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F Response Frequency for the Median and Ulnar Nerves in a Normal Population

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F RESPONSE FREQUENCY

FOR THE MEDIAN AND ULNAR NERVES

IN A NORMAL POPULATION

by

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ABSTRACT

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The F wave or F response results form the recurrent discharge of antidromically activated anterior horn cells. F response latency represents an impulse which travels to and from the spinal cord through the central segment of a nerve. Study of the F wave is commonly done to assess proximal conduction in motor nerves, to measure motor nerve conduction velocity over a longer pathway than in orthodromic motor studies, and to assess motor neuron excitability. F response characteristics less commonly studied include duration, chronodispersion, shape, amplitude, and frequency. The primary purpose of this study was to determine F response frequencies of the median and ulnar nerves in healthy subjects. Second, two different approaches to stimulation of the nerves were studied and compared. 21 healthy subjects were tested under similar circumstances, using a train of 50 stimuli at a rate of 1 Hz. F response frequency arising from all median nerves (n=42) ranged from 1 to 50 with a mean of 27.5 $\pm$ 13.3. F response frequency arising from all ulnar nerves ranged from 0 to 50 with a mean of 32.4 $\pm$ 14.1. No significant difference was found between the mean frequencies for the bar and prong

electrodes with median nerve stimulation. Median nerve mean frequencies for the bar and prong electrodes were 26.0 $\pm$ 14.7 and 29.5 $\pm$ 11.1, respectively. There was a significant difference between electrodes for the ulnar nerve ($p < 0.05$). Ulnar nerve mean frequencies for the bar and prong electrodes were 37.9 $\pm$ 9.0 and 28.3 $\pm$ 15.9, respectively. The distribution of frequencies for the median and ulnar nerves widely varied in this study. It is not clear determination of F reponse frequency for the median and ulnar nerves would be helpful in the evaluation of disease processes as there is much variability among subjects. This study suggests that the bar electrode provides a more consistent method of ulnar nerve stimulation. Results from this study highlight the need for more thorough investigation of all clinically relevant characteristics of the F response.

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CHAPTER 1

INTRODUCTION

The F wave results from the "backfiring" or recurrent discharge of anterior horn cells (alpha motor neurons) which are activated by impulses traveling antidromically from a stimulation site on a peripheral nerve.[1,2,3,4,5,6,7,8,9,10] Presumably so named by Magladery and McDougal because it was originally recorded from the foot muscles,[11] this late muscle potential is often elicited by supramaximal electrical stimulation of a nerve. F waves can be found in any muscle, occur after the motor response (M response), and are usually less than 10 percent of maximum M amplitudes.[12,13] Action potentials propagate in both directions from the point of stimulation on a nerve. Therefore, the same alpha motor axon acts as both the afferent and efferent pathway for the F wave.[14]

The F wave is important in that its latency represents an impulse which travels to and from the spinal cord through the central segment of the nerve.[15] Study of the F wave is most commonly done to assess proximal conduction in motor nerves, measure motor nerve conduction velocity (MNCV) over a longer pathway than in orthodromic motor studies, and to assess motor neuron excitability. Abnormalities of F wave conduction times occur in Charcot-Marie-Tooth disease, Guillan-Barre syndrome, diabetic polyneuropathy, uremic polyneuropathy, alcoholic neuropathies, entrapment neuropathies,

amyotrophic lateral sclerosis and radiculopathies.[2,12,16]

The clinical value of the F wave is limited by the variability of its latency and configuration which makes F response determination less applicable to many clinical problems than the M response. In polyneuropathies, particularly those where the disease process involves the proximal portion of the axon, the F wave is clinically useful. However, in the early diagnosis of radiculopathies the remaining normal segment may tend to mask a conduction deficit across the much shorter abnormal segment. In addition, prolonged latencies may not be as evident in radiculopathies because only one nerve root is involved. Relatively mild abnormalities of localized nerve lesions, such as radiculopathies, may not alter the F wave latency more than its inherent variability.[2]

Purpose

The primary purpose of this study was to determine F response frequencies of the median and ulnar nerves in healthy subjects. Lack of adequate information has given clinicians only a very limited amount of data concerning frequency, as well as most characteristics, of the F response.[17] Second, two different approaches to stimulation of the nerves were studied and compared.

Review of the Literature

The recurrent nature of the F wave has been questioned. It has been debated whether the F wave is solely a recurrent discharge of antidromically activated alpha motor neurons, a reflex response,[11,18,19] or a combination of both.[20,21]

Although it is not clear why F waves occur, evidence supporting their recurrent nature is: (1) the F wave is present in deafferented limbs after dorsal root rhizotomy and after transverse myelotomy which suggests that the response is due to antidromic stimulation of spinal motor neurons within the cord,[3,5,22] (2) single-fiber electromyography (SFEMG) has shown that the F wave requires prior activation of the motor axon and that a high correlation exists between the latencies of consecutive M and F responses. This suggests that both responses are initiated in the same nerve fiber. The latency variability or jitter of the F response is small, 10-30 microseconds (*us*) greater than the corresponding M response jitter, which excludes the possibility of synaptic transmission involvement in the F response. Hoffman reflex (H reflex) jitter variability is greater than 150 *us*,[4,23,24] (3) the F response can be obtained by stimulation of the facial nerve, a pure motor nerve,[25] (4) there is a significant similarity between the M and F conduction times over the same segment of nerve, which suggests that both M and F impulses travel along the same motor nerve fibers,[7] and (5) the F response persists when the H response, which is clearly a reflex involving an arc composed of Ia afferent fibers and efferent (alpha motor) fibers, is absent in the posterior tibial nerve.[26]

Although this study did not deal with F wave characteristics other than frequency, the discussion of these parameters is warranted as they are commonly used and interpreted in the clinic. Under identical circumstances of stimulation and recording, individual F waves vary in conduction time, latency, duration, chronodispersion, shape, and amplitude. During this discussion, keep in mind that the F response represents the summation of the recurrent discharges of individual motor unit potentials (MUP) that

vary in voltage and latency from MUP to MUP.[27]

