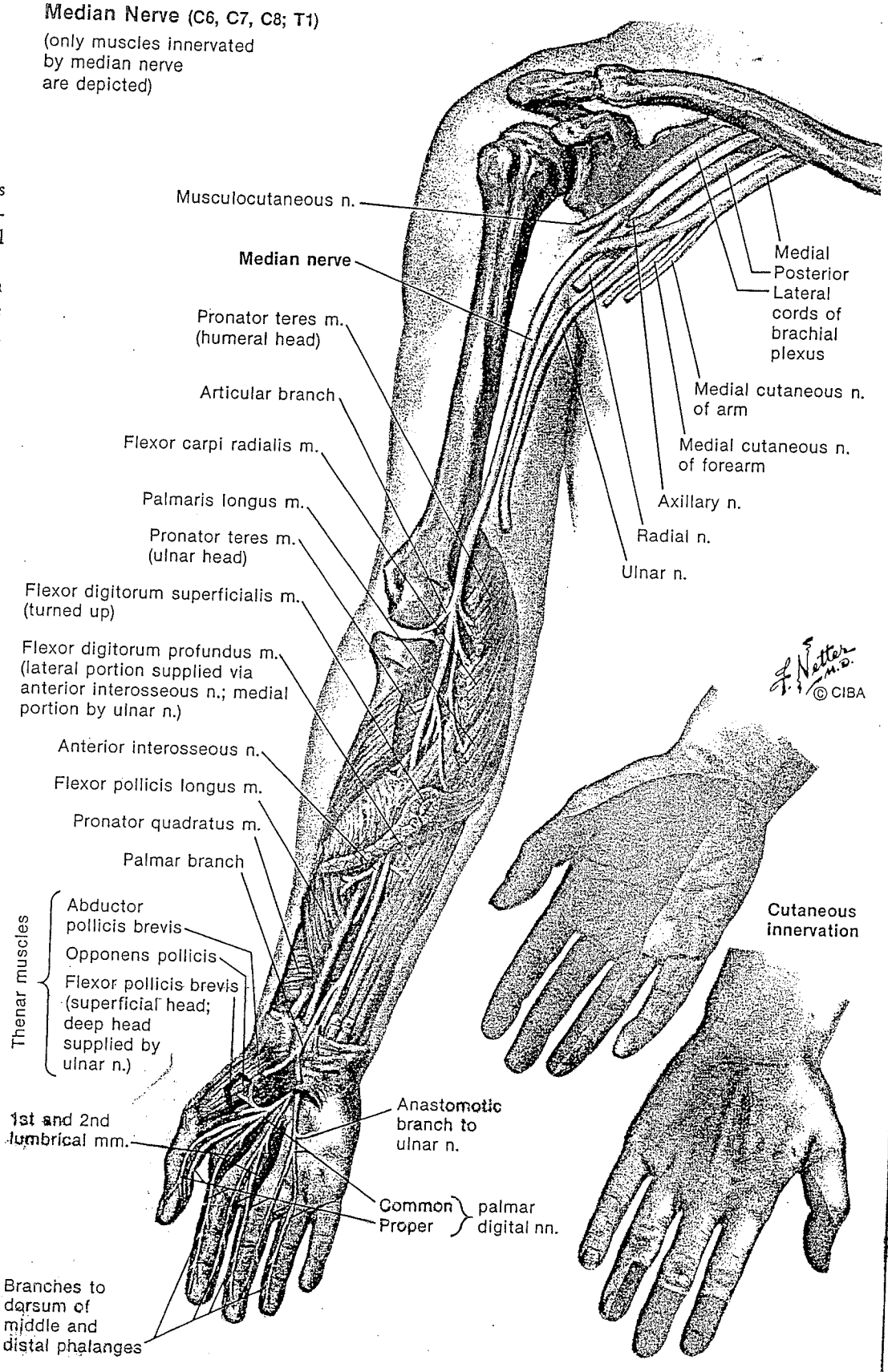
an Nerve

median nerve (C[5], C6, C7, C8; T1) *is* by the union of *medial* and *lateral roots* aris- n the corresponding cords of the brachial

se in Arm. The median nerve runs from la into the arm, at first lying lateral to the artery. At about the level of the insertion oracobrachialis muscle, the nerve inclines ly over the brachial artery, and then ls along its medial side to the cubital fere, it lies behind the bicipital aponeuro- intermediate (median) cubital vein, and in the insertion of the brachialis muscle and w joint. (The close proximity of the vein, nd nerve should be remembered when ing venipuncture in this area.) The only s given off by the median nerve in the arm nents to the brachial vessels and an incon- ig to the pronator teres muscle.

se in Upper Forearm. The nerve passes forearm between the humeral and ulnar the pronator teres, the latter separating it e artery. It then runs deep to the oti...ch between the humeroulnar and eads of the flexor digitorum superficialis, inues downward between this muscle and r digitorum profundus; it usually adheres ...e superficial flexor. In the lies branches to the prona- orum superficialis, flexor aris longus muscles, and lbow and proximal radio- ints. The longest branch is the *anterior ous nerve*, which, accompanied by the onding artery, runs downward on the ous membrane between the flexor pollicis nd the flexor digitorum profundus; it the former muscle and the lateral part of r (which provides the tendons for the d middle fingers), and ends under the quadratus, supplying this muscle and al radioulnar, radiocarpal and carpal ascular filaments help to innervate the d anterior interosseous vessels and the vessels of the radius and ulna. A *palmar branch* arises about 3 to 4 cm above the inaculum, and descends over it to supply of the median part of the palm and the minence. In the forearm, the median and rves are occasionally interconnected by ...bers passing through these com- on(s) may explain certain anomalies in supplies of the hand muscles.

e lower forearm, the median nerve more superficial between the tendons of aris longus and the flexor carpi radialis. It e palm together with the tendons of the exor muscles, through the confined carpal hat is bounded anteriorly by the tough inaculum, and posteriorly, by the carpal



or through the flexor pollicis brevis to supply its superficial head before dividing to supply the abductor pollicis brevis and opponens pollicis muscles. Sometimes, the muscular branch also supplies all or part of the first dorsal interosseus muscle. Rarely, it arises in the carpal tunnel and pierces the flexor retinaculum—an arrangement of potential clinical concern.

The *common* and *proper palmar digital nerves* vary

3 1/2 digits. Occasionally, they supply only 2 1/2 digits. The proper palmar digital branches to the radial side of the index finger and to the contiguous sides of the index and middle fingers also carry motor fibers to supply, respectively, the first and second lumbrical muscles. Therefore, the digital nerves are not concerned solely with cutaneous sensibility. They contain an admixture of efferent and afferent somatic and autonomic

ANTERIOR INTEROSSEUS NERVE

	CORD	DIV	TRUNK
Flexor digitorum profundus (D2+3) D4+5 ulnar	$C_7 C_8$	lat/med	A	M/L
Flexor pollicis longus	$C_7 C_8 T_1$	med	A	med/lo
Pronator Quadratus (most distal AIN msc.)	$C_7 C_8 T_1$	lat/med	A	med/L

Entrapments

- anterior interosseus
- pronator teres
- ligament of Struthers

Nerve

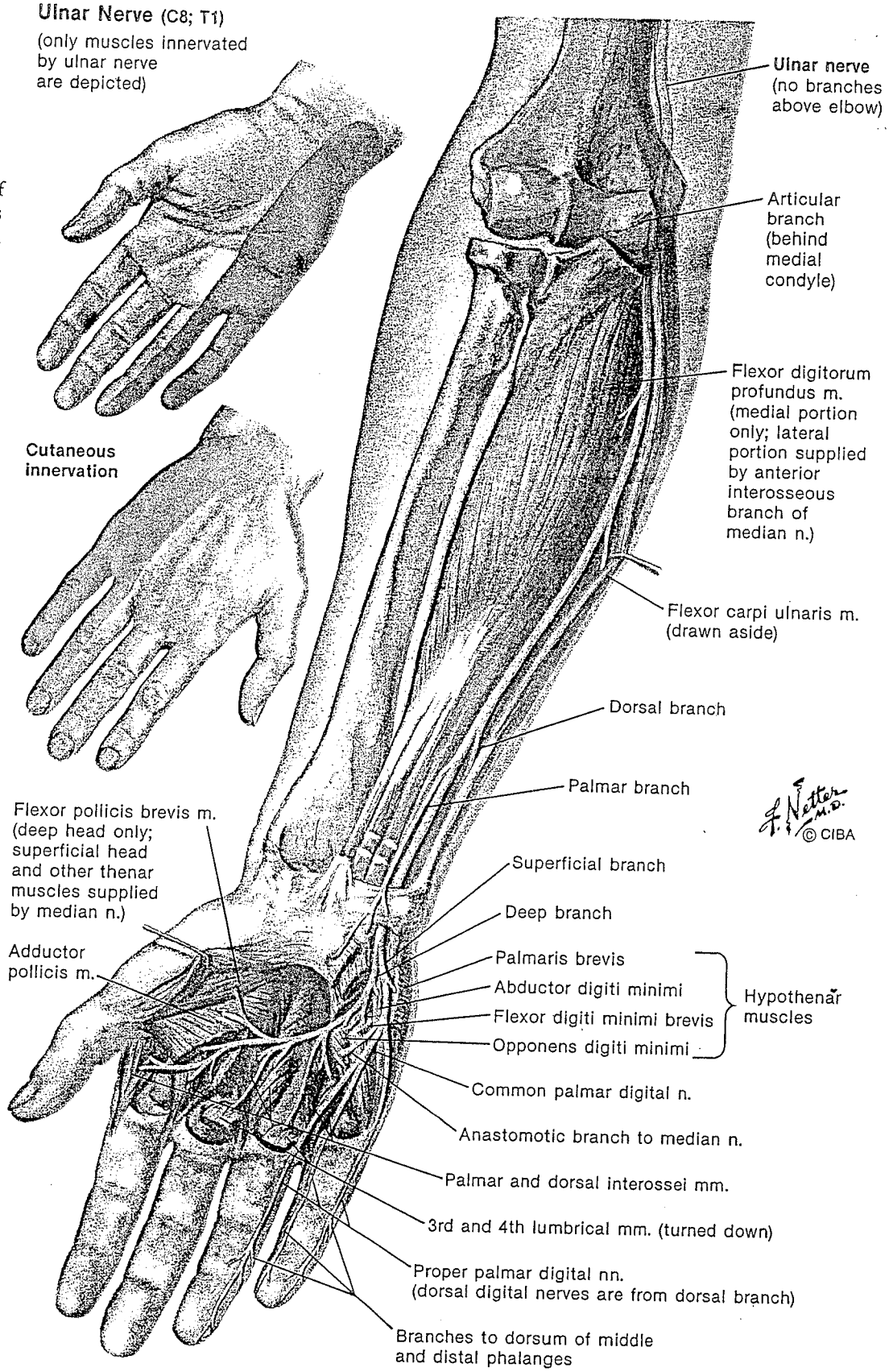
ar nerve is the main continuation of *cord* of the brachial plexus. Its fibers derived from C8 and T1, but it often litional fibers from C7.

n Arm. Initially, the ulnar nerve lies e axillary artery and vein; as it enters runs on the medial side of the brachial bout the middle of the arm, it pierces intermuscular septum and descends the medial head of the triceps brachii ongside the superior ulnar collateral lower third of the arm, it inclines pos- each the interval between the medial condyle and the olecranon. As it enters , it lies in the groove behind the condyle, between the humeral and of the flexor carpi ulnaris. Above the erve supplies no constant branches.

n Forearm and Hand. The ulnar lownward on the medial side of the ng first on the ulnar collateral liga- elbow joint and then on the flexor rofundus, deep to the flexor carpi lbow level, the ulnar nerve and artery b onsiderable gap, but they are ed in the lower two thirds of the fore- flexor carpi ulnaris narrows into its nerve and artery emerge from under ge and are covered only by skin and reach the hand by passing over the ce of the flexor retinaculum, and the lmost immediately into its superfi- terminal branches.

