sufficient to emphasize the necessity of prolonged rest in children who have had rheumatic infection. In fact, the suggestion of sanatorium treatment and notification of acute rheumatic infection is well worthy of consideration.

Next the syphilitic heart. Here the pathology of the arterial change and the recognition of the involvement of the myocardium as well as the great blood vessels, in this progressive lesion, makes it a great additional advantage in prognosis and treatment of cardiac cases to obtain the evidence of a positive Wassermann reaction.

Horder and Libman¹⁴ separate a group of cases of sub-acute infective endocarditis with very definite clinical signs such as described by Cotton¹⁵ and others. Under the title "endocarditis lenta," Starling¹⁶ and Carey Coombs¹⁷ have presented groups of cases of unusual interest; and if this condition, which anyone connected with cardiac work must have seen, is to be associated with an enterococcal type of infection we have an etiological asset of great importance. Unfortunately, so far the treatment of these chronic endocarditis cases has been practically hopeless.

IV. PHARMACOLOGY.

My fourth and final point with regard to advance is the consideration of the pharmacological aspect of cardiac disease. I do not intend to do more than indicate briefly the changes which have taken place with regard to teaching concerning remedies in common use. This group of scientists, the pharmacologists, are pushing steadily ahead, and to-day the student is taught, from a pharmacological point of view, what is the site of action of the remedy he is going to use. In such a subject, so recent and rapid in its development, we are bound to find unconfirmed statements and controversial points; but I believe that, just as physiology has now laid the recognized basis of our clinical teaching in medicine, so will pharmacology be the recognized basis of teaching of therapeutics. Pharmacologists are extending their sphere of action into consideration of problems of immunity, and one hopes that in this field they will equally show their powers of advance. To take, as an example, digitalis, its mode of action and its contained glucosides are to-day more fully understood, and thus we teach that its greatest advantage in therapeutics is the slowing of the ventricle, mainly by the depressing of conduction from auricle to ventricle. Or, again, one may consider the change of method of the administration of digitalis, as suggested by Eggleston, in large doses—a drachm and a half, followed by a drachm in six hours, and a drachm six hours later. The success claimed for this method will teach us not to rely upon small doses in urgent cases, but it is also well to remember that we must always standardize our doses of digitalis by observation of the patient.

One or two points on which we have pharmacological backing are: that calomel need not be avoided as a diuretic in renal disease associated with cardio-vascular change and oedema; that morphine, in medicinal doses, has practically no effect upon the cardiac muscle; it has a central or cerebral depressant action of enormous value; it does not influence to any extent the kidney secretion, and, except where respiratory depression must be avoided, can be given with safety in all cardiac cases.

Quinidine, a remedy of very recent introduction, is still under judgement. One point the pharmacologists have told us is that it is a depressant of the cardiac muscle, and experience has shown that we must carefully control its administration as it quickens the ventricle in the majority of cases. These two facts are most important where there is any question of the likelihood of failure of compensation. The use of adrenaline in Stokes-Adams disease, as suggested by Parkinson, and in the sudden cardiac emergency of chloroform poisoning, must also be noted. What exactly is the effect of pituitrin on capillary paresis has yet to be tested out.

There is no doubt that the work which is being undertaken from a pharmacological point of view will give us back, with a renewed confidence in them, many remedies which have been neglected.

In concluding this attempt to review some of the recent advances in the study of cardio-vascular disease it might be

said there are two distinct lines upon which progress has been made. The increase of knowledge of structure, mechanism, and function gives us a better basis for the recognition of the changes produced by disease—that is, an increased refinement of diagnostic classification. If, on the other hand, we assume that the incidence of the disease precedes these recognized changes, a point Sir James Mackenzie emphasizes, we will appreciate how developments in the study of etiology and immunity will bring with them a hope of new therapeutic methods.

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Lectures

ON

THE SYMPATHETIC INNERVATION OF STRIATED MUSCLE.*

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LECTURE II.—PART I.

THE FUNCTIONS OF THE TWO GROUPS OF MUSCLE FIBRES:

EXPERIMENTAL EVIDENCE.

In the first lecture I submitted the evidence that has accumulated during the last half-century in demonstration of the fact that the striated muscles of vertebrates consist of two kinds of fibres (in addition to the muscle spindles) and that the difference in their innervation is as distinct as the contrast in their anatomical features, one group being controlled by the spinal cord through medullated somatic nerves, the other by the central nervous system through the intermediation of the sympathetic system, the post-ganglionic non-medullated grey rami communicantes.

