

Stimulus intensity and site of excitation in human median nerve sensory fibres

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SUMMARY Median nerve sensory fibres were stimulated with minimal and supramaximal stimuli at the base of the third digit in 30 normal subjects. Evoked nerve action potentials were simultaneously recorded from two points on the median nerve just above the wrist. As stimulus voltage was increased from minimal to supramaximal, amplitudes of nerve action potentials increased, latencies decreased, but conduction velocities remained unchanged. The shortening of latencies was interpreted as movement of the effective point of nerve excitation away from the stimulating cathode towards the recording electrodes. Therefore, the effective point of nerve excitation cannot be assumed to be underneath the cathode, but at some distance from it depending on stimulus intensity. Furthermore, the fastest conducting sensory fibres in the human median nerve do have a lower threshold than slower conducting fibres.

Based on the early work by Blair and Erlanger (1933) and Gasser and Grundfest (1939), it is generally accepted that large diameter nerve fibres have lower thresholds and faster conduction velocities than small diameter nerve fibres. More recently, however, Hodes, Gribetz, Moskowitz, and Wagman (1965) and Drechsler and Laštovka (1968) concluded from their studies of conduction velocity in human motor nerves that fibres with low thresholds conduct more slowly than fibres with high thresholds. Latency (time from stimulus to onset of evoked muscle action potential) decreased with increasing stimulus intensity, but no further decrease of latency occurred with supramaximal stimulation. Hodes *et al* (1965) assumed that the effective point of excitation of a nerve trunk does not change regardless of stimulus intensity. This assumption was partly based on the reports by Henriksen (1958) and Willison (1964) that the effective site of nerve excitation was the same regardless of stimulus intensity.

In contrast, Rushton (1949) reported that even at threshold, excitation arose simultaneously over a segment of frog nerve extending a distance of 3 mm from the cathode. Dawson (1956), Preswick (1963), Pinelli (1964), and Gilliatt, Melville, Velate, and Willison (1965), and Buchthal and Rosenfalck (1966) observed shortening of latency with increasing stimulus intensity. These investigators interpreted their findings at least partly as displacement of the point of stimulation from the cathode towards the

recording electrode. Gassel (1964) believed that the shortening of latency with high stimulus intensity was the result of potentials generated in muscles closer to the stimulating electrode and conducted in volume to the recording electrode. Furthermore, Wiederholt (1969) showed in isolated mixed mammalian nerves that the effective point of excitation cannot be assumed to be underneath the cathode but at some distance from it depending on stimulus intensity.

Because of these contradictory findings and interpretations the present study was undertaken to delineate the relationship between stimulus intensity and effective site of excitation in human median nerve sensory fibres.

MATERIAL AND METHOD

Thirty healthy subjects (21 male, nine female), ranging in age from 18 to 38 years, were examined. Before placement of electrodes, the skin was cleaned with alcohol and dried. Pipe cleaners soaked in an electrolyte jelly were used as stimulating electrodes and wound around the proximal (cathode) and middle (anode) phalanges of the third digit. The stimulated finger was covered with cotton to avoid contact of the electrodes with other fingers. Beckmann miniature skin electrodes were glued to the skin over the median nerve just above the wrist (Fig. 1). A large ground electrode was placed between stimulating and recording electrodes. Interelectrode distances were as follows: stimulating cathode to R2, 12.15 cm (range 9.95 cm-14.6 cm); R2-R3, 1.94 cm (range 1.85 cm-2.15 cm). Skin

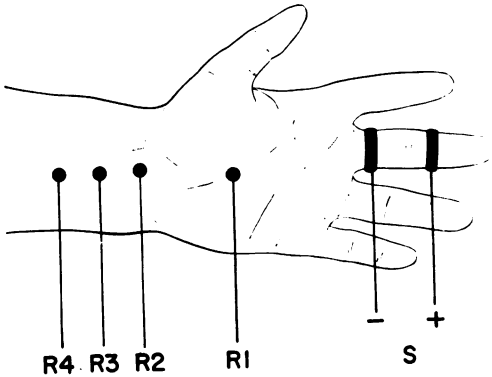


FIG. 1. Placement of stimulating and recording electrodes. Stimulating cathode, S-; stimulating anode, S+. Recording electrodes, R1, R2, R3, R4.

temperature adjacent to one recording electrode was continuously monitored and kept between 32 and 33°C.

Square wave pulses from a Grass S8 Stimulator were delivered through a stimulus isolation unit at a rate of 1/sec. Stimulus duration was kept constant at 0.1 msec and stimulus voltage varied from 30 to 40 V (minimal) to 80 to 110 V (supramaximal).

Evoked nerve action potentials were recorded simultaneously from R2 (reference R3) and R3 (reference R4). Both potentials were displayed on the upper split beam of a dual beam Tektronix 565 oscilloscope after amplification through two Grass DP9B preamplifiers. The frequency response was 0.1 Hz to 2 KHz. A time signal was displayed on the lower beam of the oscilloscope. The sweep of the oscilloscope and the stimulus could be triggered independently. The onset of the sweep could thus be delayed after the stimulus by any interval required to display potentials on an extended time base.

