be to fix the muscle fibres governed by the sympathetic system at their existing length. Obviously, therefore, athetoid movements or intermittent spasms of muscle, which depend upon the process of shortening of muscle fibres, are not dependent upon the sympathetic innervation of the muscle groups affected. No appreciable improvement of these conditions follows sympathetic ramisection, and their presence is, in general, a contra-indication to the performance of the operation. However, if marked improvement or loss of these features takes place, any remaining rigidity, which may be dependent upon the existence of plastic tone, may then be examined with a view to subjecting the patient to operation so as to enable further progress in education to proceed.

During recent years several writers have strenuously denied that any function of the sympathetic innervation of muscles had been demonstrated by experiment. It is hardly necessary, in view of the consistent results obtained by Langelaan and ourselves, to discuss in detail the reasons for the negative or inconsistent results obtained by other investigators. In some cases the negative results are due to imperfect denervation; in others to the fact that the observers were looking for an effect upon contractility, which, of course, they did not find. Our observations have been confirmed in the case of the dog by Foix,¹⁹ an investigator who was clearly free from any bias in favour of the results that he obtained, apparently unexpectedly.

Moreover, there is the very positive evidence obtained by Orbeli and his collaborators, which was summarized in

the *BRITISH MEDICAL JOURNAL* (September 20th, 1924, p. 534). Orbeli stated in 1923† that the direct influence of the sympathetic nerves on skeletal muscle is fixed beyond doubt; the ability of the autonomic fibres to alter the condition and constitution of muscle becomes transferred from a small organ, the heart, to the whole skeletal muscle, thus fulfilling the prophecy of the “chemical tonus” of Pfliiger and the “trophic innervation” of Pavlov. The sympathetic system, which controls all the vital properties of muscles and secures for them the greatest use of their reserve strength, must also affect their tone and metabolism. In 1922 Orbeli's collaborator Ginetsinsky found that stimulation of the sympathetic while fatigue was beginning to develop or had developed (as the result of stimulating the motor nerve) gradually restored the function of the fatigued and contracted muscle. The effect begins after a long period of latency, increases gradually, and reaches a maximum soon after the cessation of the stimulation of the sympathetic. Moreover, it lasts a long time.

These results are complementary to and consistent with those obtained in our experiments, and by others, as to the effects of adrenaline on fatigued muscle. The only criticism I would suggest of the work done in the Leningrad Medical Institute is that attention has been concentrated too exclusively on the phenomena of fatigue; and no adequate recognition has been given of the fact that the supporting and fatigue-sparing function of the sympathetically innervated muscle fibres is constantly being performed in every action of any muscle.

I want now to consider two factors that have been responsible for much of the discrepancy in the results obtained by various experimenters.

*Avoidance of the Effects of Asphyxia and of Anaemia of
the Brain Stem.*

It is clear from the argument of the second lecture that the results of loss of plastic tone would be more difficult to observe if any condition existed that would unduly increase the degree of contractile tone. As Dr. Royle²⁰ has pointed out, asphyxia of the animal would produce this effect. To avoid this complication he employed intratracheal anaesthesia and then oxygenated the animal freely as soon as decerebration was performed. If asphyxia tended to develop later—for example, when the tube in the trachea was too small—the rigidity of all four limbs in extension would become extremely marked, and differences in the tone of the hind limbs due to the loss of plastic tone on one side would be completely obscured. Removal of the cause of asphyxia would invariably remove the tendency for the display of such an exaggerated degree of contractile tone. In several recent papers Walshe has argued that minimal degrees of oxygen in like manner may lead to hyperexcitability of reflex arcs. Evidence is accumulating that this factor may account for “irritative” symptoms following central nervous lesions, as Royle and I have shown. But the effects of asphyxia and anaemia that are manifested as reflex hyperexcitability are foreign to the condition of tone exhibited in decerebrate rigidity. Like the state of spastic paralysis, this condition is to be regarded as being due to a release of function in the nervous system, following the removal of higher levels of nervous activity. The term “release” is employed in the sense advocated by Hughlings Jackson, and developed in the present century by the work of Head and his collaborators. It appears to me that Sherrington's method of decerebration, which should be done in the goat by section of the mid-brain under direct vision, is preferable, for the purpose of observing the presence or absence of plastic tone, to the method of decerebration by anaemia induced by tying the carotid and basilar arteries, which has been introduced by Pollock and Davis. While a preparation made by the method of these Chicago neurologists is unquestionably useful for observing the reflex activities of such an animal, it gives misleading results so far as tone is concerned. It is impossible to be certain in how great an area of the brain stem the cell stations are rendered hyperexcitable by a degree of anaemia that is insufficient to abolish function altogether.