In the present lecture I propose to discuss the evidence obtained by cutting the sympathetic and the somatic nerves respectively in proof of the fact that the functions of the two groups of muscle fibres are as sharply distinguished as their structure and mode of innervation. Our preliminary experiments were made upon goats, not only because they are large animals with the simplest type of "standing reflexes," but also because Royle and I had acquired some experience of these animals under experimental conditions in the course of our investigations on spinal shock in 1920 and 1921.

The details of the experiments upon the goat have been given in the earlier accounts of our work in the *Medical Journal of Australia*. I can more usefully employ the time at my disposal in these lectures to explain the principles that guided us in our work and to discuss the results and certain technical points that throw light upon the issues in the present controversies.

In Fig. 3 the essential connexions of the sympathetic system are represented in a purely diagrammatic way. The white rami communicantes that issue from the spinal cord in the thoracic and upper lumbar region end in the ganglia of the sympathetic cord (or in one of the peripheral ganglia not shown in the diagram). From the sympathetic ganglion two series of non-medullated nerves emerge—one proceeding directly to the viscera of the thorax and abdomen, the other, forming the grey rami communicantes, passing to the

* Delivered by Professor Elliot Smith at University College, January 26th, 1925.

mixed nerve, to reach the striated muscles (*inter alia*) along with the somatic motor nerves.

By cutting the grey rami communicantes at A (as it should be the surgeon's aim to do in all human operations on the sympathetic) sympathetic innervation of the muscles in the area of distribution (as well as of the blood vessels

FIG. 3.—Diagram of the essential sympathetic connexions.

and sweat glands) is destroyed, but the sympathetic ganglia and the visceral nerves are left undisturbed, and the patient is spared the unfortunate effects of loss of proper control of visceral function, to which he is rendered liable when the sympathetic ganglia are needlessly removed. But for experimental purposes it is often necessary to cut the white ramus at B, and this is also done occasionally (for reasons to be explained later) in human patients. In this case the efferent channels from the spinal cord to the sympathetic cord are severed, not necessarily, nor even usually, to the ganglion (as Fig. 3 might suggest) that the ramus enters immediately, but to some part of the gangliated cord or one of the peripheral ganglia. In this case, as also in those cases where the sympathetic ganglion itself (at C) is cut or excised, the activity of both the visceral branches and the grey ramus is eliminated. The somatic efferent nerve may in some cases be cut at E without interference with the sympathetic rami. Another type of experiment—the section of the posterior root at D—cuts off all afferent impulses, both somatic and splanchnic. As the tone of muscle depends upon reflex activity, cutting off the afferent limb of the reflex arc destroys tone equally with damage to the efferent fibres (somatic at E, or sympathetic at A, B, or C).

In the human patient the grey and the white fibres may be so intermingled in the lumbar region as to make it impracticable wholly to spare the white fibres in the operation that Royle has called "ramisection."

With reference to the procedure for removing the influence of the sympathetic system on the hind limb of a mammal or the human leg, I cannot put the essential points more clearly than Royle has already done in his part of the Murphy Oration, illustrating the account with drawings (Fig. 4) made from the excellent dissection by Dr. T. K. Potts of Sydney (see *Journal of Anatomy*, January, 1925).

In experimental animals the sympathetic influence was removed from the left lower limb simply by avulsing the left abdominal sympathetic trunk. This operation could not be considered in the human subject on account of the changes that would follow removal of the sympathetic nerves to the abdominal viscera. The sympathetic nerves supplying the muscles of the lower limb arise from the lumbar ganglia and pass through the rami communicantes to the mixed nerves of the lumbosacral plexus. The human sympathetic ganglia receive white (preganglionic) fibres in some cases as low as the third lumbar nerve. Usually the contribution of white nerves to the sympathetic system ceases at the level of the second lumbar nerve. The dis-

tingction of white and grey rami in this situation is impossible, as it has been shown by N. Bishop Harman that the rami of the second and third nerves may contain both white and grey fibres. The sympathetic supply to the abdominal viscera is given off from the ganglionated trunk in a medial direction, and, provided the operation of ramisection were confined to lateral branches directed from the sympathetic trunk to the second, third, and fourth lumbar nerves, the effect upon the abdominal organs would be negligible. The division of the sympathetic supply to the fifth lumbar and to the sacral nerves presented a more difficult surgical problem, but this solved itself easily, because the sympathetic supply of the viscera is usually given off above the level of the fifth lumbar nerve and complete division of the sympathetic trunk at any point below the level of the fourth lumbar nerve would not affect the viscera. The sympathetic ganglia are not regular structures and do not always correspond in position to the lumbar nerves. The first ganglion usually lies in relationship to the second lumbar vertebra or the intervertebral disc below this vertebra. Below this the trunk may have three or more ganglia. There may, however, be only two definite ganglia.

