Frequency Distribution of F-Latencies (DFL) has Physiological Significance and Gives Distribution of Conduction Velocity (DCV) of Motor Nerve Fibres With Implications for Diagnosis

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Received: 17 October 2007 / Accepted: 1 April 2008 /
Published online: 14 May 2008
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Abstract On electrical stimulation of a peripheral motor nerve, a delayed and reduced F-response is obtained, which is known to occur due to random backfiring of a few percent of the motor nerve fibres at the spinal end after antidromic conduction. F-latencies obtained from multiple stimulations vary in latency, size and shape because of this randomness. We hypothesised that, being a random process, recruitment of fibres for F-response would depend on the distribution of conduction velocity (DCV) for motor nerve fibres directly, and therefore, a frequency distribution of F-latencies (DFL) from such multiple F-responses would be an approximate mirror image of DCV, latency being inversely proportional to velocity. First, obtaining DFL from many human subjects, we have shown that this is a reproducible parameter for a nerve trunk of a subject, and hence reveals a new physiological phenomenon. DFL has a single peaked distribution, which is also expected for the DCV of a normal healthy motor nerve. To validate its hypothesised relationship to DCV further, DFLs were obtained from both median nerves of patients with unilateral carpal tunnel syndrome (CTS). The patterns of DFL from both sides remained almost the same except for a delay shift equal to that in between the two M-responses, which lends support to this hypothesis. DFL, and DCV as its suggested mirror image, appear to change systematically with certain known disorders such as cervical spondylosis, even at a subclinical stage, which needs further study. This also indicates that DFL may become a new and improved investigative diagnostic tool in neurophysiology.

Keywords F-response · Multiple F-response · Distribution of F-latency · Nerve conduction · Distribution of conduction velocity · DCV · Cervical spondylosis

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1 Introduction

A peripheral nerve consists of thousands of nerve fibres with varying conduction velocities that can be well described by a frequency distribution of conduction velocities (DCV). An ideal neural diagnosis would give a complete DCV of nerve fibres (axons) in a nerve trunk; however, there has been no simple and reliable experimental method for determination of this distribution till now. Conventional nerve conduction velocity (NCV) measurements depend on the latencies (time from stimulation to onset of response) of evoked responses from a nerve trunk or from the supplied muscle, and these provide the conduction properties of the fastest nerve fibres only. Determination of conduction properties of the slower nerve fibres, which ought to be given by the DCV, still poses a challenge for the experimentalists. The Collision method developed by Hopf, in 1962 [1] and modified later by others [2, 3] using consecutive stimulations with varying delays at two points of the same nerve, suffers from a basic inherent inaccuracy since these are based on subtraction of resulting evoked electromyogram (EMG) responses for small changes. Small measurement errors may become accentuated in such a mathematical manipulation. Besides, errors may also arise due to several effects like nerve fibre refractory period, supernormality and subnormality lasting up to 200 ms [4, 5 (p. 59, pp. 155–162)], and slow conduction velocity of muscle fibres. Analytical methods were developed to obtain DCVs from evoked nerve action potentials [6–9], but these are sensitive to the shape of the single fibre action potential chosen and therefore do not satisfy the criteria of a reliable practical method.