* Delivered by Professor Elliot Smith at University College, February 2nd, 1923.

† [As the result of a conversation with Professor Orbeli last November I have made certain verbal modifications of his expressions as translated by Dr. Horsley Gantt in the *BRITISH MEDICAL JOURNAL*.—G. E. S.]

The Choice of Laboratory Animal.

The animal selected for our experiments, in the first instance, was the rabbit. Dr. Royle procured an excellent result in the diminution in tone of the hind limb of a spinal rabbit on the side from which the lumbar sympathetic trunk had been removed. This effect was not reproduced in subsequent experiments; and the failure was attributed to the difficulty in this animal of completely excising the sympathetic trunk on the selected side without injury or removal of the trunk of the opposite side. Therefore the goat was used for all our subsequent mammalian experiments. In the second lecture I have already explained why the goat is peculiarly adapted for this type of experiment. In contrast to the goat a carnivorous animal such as the cat shows a capacity for great and numerous variations in the degree of postural tone. The cat does not take up the extensor posture when placed in the supine position. Variation in the degree of contraction in its four limbs imposes varied attitudes upon it; and no doubt in the well oxygenated decerebrate cat the variations in the degree of rigidity of the limbs are to be accounted for in a like manner. Such variations in the degree and selective activity of contractile tone possibly render the effects of loss of plastic tone less apparent than would otherwise be the case and render an analysis of the exact defect in tone more difficult at the outset. For it must be borne in mind, in this connexion, that in the experiments recorded in the literature, practically all of which were performed on cats, differences were found in the degree of tone upon the two sides following unilateral sympathectomy, which was performed in some cases before, and in others after, decerebration. For instance, Dusser de Barenne observed a diminution in tone in five cases out of nine, after removal of the lumbar sympathetic chain. Uyeno found differences in the tone of the fore limb after removal of the ganglion stellatum on one side, but attributed the diminution in tone to sensory inhibition due to the wound on this side; but in Royle's experiments this explanation is not admissible. Consequently the problem presenting itself is not to explain negative results, but the inconsistency of the effects. I believe that the factors to which attention has been called in the foregoing discussion explain the failures encountered. This is especially the case when in the past investigators have been seeking to observe quantitative diminution of tone. I have attempted to show that contractile tone is well displayed after sympathetic denervation, and under certain experimental conditions may be present in an enormously exaggerated degree. It is only when qualitative changes due to the selective removal of plastic tone are looked for that the interpretation of effects in any such instance becomes clear.

The thesis maintained in these lectures (that plastic tone is a property of the sympathetically innervated fibres of skeletal muscle) no longer rests solely upon the evidence provided by experimental decerebrate rigidity. For the same effect as that which follows sympathetic denervation in the decerebrate animal is produced by sympathetic rami-

section in human patients in those conditions of spastic paralysis which exhibit all the essential qualities of decerebrate rigidity.²¹ The excessive plastic tone characterizing these conditions is removed by the operation of ramisection. The evidence that may be obtained by studying the character of the knee-jerk is of special interest. For in both decerebrate rigidity and in the types of spastic paralysis to which reference has been made, the execution of the knee-jerks, slow before the operation, became brisk in character. This is due to the rapid rate of relaxation of the extensor muscle after completion of the jerk contraction, which replaces the former tendency of the muscle to remain shortened ("shortening reaction") when contraction ceases.

THE SURGICAL OPERATIONS.