The plan Royle adopted in the first operation was to divide the rami communicantes of the second, third, and fourth lumbar nerves (at the points marked A, B, and C in Fig. 4, the letters being used with the same significance as in Fig. 3), and to divide the sympathetic trunk at a level corresponding to the fourth lumbar vertebra (C). The

FIG. 4.—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.

exact level of section must depend, however, upon the presence of a ganglion in this situation, and also whether that ganglion is supplying any medially directed fibres.

The ganglionated trunk itself is a very variable structure, and this particularly applies to the region of the fourth lumbar vertebra. On many occasions the trunk in this

situation has been found to divide, and it was difficult to decide which division continued downward as the main trunk. The plan subsequently adopted was to define the ganglion which gives grey rami to the fourth lumbar nerve, lift it from its bed, and remove its lateral, posterior, and inferior connexions. Any medial fibres should be carefully preserved. When this ganglion is not present the ganglion supplying the third lumbar nerve may be unusually large and supply rami to the third and fourth nerves. The size of the ganglionated trunk may vary on each side of the body, and the rami may or may not come from the region of the ganglia.

The size of the rami varies with the number. A single ramus supplying a single nerve may be 2 mm. in diameter, though the usual size of a ramus varies between 0.5 and 1.5 mm. The accompanying diagram (Fig. 4) shows that the lumbar ganglion corresponding in position to the second lumbar nerve receives a large white ramus from the first lumbar nerve. In Royle's series of forty-two lumbar operations this arrangement was almost invariable; in only one instance was this large branch absent. In the first operation this ramus was mistaken for the white ramus of the second lumbar nerve and was divided, but subsequently the ramus has been avoided unless a special therapeutic effect was sought. In every operation both the white and grey rami of the second lumbar nerve have been divided. The position of the ganglia may cause considerable variation in the position and direction of the rami, but, with the exception mentioned above, the rami tend to travel laterally or laterally and downward.

The operation of cutting these three rami and the sympathetic cord at a lower level Royle has called "lumbar ramisection." The procedure for severing the sympathetic supply to the arm he calls "cervical ramisection." In this case the operation can be strictly restricted to the grey rami communicantes without cutting any white fibres or the ganglionated cord of the sympathetic. In Fig. 5 a drawing of Potts's dissection is shown.

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 composed wholly of grey (post-ganglionic) fibres, but the first thoracic nerve itself usually has both a white and a grey ramus. The sympathetic rami as a rule enter the nerve roots of the brachial plexus after they emerge from the intervertebral foramina, though occasionally rami will be found joining the nerve roots within the foramina.

According to the description of normal anatomy the nerve roots of the brachial plexus should emerge between the scalenus anticus and the scalenus medius muscles. In operations Royle says it is exceptional to find this arrangement. It is much more common to find the fifth and sixth roots piercing the scalenus anticus, and in several instances these roots have appeared anteriorly to the muscle. The seventh nerve; also is commonly separated from the eighth by a bundle of muscle fibres. The eighth and the first thoracic nerves usually emerge together in a plane posterior to the scalenus anticus. A regular plexus considerably simplifies

the operation, while the difficulty is increased if each nerve root emerges separately through the scalenus anticus.

All the grey rami proceeding to the roots of the brachial plexus are easily broken with a small strabismus hook in the operation of cervical ramisection. The grey ramus to the first thoracic nerve is found on the upper surface of the latter on the medial side of the white ramus (Fig. 5), cutting of which should be avoided if possible.

I have referred to the nature of the operations at this stage to give a precise idea of what actually is done. In the third lecture I shall return to the consideration of the indications for operation and the significance of the choice of these rami for avulsion. But before doing this I must discuss the experimental investigation of the functions of the two kinds of striated muscle.