The group led by the first author have a long clinical experience of nerve conduction measurements and have tried various approaches to understand the effect of variations in DCV on the evoked nerve and muscle action potentials, which are basically compound potentials from many nerve fibres or from many motor units in the muscles [10–13]. The idea was to use this understanding for tackling the inverse problem, i.e. of extracting some DCV information from the compound action potentials. While pursuing this work, an idea of using an entirely different approach came about, which involved the use of a delayed evoked response from muscles, known as the F-response. If a motor nerve is artificially stimulated at any point, action potentials are generated within the individual fibres, which, travelling directly to the muscle served (orthodromic conduction), elicit a compound muscle action potential, an M-response that reproduces well on repeated supra-maximal stimulation (one that has strength more than needed to stimulate all nerve fibres in a nerve trunk), and whose onset latency is conventionally used for obtaining a measure of NCV. From the stimulation site the action potentials also travel along the nerve fibres in the opposite direction (antidromic conduction), towards the cell bodies in the spinal cord. Most of these action potentials die out, but a few percent of the cell bodies backfire after a short delay, and send fresh action potentials down the nerve fibres to the muscle. These in effect produce a delayed compound muscle action potential called the F-response [14–17], which is very much reduced in amplitude with respect to the M-response because of the small number of fibres involved. An important aspect of the F-response is that, unlike the M-response, it varies in shape, amplitude and latency on repeated stimulation; sometimes there will be none. The cause has been ascribed to the randomness of recruitment; which nerve cells will backfire is not previously known, it is likely to be a random process. Based on the above information the authors propose a new method to obtain an experimental distribution of F-latencies (DFL) through multiple stimulation which, we propose, may be statistically related directly to DCV and thus provide a new way to obtain DCV, at least of the nerve

fibres participating in the type of measurement suggested [18–20]. Our experimental studies in human subjects presented here confirm that DCV can be determined non-invasively using this new methodology.

In the absence of a standard accurate method of measuring DCV, it becomes very difficult to validate the results. Therefore the authors have tested the new method on patients with carpal tunnel syndrome (CTS, a disorder due to entrapment of the median nerve at the wrist) in one hand only, and not in the other. CTS has a very clear and well-understood effect in electrophysiological measurements and may provide an important indication for validating the link between DFL and DCV.

2 Methods

A simple model may help clarify the assumptions used in the measurements. This is described in relation to typical F-response measurements on the median nerve as shown in Fig. 1 in which the nerve is electrically stimulated at wrist W and the muscle response is recorded at point R on the thenar muscle in the palm. The cell body in the spinal cord is represented by C , and J represents the neuromuscular junctions at the thenar muscle, very close to R . The antidromic conduction takes place from W to C and the backfired action potential travels back to J where muscle action potentials are generated that propagate along the muscle fibres from J to R . Delays occur at C and J , which need to be considered in an F-response.

In this study, it needs to be mentioned that each F-response is a compound potential of a few individual motor unit action potentials (MUAP), each motor unit being supplied by a single nerve fibre. This is shown schematically in Fig. 2 (the M-response is not shown) where the upper diagram (a) shows a few individual MUAPs produced at slightly different times depending on the respective conduction velocities of individual nerve fibres. The lower diagram (b) shows the resulting F-response, which is a simple combination of all the individual MUAPs shown above. The F-latency measured from the onset of the response relates only to the fastest of the few nerve fibres involved in the particular event. Since the backfiring events are random, there will be a random selection of MUAPs coming at different times in each F-response, which explains the variation in latency, shape and size of the F-responses obtained from multiple stimulations. As we are measuring the F-latency that comes from the earliest MUAP, the MUAPs from the nerve fibres with slower velocities in each response and their latencies are of no interest in the present work.

The latency t_f for a particular MUAP in the F-response may be given by,

$$t_f = t_1 + \Delta t_c + t_2 + \Delta t_m + t_3 \quad (1)$$

where t_1 is the time taken by the nerve action potential to travel from W to C ,

Δt_c is the time delay for backfiring at cell body C ,

t_2 is the time taken by the backfired signal to travel from C to J ,

Δt_m is the delay at neuro-muscular junction J , and

t_3 is the time of travel of muscle action potential from J to R .

Here t_1 and t_2 are inversely related to the conduction velocity v_n of the particular nerve fibre and t_3 is inversely related to the conduction velocity v_m of the short length of muscle fibres between the neuromuscular junctions and the active recording electrode.

Fig. 1 Model of conduction in median nerve to describe F-response parameters. *W* wrist, point of stimulation; *C* cell body in spinal cord where backfiring occurs, contributing a delay Δt_c ; *J* neuro-muscular junction, contributing a delay Δt_m ; *R* recording point on muscle

For the present work, the simplifying assumptions are as follows:

- 1) Δt_c and Δt_m are assumed constant for all the nerve fibres, irrespective of their conduction velocities.
- 2) t_3 is constant for all the motor units involved.