Slightly higher near nerve temperatures and larger diameter, faster conducting nerve fibers in more proximal segments results in a slight, but significantly faster, mean **conduction velocity** for the cord to elbow segment compared to the elbow to wrist segment for the median and ulnar nerves, approximately 5 meters/second (m/sec). However, normal subjects have also demonstrated faster distal velocities which may be accounted for by temperature gradient differences between individuals. Conduction velocity of 50 m/sec or less for the cord to elbow segment is considered abnormal for the median and ulnar nerves.[7] Conduction velocities of 48 m/sec and 50 m/sec for the elbow to wrist segments of the median and ulnar nerves, respectively, are considered abnormal.[2]

A formula for computing F wave conduction velocity (FWCV) is D X 2/F-M-1 where D is the distance from the stimulus site to the spinal cord (C7), F and M are F and M response latencies, respectively, and 1 represents the 1.0 millisecond (ms) presumed turnaround time at the proximal segment.[2]

Eisen et al reported use of a formula for computing F response conduction velocity, but advocate using conduction times versus velocities when comparing normals to patients. This avoids errors which are incurred when measuring the distance to the C7 spinous process. They consider conduction times between the cord and elbow of greater than 8.5 ms for the median nerve and 9.0 ms for the ulnar nerve as abnormal.[7]

Ongerboer et al and Dorfman and Bosley reported that conduction velocity decreases with age.[28,29] Dorfman and Bosley found that velocity decreased at the rate of 0.15

m/sec and 0.16 m/sec per year for motor and sensory nerves, respectively. These changes are most likely due to peripheral nerve axonal degeneration, diminishing numbers and density of nerve fibers, an increase in connective tissue, and a disproportionate loss of large fibers.[7] Fisher reported that in human alpha motor neurons, the smallest axonal diameters and conduction velocities are about one-half those of the largest axonal diameter fibers.[30]

Latency differences of F waves are indicative of travel along axons with different conduction velocities. Normal values have been reported by Kimura as being less than 28.8 and 29.8 ms for the median and ulnar nerves, respectively.[2] Dorfman and Bosley found that F latencies increase with age at a rate of 0.04 ms/year for the median nerve and 0.12 ms/year for the tibial nerve.[29] Despite variations in conduction velocities among axons, the latency for a particular MUP remains remarkably constant.[23,24,31,32] Kimura reported that the latency of successive F responses from single muscle fibers varies narrowly between ten to 30 microseconds (*us*).

In healthy subjects, F waves manifest only a limited range of latency differences because axons have a limited range in diameter. In the presence of a disease process, some motor axons may be more affected than others resulting in a greater range of motor nerve conduction velocities and thus, F response latencies.[33] In Fisher et al's study regarding use of the F response in the evaluation of lumbosacral radiculopathy, prolonged latency of the F response was the only significant finding in 6/41 (15%) abnormal studies with documented radiculopathy.[16]

Based on a series of 10 responses in normal subjects, Fisher found the mean latency

range to be 3.0 ms (10-15% of minimal F latency) and that the mean in comparison to minimal latency values is a more reproducible, statistically consistent measure of F wave conduction because it does not ignore the effect of inherent variability.[30]

Peioglou-Harmoussi et al, during study of the median and ulnar nerves, found a strong correlation between minimum and maximum F latency and height and a much weaker relationship between these parameters and age.[34] There are nomograms and formulas for predicting F wave latencies which take age and height into consideration.[1,35]

F response **central latency** is commonly used in the clinic in order to identify proximal lesions in the upper quarter and, less commonly, in the lower quarter. Central latency is a measure of conduction time from the point of stimulation to the spinal cord. The formula is (F-M-1)/2 where F and M represent M and F wave latencies, respectively and 1 represents the 1.0 ms turnaround time at the proximal segment.[2]

Kimura reported normal central latency values as less than 12.1 ms for the upper quarter with stimulation in the axilla.[2] It has been suggested that central latency is an unreliable measure for several reasons. The actual response time at the spinal cord has been documented as being 1.0 ms. This time was based on experimental animals, not humans.[35] Furthermore, the time between when an antidromic impulse reaches the initial segment and the subsequent orthodromic impulse has been found to be unstable.[30]

Panayiotopoulos et al introduced the term **F chronodispersion** in an article published in 1977.[36] Chronodispersion denotes the scatter or dispersion of the relative latencies of statistically significant numbers of consecutively recorded F waves. Peioglou-

Harmoussi et al found that the differences between minimum and maximum F wave chronodispersion values for the median and ulnar nerves in control subjects varied between 1.3 and 8.4 ms, with means ranging between 3.1 and 3.6 ms. Their study showed no significant differences between the right and left upper extremities, age, height, or sex.[34]

Panayiotopoulos found that F chronodispersion values provided a sensitive method for detecting abnormal nerve function in five patients with renal failure even when motor nerve conduction velocities were normal or borderline. In addition, it was found that F chronodispersion was significantly more prolonged in the patients with renal failure than in control subjects and discussed that these findings may be attributed to differences in conduction velocity between healthy and damaged motor fibers. F waves traveling along demyelinated, atrophied, or regenerating nerve fibers have longer latencies than those of healthy axons. Increased F chronodispersion may be due to an increased number of moderately slow F waves.[33]

F response **duration** is dependent on the size of individual motor units, with larger motor units having longer durations. Duration is also affected by the number of simultaneously active motor units and their relative latencies.[34] Peioglou-Harmoussi et al found that the mean duration in individual control subjects varied between 7.2 and 11.8 ms for the median nerves and 6.5 and 13.7 ms in the ulnar nerves (mean 9.4 and 10.1 ms for both median and both ulnar nerves, respectively). There was no significant difference between right and left, nor any correlation between age and sex.[34]

F response **shape** is variable and is likely determined by the position of the active

recording electrode in relation to the end-plate region of the motor unit, the degree of synchronization of the impulse as it reaches the terminal nerve branches and muscle fibers, and the possible simultaneous discharge of separate motor units.[17]

Peioglou-Harmoussi et al, in their ulnar nerve study, found that the majority of 1,800 F responses contained two or more negative peaks.[17] Although shape was not systematically reviewed in their later median/ulnar nerve study, Peioglou-Harmoussi et al agreed with their previous conclusion that there is a wide variability in F response shape.[34] The researchers could not find any correlation between shape and age or sex.