In the forearm and hand, the ulnar f articular, muscular, palmar cutane- superficial and deep terminal, and ches. Fine articular branches to the om the main nerve as it runs pos- medial epicondyle; before splitting nal branches, it supplies filaments

r forearm, the ulnar nerve gives off e flexor carpi ulnaris and the medial exor digitorum profundus. The *us branch* arises to 7 cm above ends near the ulnar artery, pierces a, and supplies the skin over the minence; it communicates with the eous nerve of the forearm and aneous branch of the median nerve. *r branch* arises 5 to 10 cm above the oste rly, deep to the tendon of nar erces the deep fascia, and lly along the dorsomedial side of , it divides into branches that sup- skin on the medial side of the back l fingers. There are usually two or *gital nerves*, one supplying the he little finger, the other splitting *l digital nerves* to supply adjacent le and ring fingers, and the third

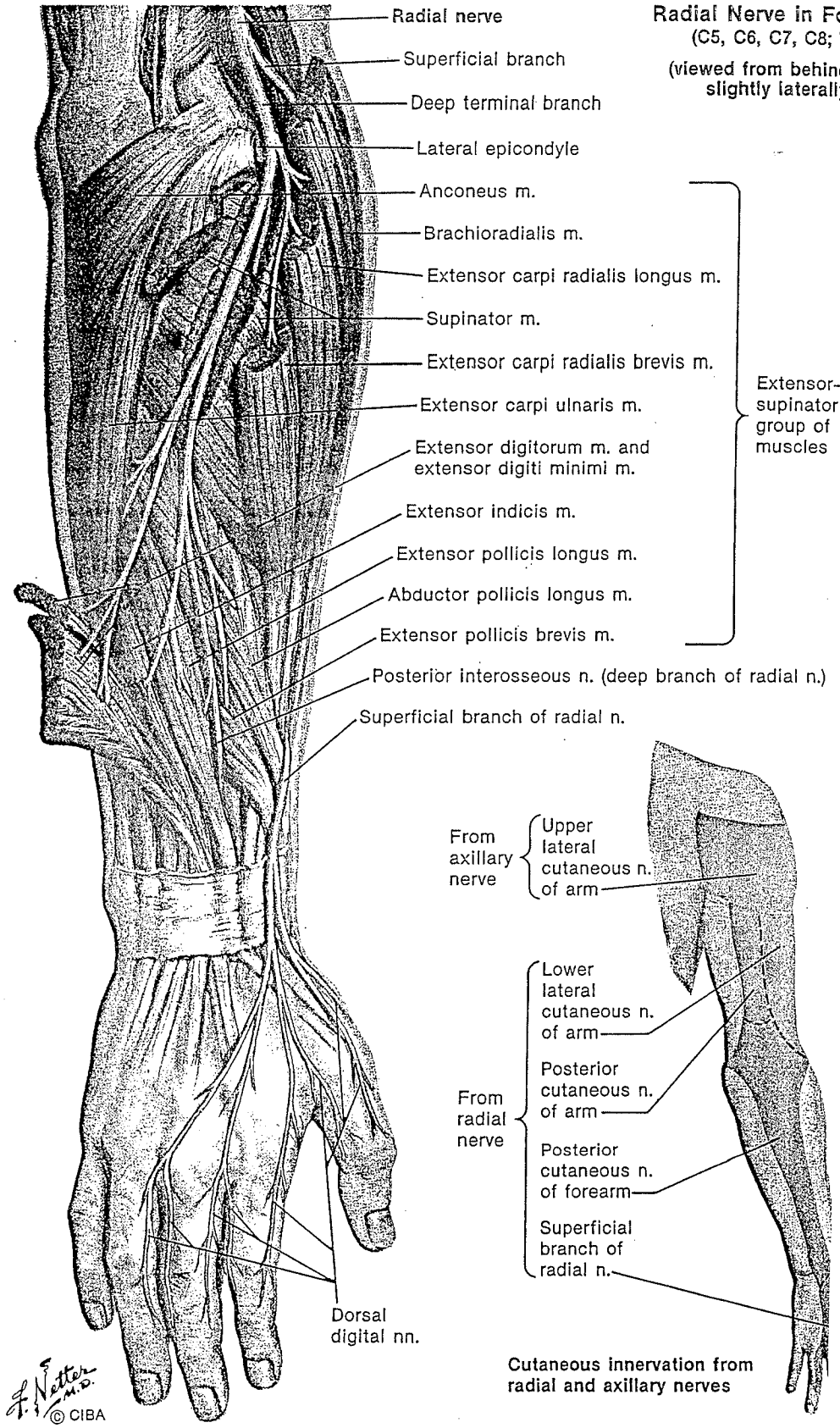


side of the palm, and gives off two palmar digital nerves. One is the *proper palmar digital nerve* for the medial side of the little finger, and the other (a *common palmar digital nerve*) communicates with the adjoining common palmar digital branch of the median nerve before dividing into the two *proper palmar digital nerves* for the adjacent sides of the little and ring fingers. In a minority of individuals, the ulnar nerve supplies 2 1/2 rather than 1 1/2 digits, in which case the

finger, perforates and supplies the opponens digiti minimi, and then accompanies the deep palmar arterial arch behind the flexor digital tendons. In the palm, it gives branches to the third and fourth lumbricals and to the interossei, and usually ends by supplying the adductor pollicis and the flexor pollicis brevis.

Variations in the nerve supplies of the palmar muscles are as common as those in the cutaneous

Radial Nerve in Forearm



Radial Nerve in For
(C5, C6, C7, C8; T1
(viewed from behind slightly laterally)

Cutaneous innervation from radial and axillary nerves

The radial nerve divides anterior to the lateral humeral epicondyle into superficial and deep terminal branches (Plate 5).

The superficial terminal branch descends along the anterolateral side of the forearm, deep to the brachioradialis and lying successively on the supinator, pronator teres, flexor digitorum superficialis and flexor digitorum longus muscles. In the upper third of the forearm, the superficial terminal branch and the radial artery converge; in the middle third, they are close together, with the nerve lying laterally; and in the lower third, they diverge as the nerve inclines posterolaterally, deep to the tendon of the brachioradialis. The nerve now pierces the deep fascia and commonly subdivides into two branches, which usually split into four or five *dorsal digital nerves*. The cutaneous area of supply is shown in the lower part of the illustration. The dorsal digital nerves also supply filaments to the adjacent vessels, joints and bones. (Note that the radial dorsal digital nerves extend only to the levels of the distal interphalangeal joints, and that the first dorsal digital nerve gives off a twig that curves around the radial side of the thumb to supply the skin over the lateral part of the thenar eminence.) The cutaneous areas on the hand supplied by the radial, median and ulnar nerves (Plates 8 and 9) show wide individual variations; communications exist between their branches, and considerable marginal overlaps are found in their zones of distribution.

The deep terminal branch winds posteroinferiorly around the lateral side of the radius and may supply additional twigs to the brachioradialis before passing between the humeral and radial heads of the supinator, or between this muscle and the upper end of the radial shaft, to reach the back of the forearm.

From this point onward, the nerve is generally called the *posterior (dorsal) interosseous nerve*, although this term is sometimes used as a synonym for the entire deep terminal branch. On emerging from or beneath the supinator muscle, the nerve the extensor digitorum, extensor digiti and extensor carpi ulnaris muscles. branches run distally to supply the extenso cis longus, extensor indicis, abductor polli gus and extensor pollicis brevis muscles. lower border of the extensor pollicis bre nerve, now much reduced in size, passes the extensor pollicis longus, and then d posterior to the interosseous membrane

, ...bial and Common
:al Nerves

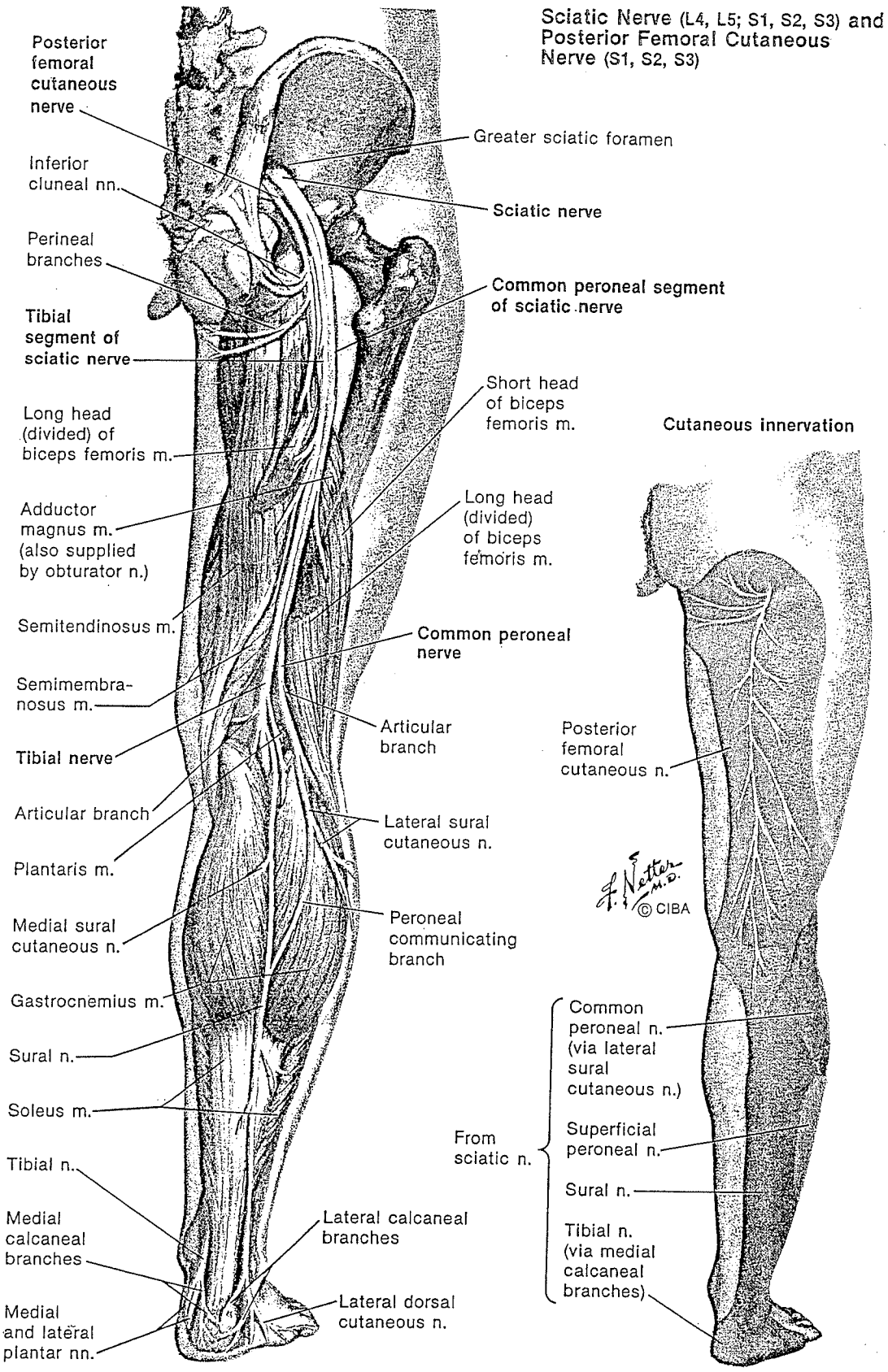
:rve

The roots of the sciatic nerve arise from
l rami of the fourth lumbar to third
res (Plate 10) and unite to form a sin-
that is ovoid in cross section and 16 to
de in adults (Plate 13). In the lesser pel-
rve lies anterior to the piriformis, below
nters the buttock through the greater
umen (in about 2% of individuals, the
ces the piriformis). Next, the nerve
terally beneath the gluteus maximus,
ests on the posterior surface of the
id the nerve to quadratus femoris. On
side, it is accompanied by the posterior
taneous nerve and the inferior gluteal
its special branch to the nerve. On
a point about midway between the
erosity and the greater trochanter, the
downward over the gemelli, the obtu-
ius tendon and the quadratus femoris,
rate it from the hip joint, and leaves
c to enter the thigh beneath the lower
ie gluteus maximus.
ic n...e then descends near the middle
: o... thigh, lying on the adductor
l being crossed obliquely by the long
biceps femoris. Just above the apex of
l fossa, it is overlapped by the contig-
as of the biceps femoris and semimem-
uscles. In about 90% of individuals,
nerve divides into its terminal *tibial*
peroneal branches near the apex of the
ossa, while in 10% of individuals
occurs at higher levels. Rarely, the
ommon peroneal nerves arise indepen-
the sacral plexus, but pursue closely
ses until they reach the apex of the
sa.