Instead of describing the details of the experimental technique, which have been published in the memoirs

already mentioned, I prefer to discuss the reasons for such extreme diversities of opinion as to the influence of the sympathetic nerves on striated muscle. This may be most profitably done by discussing certain points in experimental technique—such as (a) the reasons for allowing a considerable interval

to elapse after removing the sympathetic before performing the operation of decerebration; (b) the method of examination of the animal so as to eliminate the disturbing effects of fear upon muscular tone, or the labyrinthine and cervical influences investigated by Magnus and de Kleijn; (c) avoidance of the effects of asphyxia and of anaemia of the brain-stem in decerebrate animals; and (d) the important matter of the choice of animals for experimentation. The latter two points—(c) and (d)—will be discussed in the third lecture. In this lecture I want to direct attention to the important information

obtained from my experiments on birds, most of which has not hitherto been published, although passing references have been made to the preliminary results in the *Medical Journal of Australia* (June 14th, 1924, p. 581) and in *Surgery, Gynecology and Obstetrics* (December, 1924, p. 724).

THE FUNCTION OF THE SYMPATHETIC INNERVATION OF STRIATED MUSCLE.

In 1913 de Boer, as the result of experiments upon frogs, claimed to have shown that the sympathetic nerve supply of skeletal muscle was concerned with tone. He believed that the tone of striated muscle was governed exclusively by its sympathetic nerve supply. All subsequent workers have shown that this contention is untenable; and many of them have gone to the other extreme and denied any influence of the sympathetic on muscle tone. The truth certainly lies between these conflicting claims. De Boer's view is being replaced by the conception that only a certain element of muscle tone owes its origin to the sympathetic nervous system. In 1915 Langelaan advanced the view that the tone of skeletal muscles consists of two elements, one component being governed by the somatic supply and the other by the sympathetic innervation of the muscle. This conception was independently arrived at by Revon. Later,

FIG. 5.—Drawing of the left brachial plexus in man to show the position of the grey rami communicantes which are avulsed in the operation of "cervical ramisection." After Dr. T. K. Potts.

Langelaan (1922), as the result of experiments on frogs, added further evidence in corroboration of this opinion. He failed, however, to clear away the fundamental objection to the acceptance of his theory—namely, that no investigator had shown tone to be altered consistently in decerebrate preparations as a result of sympathetic denervation; or, conversely, that decerebrate rigidity could develop if the sympathetic innervation were left intact while the somatic nerves were severed.

The importance of decerebrate preparations consists in the fact that, from their study in the hands of Sir Charles Sherrington and others, most of the prevailing ideas of muscle tone have been derived. Sherrington proved that the tone of skeletal muscle was postural in function. He found that the typical position of the decerebrate animal was that of "reflex standing," with all four limbs rigidly extended, and the neck retracted to a greater or lesser degree. Between the phases of rigidity there were periods in which the limbs were no longer maintained in extension. During these periods, or when the extension of the limbs was overcome by passive movement, the musculature was found to exhibit a condition of what Sherrington has called "plasticity." If the leg were flexed at the knee, so lengthening the extensor muscle of the thigh, this position was retained ("lengthening reaction"). If the knee were now extended, so shortening the extensor muscle, the new position was again maintained ("shortening reaction"). Sherrington called the property of skeletal muscle which enabled it to exhibit these reactions "plastic tone." He emphasized that the degree to which this property was exhibited was independent of the length of the muscle fibres exhibiting it. It is important to remember that Sherrington was not using the word "plastic" in the popular sense of being adaptable or easily moulded; what he meant by it was the retention of any position in which a limb was placed. Following the suggestion of Gruetzner and others, he compared this property of skeletal muscle to that of involuntary muscle, such as that which surrounds the bladder wall, which enables it to adjust itself to enclose an increasing volume under practically the same wall tension. Speaking of this comparison Sherrington says: "Both are instances of the postural contraction of muscle; though the relation of the central nervous system to the postural activity is very different in the two cases." For Sherrington believed that the tone of striated muscle was entirely dependent on the intactness of the somatic motor nerve supply, while involuntary muscle can exhibit tone in the absence of its innervation.