Δt_c has been estimated at about 1 ms [5 (p. 340)]. Δt_m should also be of the same order as can be estimated from the distal latencies of about 3 ms obtained for M-responses from the thenar muscle, which include the time of travel of about 1 ms of the nerve action potential from *W* to *J* (a distance of about 60 mm at a velocity of 60 m/s), and about 1 ms for t_3 , the time of propagation of muscle action potential from *J* to *R* (a distance of a few mm at a velocity of 3 to 5 m/s [5 (p. 173)]). There may be variations in Δt_c and Δt_m for different nerve fibres, but these may be expected to be under a ms, though no specific clear data are available. Therefore, compared to an F-latency of about 25 ms, these variations in the delays may be ignored. The period t_3 has also been assumed constant for all the motor units since the path is very small and the variation for different motor units would be well under a ms. Therefore, the assumptions made above appear justified, and Eq. 1 reduces to,

$$t_f = t_1 + t_2 + k = (d_1 + d_2)/v_n + k \quad (2)$$

where v_n is the conduction velocity of the nerve fibre assumed constant throughout the length, d_1 and d_2 are the respective nerve segment lengths and k is a constant period. Thus t_f for each nerve fibre is simply dependent on its velocity v_n as the distances d_1 and d_2 are almost constant for all the individual fibres in an F-latency measurement. Now if t_f is the latency of the fastest fibre contributing to any F-response, this will be the representative F-latency of that particular event. It will also be simply related to the conduction velocity of that particular fibre, following Eq. 2.

Based on the above premise, it is clear that since the process of backfiring in F-response is random, the choice of the fastest fibre backfiring in each event of a supramaximal nerve stimulation will also be random. This naturally suggests that if multiple F-responses are obtained using nerve stimulations sufficiently spaced out in time to allow the physiological processes to restore to normalcy, the number of times that a particular F-latency (of the onset in each event) is obtained will depend on the number of nerve fibres present with the corresponding conduction velocity, because of simple statistical probability of chance. Therefore, if a frequency distribution of occurrence of such F-latencies is made, which we call the distribution of F-latencies (DFL), it should correspond simply to the DCV of motor nerve fibres in the nerve trunk that take part in the creation of F-responses (considering the possibility that not all motor fibres contribute to the F-responses). As latency is inversely proportional to velocity, these two distributions will have an inverse relationship.

The above situation is similar to drawing a sample from a box containing coins of different denominations. To make the experimental situation similar we may consider drawing a few coins in sequence in each event and returning all of them and shaking the

Fig. 2 Schematic of motor unit action potentials (MUAP) from individual backfired nerve fibres plotted from the instant of stimulation (a). Combination of the potentials creates a typically observed F-response (b). The F-latency is the latency of the fastest fibre contributing to this particular backfired group (M-response is not shown here)

box vigorously before the next event of drawing a similar sequence of coins again. It should be noted that this situation of drawing coins in sequence is distinct from a situation where several coins are grabbed and drawn together. The probabilities of the coins drawn later in each of the above sequences will be affected by the loss of the previously drawn coins, but the probability of the first coin drawn in each event will depend only on the distribution of the different coin denominations in the box. It would be actually the same as drawing a single coin in each event; we just added the others to make the experimental situation similar to an F-response. Suppose as a rule of the game, we have to pick up more coins later in each event, but they do not have any bearing on the probability of the first coin, which is the only interesting event to us. If there are adequate numbers of events, the frequency distribution of the denominations of the first coin drawn in each event would represent the actual distribution of all the coins in the box within some uncertainty, determined through statistical means.