. In the buttock, the sciatic nerve
articular branch to the hip, which
ie posterior part of the joint capsule.
supply *vascular filaments* to the inferior
y. Lower down, it supplies *muscular*
oth heads of the biceps femoris, semi-
us, semitendinosus and the ischial
ictor magnus muscles. The branch to
ad of the biceps femoris comes from
peroneal part of the nerve, while the
the other muscles are derived from
ision.

e

ne... ...s the larger, medial, terminal
sciatic nerve (Plate 14). Its fibers are
the ventral divisions of the ventral
ourth and fifth lumbar nerves and the
and third sacral nerves.
he tibial nerve continues the line of
erve through the popliteal fossa and
At its origin, the nerve is overlapped
ing margins of the semimembrano-



heads of the gastrocnemius and plantaris muscles. Passing over the popliteus and under the tendinous arch of the soleus on the medial side of the posterior tibial vessels, the tibial nerve next enters the space between the gastrocnemius and the soleus behind, and the upper part of the tibialis posterior, in front. Continuing downward, it crosses over the posterior tibial vessels to reach their lateral sides so as to lie between the contiguthe foot behind the medial malleolus, deep to the flexor retinaculum and between the tendons of the flexor hallucis longus and the flexor digitorum longus. The nerve ends at this level by dividing into the *medial* and *lateral plantar nerves*.

The tibial nerve consists of the following main branches: muscular, articular, sural, calcaneal and medial and lateral plantar; it also gives off smaller osseous (medullary) and vascular twigs.

2) Median Mot + Sens / F waves
Sens + sites c Dx of CTS

3) Ulnar Mot + Sens
Motor R EBBS - sometimes

3) Radial M + S

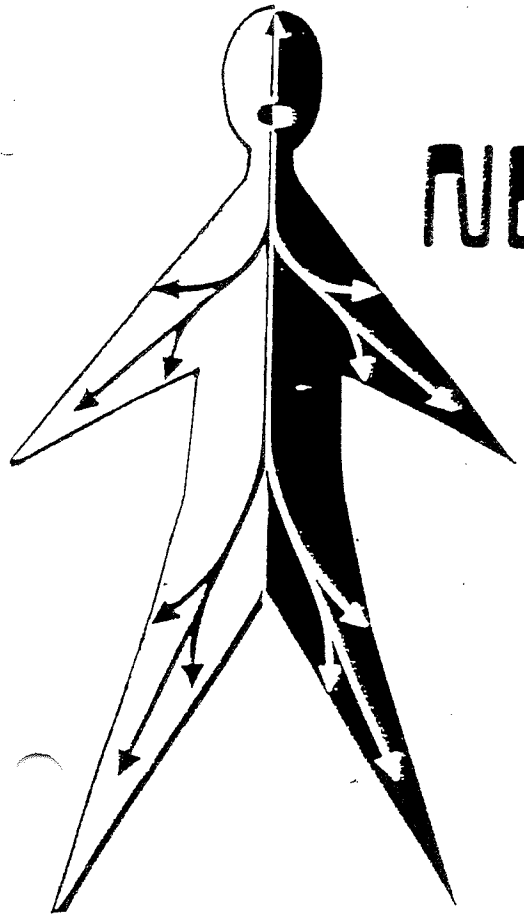
4) Peroneal M + S
sometimes c F waves
also 3 sites c Dx of foot drop

5) Tibials + Sural 4th "Reflex"

6) Tibialis anterior - if unable to find Peroneal
also for lower extremity
Rep Stim - NMJ

7) Rep Stim - NMJ
Nasalis, Mentalis, orbicularis oculi + Trapezius

8) Phrenic Nerve - diaphragm
for Dx of Compression Plexus



NERVE CONDUCTION STUDIES

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With a Foreword by

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Director, EMG Laboratory
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Designed as an aid to learning electromyography and neurodiagnosis, this manual provides a comprehensive look at performance, interpretation and possible sources of error in nerve conduction studies. Syntheses of the current literature are coupled with new insights to help physicians and technologists grasp the significance of nerve conduction study procedures and results. Two introductory chapters convey an understanding of terminology and techniques. Succeeding sections detail nerve conduction study set-ups for facial, upper extremity and lower extremity studies; reflex studies; anatomic variants for the accessory peroneal nerve and for median to ulnar crossovers; examples of electrical findings on nerve conduction studies with pathology; and basic and clinical diagnostic nerve conduction study workups.

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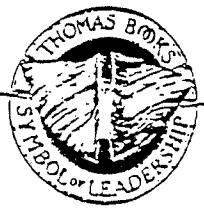

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CONTENTS

Phrenic Nerve Study Pg 59A

NERVE CONDUCTION STUDIES

distal? should be peak for sensory & distal for motor

NORMAL VALUES: MOTOR AND SENSORY CONDUCTION STUDIES (DR. Miller's LAB

	AMPLITUDE (UV/MV LOWER LIMIT/NL)	DISTANCE	LATENCY (MSEC: UPPER LIMIT/NL)	CONDUCTION VELOCITY	F WAVE	H REFLEX
A. SENSORY						
MEDIAN						
DIGIT/WRIST	9	11	3.7			
PALM/WRIST		8	Distal Lat. 2.3			
ULNAR	8	7.9	3			
SUP RADIAL (14cm)	15	14 cm	2.5			
SURAL (14cm)	6	14				
SUP PERONEAL (10cm)	12	10	4.3 arm			
			3.2			
B. MOTOR						
MEDIAN	5	7	4.5	50	32	
ULNAR TO ADM	5	7-9	3.4	50	32	
ULNAR TO FDI	5	11	4.5			
PERONEAL	2	7	6.0	37		38
POST TIBIAL	4	8.5	7.0	37		38
[illegible]	(8)					

Chapter 1

INTRODUCTION

MOST EMG EXAMINATIONS consist of two necessary but distinct parts—the nerve conduction studies and the needle examination. Both the nerve conduction studies and the needle examination are complementary testing procedures that evaluate different aspects of the peripheral neuromuscular system. Because the nerve conduction studies and the needle examination evaluate the peripheral neuromuscular system in different ways, it is unreasonable to think that one part may be performed in lieu of the other. Currently in the literature there can be found a wealth of knowledge concerning the performance and interpretation of the needle examination, but in spite of the importance of nerve conduction studies, there is little detailed information in the literature regarding its technique or interpretation.

Nerve conduction studies should be performed with the following questions in mind. First, is the problem a generalized process, or is it a local problem? That is, does the pathology affect all of the peripheral nerves, or does it affect a single nerve or localized area of the nervous system? Second, is it possible to determine the pathologic process involved, such as axonal loss (the death of a nerve fiber) or segmental demyelination (an abnormality of the myelin sheath surrounding the nerve)?

In order to answer these questions, it is first necessary to determine if each study is normal or abnormal. To do this, every laboratory must have a reliable set of normal values with which to compare these results. The most frequently used normal values are based on results obtained from a "normal" population consisting of a large number of healthy people in various age groups. These values are then compiled to give the upper and lower limits and/or the mean and standard deviation for each study. A reliable set of normal values should be compiled using the same techniques that are used when performing these studies on patients. Another way to determine the normality of a result is to compare one side with the corresponding study on the contralateral uninvolved limb. Care must be taken when judging these results to be sure the comparison is justified. For instance, the amplitudes of some responses may have a greater side-to-side

variation than others. This is especially true when the recording sites are not easily accessible or do not have definite landmarks. It is difficult and sometimes erroneous to judge normal values based on a side-to-side comparison without having previously tried the same comparison on a normal population.

Three parameters are determined for most motor nerve conduction studies: (1) the amplitude and configuration, (2) the distal latency, and (3) the conduction velocity. Generally, for sensory conduction studies, only the amplitudes and peak latencies are reported, although conduction velocities may also be determined. Even though an individual parameter may give a clue to the underlying problem or indicate what additional studies need to be done, it is only by studying multiple nerves that valid conclusions are drawn. These conclusions can give considerable evidence as to the pathology and, therefore, the prognosis of the peripheral nerve problem.

Since normal values for nerve conduction studies are based on stringent standards and procedures, utilizing these normals and maintaining their accuracy depends on procedures that are rigorously followed for each study. Machine settings, methods of measurement, placement of electrodes, stimulation sites, recording sites, and types of electrodes are all factors that can change the results. There are different published methods and procedures than those found in this manual. Each method must be judged on the type of equipment and patient population found in the individual laboratory. The only absolute rule that must be followed when performing nerve conduction studies is consistancy of procedures and methods based on the same procedures and methods used to obtain normal values from a normal population. If other methods are found to be better adaptive to the equipment and patient population in a specific laboratory, then these procedures should be used. If they are different than the procedures described in this manual (or elsewhere), then the normal values must be modified by collecting new normal values using those different procedures.

All EMG equipment should have certain basic features: a differential amplifier, a stimulator, and displaying apparatus (oscilloscope and hard copy recorder). The procedures and, therefore, the normal values described here are based on the use of a TECA TE-4® EMG machine.

A differential amplifier amplifies the difference between the electrical activity picked up by the two recording electrodes. The amplifier should have the capacity to change the magnification of the response (gain) and to record certain frequencies while blocking others out (filters). Because the same filter settings may vary slightly between different machine models, each laboratory should collect some normal values and compare them to those in this manual or to other published normal values. If an amplifier is used that has filters set in the machine, they should also be checked against the filter settings used in this manual; if they are different, the normal

values (especially for amplitude) must be modified to compensate for this difference. To minimize measurement variation, the gain and the sweep speed should, on each study, remain constant at all stimulation sites. Not only will this allow better comparisons between the different stimulation sites of each study, it will also decrease the amount of measurement variation.

The stimulator used for nerve conduction studies should consist of a stimulating component with an attached surface stimulator. The stimulating component must trigger the amplifier's sweep as well as stimulate the patient. There should be some mechanism to deliver the stimulation manually (not at specific intervals) and automatically at predetermined intervals. The ability to change the intensity of the stimulus is essential. This function may be either part of the component or part of the surface stimulator. The surface stimulator is a hand-held apparatus that is easily maneuvered to different stimulation sites along the nerve. The stimulating prongs or electrodes should be a specific distance apart (usually 2 to 3 cm).

