A Study of the Conduction Velocity of Sensory Fibers
of the Ulnar Nerve in Leprosy [1]

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Measurement of peripheral nerve conduction in man dates back to von Helmholtz ([15, 16]) and now forms a part of routine clinical examination in various neuropathic conditions. Prominent in this group is leprosy, but it is surprising to note in an editorial by Wade ([18]) that as late as 1954 sufficient information on the conduction velocity of peripheral nerves in leprosy was not available. In 1966 Granger ([10]) reported that he was unaware of any nerve conduction studies in leprosy. Because of the absence of information of such nature, which can often, without the help of a biopsy, indicate the state of peripheral nerves in various stages and forms of leprosy, a proper correlation between the large amount of histopathologic and clinical data available has not yet been fruitful.

Jopling and Morgan-Hughes ([12]) measured the conduction velocity of the motor fibers of the ulnar nerve in a case of pure neural tuberculoid leprosy. The conduction velocity of the fastest fibers in the wrist-elbow segment was found to be about 41 m/sec. (meters per second). A few fibers conducted at velocities between 11 and 25 m/sec. However, in the presence of impaired sensation over the ulnar area, they could not record sensory potentials above the wrist on stimulation of the digital nerves. In a case of tuberculoid leprosy Granger ([10]) could not record sensory action potential from the affected ulnar nerve, while the velocity of the motor fibers was about 32 m/sec.

The following experiments describe a study of the sensory conduction velocity of the ulnar nerves in 23 cases of leprosy.

MATERIALS AND METHODS

The conduction velocity of sensory fibers was measured in 41 ulnar nerves in 23 leprosy patients, two of whom were of neural type, 10 of lepromatous, and 11 of mixed type. Their ages varied between 18 and 65 years, and the duration of illness ranged from two to 25 years. All were inhabitants of a local leprosy colony, and all except one had received regular treatment during the two to three years preceding the conduction velocity measurement. Oral temperatures did not exceed 37°C in any of the patients, and the laboratory temperature varied between 19 and 30°C throughout these experiments. For comparison, conduction velocities of the sensory fibers of the ulnar nerves were measured in 23 normal persons ([3]).

Sensations tested. After the history of illness in each case had been recorded, a detailed clinical examination was carried out. The following sensations were examined: touch (with cotton wool), pressure (manual compression with index finger), vibration (tuning fork), pain (pinprick), heat (hot water in a test tube), cold (crushed ice in a test tube), and joint sense. It was seen that among 38 ulnar nerve territories loss of touch sensation occurred in 33, and loss of pain and cold sensation in 36 each, while loss of heat sensation was complete in all. Vibration sense was absent in three out of 14 patients. Joint sense was surprisingly unaffected in all, even in patients who had lost digits. Pressure sense was present in about 60 per cent of the subjects. The areas showing varying sensory loss were then outlined; these were primarily the areas of ulnar distribution.

Stimulation and recording. These were carried out according to the method described by Dawson ([6]) with certain modi-

fications. In each case the forearm and hand were thoroughly washed with soap and warm water. The position of the ulnar nerve was located by stimulating the nerve along its course and looking for the maximum motor response. Two types of electrodes were used, ring electrodes, which consisted of strips of silver 1 cm. wide for stimulating the digital nerves, and circular electrodes in the form of silver discs 1.5 cm. in diameter for stimulating and recording from the ulnar nerve trunk. The circular electrodes were applied to the recording and stimulating sites with the help of leather straps specially designed for this purpose, while the ring electrodes were applied directly. Before their application at the sites all electrodes were chlorided, coated with Electro jelly (X-Ray and Electromedicals, India) and covered with lint soaked in saline. Electro jelly was also rubbed over the stimulating and recording sites in order to reduce the resistance of the skin.