Amplitude of the F wave provides a measure of motor neuron excitability.[2] Feasby and Brown propose that large F response amplitudes are derived from larger, higher threshold motor units.[31] Surface recorded amplitudes of the F wave have been documented by Peioglou-Harmoussi et al as being between 40-2000 microvolts (uV) for the median nerve and 40-1500 uV for the ulnar nerve. Median values ranged from 100 to 770 uV in the four nerves (left and right median and ulnar nerves). No significant side-to-side differences were found for the same nerves and there was no correlation with age or sex.[17]

The same researchers discussed F%M, which is the F response amplitude presented as a percentage of the M response. They showed that the F response is a relatively small proportion of the compound M response with median F%M values for the ulnar nerve ranging from 0.8% to 4.0% (median of the median was 1.7%).[17]

Comparing their findings with those of Sica et al, Peioglou-Harmoussi et al suggest that a large proportion of surface recorded F responses following supramaximal

stimulation are composed of recurrent discharges from more than one motor unit that vary in voltage and latency. They deduced this as their F%M findings were larger than the amplitudes of surface recorded values produced by the earliest recruited motor units following direct stimulation of the ulnar nerve in Sica et al's study.[17,37]

Peioglou-Harmoussi et al found that during a train of 200 stimuli at a rate of 1 Hz, the frequency of F responses recorded with surface electrodes from the whole muscle ranged from 50% to 93% (mean=79%). F responses occurred in the majority of cases following 70% to 90% of stimuli and, thus, indicated a relatively high chance of an F response occurring with each stimulus.[17]

Furthermore, the vast majority of F responses (mean=96.6%) in each control subject occurred only once during the train of 200 stimuli, while between 1.1% and 5.4% (mean=3.4%) of responses occurred two or more times. Of those identical responses (i.e. repeaters), 89.5% occurred between two to five times, 9% between six to 10 times, and only 1.5% 11 or more times.[17]

SFEMG studies are cited in order to demonstrate that there is a low probability that an individual motor unit discharge will occur in a particular F response.[25,30]

Yates and Brown found that the F discharge frequency for individual motor units is low. Using surface electrodes for the median and ulnar nerves, they found that only 23% of motor units in control subjects generated an F response with a train of 100 stimuli.[27]

Using the single fiber EMG technique, Schiller and Stalberg found that only 41% of individual motor neurons produced an F response during a series of 200 stimuli of the

ulnar nerve. More specifically, 35% of the motor units examined produced between one to five responses per 200 stimuli, 4% produced six to 10 responses, and 2% gave rise to 11 to 15 responses. There was no neuron with more than 15 responses per 200 M responses. The researchers found that all motor units would produce an F response during longer stimulus trains.[24]

Ongerboer de Visser et al, during study of 19 patients with neoplastic lesions of the eighth cervical and first thoracic nerve roots, found that there was a positive correlation between deteriorating ulnar nerve signs and decreasing F response frequency in eight subjects. Further, low F response frequencies became normal (10-15/50) as ulnar signs improved.[28]

Very little research has been done to ascertain the normal frequency of F wave responses in the clinical environment. In light of all the controversy regarding the production of the F response, knowledge of its frequency would be of value, particularly since the frequency may be altered by neuropathic processes which affect upper and lower motor neurons. More control data is needed in order to study the effect of upper and lower motor neuron disease on F response frequency.

Hypothesis

The hypothesis of this study is that F wave response frequencies for the median and ulnar nerves in normal individuals will not significantly vary from individual to individual and will approach the 80 percent level.

CHAPTER 2

METHOD

The study was approved by the Human Subjects Committee, Department of Community Health Professions and Program in Physical Therapy, Old Dominion University.

Subjects

21 healthy volunteers with no history of cancer, diabetes, myopathy, intervertebral disc disease, alcohol abuse or any other systemic or neuromuscular disease were recruited. A total of 42 median and 42 ulnar nerves were tested. There were three males and 18 females with ages ranging from 21 to 46 years (30.05 ± 7.08). All subjects gave written informed consent prior to participation in the study.

Instrumentation and Procedure

Data was collected, stored on 3 1/2 inch floppy disks, printed and accessed as needed using the Cadwell quantum with Okidata printer.* Data collection from each subject took approximately 80 minutes. All testing was performed by one examiner (PJK).

Upper extremity length was measured bilaterally with a measuring tape while standing with the arm abducted. Landmarks were from C7 spinous process to the radial styloid (forearm supinated) and C7 to the ulnar styloid (forearm pronated) for the median and ulnar nerve measurements, respectively.

Both the median and ulnar nerves were tested bilaterally and in a random manner in all subjects. The subjects were supine on a firm plinthe with the upper extremity which was being tested at the subjects side (anatomical position). The recording surface metal disc electrode, 1.0 cm in diameter, was placed over the motor point of the abductor pollicis brevis and abductor digiti minimi for the median and ulnar nerves, respectively; the reference metal disc electrode, 1.0 cm in diameter was placed distally over the respective tendon. Ground, recording, and reference electrodes were affixed with tape.

* Cadwell Laboratories, Inc. *Cadwell Quantum 84™ Operator's Manual.* Kennewick, Washington, 1988.

Two types of stimulating electrodes were used--a bar electrode (disc 1.0 cm in diameter with 3.0 cm interelectrode distance between the anode and cathode) which was taped to the skin to avoid movement of the electrode and the standard prong electrode (prongs 0.8 cm diameter with 2.5 cm interelectrode distance between the anode and cathode) which was held in place by the examiner. Type of stimulating electrode was randomly chosen by coin toss and placed at the wrist, 8.0 cm proximal to the recording electrode, with the anode distal to the cathode to avoid anodal block of the antidromic impulse. The median nerve was stimulated between the flexor carpi radialis and palmaris longus tendons. The ulnar nerve was stimulated lateral to the flexor carpi ulnaris tendon at the wrist.