A display screen, or oscilloscope, is used to display the response derived from the amplifier. With this, there must be some method of measuring time (milliseconds) and amplitude (microvolts and millivolts). The ability to store each response on the oscilloscope is very helpful and sometimes imperative when the normal values are based on the comparison of response configuration and/or the superimposition of a series of responses. A hard copy feature should also be present on all EMG equipment. This feature not only provides a permanent record but it also produces more accurate results because the time, size, and configuration of each response can be measured directly from this record.

Other components such as signal averagers, counters, and delay lines might serve specific needs in individual laboratories but are not necessary for procedures in this manual.

Chapter 2

TECHNIQUES

IT IS IMPORTANT THAT every EMG laboratory have certain standard procedures. In this chapter, definitions of terms and general procedures used for this manual will be explained in detail (specific procedures will be described in Chapter 3). The machine that all studies will be performed on is a Teca model TE4 with NS6 stimulator, using two AA6 MkII amplifiers, and a storage scope. Even though this manual is based on specific equipment, with slight modifications, most procedures and techniques can be altered to fit other equipment.

DEFINITIONS (1, 50)

Basic terms used on nerve conduction studies must be defined. so the procedures can be adequately described. The following is a glossary of terms, with illustrations.

amplitude: (Fig. 2-1) The height (voltage) of the response in microvolts or millivolts, which approximately correlates with the number of nerve or muscle fibers responding to stimulation.

anode: The positive terminal of a source of electrical current. The prong on the hand-held stimulator that is usually farthest away from the recording electrode (S2).

antidromic impulse: A nerve impulse that is traveling in a direction opposite the physiologic direction.

artifact: Unwanted electrical contaminant, can be either physiological or nonphysiologic in nature.

baseline: (Fig. 2-2) A chosen reference point of "0" volts (or amplitude) serving as the base of the response.

calibration signal: (Figs. 2-1 and 2-3) A set of graduatives to indicate amplitude or time.

cathode: The negative terminal of a source of electrical current. This prong of the hand-held stimulator is usually closest to the recording electrodes and is the prong under which the initial depolarization of the nerve takes place (S1).

compound muscle action potential: Nearly synchronous summated action

1
AMPLITUDE MEASUREMENTS

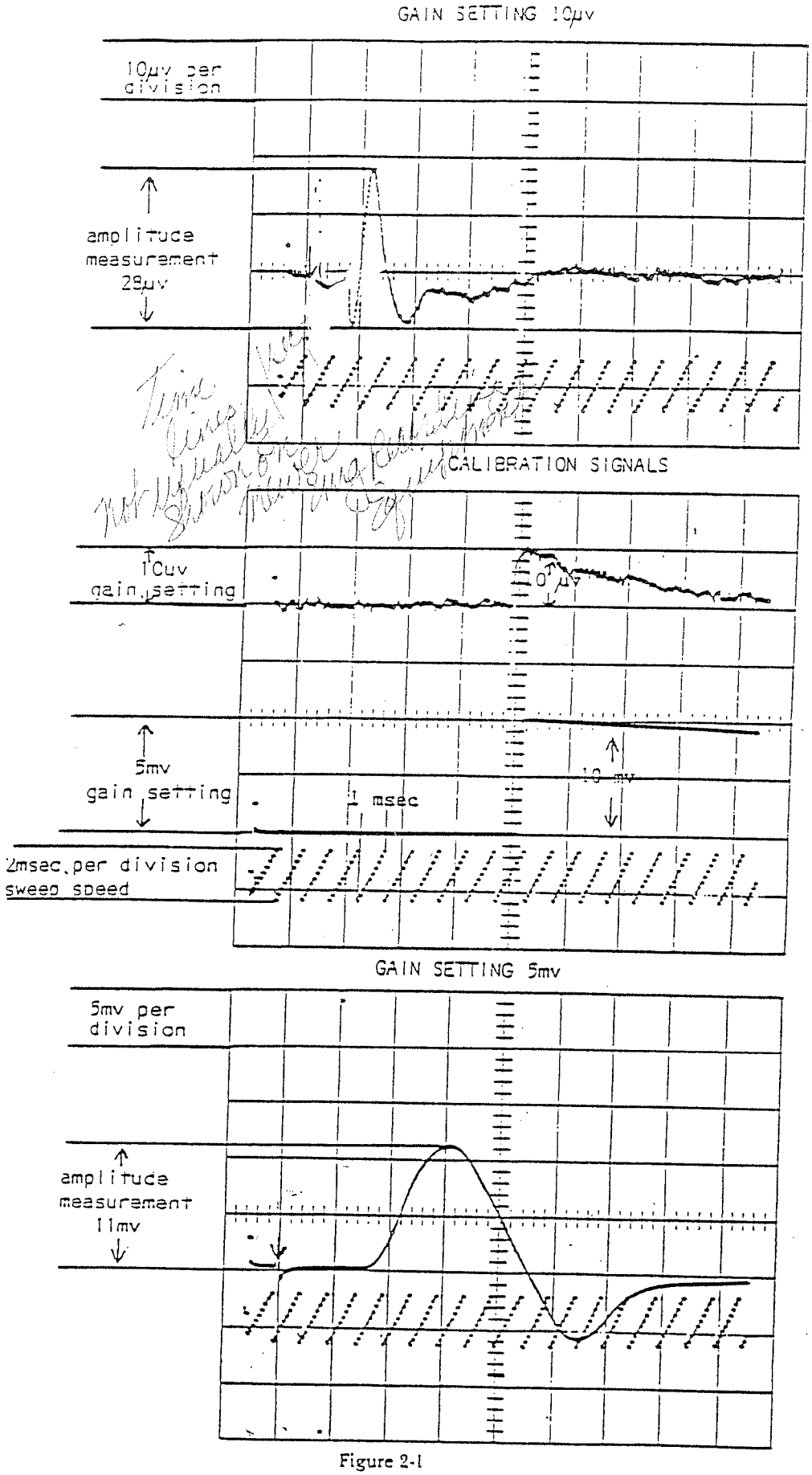


Figure 2-1

potentials obtained by stimulating a nerve and recording from a muscle.

compound nerve action potential: Nearly synchronous summated action potential obtained by stimulating and recording from nerve fibers (mixed, motor, or sensory).

compound sensory action potential: Nearly synchronous summated action potential obtained by stimulating and/or recording from pure sensory fibers.

conduction velocity (nerve): A measurement of distance per time (meters per second), usually calculated between two stimulation sites.

depolarization: To change the electrical charge across a cell membrane.

distal latency: The latency obtained by stimulating at the distal stimulation site.

G0: The ground electrode.

G1: The recording or active electrode.

G2: The reference or indifferent electrode.

gain: (Figs. 2-1 and 2-3) An amplitude setting that defines the amount per division of the response.

latency: (Fig. 2-4) Time interval from stimulus artifact to the response (takeoff or peak). The time required by an impulse to travel from the stimulation site to the recording site.

meters per second: Abbreviated M/sec, measurement of distance per time, unit measurement for nerve conduction velocity.

microvolts: Abbreviated μv, a unit of amplitude measurement. 1×10^{-6} volts.

millisecond: Abbreviated msec, a unit of time measurement. 1×10^{-3} seconds.

millivolt: Abbreviated mv, a unit of amplitude measurement. 1×10^{-3} volt.

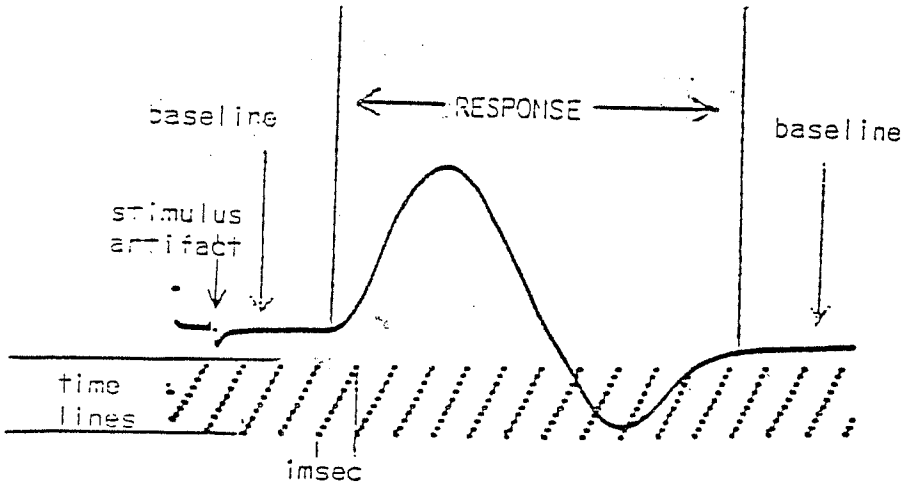


Figure 2-2

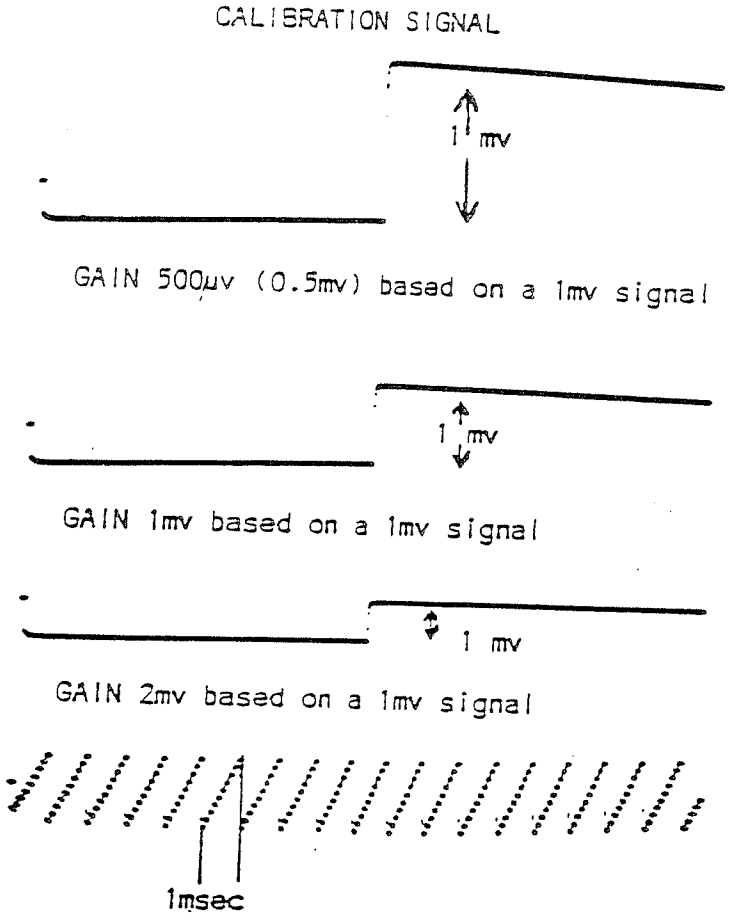


Figure 2-3

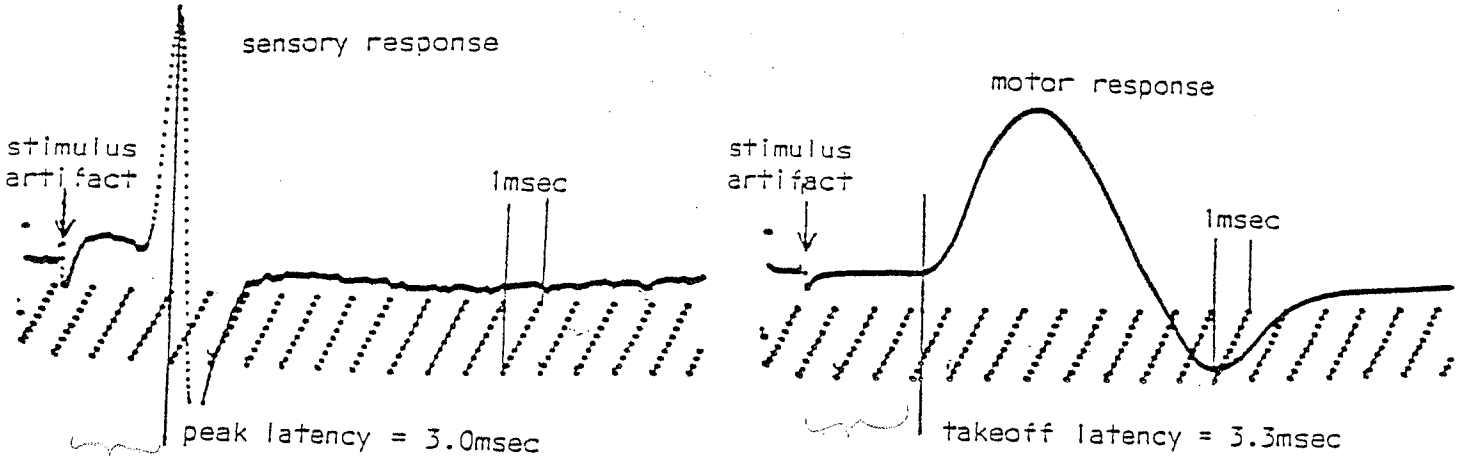


Figure 2-4

mixed nerve: A peripheral nerve that contains both sensory and motor fibers.

