Preliminary Note

ON

INVESTIGATIONS UPON ONE THOUSAND CONSECUTIVE CASES OF PERIPHERAL NERVE INJURY.

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THE most important preliminary to every communication on nerve injuries is a full statement of the methods employed to obtain the stated results.

In reading and criticizing the work of others our chief difficulties arise from a lack of knowledge of the methods that they have employed to arrive at their conclusions.

First, to be of practical value, routine observations on cases of nerve injury should be made at regular intervals if possible.

Secondly, a system of careful case-taking and charting is necessary.

Thirdly, there must be a standardization of methods used so that the successive observations are exactly comparable.

In recording sensory changes the commonest mistakes arise from the use of moderately coarse stimuli, which appeal to deep sensation although intended to stimulate the more superficial sense organs.

Recent writers have omitted to draw attention to the fact that local temperature changes cause most remarkable variations in sensory functions. Examination in a cold room, and of a cyanosed, oedematous, or chilled limb, will give many motor, sensory, and electrical variations from the healthy state. From observations so made misleading conclusions are drawn unless the observer be experienced enough to recognize and correct the causes of the phenomena encountered.

The methods employed for routine work by us are rougher than we would wish, owing to the large number of patients to be examined and reported upon. Certain patients only are picked out for special observation. These patients are chosen, some because their lesions are definite, and others because of a high degree of intelligence, which facilitates the recording of their sensations, etc.

PRELIMINARIES TO EXAMINATION.

Attention is directed to the following points in recording the history of the lesion:

The nature of the injury.

The position of the patient at the time that the injury was received.

Immediate effects.

After-history, which includes notes on the surgical treatment to date.

Temperature of the Limb.

It is misleading from a diagnostic point of view to examine a cold limb, either electrically or to note sensory disturbances. Head and Rivers noted the relapse of sensibility from the delicate epicritic sensation to the more primitive protopathic under the influence of low temperatures, and we have repeatedly confirmed this in recovering lesions. Unless thermal sense is to be minutely noted we are in the habit of warming up cold limbs a little above body temperature in warm water.

More recently we have used a bath of liquid paraffin wax. The wax should have a low melting point, not more than 40° C., and the bath should be kept at a standard temperature by electric heating. Many of the conflicting reports recently published—on electrical reactions, for instance—are due to the work being done on cold limbs. It is possible to obtain almost any variation in electrical responses with chilled nerve and muscle. This may be proved by adapting a healthy limb to heat or cold and noting the responses to electrical stimulation. Where vasomotor functions are much impaired the

variations in electrical responses are most striking. There are doubtless problems of pathological chemistry which, when solved, will account for local variations in such cases.

Shaving of Skin.

This is not done as a routine. We have removed the hairs for certain observations, especially where sensation is returning and it is desirable to exclude "hair sensibility," or to note something of its influence by exclusion.

Shaving upsets an area of recovering skin sensibility for hours. The warming of a skin area, or shaving, is most conveniently left until the inspection examination is complete, but should be done before the palpation and sensory observations are carried out.

THE EXAMINATION.**1. Inspection.**

The limb or part is fully inspected to note:

Bones.—(a) Position of wounds and scars; (b) attitude of the limb.

Joints.—(c) Presence of contractures.

Muscles, etc.—(d) Muscular atrophy, its distribution, and whether in any special group, distribution with reference to nerve supply or joint control; (e) muscular tremor or fibrillation. It should be recalled that muscular atrophy does not appear in most cases of complete nerve division until some weeks after the injury. In three months it is pronounced as a rule.

Skin.—The skin is next scrutinized for trophic changes—ulcers, blebs, delayed shedding of epidermis, "branny skin," "glossy skin," etc. The distribution with regard to nerve and root areas of such changes.

Nails.—The finger-nails give more reliable information than toe-nails. Colour, shape, striations, brittleness, rate of growth, etc., are noted.

Vasomotor.—Colour of the skin, dryness or hyperidrosis, oedema; the exact limits of these changes.

Hairs.—General arrangement of (regular or irregular), hypertrichosis, or, on the other hand, absence of hairs.

2. Palpation.

Scars.—First the wound region is examined. Scar induration and fibrous nodules, or neuromata in superficially placed nerves are noted.

Nerves.—Quite gentle pressure is next exerted over the nerve trunks to note any paraesthesia caused. This is usually described by the patient as a bursting sensation, or a tingling, or "pins and needles sensation" and referred to the skin area supplied by the nerve under the finger. The exact level on the nerve trunk peripheral to the injury that the palpating finger reaches before the paraesthesia ceases to be felt should be noted.