A pulse duration of 0.1 ms, sweep speed of 5.0 ms/division, and sensitivity of 200 uV were used. Pulse duration was increased to 0.2 ms if the F response could not be elicited at 0.1 ms. Filter setting was 1 Hz to 10 kHz. A train of 50 supramaximal stimuli (approximately 20 percent greater than that required to elicit an M response) was applied at a frequency of 1 Hz. Stimulus intensity was increased as needed if the F response could not be elicited at lower intensities. Due to limitations in storage capacity of the Cadwell Quantum, a train of eight stimuli was collected and stored. The process was repeated for each nerve until a total of 50 stimuli had been reached. Approximately 20-25 seconds elapsed between trains of eight stimuli. Only those baseline deflections which showed a clear deviation and had an amplitude of at least 40 uV were accepted as F responses.

Each subject was encouraged to relax to avoid any effect of volitional movement.

An average room temperature of 24.5°C (range 22-28°C) was maintained throughout testing.

Data Analysis

Median nerves (n=42) and ulnar nerves (n=42) were separately grouped in order to determine the range and mean frequency of F responses. Percentages were calculated for the means to represent the occurrence of F responses in a train of 50 stimuli. The t-test was used to determine if there was a significant difference in frequencies between right and left for both the median and ulnar nerves. Right and left sides were grouped for each nerve and the t-test was used to determine if there was a significant difference in mean F wave frequencies for the bar and prong stimulating electrodes for each nerve.

CHAPTER 3

RESULTS

F response data for median and ulnar nerves (n=42) is summarized in Table 1 to include mean and range of frequency. The eight sets of data are grouped by nerve, side tested, and type of stimulating electrode.

Table 2 represents mean and range of F response frequencies for the median and ulnar nerves with data grouped by nerve and type of stimulating electrode.

Table 3 represents mean and range of F response frequencies for the median and ulnar nerves with data grouped by nerve.

During a train of 50 stimuli, F response frequencies arising from all median nerves ranged from 1 to 50 with a mean of 27.5 ± 13.3 (55%). F response frequencies arising from all ulnar nerves ranged from 0 to 50 with a mean of 32.4 ± 14.1 (65%). It is evident that the distribution of frequencies for the median and ulnar nerves in all 21 subjects is widely varied. This is illustrated in Figures 1 and 2 for the median and ulnar nerves, respectively.

F response frequencies comparing bar and prong stimulating electrodes for the median and ulnar nerves is illustrated in Figures 3 and 4, respectively. No significant difference was found between the mean frequencies for the bar and prong stimulating

electrodes ($p < 0.05$). Median nerve mean frequencies for the bar and prong electrodes were 26.0 ± 14.7 and 29.5 ± 11.1, respectively. There was a significant difference between electrodes for the ulnar nerve ($p < 0.05$). Mean frequencies for the bar and prong electrodes were 37.9 ± 9.0 and 28.3 ± 15.9, respectively.

CHAPTER 4

DISCUSSION

Literature shows that F wave characteristics do not significantly differ for right and left median and right and left ulnar nerves. Cornwall and Nelson found no significant differences in F Wave Distal Latencies (FWDL) or F Wave Conduction Velocities (FWCV) between right and left median nerves.[38] Kimura found no significant differences in F wave latencies and conduction velocities for the right and left median and ulnar nerves.[15] Peioglou-Harmoussi et al found no significant differences in minimum and maximum latencies, chronodispersion, amplitude, or duration for the median and ulnar nerves.[34]

In data analysis for this study, no significant differences were found between the right and left median and ulnar nerves ($p < 0.05$). Supported by past findings regarding other characteristics of the F response and present data, F wave frequencies were pooled for the right and left extremities for each nerve in order to obtain a larger sample size for statistical analysis.[15,34,38]

Opinions vary on the number of F responses required to constitute a valid F wave study (i.e. minimal latency).[1,35] Literature is vague, in some cases, as to whether the number of stimuli offered during testing or the number of actual F responses elicited was counted in data collection.

Lachman et al, in their study of the median nerve, offered stimuli until a total of 10 F responses were elicited.[35] Panayiolopoulos et al, in their study of the deep peroneal nerve, found that only one to three of 20 consecutive F responses were conducted along the fastest motor fibers and, thus, suggested collection of 20 consecutive F responses.[1]

Peioglou-Harmoussi et al, during study of the median and ulnar nerves, suggested that one must stimulate until a minimum of 20 responses are gathered. With 20 responses, there is a 59% probability of being within 0.5 ms or 76% probability of being within 1.0 ms of the minimal latency.[34] Peioglou-Harmoussi et al, in another study of the ulnar nerve, used a train of 200 stimuli. Amplitudes of F responses from this study were compared with amplitudes from their previous study. Collected data was similar in both cases. Therefore, the researchers suggest that a train of 20 stimuli is probably adequate for routine clinical use.[17,34]

Fisher used 20 stimuli in his study of the posterior tibial nerve. He concluded that 50 would be more representative, but less practical for clinical use.[30] Yates and Brown, in their single motor unit study of the ulnar and median nerve, recommended a train of 50 stimuli for research purposes in order to observe F discharges in most of the motor units capable of generating a recurrent action potential.[27] They showed that the more stimuli in a train, the larger the fraction of motor units with an F response. For example, less than 5% of motor units had F discharges if the stimulus train was less than 20. An increase in the number of stimuli to 50 increased the proportion of units with an F discharge to over 20%. Further increases did not significantly increase the fraction of motor units with an F discharge. After consideration of cited literature, a train of 50

stimuli was used for this study.

Like F response amplitude, frequency is a measure of motor neuron excitability.[2] There are three important sites to consider for successful propagation of an F response: (1) the proximal end of a myelinated axon, (2) the axon hillock, and (3) the soma-dendritic membrane.