From the reports that have reached us Dr. Royle and I have been convinced that most of the failures have been due to two main causes: (a) the neglect to determine whether voluntary control and excess of plastic tone were present, and (b) faults in the technique of the operation, more especially the failure to cut the appropriate rami communicantes. The long discussion in this lecture (publication of which has been deferred to next week's JOURNAL) should make clear how to choose cases that are likely to benefit from ramisection.

The basic principle of the operation of sympathetic ramisection is that it removes plastic tone. It is only indicated when plastic tone is in excess and hampers the voluntary activities which have persisted in spite of the central lesion. A study of the nature of the spasticity of the spastic limbs, and an estimate of the anatomical defect of the central mechanism responsible for the condition, must go hand in hand, and only when the physiological indications are discoverable is the operation to be undertaken.

With reference to the operation it is a matter of great importance not to remove the sympathetic ganglia, because the unnecessary removal of their control of visceral function is wholly unwarrantable. Dr. Royle attaches great importance to the adoption of the lumbar route for the

operation of lumbar ramisection, not simply because it is for the patient a less formidable procedure than the abdominal route involves, but especially because it permits a clearer view of the rami and a more certain identification of the right ones to avulse.

In the second lecture I indicated which rami should be cut, and why.

THE OPERATION OF LUMBAR RAMISECTION.

Royle has given the following account of the surgical technique.

The patient should be made to lie on the side opposite to that of operation and should be inclined slightly toward the surgeon, who faces the patient's back. The space between the ribs and the crest of ilium should be made as wide as possible by placing a sandbag beneath the patient,

FIG. 9.—Drawing to represent the arrangement of the rami communicantes passing to the left lumbar nerves in man. After Dr. T. K. Potts. The black bars represent the places where avulsion is effected in the operation of "lumbar ramisection." The letters will facilitate the interpretation (with the help of Fig. 3), A being a grey ramus, A B a mixed ramus, and C the sympathetic cord.

or, better still, by using the adjustable support devised for operations on the kidney.

Step 1.—The incision is made from the last rib to the crest of the ilium and thence forward to the anterior superior spine of the ilium. If the quadratus lumborum muscle can be palpated, the downwardly directed part of the incision should follow its lateral margin, but if not, the lateral margin of the sacro-spinalis should serve as a guide. The forwardly directed part of the incision should lie about 1 cm. below the actual crest of the ilium. This enables the attachment of the external oblique muscle to be exposed. The flap of skin and fascia outlined by this incision is reflected forward to expose the attachments of the latissimus dorsi to the lumbo-dorsal fascia and of the external oblique muscle to the crest of the ilium.

Step 2.—The trigonum lumbale Petiti is next defined and from this point forward the oblique muscles are freed from the crest of the ilium to within 6 or 8 cm. of the antero-superior spine of the ilium. In doing this it is possible in most subjects to divide the external oblique through definite tendinous tissue close to its insertion and to avoid cutting the actual muscle fibres. This gives a decided advantage in closing the wound. The internal oblique and the transversus abdominis muscles are divided through the muscle fibres close to their attachment. The dissection is then carried upward and the lumbo-dorsal fascia is divided at the lateral border of the quadratus lumborum. In doing this it may be necessary to cut through the fibres of the latissimus dorsi.

Step 3.—The abdominal wall is now free to be thrown forward and after dividing the fascia transversalis the hand can be passed in front of the quadratus lumborum and the psoas muscles until the medial border of the quadratus lumborum muscle is palpated. Suitable retractors are then placed in position. Care should be taken not to disturb the fascia covering the quadratus lumborum and the fascia covering the psoas muscle.

In a very fat subject, however, the approach to the sympathetic trunk may be rendered more easy by leaving the fascia transversalis intact except at the medial border of the psoas muscle, where it must be pierced to reach the sympathetic trunk. The ganglionated sympathetic trunk can often definitely be palpated where it lies at the medial border of the psoas muscle before it can be seen. The psoas itself sometimes constitutes a difficulty in the adult subject by obscuring the trunk from view, and a suitable retractor is necessary to flatten the muscle. In children and poorly developed subjects this difficulty is not great.