Joints.—Joints of a limb should be gently moved passively to demonstrate the degree of stiffness, ankylosis, etc. Voluntary movement on the part of the patient should next be observed. Individual muscle and tendon are watched and palpated so that mimicry by surrounding muscles which are healthy will not mislead the observer.

Muscles.—Limbs should be placed in neutral positions to avoid the effect of gravity on weak muscles; a useful manoeuvre to note returning voluntary power after paralysis. It is easy to judge the amount of effort that the patient is exerting by watching the surrounding muscles. Muscles should also be palpated to obtain a correct idea of their tone, "spasm," or fibrous contracture. Pain on pressure or pinching of the muscle is noted in irritative nerve lesions.

3. Percussion.

Direct percussion of muscle bellies and tendons is necessary to observe the nature of the response to this form of mechanical stimulus.

Slow contractions are obtained by direct percussion of the muscle bellies in cases of muscles where reaction of degeneration is subsequently found to be present; the amplitude of the curve of muscle contraction in such cases is considerable, with a slow rise and fall. Cold limbs are associated with a contraction of small amplitude and of a sluggish character.

In cases of "reflex contracture" (the physiopathic contracture of Babinski and Froment) a slow contraction of large amplitude is the rule.

SENSORY EXAMINATION.

1. *Light Touch.*

We have used an artist's small brush with ermine hairs, of which all but a few are removed. This is much easier to work with than cotton-wool and the strengths of the stimuli vary less. The brush is applied with short stroking movements, holding it in a slanting direction so that contact with the skin occurs at an acute angle. In this way no deformation of skin by pressure takes place. The calibrated hairs originated by Von Frey have not been used in routine examinations owing to the large number of cases to report upon in a limited time. In recovering lesions and in some partial lesions the skin has been shaved to note the effects of "hair sensibility" stimulated by tension on the pilomotor apparatus during examination of touch and pressure, etc. Where anaesthesia is complete, shaving is unnecessary. Shaving, when required must be performed some hours before the sensory examination is attempted, because of persistent paraesthesia which follows such coarse skin stimulation in many recovering cases.

2. *Sensation to Pin Prick.*

We have used the spring algometer described by Head and Holmes for investigating this sensation.

The chief value of this instrument is that the needle is controlled by a spring, the pressure of which can be adjusted. In this way a standard stimulus is obtained, and the value can be charted. Readings obtained at later examinations may then be safely compared and progress noted. The sensation of pin prick is a compound one, made up of a sense of pressure, which the patient describes as "blunt," and a sensation of "sharpness," which is distinctly of a class of discriminating sensibility (epi-critic).

3. *Thermal Sensibility.*

It is very difficult to obtain accurate and strictly comparable records of sensation to heat and cold.

Small nickel-silver tubes fitted with corks and thermometers are used for large areas; Goldscheider's pointed solid metal cylinders and medium copper wire for punctate sensibility. The varying external temperature, skin temperature, etc., make the difficulties very great and the examinations long and tedious. Except for selected cases and spinal cord cases, we have so far found it impossible to make routine examinations of thermal sense. Unless all the fallacies are guarded against, observations are inaccurate and may be actually misleading.

4. *Deep Sensibility.*

(a) *Pressure.*—Threshold values may be obtained by some form of algometer. We have used the algometer described by Head and Holmes for many cases. With a small disc of cork on its point a pure tactile pressure effect can be obtained when the weights are added. When the point is used without its shield, then pressure pain is invoked. In both cases the stimulus is standardized, and in the subsequent examinations readings charted some weeks before may be strictly compared.

(b) *Roughness.*—The Graham Brown aesthesiometer is used to obtain threshold values, and the result compared with the reading on the healthy side. In recovering lesions the radiating tingling and other sensory abnormalities present make the readings almost valueless.

(c) *Localization.*—For charting this sensory function a large diagram of the part under examination is used. The

patient points with a pencil to the spot corresponding to where he feels the pressure (in deep sensibility) or the spot lightly touched (discriminating sensibility). Localization may be conveniently noted during the examination of touch and pressure.

(d) *Joint and Muscle Sense, Bone Sense.*—Joint and muscle sense may be tested by gentle passive movements. The bone sensation to tuning-fork vibration is noted in routine. Difficulties will be experienced from "overflow" conductions, especially near joints.

5. *Discriminating Sensibility.*

(a) *Size and Shape.*—Common everyday objects are used to observe this function. The patient names them, their size, thickness, etc., by his sense of touch unaided by sight.