motor response: (Fig. 2-4) A response obtained by stimulating a motor or mixed nerve and recording from the muscle it innervates.

negative deflection: By convention, an upward deflection from the baseline.

orthodromic impulse: A nerve impulse that is traveling in the physiologic direction.

peak: The point of the response that is most negative or most positive with reference to the baseline; usually the negative peak is used when measuring amplitudes.

peak latency: (Fig. 2-4) The time from the stimulus artifact to the peak of the negative response.

positive deflection: By convention, a downward deflection from the baseline.

response area: The area under the negative curve of the response.

response duration: (Fig. 2-5) There are two accepted ways to measure response duration: time measured from where the response initially leaves the baseline to (1) where it again crosses the level of the baseline or (2) where it returns to the baseline.

sensory response: (Fig. 2-4) A response that is obtained by recording and/or stimulating a pure sensory nerve.

stimulus artifact: (Figs. 2-6 and 2-7) Deflection from the baseline produced by the onset of the stimulus; shock artifact.

stimulus delay: (Fig. 2-6) Time between the beginning of the sweep and the stimulus. The number of msec displayed before the onset of the stimulus, signified by the stimulus (shock) artifact.

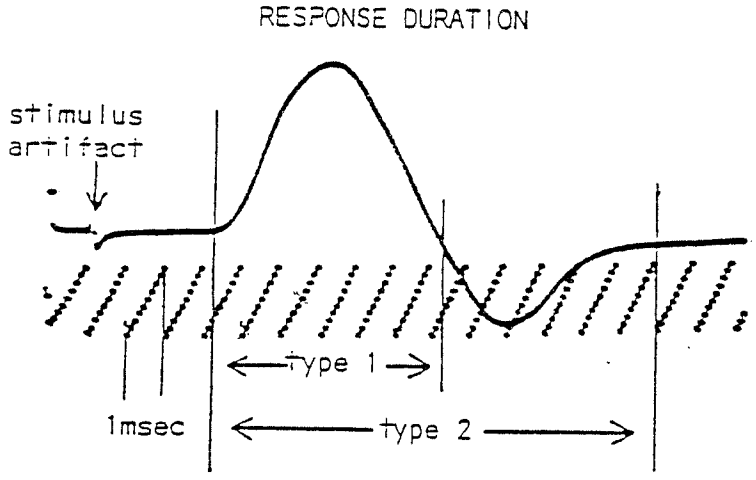


Figure 2-5

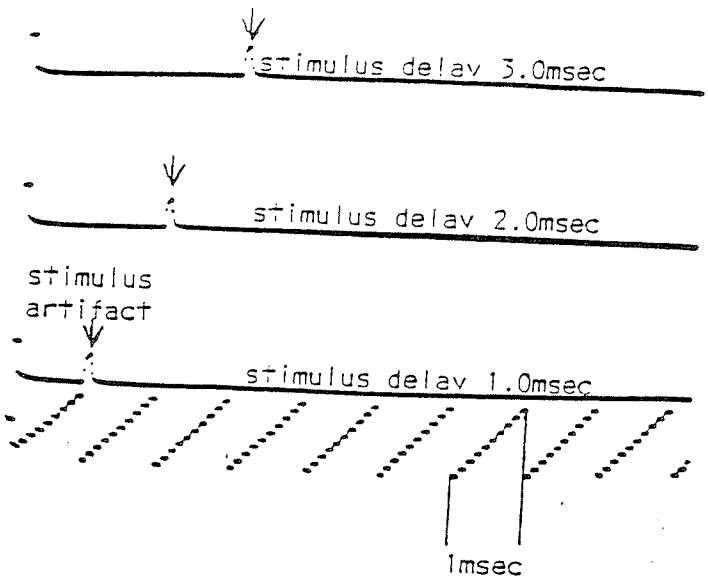


Figure 2-6

stimulus duration: (Fig. 2-7) The amount of time a stimulus is sustained, usually .05 to .2 msec.

sweep speed: (Fig. 2-8) Number of msec per division. Determines the amount of time segments displayed on a screen.

takeoff latency: The time from the stimulus artifact to the initial deflection (usually negative) of the response from the baseline.

time line: (Figs. 2-2 and 2-7) Standard time scale located below the response.

voltage: Potential difference between two points. The electrical intensity of the stimulus, or the amplitude measurement of the response.

MEASUREMENTS (10, 21, 31, 45, 48, 66)

The technical aspects of nerve conduction studies include positioning of the patient, applying electrodes, stimulation of nerves, and obtaining a response. For each study there are three different types of measurements that must be made—amplitude, latency, and distances. The amplitudes and latencies are measured from either an oscilloscope, storage scope, or hard copy, and the various distances are measured directly on the patient. Variations for individual studies will be discussed later (Chapter 3).

Every study requires that three electrodes be applied to a patient: G0, G1, and G2. G1 and G2 are the electrodes used to record the response. G1, the recording electrode, is placed directly over the nerve or over the belly of the muscle to be studied. Placement of G2, the reference electrode, will vary depending on the individual study, but it is generally placed further from the stimulating electrode than G1. G0, the ground electrode, is placed

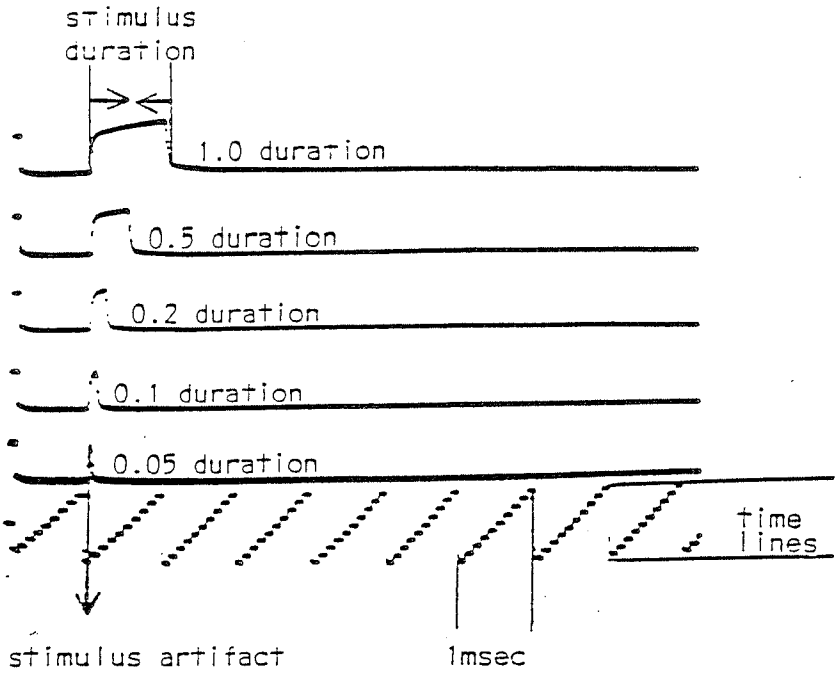


Figure 2-7

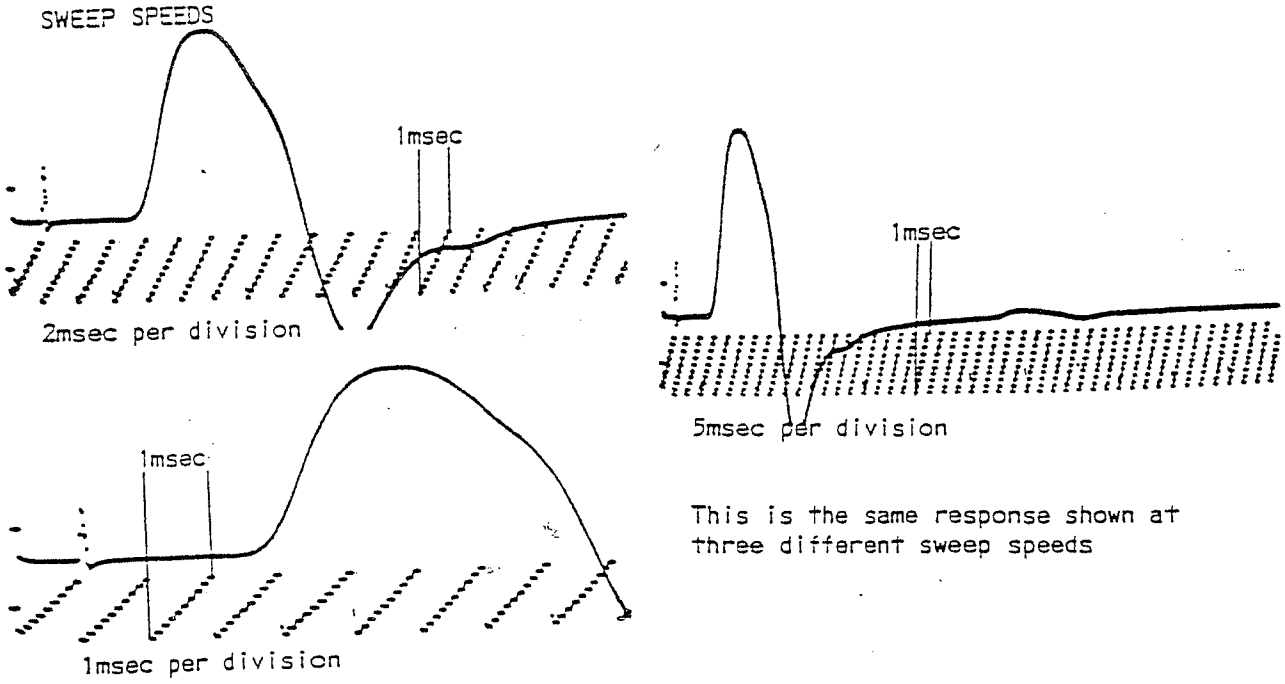


Figure 2-8

between G1 and the stimulation site. In all routine studies, the order of these three electrodes remains the same, that is, G0 then G1 then G2, with G0 located closest to the stimulation site. Each time a nerve is stimulated a current passes between the cathode and the anode of the hand stimulator, which depolarizes the nerve. The hand stimulator is placed directly over the nerve and the intensity of the stimulus is increased in small increments until a response first appears. The stimulus is then increased slowly until a plateau is reached (i.e., amplitude ceases to increase). The stimulus is then increased slightly to be sure the response is supramaximal. All measurements are obtained from supramaximal responses. In order to insure that a response is supramaximal, it is sometimes necessary to increase the duration of the stimulus. Most routine nerve conduction studies can be performed with a stimulus duration of 0.1 msec, or 0.2 msec, but occasionally it is necessary to increase the stimulus duration even further, to 0.5 msec, or 1.0 msec.