Propagation of an F response is dependent on the depolarization of the axon hillock and myelinated axon. No recurrent discharge occurs when an antidromic discharge produces subliminal depolarization in hypoexcitable cells. Conversely, F waves may not occur in hyperexcitable cells which discharge too rapidly during the refractory period. Blocking of the antidromic potential usually occurs at the axon hillock because of the change in the membrane surface at the transition between the axon and soma. The orthodromic action potential and recurrent response is limited by the occurrence of a soma-dendritic spike and repolarization of the axon hillock.[24]

Both median and ulnar nerves had broad ranges of F response frequencies (0-50) in this study. Despite no history of neuropathy and increases in stimulus intensity and duration during testing, an F response could not be elicited in one ulnar nerve. Eisen et al and Ongerboer et al suggested that an absent F response may be indicative of a proximal lesion. On the other hand, Yates and Brown found that motor units occasionally have much higher F discharges in a pathologic nerve (Guillain-Barre syndrome).[7,27,28]

Present findings, with frequency ranges of 2% to 100% for the median nerve and 0% to 100% for the ulnar nerve, are not consistent with those of Peioglou-Harmoussi et al

who found that F responses could be elicited from the abductor digiti minimi with a 50 to 90% frequency.[22] Findings from this study are more compatible with Ongerboer et al's study which reported that 10 to 15 F responses during a train of 50 stimuli of the ulnar nerve were considered within the normal range. However, results from their study are ambiguous as it is not clear if the researchers stimulated a maximum of 50 times stopping the stimulus train when 10 to 15 responses were elicited or if 10 to 15 responses were the maximum number of responses that could be recorded in a train of 50 stimuli.[28]

Peioglou-Harmoussi et al tested the ulnar nerve in subjects with a train of 200 stimuli.[22] Present research, using an interrupted train of a significantly smaller number of stimuli (n=50), did not duplicate the methods of past studies. The interrupted method of stimulation may be a possible explanation for the comparatively low F discharge frequencies in the present study.

Using SFEMG, Schiller and Stalberg sampled the abductor digiti minimi and found that the F response frequency of one neuron is generally low, from 0 to 15 per 200 stimuli. In longer experiments, where the same potential was recorded for 20-45 minutes, all motor neurons showed occasional F responses. Spastic subjects had as many silent neurons as normal subjects, but the responding neurons more frequently produced F responses.[24]

Considering the results of Schiller and Stalberg and Yates and Brown's studies using SFEMG, one may account for the varied and comparatively decreased F response frequencies found in this study of whole muscles.[17,27] The number of motor units within the hypothenar muscles has been estimated to be 300 to 380 using the motor unit count

method.[39] On the basis of single unit F response frequencies observed in Schiller and Stalberg's study, a motor unit pool of this size might be expected to generate a minimum of 150 and an average of 370 late responses from individual motor units during a train of 200 stimuli.[17]

This estimate exceeds the observed frequency in this study. This may be due to the fact that small motor units were excluded (less than 40 uV). In addition, surface electrodes are less precise than the SFEMG technique and, thus, it is not possible to pair F responses with individual motor units. Therefore, an unknown proportion of responses in this study may have been the summation of two or more different motor units which simultaneously generated F responses leading to an apparent decrease in observed F responses in this study.

Incorrect placement of recording electrodes is an unlikely explanation for the lack of and inconsistency found in F responses in this study as a maximum motor unit potential (MUP) was elicited for each nerve prior to beginning the trial of 50 stimuli. Inconsistent placement of the stimulating electrode may very well partially account for some of the discrepancy. Especially with the prong electrode, movement of the stimulator excites different pools of motor neurons with each stimulus.

Significantly more F responses were elicited with the stationary bar compared to the prong stimulating electrode for the ulnar nerve. A significant difference between electrode types was not found for the median nerve. A possible explanation for the observed increase in frequency when using the bar compared with prong electrode to stimulate the ulnar nerve includes use of a more stationary and consistent method of

stimulation. By allowing movement of the prong stimulator during and between trains of eight stimuli and, thus, stimulating different groups of motor neurons, one may decrease the reliability of the test.

No techniques were used to facilitate an F response (i.e. Jendrassik maneuver, voluntary contraction, or post-tetanic facilitation) as there is documented controversy regarding whether the antidromic responses obtained under these conditions are purely motor. Hagbarth concluded from his study on post-tetanic potentiation of myotatic reflexes in man that the F response could become an H reflex either by voluntary contraction of muscles or by a preceding tetanus in the neuron.[18]

Furthermore, it is believed that a slight voluntary contraction may enhance the F wave.[2,28,40] Conversely, it has been reported that contraction of the agonist consistently facilitates the H reflex recorded from the calf muscles, but inhibits the F wave.[13]

Using SFEMG, Schiller and Stalberg found inconsistent discharge characteristics of single motor neurons in terms of F response frequency during activation produced by slight contraction of the contralateral or ipsilateral abductor digiti minimi. For example, in one case the mean number of F responses significantly increased ($p < 0.05$) from 1.822 to 30.4 ± 18.5 per 200 M responses during activation. In a contrary case, the mean number of F responses significantly decreased (p,0.001) from 32 at rest to two per 200 M responses. In five cases with few or no responses at rest, there was an increase in the number of F responses during activation of the contralateral or ipsilateral abductor digiti minimi. In five instances with a high number of F responses at rest, there was a decrease in or total inhibition of the number of F responses during activation. This

change was consistent with re-tests.[24]

Slight temperature differences in the room and among individual subjects may account for the wide range of F response frequency values obtained in the present study. No known studies have been done to determine the effect of room temperature on F response frequency. Just as variations in conduction velocities can not be considered abnormal as a lone finding, a decrease in frequency can not be considered pathologic without other supporting evidence.