The objection to the view that the tone of skeletal muscle is partially governed by the sympathetic nervous system, which has been put forward because experimenters employing the decerebrate preparation have obtained negative or apparently inconsistent results, disappears with the publication of our experiments (the memoirs of Royle and myself). In this work evidence of the connexion of the sympathetic innervation with the tone of skeletal muscle is forthcoming, not only from experiments upon the decerebrate goat, but from the effect of sympathetic ramisection in patients suffering from forms of spastic paralysis, which prior to operation revealed all the essential qualities of decerebrate rigidity. In normal, "spinal," and "decerebrate" animals, and in human patients, sympathetic denervation of the limb musculature led to a consistent qualitative alteration in muscle tone. The defect was found to be a lessening of the efficiency of the muscle in maintaining a position once it had been assumed. This was the case whether the position had been imposed passively, reflexly, or by voluntary contraction; and, as I have previously argued,¹¹ is due to the same fundamental change—namely, the loss of plastic tone. In the decerebrate preparation, after passive movement, the limb deprived of its sympathetic innervation failed to maintain the new position imposed upon it, when the extensor muscles were either lengthened or shortened. Instead, the limb would fall back to a posture determined by the action of gravity and the length of the fibrous tissues entering into its composition. This illustrates the effect of sympathetic denervation to remove plastic tone, as evidence of which is the absence of the "lengthening and shortening reactions" of

Sherrington. The skeletal muscles of human patients show a similar qualitative alteration. This is clearly shown, for instance, in one of Dr. Royle's patients with spastic paraplegia supervening upon a gunshot wound of the cerebral cortex. Prior to operation this patient clearly exhibited "lengthening and shortening reactions" of the extensor muscle of the knee. Before operation, if the left thigh were lifted from the bed the unsupported leg would remain extended for a long period of time. If the extended leg were passively flexed at the knee-joint it would remain flexed in its new position. If it were now passively extended the extended position would be maintained. After left lumbar sympathetic ramisection these reactions, which are identical with the "lengthening and shortening reactions" of the decerebrate preparation described by Sherrington, were no longer exhibited—that is, plastic tone was removed by the operation.

But it is important to notice that tone does not entirely disappear after sympathetic denervation. Only one efferent pathway to the skeletal muscle has been removed (compare Fig. 3). The remaining somatic innervation is responsible for another component of muscle tone. In the acute decerebrate preparation, for instance, notwithstanding the removal of its sympathetic nerve supply, the typical extensor attitude of the limb is assumed. The neuromuscular mechanism concerned in imposing the extended position is obviously intact—that is, the medullated somatic nerves are responsible for this function. It will readily be seen that the extensor muscles must be shortened in order that the extensor attitude of the limb may be attained. The antagonistic muscle groups, on the other hand, are reflexly inhibited, as Sherrington's studies of the acute decerebrate preparation have shown. Their component of tone, which is somatic in origin, and is exhibited as a degree of contraction of selected muscle groups, may, following Langelaan, be called "contractile tone."

Contractile and plastic tone are both postural in function. Contractile tone imposes posture as a result of shortening of appropriate muscle groups; plastic tone takes part in maintaining this posture, once it has been attained, by fixing the length of the muscles exhibiting contractile tone. On account of the responsibility of these two components of tone in the production and maintenance of posture they may together be regarded as constituting postural tone.

As Sherrington has shown (by cutting the appropriate afferent nerves) the production of postural tone depends upon the existence of proprioceptive impulses. Posterior nerve root section in all the spinal segments connected with a given muscle removes both contractile and plastic tone. Impulses arising in the muscles, therefore, discharge (via the central nervous system) through both the somatic motor nerve roots and the white rami of the sympathetic nervous system. In other words, contractile tone is subserved by a somatic proprioceptive reflex arc; plastic tone is governed by a sympathetic reflex arc. As the result of the limited connexions of the sympathetic nervous system with the spinal cord, these reflex arcs for a given muscle group are usually situated at different levels of the central nervous axis. Purely spinal reflexes are, however, inadequate in higher vertebrates for the exhibition of the postural tone responsible for the natural attitudes of the body. The reflexes responsible for the extensor attitude of the lower extremities depend, for instance, upon reflex arcs that pass as high as the pons in the brain stem. It appears that the vestibulo-spinal tract is the descending limb of the reflex arc subserving the contractile tone to the extensor muscles of the limb; while plastic tone depends upon a reflex arc the descending limb of which is constituted by the panto-spinal tracts. I have recently argued¹² that these reflex arcs are governed by the tectum, substantia nigra, and red nucleus of the mid-brain, and the corpus striatum and the cerebral cortex by way of the cerebellum. The influence of all these structures upon postural tone is produced ultimately through both the somatic and sympathetic efferent connexions to skeletal muscle. In other words, there are two final common pathways to each muscle. The excitatory impulses emerging through the somatic motor pathway all give rise to a contraction of the muscle or to contractile tone. The effect of the excitatory impulses emerging through the sympathetic rami communicantes is to fix the existing length of the

muscle (plastic tone). It is obvious that this is a primary subdivision of postural tone according to the properties subserved by the two efferent connexions of skeletal muscle. The sources of the impulses emerging through each pathway are numerous in each case, as already mentioned. Both connexions are in fact final common pathways in the sense of the term employed by Sherrington.