Amplitude measurements are based on the gain settings of the machine. The TECA TE4 machine, when properly calibrated, indicates a gain equal to one division on the oscilloscope or storage scope, or 1 cm on the recording paper. Most amplitudes are measured from the baseline to the peak of the response in either microvolts or millivolts. Based on the gain per division, this is accomplished by measuring the height of the response from the baseline to the highest point, or peak, of the response (Fig. 2-1).

Latencies are a time measurement. They are determined in two ways, one to the takeoff and the other to the peak. Takeoff latencies are measured from the stimulus artifact to the initial deflection of the response from the baseline, while peak latencies are measured from the stimulus artifact to the negative peak of the response. To determine the latency, a vertical line is drawn through the response perpendicular to the baseline, and the time lines between the shock artifact and that line are counted (Fig. 2-4).

Distances are determined by measuring as closely as possible the anatomic course of the nerve along the surface of the limb. At each stimulation site, a mark should be made where the cathode (S1) of the hand-held stimulator is placed. Distances are then determined by measuring from the proximal cathode mark to the distal cathode mark, or from the distal cathode mark to the recording electrode (G1) (Fig. 2-9). When there is more than one proximal stimulation site, each measurement is taken from the proximal stimulation site to the most distal stimulation site of the study. A comparison between conduction velocities obtained with different proximal stimulation sites can then be made. Measurements can be made between two proximal stimulation sites but are not recommended because the percentage of error increases with shorter distances.

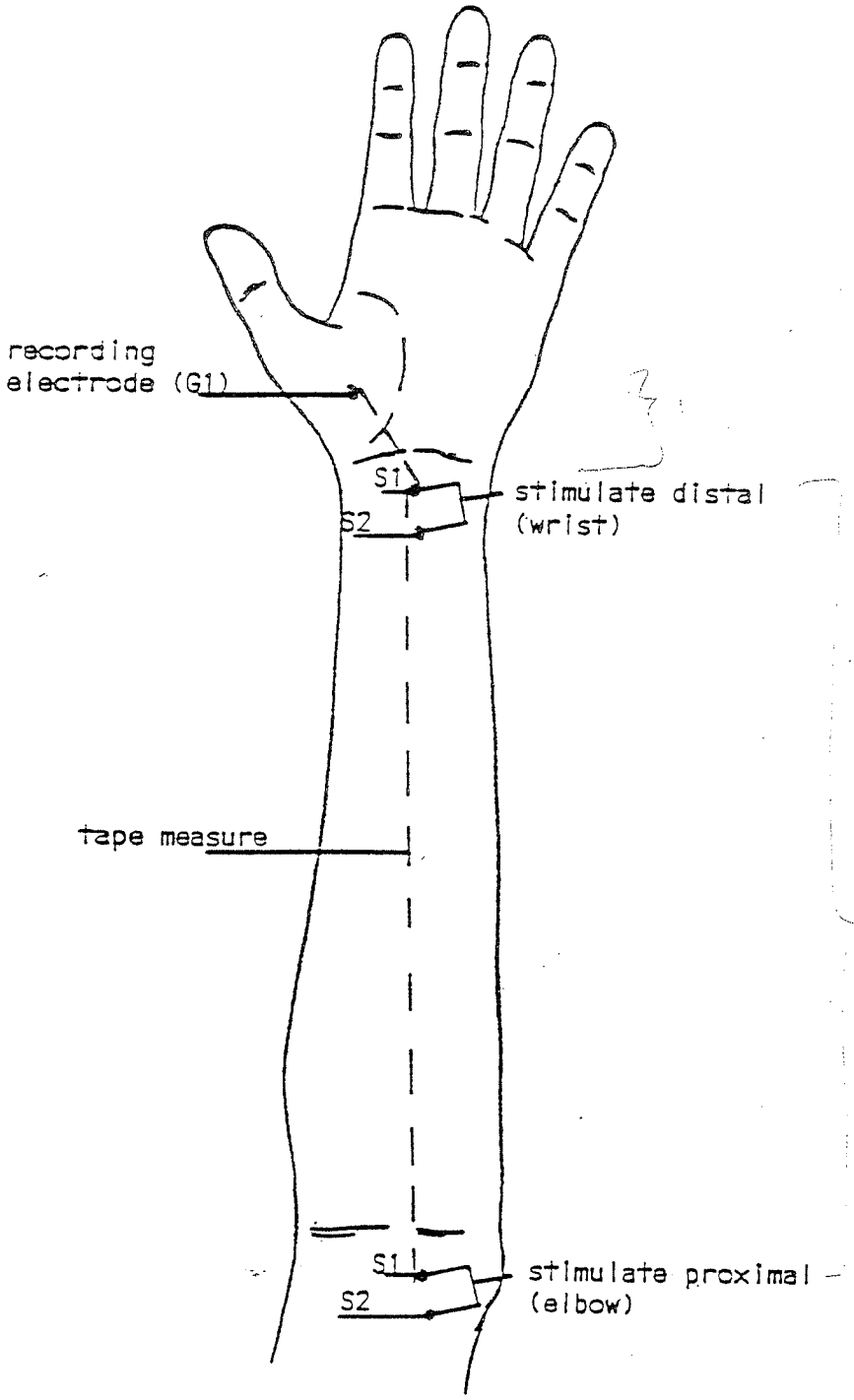

recording
electrode (G1)
S1
S2
stimulate distal
(wrist)
tape measure
S1
S2
stimulate proximal
(elbow)

Figure 2-9

CALCULATIONS (10, 21, 31, 45, 48, 66)

Calculations are based on the measurements already made. For the sake of clarity and completeness, a standard nerve conduction study work sheet should be used and all measurements and calculations should follow a standard format. To avoid technical errors, all measurements and calculations should be completed before the next study is started, and each study should be logged on the work sheet as it is performed. Figure 2-10 is an example of a standard nerve conduction study work sheet that contains all necessary information for complete and retrievable studies. The nerve stimulated column should provide the name, type, and side of the nerve being stimulated. For example, if the left ulnar motor nerve is stimulated, it is written (L) ulnar (m). The stimulation site column should specify where the hand-held stimulator was placed. For example, if the nerve is stimulated at or slightly above the elbow, then "elbow" should be logged in this column. Specifying the recording site is extremely important because one nerve may have more than one recording site. For example, both the abductor digiti minimi and the first dorsal interosseous muscles may be used as recording sites for the ulnar motor. Both of these are separate studies and should be logged on the work sheet as such. The gain for each study should be specified and it must remain constant for each stimulation site. Amplitude, latency, and distances are measured, then logged next to their corresponding stimulation site. By definition, the latency obtained by stimulation at the distal site is the distal latency. To calculate the conduction velocity, the distal latency should be subtracted from the proximal latency, and the results divided into the measured distance between the distal stimulation site and the proximal stimulation site. (Fig. 2-10).

TECHNICAL PITFALLS AND ERRORS (10, 20, 31, 42, 48, 53, 66)

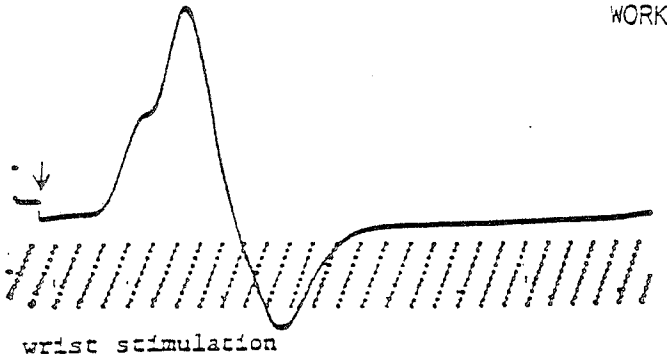
The recognition of technical pitfalls and errors and how they are manifested is necessary to ensure accurate results. The performance of nerve conduction studies is deceptively simple, but the importance of standardization cannot be overemphasized. Normal values are based on specific technical procedures; therefore, any alteration of these procedures can cause a variation in the results. This fact must be fully appreciated because most of the errors that occur on nerve conduction studies are needlessly caused by incorrect or inconsistent technical procedures or anatomic variations.

The following is a list of some of the more common sources of error.

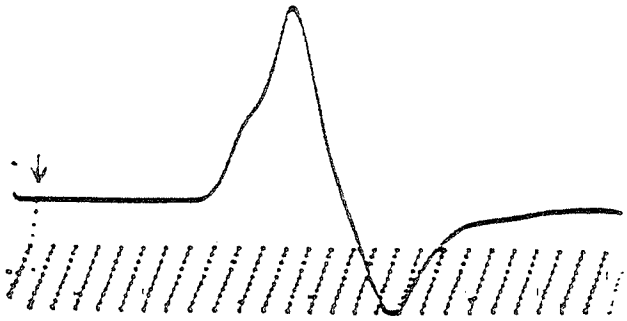
Machine Settings

The calibration signal should be checked prior to each study, and once a machine is calibrated, all components must remain constant. If it is

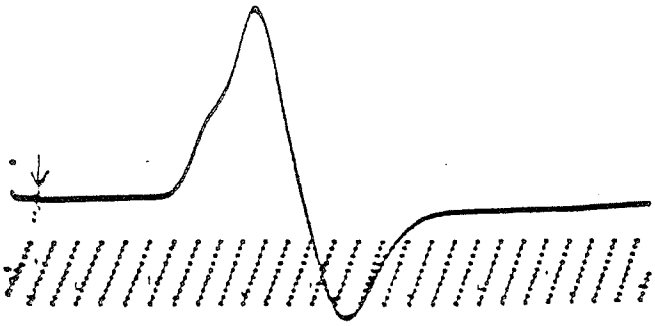
COMPLETED NERVE CONDUCTION STUDY
WORK SHEET



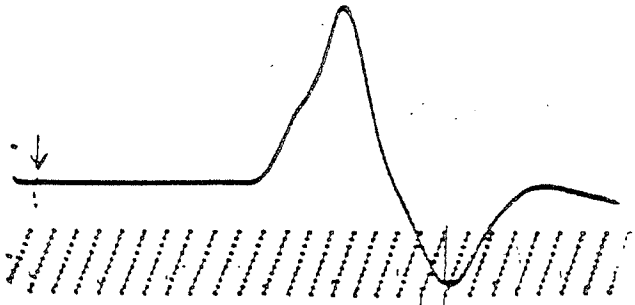
wrist stimulation



elbow stimulation

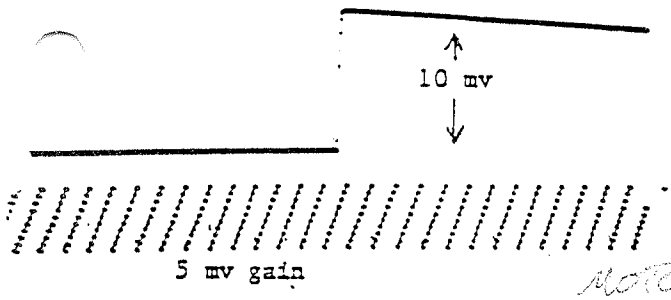


below elbow stimulation



axilla stimulation

1msec



10 mv

5 mv gain

see normal values in section III

ADM = abductor digiti minimi

age - 42

Nerve Stimulated	Stimulation Site	Record Site	Gain	Amp.	Lat. msec	Distance cm.	C.V. M/sec
(L) ulnar(m)	elbow	ADM	5mv	14.0	7.4	28.0	58
	wrist			14.0	2.6	4.5	
					4.8		
	below elbow			13.5	5.6	18.0	60
					7.6		
					8.0		
	axilla			12.5	9.4	40.0	59
					2.6		
					6.8		

Figure 2-10

necessary to change one or more of the components, the calibration signal must be rechecked. Figure 2-11 illustrates the different calibration signals received using different amplifiers with all other components remaining constant. Obviously, amplitudes would be incorrect if measured without the differences in machine input or calibration being taken into account. Inconsistent filter settings are another source of error in amplitude measurement. The amplitude of a motor response at standard filter settings can be significantly decreased if sensory filter settings are used instead (Fig. 2-12). Even though EMG machines are built to accurately reproduce a response on different sweep speeds and gain settings, these responses are subject to a certain amount of human error in the mechanics of measurement (unless performed on a machine that automatically measures both amplitude and latencies). Because of this, different sweep speeds or gain settings used on the same study can cause different latency measurements, which could affect the distal latency and conduction velocity. Whenever possible, settings should remain constant throughout each individual study.