Clinical Implications

Unknown factors operating at the level of the proximal peripheral nerve roots or spinal cord and inconsistent firing of F responses bring into question the validity of using F discharges as a clinical test. The uncertainty surrounding production of F responses may instead justify use of abnormal sensory parameters (i.e. decreased amplitude, increased dispersion of sensory evoked potentials) as better indications of disease than study of motor parameters. One exception to this is when the suspected lesion is proximal to the dorsal root ganglion (i.e radiculopathies), in which case the peripheral sensory axon is not effected.

Peioglou-Harmoussi et al found that in a population with ages ranging from 20-60 years, F%M amplitudes slightly, but significantly, decreased with age. This reflects a combination of decreased M amplitude and an increased F response amplitude, probably due to the increased size of individual motor units or increased synchronization and/or numbers of motor units. Increased central excitability with an increase in age is unlikely

as there appears to be no evidence of this correlation in the literature.[34] One must consider these apparent amplitude differences between older and younger populations when assessing F response frequencies. Younger populations may elicit F responses with low amplitudes that are not discernable on the oscilloscope, especially with slighly improper electrode placement and/or interference. There may be an apparent difference in frequency with age, due to the inability to discern low amplitude responses.

As cited by Yates and Brown in their SFEMG study, a train of 50 stimuli seems to be the smallest number that is representative of the surface voltage or latencies of motor units with the shortest conduction times. Longer trains are uncomfortable and time consuming. In addition, trains of stimuli longer than 50 did not increase the number of motor units with F discharges.[27] Other clinicians repeat stimulation until a minimum number of (10-20) F responses is recorded. However, this method does not consider any effect that nervous system pathology may have on F response frequency. The number of stimuli needed to achieve a representative test is not supported by research.

No significant differences were found between right and left median or right and left ulnar nerves. Side-to-side comparison of frequency may be a way to assess unilateral radiculopathy or neuropathy if more evidence is produced to show that F response frequency is altered with disease.

Use of the bar compared to prong stimulating electrodes may be a less efficient, more time consuming method of testing. However, the apparent benefit of having a stable stimulating electrode which yielded a higher F discharge frequency in this study may support taking a few extra minutes to use a bar electrode in a clinical setting.

Future Study

This study should be duplicated under similar circumstances in order to verify present findings. Examiner error, placement of electrodes, and testing environment are extraneous variables which may have contributed to a decrease in reliability. A limitation of this study was the waveform storage capacity of the Cadwell Quantum. Future studies may use a program which has a greater storage capacity.

Further investigation to compare F wave frequencies comparing bar and prong stimulators would be valuable. Although use of a bar stimulating electrode is not a conventional method of study, it may prove to be a more reliable way of testing F response frequency.

Study of the number of stimuli necessary to achieve a reliable representation of surface recorded F responses would be invaluable. More information is needed to compare normal subjects to those with neuropathic processes.

Room and limb temperature may effect F discharge frequency. Studies could be done to determine if there is a correlation between temperature and frequency of the F response.

F response frequency data specific to a normal, elderly population would be valuable, especially since F%M amplitude significantly decreases with age. In this case, one may expect the number of discernable, higher amplitude F responses to increase with age.

All characteristics of the F response, including F response frequency, may be altered by pathological changes in the upper and lower motor neurons. Once a baseline of normal F response frequencies has been established for all age groups, study should include subjects with diseases of the upper and lower motor neurons.

Tang, who found that standing for three minutes produced increased F chronodispersion in lumbar stenosis and root compression syndromes, suggested that one should adapt electrophysiologic testing to those clinical tests that induce symptoms.[41] Future study may include changing position of the upper extremity to determine the effect on F response frequency in a normal population and also with various pathologies (i.e. thoracic outlet syndrome).

CHAPTER 5

CONCLUSIONS

Abnormalities of F response latencies and conduction velocities have historically been used in the clinic to assist in the evaluation of neuropathies, radiculopathies, and other disease processes. However, there are varying opinions regarding use of F response findings in the clinical setting. It is not clear from this study whether the frequency of F responses would be helpful in the evaluation of disease processes as there is much variability among subjects. There is support for using a bar, instead of prong, stimulating electrode as the bar electrode provides a consistent way of stimulating the pool of motor neurons. Results from this study further highlight the need for more thorough investigation of all clinically relevant parameters of the F response.

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Table 1. F response frequency of the median and ulnar nerves during a train of 50 stimuli in 21 healthy subjects--grouped by nerve, side tested, and electrode used

nerve (n)	mean ± SD	% of occurrence	range
LMB (13)	27.2 ± 14.3	54	5 - 49
RMB (11)	24.5 ± 15.8	49	1 - 47
LMP (9)	34.1 ± 10.6	68	22 - 50
RMP (9)	24.9 ± 10.1	50	11 - 43
LUB (8)	38.9 ± 8.7	78	30 - 50
RUB (10)	37.2 ± 9.7	74	19 - 50
LUP (13)	25.5 ± 18.0	51	0 - 50
RUP (11)	31.5 ± 13.0	63	7 - 50

L = left M = median nerve B = bar stimulating electrode

R = right U = ulnar nerve P = prong stimulating electrode

Table 2. F response frequency of the median and ulnar nerves during a train of 50 stimuli in 21 healthy subjects--grouped by nerve and electrode used

	n(L+R)	mean ± SD	% of occurrence	range
MB	24(13+11)	26.0 ± 14.7	52	1 - 49
MP	18(9+9)	29.5 ± 11.1	59	11 - 50
UB	18(8+10)	37.9 ± 9.0	76	19 - 50
UP	24(13+11)	28.3 ± 15.9	57	0 - 50

L= left M = median B = bar

R = right U = ulnar P = prong

Table 3. F response frequency during a train of 50 stimuli in the median and ulnar nerves of 21 healthy subjects--grouped by nerve

nerve	n (B+P)	mean $\pm$ SD	% of occurrence	range
median	42(24+18)	27.5 $\pm$ 13.3	55	1-50
ulnar	42(18+24)	32.4 $\pm$ 14.1	65	0-50