The stimulus was a rectangular pulse of 0.3 msec. (millisecond) duration delivered from a Grass stimulator (Model S-4E) at the rate of 1/sec., through an isolating transformer. After application of the electrodes the 5th digital nerve was stimulated and the resulting potential was recorded, first above the wrist and next above the elbow. The ulnar trunk was then stimulated above the wrist and the resulting potential was similarly recorded above the elbow. Evoked potentials were first fed through a preamplifier (Tektronix, type 122), into an oscilloscope (Tektronix, type 315 D), which was triggered by the stimulator. After the action potential had attained its maximum size and no further increase in the amplitude was seen on further increase of the stimulus strength, 20 or more superimposed sweeps of the evoked potential were photographed with an oscilloscope camera (Southern universal recording camera M 731). A time signal at intervals of 1 msec and a calibration signal of 10 μv were also photographed with each experiment. Measurement of the latencies (hence conduction velocity) was made from the start of the stimulus to the first detectable rise of the evoked potential and from the start of the stimulus to the peak of the main negative deflection. The first measurement refers to the fast fibers, designated as F, and the second to the fibers of average velocity designated as AV, throughout this paper. The following were recognized as probable sources of error:

1. As there was considerable dispersion of the potentials, it was often difficult to measure the velocity of the fast and the slowest fibers with certainty.

2. Because of the loss of terminal phalanges and accompanying contracture, the length of the ulnar nerve could not be measured accurately.

3. Pathologic thickening and fibrosis introduced additional uncertainty about the exact site of stimulation.

4. No special precautions were taken for controlling the temperature, and the laboratory temperature varied between 19-30°C during these experiments. As shown elsewhere ([3]), this probably influenced the measurements to some extent.

5. All but one patient received regular treatment during the preceding two to three years; therefore these results may not be applicable to untreated cases.

RESULTS

Action potentials from leprous nerves. Records of the action potentials in a normal person and typical cases of leprosy are shown in Figure 1. The upper line (Fig. 1, No. 1) was taken from a normal person. Lines 2 and 3 were taken from two patients who had mild impairment of sensation, and line 4 was taken from a patient with complete sensory loss. It will be noted that the potentials from leprosy patients in general were smaller in amplitude, the maximum amplitude being less than 15 μv. The absence of the typical triphasic character of the potentials seen in normal persons is conspicuous in records from leprosy cases. Late waves, dispersion and polyphasic potentials, were occasionally observed. In particular recording of action potentials above the elbow after stimulation of the digital nerves was not possible in every case, probably because of dispersion. Other factors were thickening of both the skin and the nerve and a considerable raising of the thresholds.
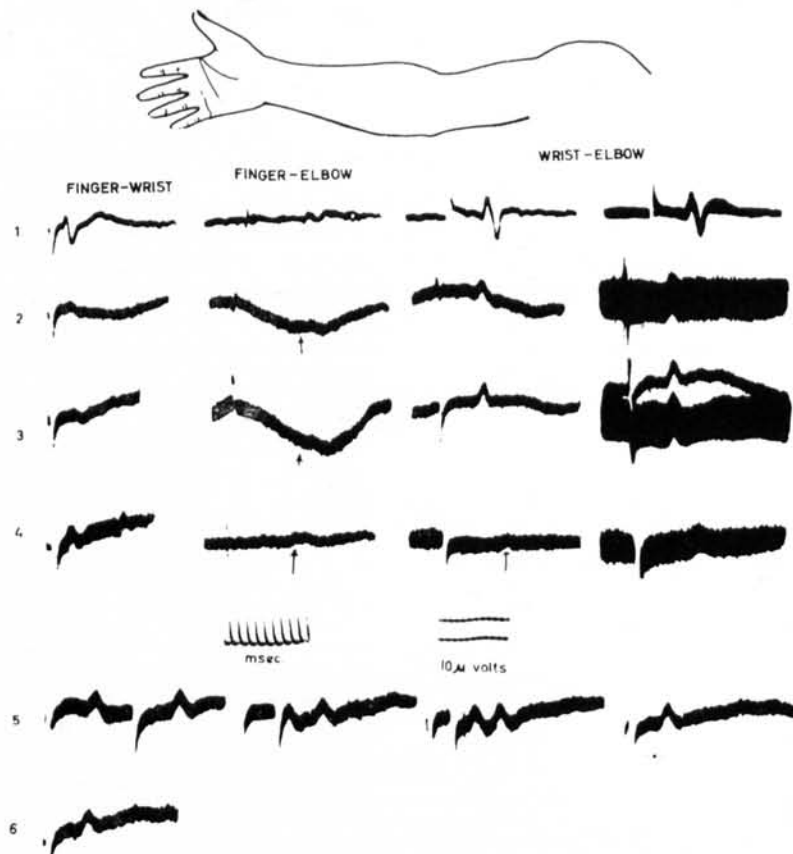
FIG. 1. Line 1 shows action potentials of the sensory fibers of the ulnar nerve of a normal person recorded at room temperature. Lines 2 and 3 give the same for leprosy patients with partial sensory loss. The record in line 4 was taken from a leprosy patient with total sensory loss over the ulnar area. Note the reduction of amplitude, increase in latency and dispersion of the potentials in records 2, 3 and 4; in line 4 the first record also shows two action potentials. Arrows mark the onset of the potential wherever it is not very clear. Records in lines 5 and 6 show the effects of two stimuli of equal intensity delivered at the wrist with decreasing interstimulus intervals, while action potentials were recorded above the elbow. The third pair of potentials in line 5 have equal amplitude and velocity, the interstimulus interval being about 2.7 msec. Both ulnar nerves in this patient had conduction velocities within normal limits. Time scale and calibration apply to all records.