TECHNIQUE OF EXPERIMENTS IN WHICH THE DECEREBRATE ANIMAL WAS EMPLOYED TO DETERMINE THE EFFECT OF REMOVING THE SYMPATHETIC INNERVATION OF SKELETAL MUSCLE.

The negative and inconsistent results obtained by previous investigators employing the decerebrate preparation to determine the function of the sympathetic innervation of skeletal muscle call for comment. The following points appear to have been of importance in leading to the success of the experiments of this kind in the hands of Dr. Royle.

The Interval between the Removal of the Sympathetic Cord and the Operation of Decerebration.

In our experiments on goats the lumbar portion of the sympathetic trunk was removed from one hind limb. This was done as a preliminary procedure. Then, at a variable period after this operation decerebration was performed. In our first series the interval between the two operations varied from seven to seventy-three days. The best contrast between the hind limbs on the operated (left) and unoperated (right) side was seen in the animal in which the interval between the operations had been longest. In this animal extension of the left limb was easily overcome in contrast to the opposite limb. When not handled with the animal lying in the supine position, so fixed as to eliminate the disturbing influences, vestibular and cervical (such as Magnus and de Kleijn have described), the left limb rapidly fell from its temporary position of extension to a passive posture of semiflexion. In this stage of relaxation the "lengthening and shortening reactions" were absent.

These effects depend upon the loss of plastic tone. The comparative ease in performing passive flexion of the extended limb is due to the fact that contractile tone, which is responsible for thus imposing this position, alone has to be overcome to alter the position. On the intact side, while contractile tone is responsible for the position of extension, it is assisted by plastic tone, which tends to fix the length of the muscles necessary to maintain this position. When contractile tone is overcome on the partially denervated (that is, deprived of sympathetic nerves) side no further resistance to movement is offered. On the opposite side, though resistance suddenly gives way when reflex shortening of the extensor muscles (that is, contractile tone) is overcome, some degree of resistance to passive flexion is still

maintained, because plastic tone still persists. As Walshe has pointed out, this phenomenon has its counterpart in the clasp-knife effect of decerebrate rigidity.

Decerebrate rigidity is due to the presence of an exaggerated degree of both contractile and plastic tone. The extended position imposed by contractile tone (as the result of the

FIG. 6.—Decerebrate goat with both fore limbs and the right hind limb rigidly extended. The left hind limb (deprived of its sympathetic innervation) is relaxed. Head and neck fixed to prevent Magnus and de Kleijn phenomena. Note the force necessary to bend the right hind limb.

selective reflex shortening of the extensor muscles) is rigidly maintained by the fixation of the extensor muscles in their shortened state by plastic tone. In the absence of plastic tone this rigid fixation is no longer apparent, and the limb fails to maintain the extended posture (Fig. 6) once the reflex shortening of the extensors dependent upon impulses emerging through the intact medullated somatic nerves ceases. The active posture of extension is now no longer maintained.

When the limb was passively extended or relaxed spontaneously it would fall into a semiflexed position determined by gravity and the length of the fibrous tissues contained within the limb. If the knee-joint were now passively flexed or extended the leg would resume its original posture. In other words, a passive posture characterized the limb instead of the ability to occupy active postures, which is the property of the normal musculature in the decerebrate preparation. For the "shortening and lengthening reactions" are no longer exhibited—that is, plastic tone is absent.

Unquestionably these three manifestations of the loss of plastic tone are not so clearly exhibited when the interval between lumbar sympathectomy and decerebration is short—for example, when decerebration is performed on the same day as that on which the lumbar sympathetic trunk is removed. I have records of three decerebrate preparations that exhibited the "lengthening and shortening reactions" in this way when both procedures were carried out on the same day. In each of these, however, the resistance to passive flexion and the tendency for the maintenance of the extended position were definitely less than on the control side.