B = bar stimulating electrode

P = prong stimulating electrode

FIGURE 1. MEDIAN NERVE

F RESPONSE FREQUENCIES PER SUBJECT

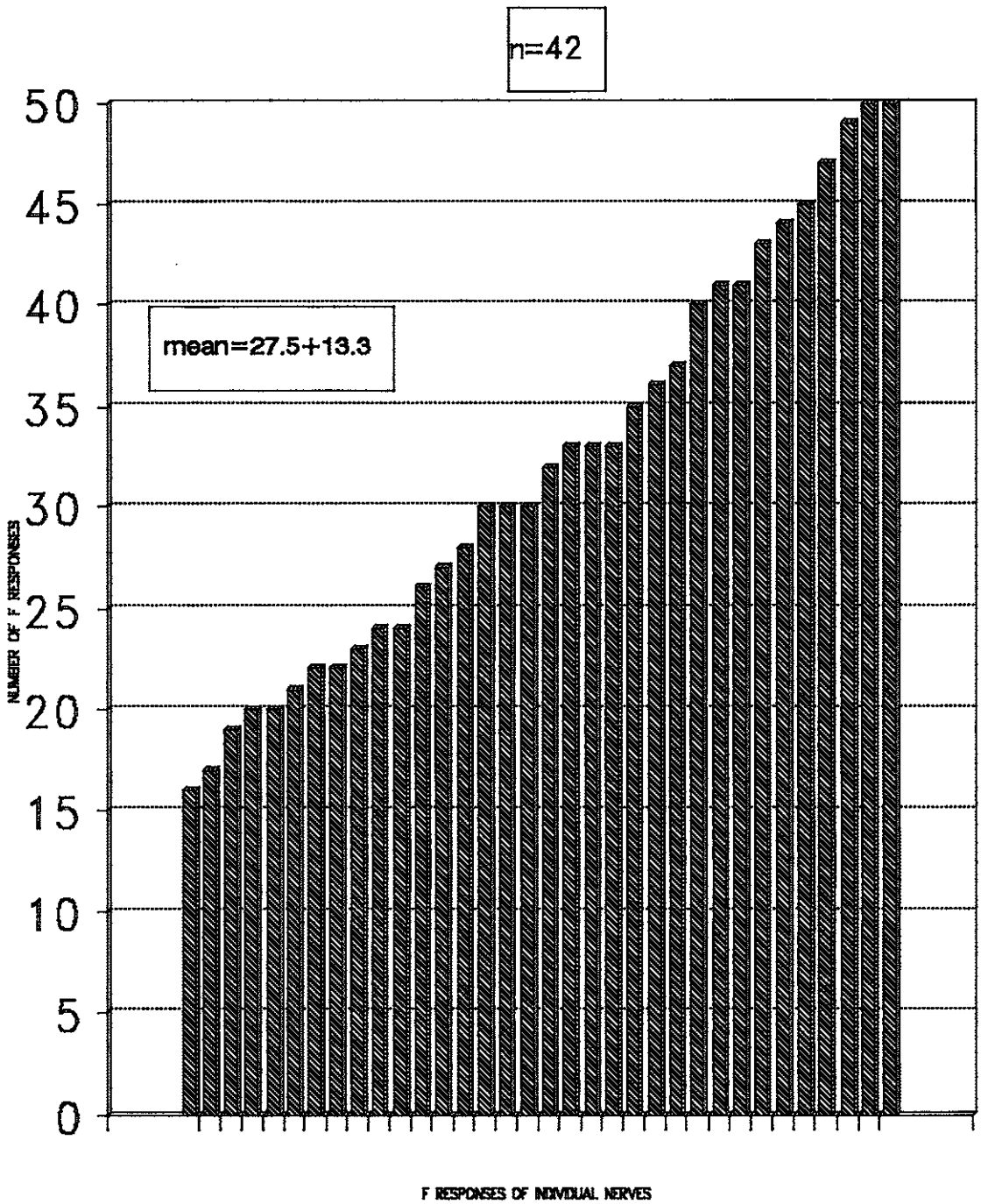

FIGURE 2. ULNAR NERVE

F RESPONSE FREQUENCIES PER SUBJECT