Figure 1 (Nos. 5 and 6) shows the effects of two stimuli applied to the ulnar nerve above the wrist at decreasing intervals in a case of bacterial positive, early lepromatous leprosy. In normal persons it was observed that the shortest interval required between two stimuli, so that the evoked potentials attained equality in magnitude and velocity, was less than 2 msec. ([3]). In the case of the lepromatous leprosy patient cited above, the minimum interval was found to be about 2.7 msec, which indicates a prolongation of the refractory period. The conduction velocity of the sensory fibers of both the ulnar nerves was within normal limits in the same patient. Although much significance cannot be attached to a solitary observation, it appears that alteration of the refractory period precedes the reduction of conduction velocity.

From Table 1 it will be seen that the velocity of average digital fibers (AV) between finger and wrist is about 36 m/sec. in

TABLE 1. *A comparison of the conduction velocity (m/sec. ± S.E.) of sensory fibers of the ulnar nerve in normal persons and leprosy patients.*

Section of hand	Type of fiber	No.	Normal persons	No.	Leprosy patients	D ff.	t	p
Finger to wrist	Av.	29	52.5 ± 0.7	38	35.9 ± 1.1	10.6	12.6[a]	0.01
	Fast	29	68.8 ± 1.1	2	38.0 ± 0.0	30.8	8.8	—
Finger to elbow	Av.	33	55.3 ± 0.5	17	45.4 ± 1.1	9.9	8.2[a]	0.01
	Fast	33	63.0 + 0.7	2	49.4 ± 0.7	13.7	13.9	—
Wrist to elbow	Av.	33	54.9 ± 0.5	41	45.7 ± 1.1	9.2	7.9[a]	0.01
	Fast	33	67.2 ± 0.8	18	56.6 ± 2.1	10.5	4.7[a]	0.01

[a] Highly significant.

leprosy patients, while in normal persons the velocity is nearly 53 m/sec. The fast fibers (F) in normal digital nerves have a velocity above 60 m/sec., while in the diseased group it is less than 40 m/sec. (2 cases). The reduction from normal is nearly one-third. In the finger-elbow section the velocity of the F fibers has not been recorded in each case because of marked dispersion of the potential, but the AV fibers conducted at a velocity of about 40 m/sec. In two cases only, the conduction velocity of the F fibers was measured; it was found to be less than 50 m/sec., as compared to 63 m/sec. in the normal. The reduction is almost one-fourth. In the wrist-elbow segment the AV fibers conducted at about 54 m/sec. in the normal, while in the leprosy patients the mean velocity was about 46 m/sec. The normal velocity in the F fibers was about 67 m/sec., while in the disease group it was approximately 57 m/sec.

From Table 1 it may be seen that the average digital fibers between the finger and wrist conducted at a speed of 36 m/sec., while the same fibers, conducted at a speed of 45 m/sec. in the finger-elbow segment. In normal persons the velocity differential in these two segments is less than 3 m/sec., while in leprosy patients it is about 9 m/sec. As the difference of temperature between the above segments fails to explain a difference of 9 m/sec.([3]), it is possible that the fibers are passing through a zone of constriction and the possible site

may be above the wrist, where the nerve is usually thickened. The observed difference could also be partly due to diffuse involvement of the nerve fibers. It is also known that pathologic involvement or injury of the nerve fibers in distal segments may reduce their conduction velocity over proximal segments ([1, 6, 10]). Therefore, it is probable that the velocity of the sensory fibers of the ulnar nerve can be reduced in the proximal segment in the presence of distal involvement alone. As an overall reduction of velocity was seen, in the present experiment it is difficult to decide how much of the reduction observed in the proximal segment was due to involvement of the fibers in this segment and how much was caused by their involvement in the distal segments alone.