The explanation of the progressive loss of plastic tone may be that this property of skeletal muscle is less dependent upon impulses emerging from the central nervous system than is contractile tone. In this respect skeletal muscle would resemble, to a certain degree, smooth muscle, the tone of which is not absolutely dependent upon its nerve supply. However, there are difficulties in accepting this analogy as an adequate explanation, because recovery in the tone of involuntary muscle occurs as time advances following denervation. But in view of the fact that only some muscle fibres receive sympathetic nerve fibres and are therefore alone responsible for the property of plastic tone (see the first lecture), it is feasible that these denervated "fixing" fibres slowly lose this property following sympathetic denervation, so differing from the neighbouring "movement fibres," which are absolutely dependent for their property of contractile tone upon the intactness of the central connexions of the somatic nerve fibres that supply them. Moreover, in the lumbar operation so far employed, it is necessary to bear in mind that all the sympathetic ganglia from which the grey rami to the lower limb arise are not removed, though efferent impulses from the spinal cord to them are eliminated. This fact may perhaps in some measure account for the progressive loss of plastic tone. However, the whole problem of the determination of the time necessary to produce the complete effect after sympathetic denervation is now being investigated. It can best be solved by studying the effects of the operation in the chronic decerebrate animal described by Bazett and Penfield.¹³ Delaying the operation of decerebration until a long interval after the removal of the sympathetic cord disposes of certain claims that have been made in the attempt to explain the changes revealed after sympathetic denervation. In the first instance diminution in tone cannot be ascribed to sensory inhibition due to the wound inflicted in performing the operation of sympathectomy,¹⁴ for ample time is provided to allow healing of the wound to occur. Nor are the changes due to vaso-dilatation, because the diminution in tone persists, or even increases in degree, although the vasomotor changes are a maximum immediately after the operation.

Sympathetic ramisection in human patients affords similar results in this direction; for the loss of plastic tone has persisted for twelve months in the case of Royle's first patient subjected to the operation, although obvious vasomotor changes were present only in the first few weeks. In other patients the circulatory disturbance has been of greater duration; but it had a general tendency to be reduced in degree, while the loss of plastic tone was still apparent. Some of the effects of sympathetic ramisection upon tone may, however, be due to the attendant increase of blood supply to the limb. I refer to its effect upon contractile tone. Dr. Royle has noticed, for instance, that cold has less effect in increasing contractile tone in the limb of a spastic paraplegic which has been subjected to operation than in the limb of the opposite side. As a result of vaso-constriction the limbs of the spastic paraplegic are

invariably colder than normal. The advent of vaso-dilatation (with an attendant increase in temperature of the limb) lessens the degree of contractile tone. This reduction is greater immediately after the operation than it is subsequently, for the vasomotor changes become less marked as time proceeds. But the reduction in plastic tone progresses in the opposite direction.

The Method of Examination of the Animal.

After removal of the sympathetic innervation of one limb the otherwise intact goat can walk, and run, in the normal manner. The characteristic change produced by the operation is revealed, however, if the animal is placed in the supine position with its head held rigidly in the mid-line. All limbs take up an extended posture under these conditions, but, as Dr. Royle has shown, when the cause for alarm is removed by gentle handling of the animal—for fear excites the defensive reaction of extension—the lower limb of the operated side falls from the extended position into a passive posture determined by mechanical factors. This method of examination for changes in the postural tone of the limb was adopted with advantage for the decerebrate preparation. The goat is placed in the supine position in a cradle and the head is held firmly in the median line, or the animal is first encased in a leather jacket which fits round the trunk and neck, and then placed in the cradle. In this way the effects of the tonic labyrinthine and neck reflexes of Magnus and de Kleijn are excluded. Under these conditions the typical extensor posture, as already explained, is assumed by all four limbs. But after a short period the limb which has been deprived of its sympathetic innervation falls under the action of gravity to a passive posture of abduction and semiflexion.

By this method of examination any defect in the maintenance of posture is readily indicated by failure of the skeletal musculature to support the weight of the limb. This is a matter of importance, for efforts to test for diminution of tone by passive movement set up a reflex spasm of the musculature of the limb which is evidence of the excitability of the nervous connexions responsible for contractile tonus. Clinicians are familiar with this observation. For spastic muscles may before palpation show no evidence of an increased degree of contraction: but a reflex tonic contraction is set up immediately passive movement is attempted. In the first phase the posture is maintained predominantly by plastic tone. After examination of the limb is commenced increased contractile tone is superadded. Obviously the effect of passive movement will be to obscure any diminution in the degree of plastic tone. Nevertheless, passive movement overcomes contractile tone alone more easily than contractile and plastic tone combined.

The results of my experiments on the wings of birds are so important and illuminating that, at the risk of making this account unduly long, I must make some reference to them.

REFERENCES.