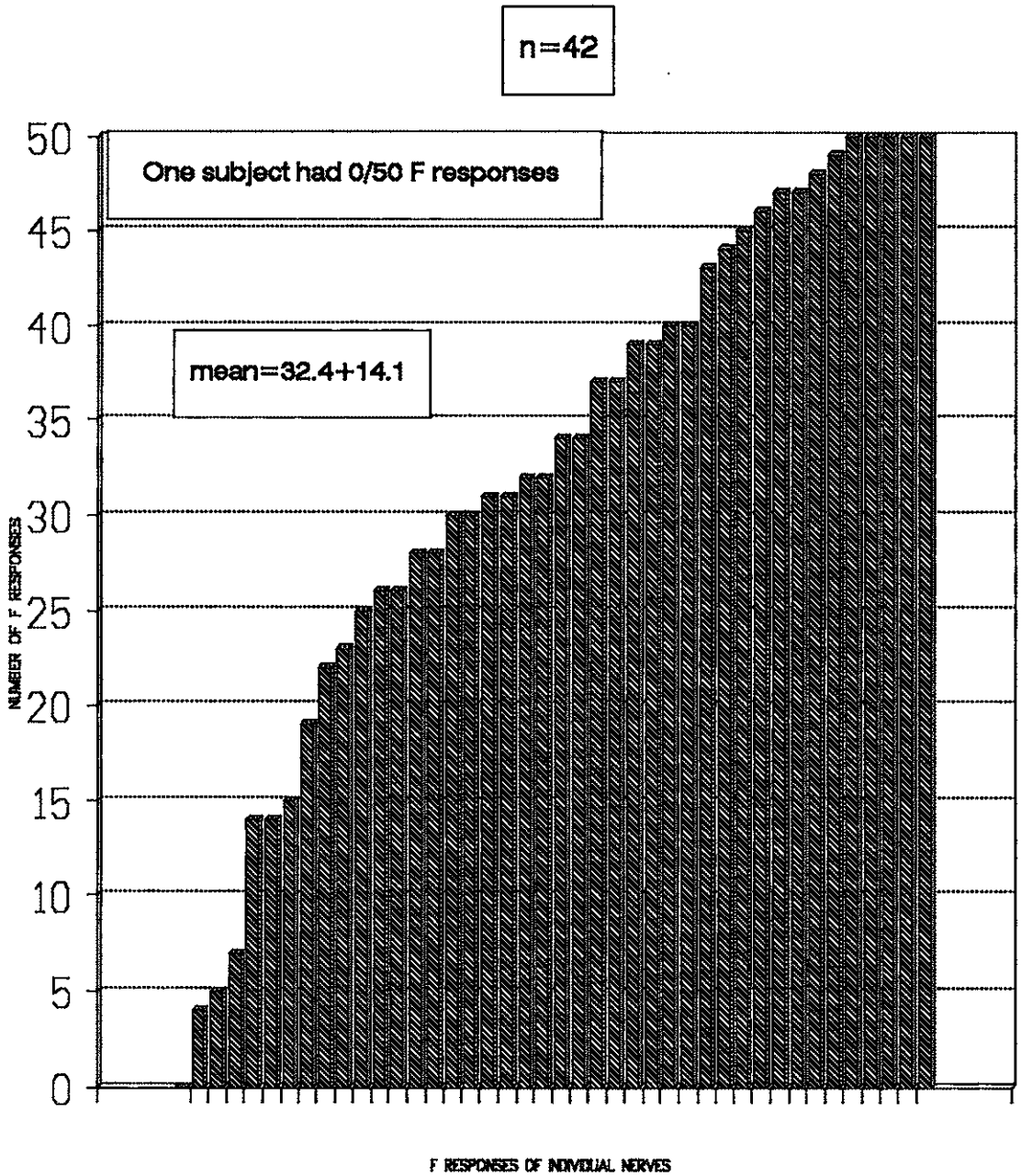

FIGURE 3. MEDIAN NERVE
BAR VS. PRONG STIMULATING ELECTRODES

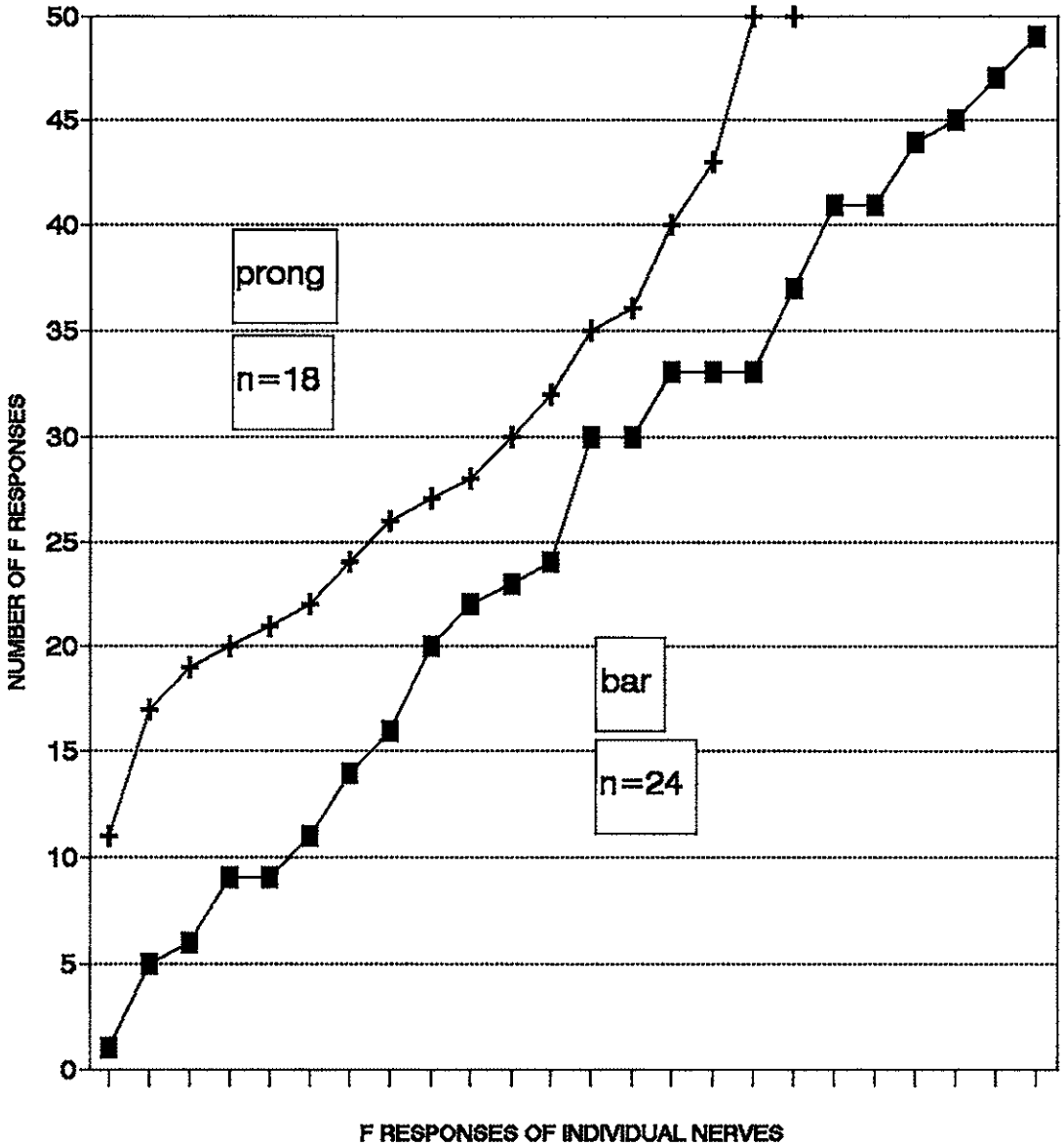

FIGURE 4. ULNAR NERVE

BAR VS. PRONG STIMULATING ELECTRODES