When the velocity reductions are considered separately, it is seen that considerable reduction occurred in both the AV and the F digital fibers. On the other hand, when the whole ulnar trunk (which also includes the digital fibers) was stimulated above the wrist and mixed antidromic motor and orthodromic sensory potentials were recorded above the elbow, much less reduction of the conduction velocity was noted. Cutaneous afferents are known to be primarily affected in leprosy; therefore the disparity observed, under identical experimental situations, indicated a different source of origin of the less affected fibers. In all probability, the majority were muscle affer-
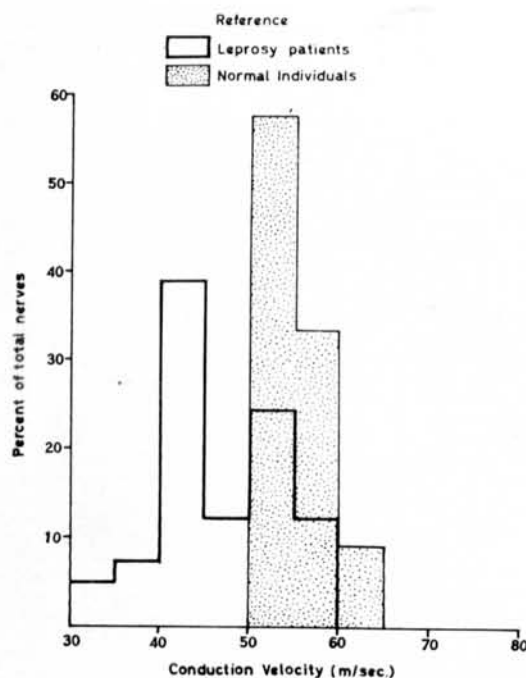
FIG. 2. Histogram showing distribution of conduction velocities of the A (average) fibers of the ulnar nerves in normal persons (shaded) and leprosy patients (unshaded). The histogram for the leprosy patients shows two peaks, one between 40 and 45 m/sec and the other between 50 and 55 m/sec. Note the overlapping in conduction velocities of normal and leprosy nerves in the range between 50 and 60 m/sec. (See text for detailed discussion.)

ents, but some fibers might have come from the unaffected cutaneous areas. But, the preservation of vibration sense, voluntary muscle power, and joint sense, provides supporting evidence for their origin from the muscle and deeper structures.

Figures 2 and 3 represent the conduction velocities of the AV and F sensory fibers of the ulnar nerve in healthy persons and in leprosy patients. It will be observed that in the wrist-elbow segments there were some fibers in the ulnar nerves with velocities in the range 50-60 m/sec. in about 36 per cent of cases (Fig. 2). These values of conduction velocity are well within the normal range. In 44 per cent of cases the velocity of the fast fibers (Fig. 3) ranged between 60 and 70 m/sec. From a comparison of both cases it appears that a larger number

of F fibers survived in the diseased nerves. Relatively small involvement of the muscles which are innervated by fast afferent fibers provides strong evidence that a considerable portion of these fibers have their origin either in the muscles or the joints or both. The conduction velocities of the digital fibers in the finger-wrist and finger-elbow segments were 36 and 45 m/sec. respectively. It is therefore evident that a considerable loss of such fibers or a considerable reduction of their velocity occurs in leprosy.