(b) *Texture.*—Wool, cotton, cloth, silk, indiarubber, etc., are compared in turn by the patient, who is allowed to use his sense of touch only. He names each fabric in turn.

6. *Recognition of Two Blunted Points applied Simultaneously.*

For observation of this sensory function two blunted compass points have been used. The points are applied at the same moment in the longitudinal axis of the limb, and the patient simply states whether he feels two points or only one. To make control observations the readings from the healthy side are taken first, the skin being touched with two points, or with one as a variation. The distances apart of the points and a record of the patient's answers are kept.

FIG. 1 AND FIG. 1A.—The hatched area shows the average loss to light touch in our series of complete lesions of the ulnar nerve above the wrist. The outer crossed line shows the larger area over which discriminating sensibility is lost. The inner crossed line corresponds to the points at which pin prick is first appreciated, but as a "blunt" sensation.

ELECTRICAL EXAMINATION.

A. *With Interrupted Current.*

The limb must be thoroughly warm and the skin moist so that its resistance may be as low as possible. No preliminary massage should be allowed. An ordinary medical induction coil is used, and the current from its secondary employed.

A key "make" and "break," or metronome with mercury cups is attached to the testing electrode. A large pad for the indifferent pole is placed over the nerve trunk centrally and away from the field of exploration.

A small "button" electrode is used on the motor points of the muscles and then on the nerve trunk if superficially placed.

A positive reaction to faradism is valuable and will definitely exclude a serious lesion of the lower neuron system—that is, the motor cell in the cord and its peripheral process.

A positive reaction to the rapidly interrupted current will also be observed in hysterical (pithiatic) cases; reflex (physiopathic contracture) cases, lesions of the upper motor neuron; functional cases generally, and cases of malingering.

For the lower neuron lesion a stimulus of much longer duration is necessary to invoke a response. A patient with a recovering peripheral nerve lesion is nearly always able to move affected muscles before faradic responses are obtainable (cf. also Duchenne).

Character of Contraction.—Slow with small amplitude in the muscles of cold limbs, partial lesions of peripheral nerves, or where limbs have been immobilized in splints for a long time. Slow, prolonged, and of large amplitude in recovering lesions of nerves. Brisk responses in healthy muscles where the limb is warm. Quick with increased amplitude in "reflex contractures" and in some functional cases.

B. Examination with the Constant Current.

We have used a switchboard fitted with a wire rheostat for the purpose of varying the strength of the current, which is supplied from a motor transformer adjusted to give a constant current at a hundred volts pressure. A milliammeter and a switch for reversing the direction of the current through the patient's circuit complete the apparatus. The electrodes used for the faradic test are also employed for galvanic stimulation. The large pad is placed on the root of a limb over its nerve trunks, or to the side of the spine. The small electrode is applied to the skin over the muscle bellies, choosing points as near as possible to the motor points, or simply over the main mass of muscle substance. The small electrode is first made the kathode by leaving the pole-reverser switch at "normal." The current is gradually increased by sliding the traveller of the rheostat in the direction marked "strong." After each small addition the current is broken and restored again by means of the testing key (or metronome). The smallest amount of current necessary to cause a contraction with the negative pole (kathode) is noted. The direction of the current is then changed by swinging over the pole-reverser switch, so that the testing electrode now becomes the anode, or positive pole. The current is made and broken as before, and the amplitude and other characters of the contraction are noted and compared. Most stress is laid upon the character of the muscular contractions, particularly upon the slow rising, slowly subsiding, "worm-like" or "wave-like" contraction which seems to spread in both directions along the muscle fibres from the neighbourhood of the electrode. With the kathode on the tendon of a muscle a "longitudinal reaction" may be sought. This consists of a slow undulating response which sweeps over the muscle from the point of stimulation, and it is found in those cases where the muscle gives a classical reaction of degeneration. We should here emphasize that although the classical reaction of degeneration is sometimes absent in cases of undoubted complete discontinuity of the nerve, yet in a very large number it is certainly present, and the character of the muscle contraction is most reliable, always provided that the observer will take care that a limb is reasonably warm before examination.

Analysis of the First Thousand Neurological Records.