- ¹¹ Brain, 1924. ¹² Surgery, Gynecology and Obstetrics, 1924. ¹³ Brain, 1922. ¹⁴ Compare Uyeno, *Journ. of Physiology*, 1922, p. 359.

(To be continued.)

TUBERCULOSIS INCIDENCE AND CLIMATE IN INDIA:

RAINFALL AND WET WINDS.

BY

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IN 1923 I published maps¹ showing a close world-wide relation between high rainfall and high leprosy incidence, and also demonstrated the same point in detail for India by means of the leprosy census figures and a study of the rainfall records of two thousand stations in that country, the only exception being that the disease appears to have spread from the wet Bombay coast into the comparatively dry Deccan along the oldest known trade routes in India. I also collected data regarding the incidence of tuberculosis in a number of tropical countries, but found the relation to rainfall to be less striking than in the case of leprosy, while M. Kerandel² has recently come to a very similar

conclusion from a study of tuberculosis in the French colonies, as, although the hot, dry climate of the Sudan is unfavourable to the development of tuberculosis, he found no general close relationship between climate and the incidence of the disease. This is largely due to the variations in the type of the disease with the degree of tubercularization of races. Those recently infected, such as in some areas of Oceania and tropical Africa, show the acute rapidly fatal infantile type with a low percentage of positive tuberculin reactions; while in Indo-China, with evidence of centuries of tuberculosis, the more chronic European type with a fairly high percentage of tuberculin reactions is found. This is also the case in India, where I met with many cases of fibroid phthisis in the *post-mortem* room, in spite of the disease running a somewhat more rapid course in that hot climate than in Great Britain, as A. Powell³ also found in Bombay.

India, therefore, presents very favourable conditions for a study of the incidence of tuberculosis in relation to climatic conditions, for this large country shows extremes of rainfall from 500 inches on the south side of the Khasia Hills of Assam to 5 or less in North-western India. It also affords splendid meteorological records, and reliable data regarding the incidence of phthisis in the jail population; these institutions are under Indian Medical Service officers, and necropsies are regularly performed on fatal cases, and the actual figures and the rates per mille are published in the annual reports of the Sanitary Commissioner with the Government of India. For the purposes of the present inquiry I have worked out the phthisis rates of all the jails for ten consecutive years; they total over one million persons. I have selected a decade subsequent to the 1891-92 influenza pandemic, and prior to that of 1918, which so greatly increased deaths from tuberculosis in India. The yearly figures for each of the areas into which India has been divided in relation to the climatic features for the purposes of the Sanitary Commissioner's report, show such closely similar figures year by year that they are clearly sufficient for the purpose in view.

The distribution of pulmonary tuberculosis in the Indian jails thus obtained is shown in rates per mille of the jail population in Map 1, the crossed lines representing over 10 per mille, the single horizontal lines 7 to 10, the dotted areas 5 to 7, and the unshaded parts under 5 per mille, the actual figures being entered in the squares in each area, with the number of the area above it. The left-hand small inset map shows the annual rainfall distribution of India, while that on the right gives the absolute humidity, or mean daily aqueous vapour pressure, of July at the height of the south-west monsoon rainy season; this allows ready comparison of the high and low tubercle areas with the rainfall and humidity, which may now be considered. The numbers in parentheses refer to those of the different areas for convenience of reference.

Relation of Tuberculosis to Rainfall.

The first point to be noted is the general relation, with certain exceptions, of high tubercle rates and high rainfall, as shown by the very high tubercle rate of 13.7 in Bengal with the very heavy rainfall of over 75 inches, and of 10.9 in the West Coast area (10) with 100 inches of rain annually. Connecting these two areas is the eastern Madras coast (11b and 11c) with 10.6 to 12 per mille, and an annual rainfall of 30 to 50 or more inches; here it is important to note that, although the total rainfall of the Madras coast is less than that of Bengal and the western coast, it is distributed over seven or eight months of the year, instead of being limited to the four monsoon months from the middle of June to the middle of October, as in most parts of India, for the Madras coast gets part of the south-west monsoon, followed by the exclusive influence of the north-east monsoon from October to December, so that its climate is particularly humid. Its relative and absolute mean annual humidity is, in fact, greater than that of any other part of India except Lower Burma. On the other hand, Central Madras (11a) has the comparatively low annual rainfall of 20 to 30 inches, but the high tubercle rate of 11.7 per mille. This exception requires explanation; this area has a low leprosy incidence. The Andaman