In order to detect possible early involvement of peripheral nerves in leprosy the conduction velocity of ulnar nerves in three children between 10 and 14 years of age, born of leprosy patients, was recorded. It was observed that even if they were born of and brought up by infected parents they had no clinical signs of leprosy and the conduction velocity of the sensory fibers of the ulnar nerves was within normal range.
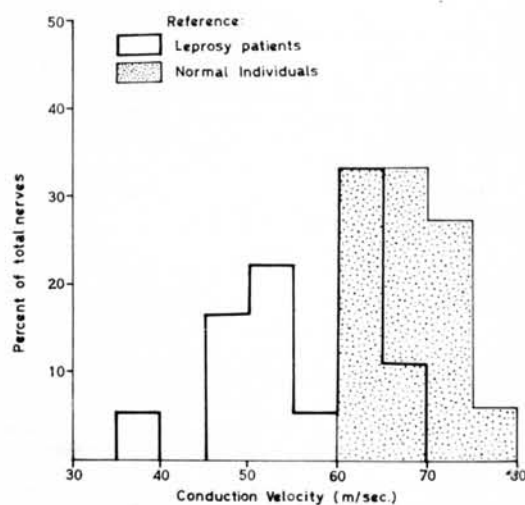

FIG. 3. Histogram showing distribution of conduction velocities of the F (fast) fibers of the ulnar nerves in normal persons (shaded) and leprosy patients (unshaded). The histogram for the leprosy patients shows three peaks, one between 35 and 40 m/sec, one between 50 and 55 m/sec, and one between 60 and 65 m/sec. Note the overlapping in conduction velocities in the range between 60 and 70 m/sec. (See text for detailed discussion.)

DISCUSSION

More than a hundred years ago damage to peripheral nerves in leprosy was recognized by Danielssen and Boeck ([2]) and Virchow ([14]), but information on the conduction velocity of peripheral nerves in leprosy is still insufficient. In 1934 Weddell *et al.* ([20]) reported that the histologic changes observed in peripheral nerves in lepromatous and dimorphous leprosy lesions are enough to account for a block of the conduction of propagated impulses. Technical difficulties involved in recording purely sensory action potentials of the ulnar nerve in normal persons have been outlined by Dawson ([6]), Gilliatt and Sears ([9]) and Vyklicky ([17]). Besides these, special problems occur in leprosy, where not only is the skin abnormally thickened, but the nerve fibers suffer various stages of degeneration. Moreover, thresholds of the fibers are considerably raised as a result of pathologic fibrosis and thickening.

Limitation of the technic. The potentials recorded by the present technic are produced by the myelinated fibers and thus can provide information about such fibers only. But when the limitations of the technic used are taken into consideration, the information provided seems to be of considerable clinical significance, particularly with respect to the pathologic state of the nerve fibers. Conduction velocities recorded in the experiments here reported indicate an overall reduction that is statistically significant. It will also be seen that the most affected fibers are the cutaneous afferents, where the velocity of average digital fibers is reduced nearly 50 per cent. In view of the known pathologic change seen in early cutaneous nerve involvement in all types of leprosy, and in view of the established fact of centripetal spread of the disease, it is naturally to be expected that the distal segment would sustain more damage. Such lesions could be either diffuse or localized, but the exact nature cannot be decided from the observations here reported. However, the increase in the velocity of digital fibers in the finger-elbow segment (compared to the distal, i.e., finger-wrist segment) indicates a possibility that the site of lesion could be localized. It seems unlikely that the slower component of the

normal myelinated fibers alone could account for the potentials recorded in the leprosy patients.

Dispersion of the potentials. Dispersion of the potentials is conspicuous particularly in the digital potentials recorded above the elbow. Polyphasic waves displaying late components were often seen, but a split of the main negative deflection was not observed. It appears that the fast elements in cutaneous fibers suffer considerable damage, which can be associated with the observed loss of light touch sensation. The late waves were particularly inconsistent, and no measurement of their velocity was made; however, their conduction velocity would not exceed 3-5 m/sec. Such late waves were almost unknown in the control group and therefore these could be attributed only to pathologic changes in the peripheral nerves. *Failure of recording action potentials does not imply absence of nerve fibers.*

Absence of detectable potentials from the areas showing complete loss of sensation may mean (1) absence of the myelinated fibers, or (2) a failure of the surviving fibers to be stimulated (as a result of a raising of their thresholds), or (3) a complete dispersion of the waves. As the C fibers are known to serve almost all the modalities of cutaneous · sensations and their action potentials are beyond the present technic of recording, failure to record action potentials need not mean absence of nerve fibers. However, it has been clearly shown in Figure 1, tracing 4, that even in the absence of sensations (detected on clinical examinations) action potentials could be elicited from nerve fibers supplying the areas concerned. Therefore, it is certain that sufficient fibers in the myelinated group survived to account for the presence of these potentials. Such an inference gets further support as sensations reappear over the anesthetic areas after antidromic stimulation ([4, 5]). Most of the digital potentials undergo considerable dispersion and therefore could not be recorded at the level of the elbow. It cannot be ruled out, however, that the potentials recorded above the elbow on stimulation of the ulnar trunk above the wrist received some contribution from the digital fibers.