Nerves Injured.	Times Injured.	Nerves Injured.	Times Injured.
Ulnar...	527	Anterior tibial ...	5
Median ...	242	Musculo-cutaneous (leg) ...	2
Musculo-spiral ...	204	Anterior crural ...	5
Radial (cutaneous) ...	20	External saphenous ...	1
Posterior interosseous ...	19	Internal saphenous ...	2
Musculo-cutaneous (arm) ...	24	Spinal cord ...	5
Internal cutaneous (arm) ...	26	Cauda equina ...	2
Brachial plexus:		Functional cases:	
Root lesions ...	17	Hand ...	1
Outer cord ...	17	Arm ...	1
Inner cord ...	19	Physio-pathic cases:	
Posterior cord ...	24	Hand ...	4
Cervical roots ...	12	Arm ...	1
Circumflex ...	2	Leg ...	3
Facial nerve ...	2	Hemiplegia ...	3
Spinal accessory ...	2	Syringomyelia ...	1
Sciatic ...	121	Brown-Séquard paralysis ...	2
External popliteal ...	97	Causalgia ...	4
Internal popliteal ...	8	Trench fever paralysis ...	1
Posterior tibial ...	8	Muscular lesion ...	1

In some cases of the above series multiple nerve injury was present.

NOTES ON SOME OF THE INJURED NERVE TRUNKS.

Brachial Plexus.

A. Roots.—Lesions of cervical roots occurred in 29 instances. Wounds above the clavicle most frequently

injure cervical roots 5 and 6, either separately or after their junction to form the upper trunk. Damage to the lower roots we have seen less frequently, owing to the fact that concomitant vascular injuries cause speedy death from haemorrhage. Recovery after complete division is surprisingly slow even in the case of such a purely motor root as the fifth cervical.

B. Cords.—The outer cord was involved 17 times, the inner cord 19 times, the posterior cord 24 times.

Recovery after suture occurs earlier than one would expect in lesions so remote from the periphery.

Musculo-spiral Nerve.

This nerve was injured 204 times.

Return of function is apparently more rapid than in any other nerves after suture. The length of interval between the date of injury and the date of repair seems to bear no constant relationship to the rapidity with which recovery takes place. The local sepsis, scar tissue, and other conditions at the site of injury strongly influence prognosis.

We have confirmed the fact that the radial branch of the musculo-spiral has no exclusive area of supply for deep sensibility. This is mainly supplied by the median and ulnar nerves under

the radial skin area. The musculo-spiral has few pain fibres in its bundles. Where the nerve is divided in the upper arm, voluntary movement after suture is noted in the dorsiflexors of the wrist in from seven to eight months on an

average. The last muscles to recover, as a rule, are the thumb extensors. In a few cases we have observed the return of a degree of power in all muscles in so short a time as fifteen months. One of these patients has since

re-enlisted and has proceeded on active service. Much inco-ordination is evident at first when voluntary movement returns.

Median Nerve.

This nerve was injured 242 times.

The fibres of supply to the outer interosseous muscles may be distributed via the inner head of the median instead of by the ulnar nerve as usual. It is not uncommon to notice a healthy abductor indicis (first dorsal interosseous muscle) in a case of completely divided ulnar nerve in the forearm—a useful fact to remember when recording progress of ulnar nerve function after suture.

The median flexor group in the forearm recover much before the intrinsic muscles of the hand after nerve repair. The average lapse of time after suture of the nerve before voluntary power is noted in the flexor group of the forearm is from seven to eight months.

The small muscles in the hand take from fourteen to twenty months or even longer for recovery. Voluntary movements seem to appear earlier in cases where re-education exercises are given to co-ordinate the muscle groups than in cases where such treatment has not been carried out.

The inner cord and inner head of the median contain the bulk of those fibres, in the upper extremity, which, when irritated, give rise to the syndrome of "causalgia." The symptoms are always associated with the development of scar tissue in the nerve bundles. The fibrosis may be very small in amount and to the naked eye invisible, but is quite a feature of these cases microscopically.

Alcohol injections for true causalgia have proved of little permanent value in our experience. The intense continuous pain of causalgia with its effects on the patient's mentality, the gradual contracture, and increasing uselessness of the hand, justify complete resection of the affected

FIG. 2 AND FIG. 2A.—The same convention holds good for these diagrams as regards the skin area supplied by the median nerve.

length of nerve. The resection must extend beyond the scar tissue, in the central end especially, to ensure relief from pain. End-to-end suture or nerve graft repairs the nerve.

Relief from pain has been immediate in the cases so far thus treated.

All cases of causalgia syndrome are not associated with the typical "burning pain" (thermalgia), in which the name had its origin.

Ulnar Nerve.

This nerve was injured 327 times.