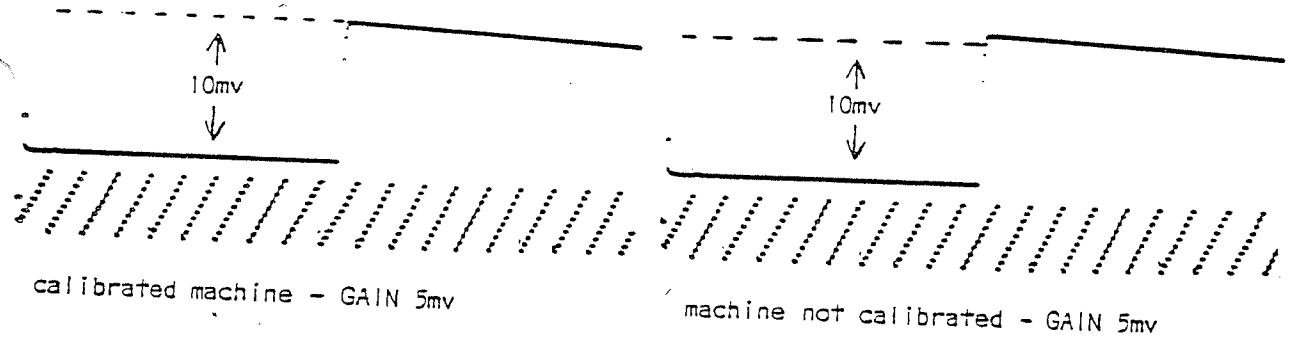


Figure 2-11

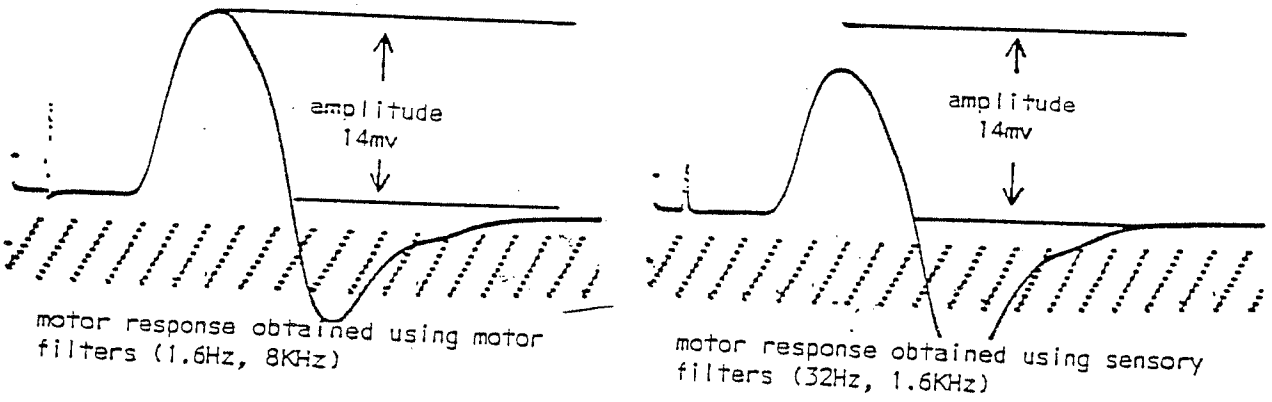


Figure 2-12

Artifact

There are, in most EMG laboratories, many different kinds of artifact with which one must contend. The amount and type of artifact will vary depending on (1) the location of the laboratory, (2) shielding and grounding in the machine as well as the EMG room itself, (3) equipment sharing the same electrical circuit as the EMG machine, (4) type of lighting in the EMG room, (5) the status of the patient, etc. Artifact caused by poor grounding, inadequate shielding, 60 cycle noise from fluorescent lighting, and other machines that share the same electrical circuits usually produces so much baseline noise and movement that their presence is unequivocal and unlikely to be mistaken for a response (Fig. 2-13). Much of the artifact found in the EMG laboratory is an annoyance but the real hazards are caused by artifact that can be mistaken for a response or artifact that causes an alteration of the response causing erroneous interpretation of results. Most artifact that might be mistaken for a response is found while performing sensory studies. When the sensory response is very low or

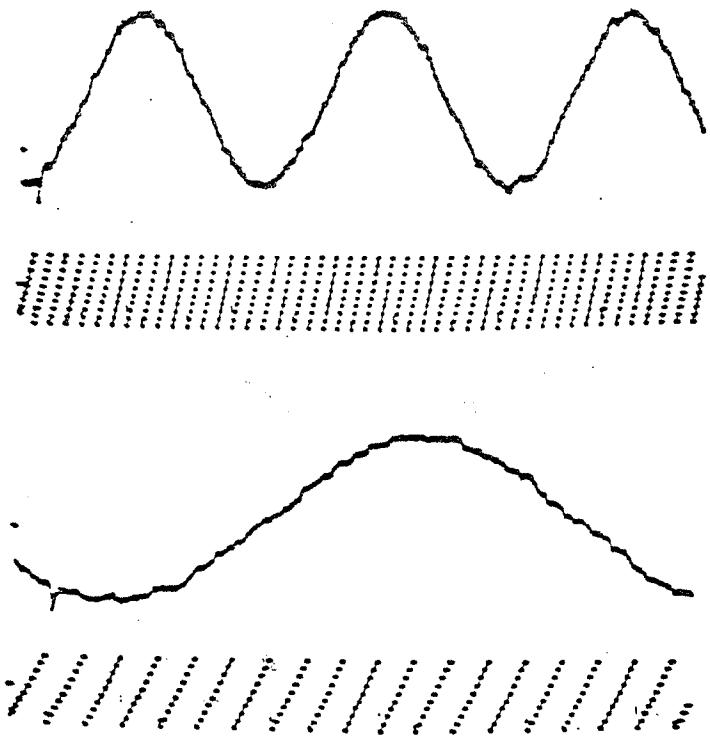


Figure 2-13. Artifact from florescent lighting.

absent, a high stimulus can introduce motor artifact that looks like a sensory potential. A sensory potential and motor artifact can usually be distinguished by recording orthodromicaly or by moving the stimulating electrodes slightly proximal or distal. If, by moving the stimulator, the response moves in the proper direction and remains consistent, it is probably a sensory potential. When performing sensory studies, the audio should be on so that motor artifact, caused by voluntary muscle activity, can be heard. A response that is altered by an artifact should be repeated. Usually, artifact is caused by technical problems in applying electrodes or from sweat and other substance bridging the electrodes. Either of these can cause a difference in the amplitude of the response. Wiping the recording area clean with alcohol or acetone and reapplying the electrodes will usually eliminate this problem (Fig. 2-14).

Electrodes or Electrode Placement

Standard electrode size, interelectrode distance, and electrode placement are all necessary to insure accurate measurements. The size of the electrode is of particular importance when recording from larger more proximal muscles where not only the surface area of the electrode but also the surface area of the muscle come into play. Using a larger electrode on larger muscle lends itself to better comparison studies because the belly of the muscle is physically larger causing placement of smaller electrodes to be more variable. Inconsistent interelectrode distance could also cause variations. This is especially true with sensory studies when G2, the reference electrode (as well as G1, the active electrode), is recording over the nerve. An increase in the interelectrode distance will generally increase the amplitude of the response unless the electrodes are so far apart that G2 is essentially recording from a "0" point. Amplitude, latency, and configuration changes can occur if the placement of either the recording electrode or the reference electrode is not accurate. Generally, if the recording electrode is not over the belly of the muscle, the takeoff of the response will not be initially negative and the amplitude will be decreased. If the reference electrode on a motor study is placed on the muscle instead of the tendon (or some other "0" point), this will also decrease the amplitude of the response (Fig. 2-15). Placement of the stimulating electrodes is important because if the wrong nerve or multiple nerves are stimulated at the same time, a volume conducted response from the wrong or multiple muscles will be obtained. Sometimes, stimulation of two nerves is difficult to avoid if the patient is very thin and the nerves are close together, or a patient is heavy enough that an increase in the stimulus duration must be used (Fig. 2-16). Changing the stimulation site slightly and approaching supramaximal stimulation with smaller increments usually eliminates this problem.

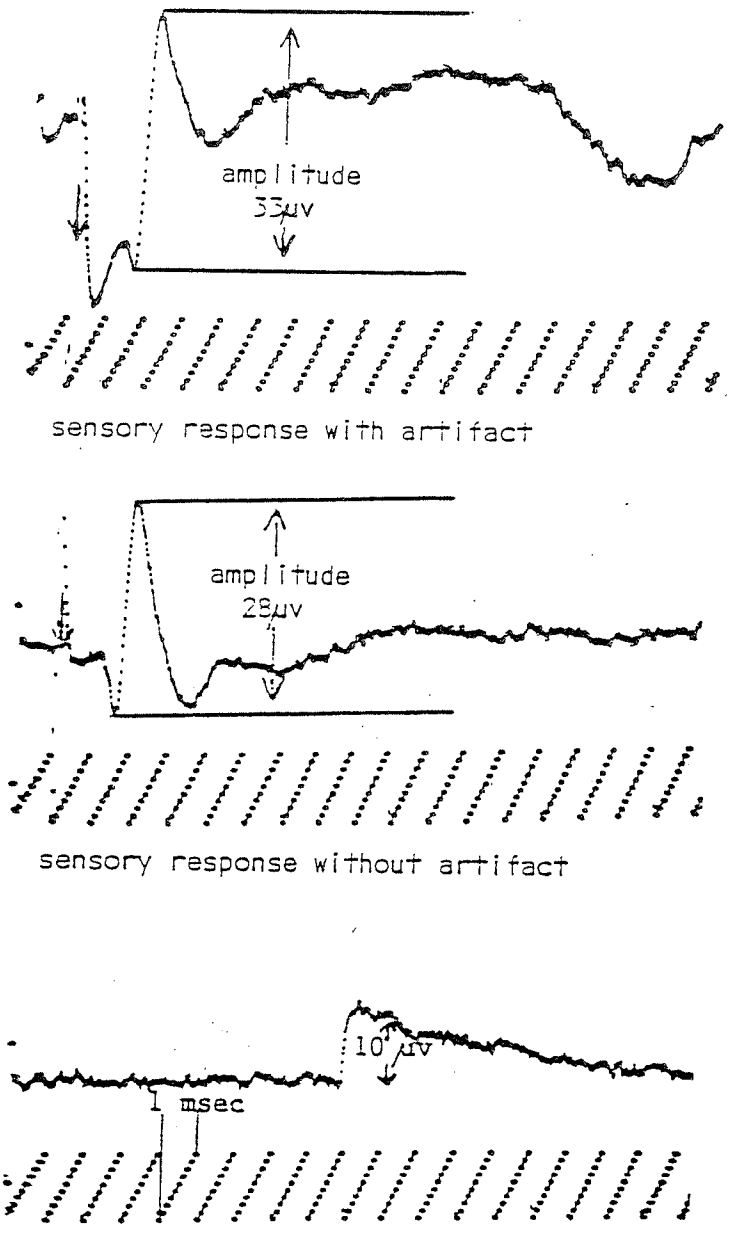


Figure 2-14

Measurements

Variations in measurements—caused by changing the position of the limb, using short distances, not using a metal tape measure, or not marking stimulation sites—can lead to significant errors on the nerve conduction studies results. Changing the position of the limb can cause conduction velocity variations because the latencies will remain constant but the

distances measured between the two stimulation sites will vary. It is important to remember that, when collecting and using normal values, the position of the limb must remain exactly the same. The best way to insure a uniform measurement is to have the limb in the same position fully supported by a constant medium such as a bed or some other apparatus that will hold the limb in a fixed position with reference to the body. Sometimes it may be necessary to alter the position of the limb because of a patient's inability to achieve or maintain the usual position. In this instance, the contralateral uninvolved limb should be tested with the limb both in the altered position to obtain a side-to-side comparison and in the usual position if a rough comparison to the normal population is sought.