The ganglionated sympathetic trunk will be found lying on the bodies of the lumbar vertebrae near the medial border of the psoas muscle. The abdominal sympathetic trunk on the left side is easy to define, if the medial border of the psoas is sought. In this situation a thin layer of connective tissue passes from the psoas muscles across the sympathetic trunk and great vessels to the region of the psoas on the opposite side. This is easily slit with a blunt dissector and the sympathetic trunk comes into view. On the right side the trunk lies under the lateral margin of the inferior vena cava and is usually placed anteriorly to

the lumbar vessels. This, however, is by no means constant, for on several occasions Royle has experienced difficulty from the lumbar veins crossing anteriorly to the sympathetic trunk. When this occurs the operation may be simplified by removing one or more of these veins. On the left side this complication has not been met, but in young subjects the lumbar arteries can be mistaken for rami communicantes, which they sometimes resemble in size and direction. In a few instances the lumbar lymphatic vessels and an unusually low formation of the receptaculum chyli has made the definition of the sympathetic trunk more difficult. In one instance the lymphatic vessels lay between the sympathetic trunk and the attachments of the psoas muscle. On lifting the lymphatic vessels the rami appeared from under their posterior surfaces, and patient dissection was required to define each structure.

In defining the sympathetic trunk long blunt dissectors are necessary. Royle's dissectors are 25 cm. long and have rounded ends. A long probe with a flat handle and curved on its end like a strabismus hook is useful for lifting the sympathetic trunk when defining its branches. Long straight, or slightly curved, artery forceps, 20 cm. long, are also essential, and four should be provided. The structures of the abdominal wall and abdominal viscera demand a large, broad, and deep retractor. Royle's retractor for use in operations on the average adult is 8.75 cm. wide and 12.5 cm. deep. It is constructed to act as a light-reflecting surface and has a shelf extending forward from its lower edge so as to depress structures medial to the ganglionated cord. The sympathetic trunk and the rami communicantes should be clearly defined before section. The method of dividing the rami communicantes is usually by avulsion.

Each ramus may be seized by a pair of artery forceps and drawn away from its lateral connexions, though in many instances it is necessary to divide a big ramus with a long pair of blunt-pointed scissors. In young subjects the rami may be easily and effectively broken with the blunt dissector. When ramisection of the second, third, and fourth lumbar nerves has been effected, the ganglionated cord is then divided at a level corresponding in position to the fourth lumbar nerve. The operation is then completed. The edges of the lumbo-dorsal fascia are first sutured in the region of the trigonum lumbale. The oblique muscles are then sutured to the crest of the ilium and a special point is made of suturing the tendinous portion of the external oblique to its original attachment and to the adjacent fascia lata. When this is done carefully the raw area on the crest of the ilium comes in contact with a raw area of considerable width on the under surface of the external oblique tendon, and this facilitates adhesion. The lumbo-dorsal fascia and the latissimus dorsi muscles are then sutured. The skin is closed without drainage.

The whole operation should be performed with very little loss of blood except from small vessels occasionally encountered in freeing the oblique muscles. There is no bleeding in the depth of the wound if the approach is

FIG. 10.—Dissection to show right lumbar rami communicantes as seen in the operation of lumbar ramisection. The incision runs from the twelfth rib along the border of the erector spinae muscle and is continued for three inches along the crest of the ilium. The tips of the transverse processes are seen in relation to the quadratus lumborum muscle, and the genito-femoral nerve is seen on the anterior aspect of the psoas.

confined to the plane between the peritoneum and the fascia covering the quadratus lumborum and the psoas muscles. Sharp instruments should not be introduced into this wound. The essential dissection can be done with blunt dissectors and long artery forceps.

The ilio-hypogastric and ilio-inguinal nerves are both drawn forward with the abdominal wall and the ureter with the parietal peritoneum. The incision has been designed so far as possible to divide only fibrous structures in approaching the sympathetic trunk. The internal oblique and the transversus abdominis muscles have, usually, to be divided through their muscle fibres at their insertion to the crest of the ilium. The incision also avoids all important nerves and blood vessels, and, if carefully sutured, should leave the abdominal wall as strong as before the operation.

THE OPERATION OF CERVICAL RAMISECTION.