Confirmation of histologic findings. Recording of the sensory action potentials in a majority of the leprosy patients is in agreement with the findings 'of several workers who have demonstrated the presence of healthy fibers within anesthetic areas, e.g., Jayaraj and Chaudhury ([11]). Having failed to elicit any sensation they even speculated that impulses, if any, would be passing "silently" in the surviving healthy fibers. As no such "silent" impulses are known to exist, and sensations have been produced over the 'anesthetic areas by antidromic stimuli, it becomes more than clear that the receptors are deranged. The exact nature of their derangement, however, cannot be decided, but the reappearance of sensations over the anesthetic areas on antidromic stimulation shows that these are kept in a state of reduced excitability.

Refractory period of the affected fibers. In order to study the refractory period of the nerve fibers in leprosy, the effect of two stimuli at decreasing interstimulus intervals was recorded in a case of lepromatous leprosy till the second potential attained the same amplitude and same velocity as those of the first one. It was seen that the minimum interval was about 2.7 msec. as compared with the normal, which ranged between 1.8 and 2.0 msec. ([3]). The increase in the refractory period could be due to early pathologic changes in the nerve fibers. Surprisingly, as stated before, the velocity of sensory conduction was within normal limits in both ulnar nerves in this patient. It appears as if the refractory period of the nerve fibers is affected prior to a reduction of velocity. It may be that the refractory period and the frequency of the receptors are affected similarly or even earlier. This observation requires further study and evaluation, and if found true it can provide a means for detecting very early changes in the peripheral nerves in leprosy, before demonstrable histologic changes could possibly be seen.

Muscle and joint afferents. Joint sense was found unaffected in all the patients, while vibration and pressure were affected less than other sensations. In the digital fibers the maximum velocity varied between 38 and 49 m/sec., which is inconsistent with the maximum velocity of the fibers that convey vibration, and perhaps joint sensations unless a considerable re-
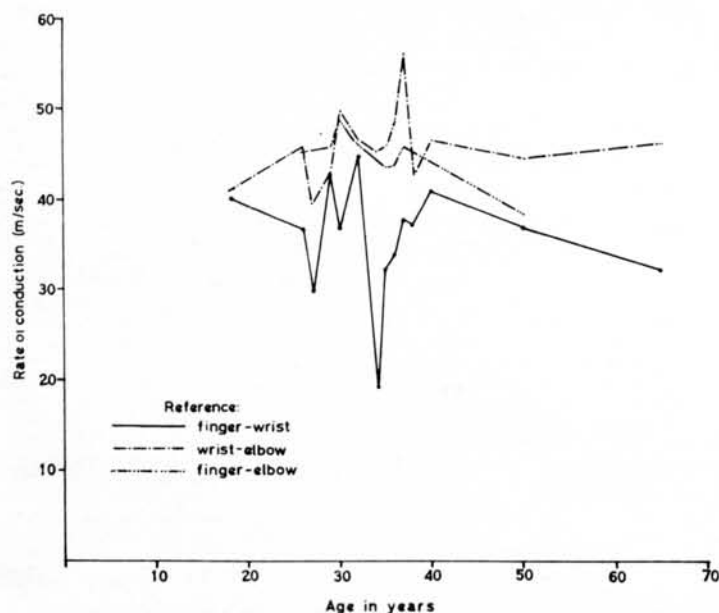

FIG. 4. Graph showing the relation between conduction velocity and age of the patients. In the graph a slowing of the velocity can be observed after the age of 35 years. The conduction velocities in different segments are indicated by different lines shown to the left of the picture.