Using short distances (less than 10 cm) for conduction velocity determination increases the percentage of error and should be avoided whenever possible. When more than one conduction velocity is obtained per study (same recording site), each conduction velocity should be figured using the proximal stimulation site and the most distal stimulation site of that study. Also, there should be at least 10 cm between any two of the proximal stimulation sites. Conduction velocities figured in this manner will be more accurate and can then be compared to one another and to a normal population. Errors in measurement can also be avoided if the cathode placement at each stimulation site is carefully marked and if measurements are made with a metal tape measure. Marking of the stimulation site is important because frequently the stimulator will be moved several times before a supramaximal response is obtained and measurements must be made from the point of stimulation that correlates with this response. Metal tape measures, unlike the cloth variety, will not stretch after continuous use and are therefore more conducive to accurate measurements.

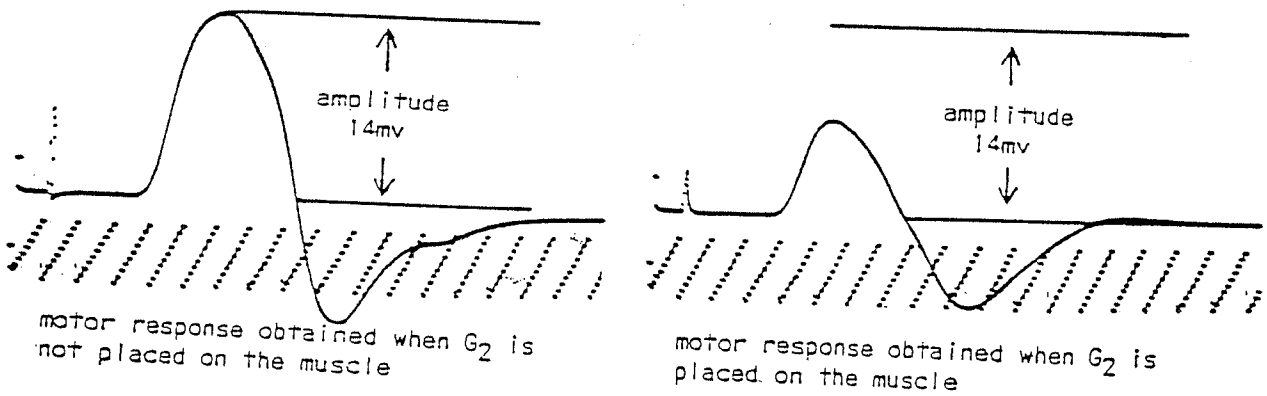


Figure 2-15

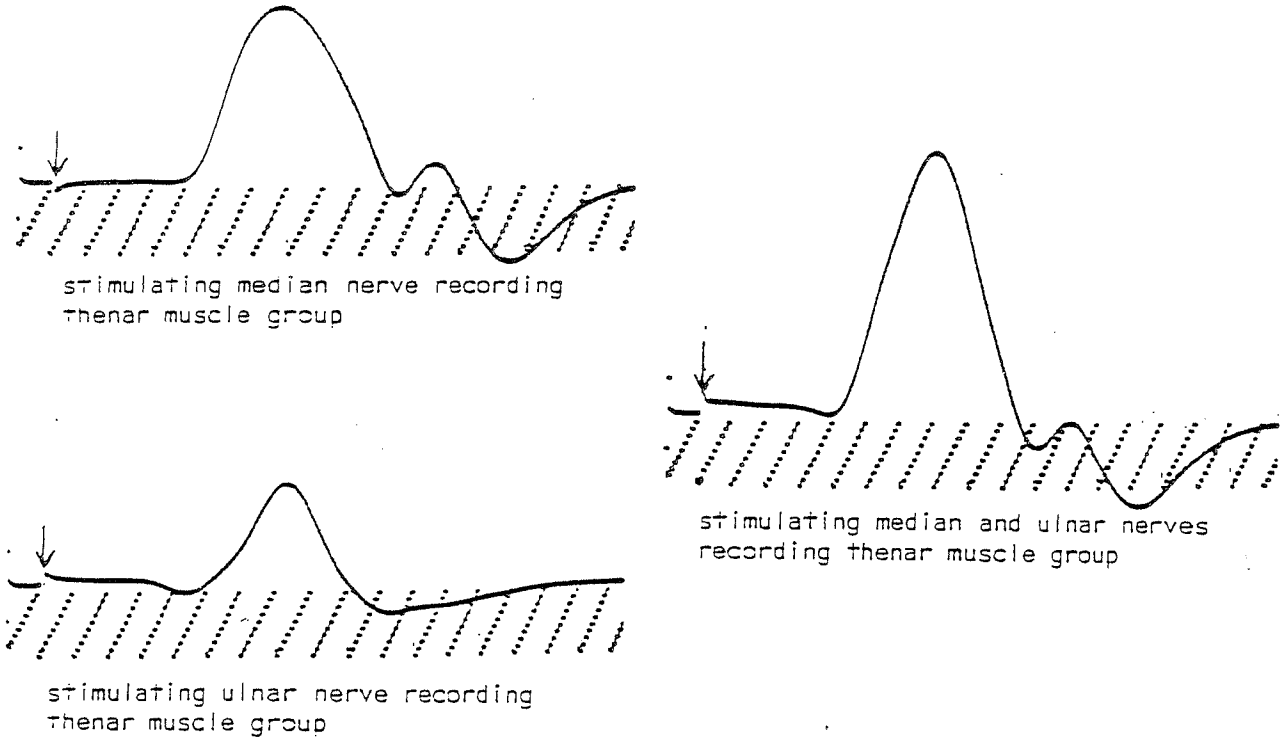


Figure 2-16

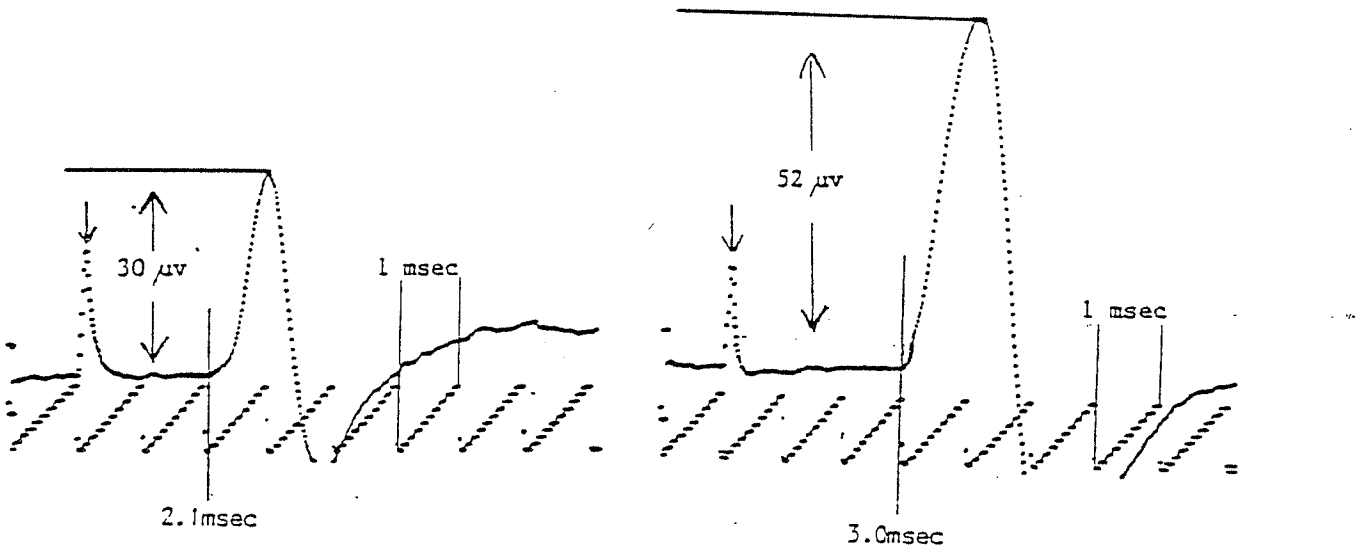
Other

Not all sources of error stem from inaccurate technical procedures. Occasionally, the motor point of a muscle is different from the standard location; consequently, it is necessary to adjust the placement of the recording electrode to obtain reproducible latencies and good amplitude measurements. If the distance between the recording electrode and the stimulating electrode is within the standard range of normal, the results obtained may still be compared to those of the normal population. In these instances, a notation of the new recording site should be made on the work sheet to insure accurate comparisons should the patient return for a follow-up study. Other anatomic variations such as crossovers and accessory peroneal nerves can cause considerable deviation from the normal ranges. Although these are normal variations found frequently in the general population, their recognition and documentation is extremely important to the nerve conduction study interpretation. Each of these anatomic variations will be discussed in detail in Chapter 5.

Another very common yet frequently neglected source of error is variation with temperature (21, 27). The effect of temperature is most prominent on sensory studies, but it can also affect motor studies. If the

distal temperature is below normal, the sensory amplitudes (obtained from distal recording sites) will increase and the distal latencies will be prolonged (Fig. 2-17). Likewise, if the entire limb is cold, the conduction velocity will be slowed. As a general rule, if the amplitudes are normal or higher than normal and the distal latencies are prolonged, or more than one distal latency on the same limb is prolonged, the limb temperature should be taken and adjusted so it is within the normal range (intermuscular temperatures: 35°C to 37°C in the first dorsal interosseous and 28.5°C to 33°C in the extensor digitorum brevis) (48, 50). In most instances, any of these sources of error can be avoided or corrected if they are recognized.

SENSORY AMPLITUDE VARIATION WITH TEMPERATURE



ulnar (sensory-antidromic), recording fifth finger with a normal temperature in the first dorsal interosseous of 35'C

ulnar (sensory-antidromic), recording fifth finger with a cold temperature in the first dorsal interosseous of 30'C

Notice that, along with the prolonged distal latency in the cold hand, the amplitude and the duration (or area) of the response is increased.

Figure 2-17