The rami communicantes only are divided in the cervical operation. The sympathetic trunk does not come into the field of operation excepting in the approach to the first thoracic nerve. The rami above the first thoracic nerve are post-ganglionic fibres, but the first thoracic nerve itself usually has both a white and a grey ramus. The sympathetic rami usually enter the nerve roots of the brachial plexus after they emerge from the intervertebral foramina, though occasionally rami join the nerve roots within the foramina.

Step 1.—The patient lies with the chin turned away from the side of operation and with a small pillow placed beneath the shoulders. The field of operation is reached through an incision extending from the clavicular insertion of the sterno-mastoid backward and slightly upward across the posterior triangle. In young subjects and in those patients in whom the nerve roots all emerge from behind the scalenus anterior this incision suffices, but occasionally it is necessary to make a second small incision upward along the posterior border of the sterno-mastoid to be sure of reaching the connexions to the fifth and sixth nerves.

Step 2.—The platysma is divided and the external jugular vein is secured in the line of the original incision. The anterior layer of the cervical fascia is divided and blunt dissection is then carried out to expose the deeper layer of fascia covering the brachial plexus and the scalenus muscles. Between these two layers of fascia the superficial cervical

FIG. 11.—Diagram to illustrate the arrangement of the cervical rami communicantes on the right side. After Dr. T. K. Potts.

artery will be found occasionally. The transversus colli artery appears in a deeper plane crossing the nerve roots, and in Royle's experience most frequently between the seventh and eighth nerve roots. To obtain a clearer view of the plexus this artery should be tied and divided. The omo-hyoid muscle, appearing in this space, can be retracted downward.

Step 3.—In the upper part of the plexus it is necessary to look for and define the phrenic nerve as it lies on the anterior aspect of the scalenus muscle. The nerve

roots are then exposed and traced to the intervertebral foramina. The subclavian artery is identified and pulled forward to expose the eighth cervical and the first thoracic nerve. The rami communicantes are not easy to define. Those to the fifth and sixth nerves may come across the anterior surface of the scalenus anterior to join the nerve trunks or they may come through the muscle itself (Fig. 12). In addition there may be two or more branches; and it is necessary in dealing with each of the nerve roots to be sure that all anterior connexions are divided right up to the intervertebral foramina. Grey rami may join

FIG. 12.—Royle's figure of the rami communicantes, as exposed in his operation of cervical ramisection, modified by Dr. John Beattie and Miss Audrey Russell. Note the three slips of the anterior scalene muscle between which the grey rami to the upper three nerves emerge. Position of clavicle indicated by broken lines.

the nerve roots on their antero-inferior aspects, and in many instances must be sought there. This particularly applies to the eighth nerve. Medullated muscular branches will also be found on the anterior aspect of the nerve roots. These may be confused with sympathetic rami, and if there is any doubt should be removed. When the phrenic nerve receives communications from the fifth cervical nerve it will be found necessary to retract it laterally to get a clearer view of the trunk of the fifth nerve. The greatest difficulty will be found in connexion with the eighth cervical and the first thoracic nerves. In approaching this part of the dissection the first rib should be palpated and the first thoracic nerve sought as it crosses the neck of the rib. This nerve trunk can then be traced into the thorax. The cervical sympathetic trunk will be found on a plane posterior to the subclavian artery, and if it can be well defined no difficulty will be experienced in picking up the communicating rami to the eighth nerve. At this point the trunk usually moves to a more medial position as it travels into the neck, but sometimes it will be found lying upon the root of the eighth nerve. The grey ramus of the first thoracic nerve is found on its superior surface medial to the white ramus, which should be avoided if possible. The rami in this operation may usually be easily broken with a small strabismus hook. After ramisection has been completed the wound is closed by drawing together the edges of the platysma and by suturing the skin without drainage.

REFERENCES.

- ¹⁸ *Principles of General Physiology*, third edition, p. 545. ¹⁹ *Rev. Neurolog.*, July, 1924, p. 4. ²⁰ *Med. Journ. of Australia*, September 27th, 1924, p. 315. ²¹ Compare Walshe, *Lancet*, September, 1923, p. 644; Riddoch, *Proc. Roy. Soc. Med.*, July, 1922, *Neurolog.*, p. 47.

(To be concluded.)