duction of velocity is assumed in these fibers. The afferent fibers in the main ulnar nerve between the wrist and elbow include the muscle and joint afferents in addition to the digital and cutaneous fibers supplying the hypothenar area and the medial border of the palm. Dawson ([6]) reported that the fastest digital afferents in man have a velocity of about the same magnitude as the muscle afferents from the small muscles of the hand. A maximum velocity of 49 m/sec recorded in the digital fibers therefore shows a considerable reduction. On the other hand, those afferent fibers in the main ulnar nerve which conducted at a velocity of about 57 m/sec., are not much slower than the fast fibers present in normal ulnar nerves. These fibers could therefore be the muscle afferents associated with the presence of vibration sense, muscle sense, and perhaps joint sense. The type of fibers carrying joint sense in man is not known. Gardner ([8]) observed that the fibers supplying the knee joint in the cat range from 2-16μ in diameter and have a bimodal distribution with peaks in the range 2-5 μ and 7-10 μ, the latter group being more in number. If these findings are applicable to man, survival of joint sense in leprosy indicates the presence of some fibers in the above range.

Effect of age. Wagman and Lesse ([19]) reported that structural changes in the peripheral nerves occur after the age of 60 years, resulting in the reduction of their conduction velocity. Plotting the velocities measured in the leprosy patients against age (Fig. 4) indicates that the pathologic process of aging probably starts earlier in leprosy.

SUMMARY

The conduction velocity of the sensory fibers of the ulnar nerve has been studied in leprosy patients.

Sensory potentials have been recorded from the afferent nerves supplying anesthetic areas, and therefore a loss of sensation in leprosy does not necessarily mean destruction of all nerve fibers. This conforms with the histologic observations of Weddell, Jamison and Palmer and of many other workers, who noted the presence of healthy nerve fibers in leprosy lesions.

It has been shown that a significant reduction of the conduction velocity occurs in all forms of leprosy. The cutaneous afferent fibers are affected more than the muscle afferents.

A prolongation of the refractory period of the nerve fibers probably precedes the reduction of velocity. The significance of this finding is discussed.

It appears that the cutaneous receptors are deranged, but not totally destroyed, over all anesthetic areas in leprosy, and sensations can be induced to reappear.

RESUMEN

La velocidad de conducción de las fibras sensoriales del nervio ulnar ha sido estudiado en pacientes de lepra.

Los potenciales sensoriales han sido registrados en los nervios aferentes que inervan regiones anestesiadas, y por lo tanto la pérdida de sensibilidad en lepra no significa necesariamente destrucción de todas las fibras nerviosas. Esto está de acuerdo con las observaciones histológicas de Weddell, Jamison y Palmer y de muchos otros estudiosos del tema, quienes notaron la presencia de fibras del nervio sanas en lesiones leprosas.

Se ha demostrado que una significante reducción de la velocidad de la conducción ocurre en todas las formas de lepra. Las fibras cutáneas aferentes son mas afectadas que las fibras aferentes de los músculos.

Una prolongación del período refractario de las fibras nerviosas probablemente precede la reducción de la velocidad. El significado de este hallazgo es discutido.

Pareciera que los receptores cutáneos están desorganizados, pero no totalmente destruidos, sobre todas las áreas anestésicas en lepra, y que las sensaciones pueden ser inducidas a reaparecer.

RÉSUMÉ

La vitesse de conduction des fibres sensitives du nerf cubital a été étudiée chez des malades de la lèpre.

Des potentiels sensoriels ont été enregistrés au niveau des nerfs afférents innervant les zones anesthésiques. Ceci indique qu'une perte de la sensibilité n'implique pas nécessairement la destruction de toutes les fibres ner-

veuses. Cela est en accord avec les observations histologiques de Weddell, Jamison et Palmer ainsi que de nombreaux autres chercheurs, qui ont relevé la présence de fibres nerveuses intactes dans les lésions lépreuses.

On a démontré qu'une diminution significative de la vitesse de conduction survenait dans toutes les formes de lèpre. Les fibres afférentes cutanées sont plus atteintes que les muscles afférents.

La diminution de la vitesse est probablement précédée par une prolongation de la période réfractaire des fibres nerveuses. La signification de cette observation est discutée.

Il semble que les récepteurs cutanés soient troublés dans leur fonctionnement, mais non totalement détruits, dans toutes les zones anesthésiques, chez de malades de la lépre. Il semble également que la réapparition de certaines sensations puisse être provoquée.

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