A minimum of 20 potentials were photographed at each stimulus voltage, and measurements were made on en-

larged superimposed line drawings. In all traces, upward deflection indicates change at the active recording electrode toward negativity.

Latency was measured from the beginning of the stimulus artefact to the onset of the negative deflection on the evoked potential and not to the point where the potential crossed the base line (see Gilliatt *et al.*, 1965). Conduction time was measured as the time from the onset of the negative deflection of the evoked potential at the electrode closest to the stimulating cathode to a similar point on the evoked potential at the electrode furthest from it. Conduction velocity was expressed as metres-per-second and calculated by dividing the interelectrode distance (R2-R3) by the conduction time.

RESULTS

Stimulus voltage was gradually increased until a small nerve potential was just discernible and until each stimulus consistently evoked a response. A stimulus voltage of 30 to 40 V was required to elicit this 'minimal' response (Fig. 2A). The stimulus voltage was then increased slightly above that voltage beyond which no significant increase of amplitude of evoked potentials occurred. This 'supramaximal' response was elicited with 80 to 110 V (Fig. 2B). Amplitude of evoked potentials doubled from minimal to supramaximal stimulation (see Table). Latencies decreased equally by 0.16 msec at both recording electrodes from minimal to supramaximal stimulation. This latter finding suggests that conduction time and, therefore, conduction velocity remain unchanged. Critical measurements of conduction time were made at higher amplification and faster sweep speed (Fig. 3). Again, no change of conduction time between recording electrodes was found from minimal to supramaximal stimulation, but both potentials moved an equal distance closer to the stimulus artefact.

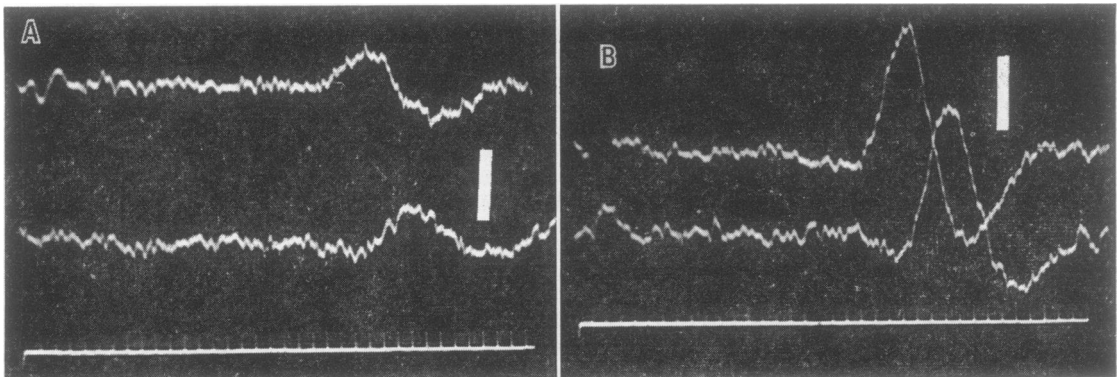


FIG. 2. Median nerve sensory potentials. A minimal (35 V) stimulation, B supramaximal (90 V) stimulation (stimulus duration 0.1 msec). Upper beam R2-R3, lower beam R3-R4. Time marker 0.1 msec, amplitude marker 0.02 mV.

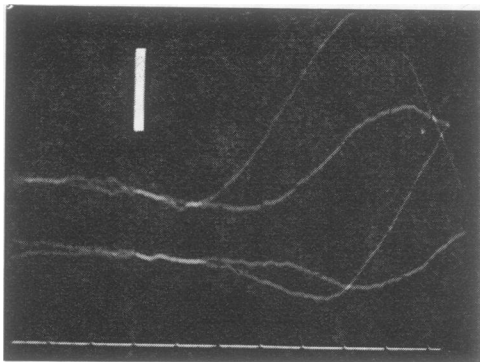


FIG. 3. Superimposition of median nerve sensory potentials evoked by minimal (35 V) and supramaximal (90 V) stimulation (stimulus duration 0.1 msec). Upper beam R2-R3, lower beam R3-R4. Each sweep triggered after a fixed delay from stimulus. Time marker 0.1 msec, amplitude marker 0.02 mV. Note movement of potentials toward left with increased stimulus voltage.

It is sometimes difficult to determine accurately the beginning of a very small potential because the slope of the rising portion of the potential is relatively gradual. The shortening of latency from minimal to supramaximal stimulation could possibly be explained on this basis. That this is clearly not the case is illustrated in Fig. 4.