The muscular supply is very constant except for some of the small muscles on the radial side of the hand, especially the first dorsal interosseous. It is not surprising that these fibres of the inner cord are sometimes distributed by the median nerve after the cord splits into its terminal branches instead of by the ulnar. As a rule, these particular fibres lie on the outer and posterior aspect of the ulnar nerve. Early recoveries after suture have not been seen. Complete return of discriminating sensibility has not yet been noted in the case of the ulnar nerve. An average of nine months usually elapses after nerve suture before voluntary power returns in the ulnar supplied muscles of the forearm.

Sciatic Nerve.

This nerve was injured 121 times.

The external popliteal fibres are more frequently damaged; in relation to the internal popliteal fibres in the proportion of 97 to 8 in our series.

The external popliteal nerve is very similar in its functions to the musculo-spiral, and behaves in the same way after suture. It recovers quickly where repair is easy and local conditions are good at the site of suture. There is no area supplied with deep sensibility exclusively by the external popliteal nerve.

The internal popliteal fibres correspond in function to the median in the upper limb. They contain the bulk of the pain fibres, and are slow to regenerate after repair. These nerves obey the same rules in recovery of motor and sensory functions as their corresponding nerves in the upper limb.

NOTE ON THE VALUE OF TINEL'S SIGN.

In some cases gentle pressure or percussion over the trunk of a nerve distal to the site of injury gives rise to a tingling sensation in the skin supplied by that nerve. Tinel has elaborated the sign and has stated very fully its significance and uses. We have confirmed his statements and find the sign a reliable one if precautions are taken to avoid confusion with irritation symptoms. The sign is of value in gauging progress.

In regeneration of nerve fibres the sign may be elicited at progressively lower levels over the nerve trunk. In the case of the ulnar nerve, for example, the sign may be elicited at the elbow, and nowhere below, at the first examination. A few weeks later it may be noted that gentle pressure in the forearm over the ulnar trunk gives rise to a "pins and needles" sensation in the ulnar area of the hand, and so on until pressure over the nerve at the wrist is also associated with paraesthesia in the ulnar supplied skin.

Tinel's sign may be noted with ease on an ordinary

ward round, when time for a thorough examination of sensory improvement is not available.

Nerve suture should be delayed so long as the "tingle" continues to be felt when the nerve is gently pressed at progressively lower levels.

GENERAL CONCLUSIONS.

We may state that so far our observations after nerve repair point to the following general facts:

Trophic and vasomotor functions recover first. Trophic ulcers may heal surprisingly quickly after repair of peripheral nerves.

Deep sensibility recovers next, and usually in the order of sense of pressure, perception of movement in joints, etc., and then roughness and pressure pain. Accurate gauging of position and range of movements are slower in their reappearance. Localization of tactile pressure recovers earlier.

Radiating ill-localized sensations referred to wide areas and usually associated with tingling appear next; they

have a high threshold value, and conform largely to the "protopathic sensation" of Head and Rivers. Next in order come accurate perception of light touch with a gradual disappearance of radiating sensations and a gradual lowering of the threshold value of the stimulus required to obtain responses from the patient.

Last of all, and very imperfectly as so far observed, the discriminating sensations—that is, stereognostic sense, etc., and lowering of threshold values to those of normal skin.

We shall have some criticism to offer in a subsequent paper on the various sensory phenomena,

including the commonly accepted views of discriminating sensibility.

Voluntary movement appears in the highest members of a group of muscles first, and gradually extends downwards as a rule. Motion usually follows the return of "protopathic" sensation. It is present long before the radiating ill-localized sensations are abolished.

Electrical Reactions.

The first change after nerve suture is a brisker response to the anodal closing stimulus. If local temperature effects are eliminated this fact is a reliable guide to progress. Gradually the polar reversal changes through polar equality to normal polarity with increasing briskness of contraction. The muscles are quicker to respond and relaxation is more rapid until the normal galvanic twitch is obtained. This is not invariable even when all precautions are taken, but it is certainly the rule.

The faradic responses are usually much slower in reappearing, and we have seen muscles act by volition weeks before the slightest faradic response is obtainable. Occasionally, however, the faradic responses return soon after voluntary movement. Electrical examinations by means of condenser discharges we have found disappointing.

The method by determination of the "chronaxie" of muscle is a subject to be reported upon later.

We wish to thank Lieut.-Colonel Littlewood, C.M.G., for permission to publish the work, and our surgical colleagues, without whose co-operation the work would have been impossible.

FIG. 3.—This shows the average overlap in the palm of the median and ulnar supply. Deep sensibility is not charted in these diagrams.

FIG. 4.—This shows the average overlapping areas on the dorsum of the hand of the median, ulnar, and radial supplies.