Conduction velocity appears to increase from minimal to supramaximal stimulation if it is calculated as the distance from the stimulating cathode to the recording electrode divided by the latency. In

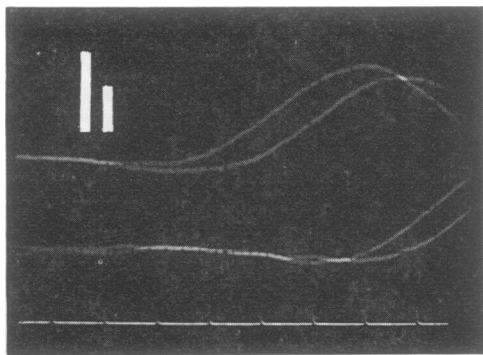


FIG. 4. Superimposition of median nerve sensory potentials. Amplification is adjusted in such a manner that potentials evoked by stimulating with 40 V and 80 V appear to have the same amplitude (stimulus duration 0.1 msec). Upper beam R2-R3, lower beam R3-R4. Each sweep triggered after a fixed delay from stimulus. Time marker 0.1 msec, amplitude markers 0.02 mV. Note movement of potentials toward left with higher stimulus voltage.

the present study, however, conduction velocity was determined by dividing the distance between two recording electrodes by the conduction time of the nerve action potential from one electrode to the other. With this method, conduction velocity determination is independent of latency measurements. If conduction velocity increases with supramaximal stimulus voltage, conduction time should become shorter. As illustrated in Fig. 3, this was not the case. Since conduction time and conduction velocity do not change with increasing stimulus intensity, the obvious decrease of latency cannot be explained by recruitment of progressively faster conducting nerve fibres. If the decrease of latency indicates a shortening of conduction distance, the effective point of nerve excitation must have moved closer to the recording electrodes. This movement of the effective point of excitation from minimal to supramaximal stimulation was found to be approximately 1.0 cm (see Table). The distance of movement can be calculated from the known conduction velocity and the difference between latencies. The latter value can be obtained directly by measuring the movement of the evoked potentials (see Fig. 3).

TABLE

EFFECTS OF MINIMAL (30 TO 40 V) AND SUPRAMAXIMAL (80 TO 110 V) STIMULATION OF MEDIAN NERVE SENSORY FIBRES ON AMPLITUDE OF EVOKED POTENTIAL, LATENCY, CONDUCTION VELOCITY, AND MOVEMENT OF POINT OF EXCITATION (STIMULUS DURATION 0.1 msec)

Amplitude* (mV)	min. stim.	supramax. stim.
R2	0.015 ± 0.008	0.031 ± 0.011
R3	0.011 ± 0.004	0.024 ± 0.008
Latency* (msec)	min. stim.	supramax. stim.
R2	2.24 ± 0.24	2.08 ± 0.23
R3	2.55 ± 0.27	2.39 ± 0.24
Conduction velocity* (m/sec)	min. stim.	supramax. stim.
R2-R3	66.28 ± 8.12	64.26 ± 9.31
Movement of point of excitation from minimal to supramaximal stimulation* (cm)		
measured at electrode R2	1.04 ± 0.32	
measured at electrode R3	0.94 ± 0.30	

*Values are the mean of 20 trials per subject with standard deviation of the mean (30 subjects).

DISCUSSION

Human sensory nerve function is usually evaluated electrodiagnostically with a technique first described by Dawson (1956). Sensory fibres of one or two digits are stimulated, evoked potentials are recorded from electrodes placed over the respective nerve above the wrist, and latency is measured. However,

conduction velocity cannot be measured with this method because utilization time and more importantly the effective site of nerve excitation are variable depending upon the stimulus intensity. Conduction velocity can be measured by recording from two points on the nerve. One electrode is usually placed above the wrist and another at the elbow. Although conduction velocity is measured directly with this technique, evoked potentials differ considerably in configuration, making accurate measurements difficult. Furthermore, evoked potentials are usually not recorded simultaneously, which introduces another source of variability. The method described in this paper has none of these shortcomings. Evoked potentials are recorded simultaneously and are of almost identical configuration because of the very small interelectrode distance.

Conduction velocity and amplitude of evoked potentials found in this study (see Table) are in agreement with those reported by others (Buchthal and Rosenfalck, 1966; Thomas, Lambert, and Cseuz, 1967). Latency decreased equally by 0.16 msec at the two recording electrodes from minimal to supramaximal stimulation. Furthermore, direct measurements of conduction time showed no change regardless of stimulus intensity. It is unlikely that this shortening of latency can be explained solely by shortening of utilization time. Blair and Erlanger (1935) reported a marked decrease in response time with a slight increase in stimulus voltage above threshold and additional voltage increases produced progressively less effect. Furthermore, Wiederholt (1969) observed in isolated mammalian nerves that latency continues to decrease well beyond maximal stimulation. Because conduction velocity did not change from minimal to supramaximal stimulation, the shortening of latency cannot be interpreted as recruitment of faster conducting fibres with higher stimulus intensity. The only alternative explanation for this shortening of latency is that the area of the nerve which is excited enlarges as stimulus intensities increase. Latency will consequently decrease because of a shorter conduction distance. It is also well recognized in clinical nerve stimulation studies that with high stimulation voltage, nerves at a considerable distance from the cathode may be excited.

Undoubtedly there is a range of conduction velocities in the fastest conducting human A fibres as reported by Thomas, Sears, and Gilliatt (1959) and Hopf (1962, 1963). However, the decrease of latency with increasing stimulus intensity observed

in the present study does not reflect this range of conduction velocities but is due to displacement of the effective point of nerve excitation.

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