Hence the distribution of the onset F-latency (DFL) will depend on the DCV of the motor nerve fibres, specifically of those that contribute to F-responses, which is our hypothesis, under test. If the hypothesis is correct, DFL is expected to reproduce within statistical limits if obtained repeatedly from the same nerve trunk of a subject. This is an important corollary of the hypothesis and thus confirmation of this corollary would lend further support to the original hypothesis. For this purpose, an experimental study on human subjects was performed, described below. If the above hypothesis is borne out through the proposed experimental work, this may be considered a new physiological response, and will also provide a direct experimental method for obtaining a relative DCV of motor nerves that contribute to F-responses, which may be very important for neuro-diagnosis.

A home-made computerised EMG equipment, designed and fabricated by the first author with initial expertise gained from the University of Sheffield, UK [21], has been providing routine clinical service in Bangladesh through a non-Government and non-profit research and development (R&D) organisation since 1988, and was used for the measurements in

this study as well. The data acquisition software was modified appropriately for this study. Ten adult subjects, aged between 23 and 45 yrs with a mean of 31.6 yrs (± 8.1 yrs) and with informed oral consent, volunteered to participate and were considered irrespective of neurological history. To each of the median nerves of these subjects about 40 supramaximal electrical stimulations were applied at the wrist in sequence, with intervals of a few (~ 4) seconds between each to obtain about 30 F-responses from the corresponding thenar muscle (abductor pollicis brevis). The muscle was kept relaxed during the experiment. The actual number of stimulations given varied somewhat depending on the cooperation of the subject. Stimulations that did not produce any F-response were rejected. The time sequence of the collected F-latencies from each nerve was maintained and recorded. The measurements were carried out at room temperature, which remained steady at or around 30°C. Following this protocol, 20 data sets for multiple F-latencies were collected from the right and left median nerves of 10 subjects.

After each antidromic stimulation, a motor cell body may remain in a transitional state over a certain period of time that may affect its backfiring response on repeated stimulation. As no rigorous experimental data are available till now regarding the time interval needed to cross beyond such transitional phase except the refractory period of about 1 ms, which again may extend under supernormality and subnormality conditions to about 200 ms [5 (p. 59)], a large interval of about 4 s was chosen to keep a large enough margin, so as to expect random behaviour in each stimulation.

To obtain the experimental DFLs, latency groups or bins were chosen to have 2 ms intervals with group means starting from 20 ms as no F-latency was observed below this value for adult subjects. As can be seen for the second subject (MM) shown in the lower set of graphs in Fig. 3, all the non-zero F-latencies are between 23 ms and 35 ms (taking the appropriate minimum and maximum of the corresponding group means of 24 ms and 34 ms respectively), i.e. there is a maximum difference of about 12 ms between the fastest and the slowest nerve fibres contributing to the F-responses obtained from this subject. The difference is only 6 ms for the first subject (RH) as can be seen in the upper set of graphs in

Sub-RH: DFL, Lt Median

Sub-MM: DFL, Lt Median

Fig. 3 Distribution of F-latencies (DFL) of median nerve for odd, even sequenced and total data from two subjects (RH and MM). The number of events (n) for each data set is also indicated

the same figure. This indicates that although the number of motor nerve fibres contributing to the thenar muscle may be large, the ones that we are looking for can be grouped under approximately six peaks if grouped into 2-ms bins. This corresponds to six denominations of coins in the above experimental simile. Therefore, about 30 F-latencies designed for this experiment appear adequate to give a statistical estimate of the DFL.

According to the above grouping, respective DFLs were obtained for all the 20 data sets. To test the reproducibility of the DFLs, the raw F-latency data from each nerve were separated into odd and even data points in terms of time sequence of collection, and fresh DFLs were plotted for these odd and even data sets following the above latency grouping. These odd and even sequenced data sets are essentially two independent sample sets for the same subject. For this test, correlation coefficients were calculated for each of these pairs of DFLs. In addition, a visual comparison of the patterns was also made.

If the above correlation holds good then we can make two inferences. First, DFL is a parameter which reproduces well and therefore, represents a new physiological phenomenon. Second, the above-mentioned hypothesis that DFL is a direct reflection of the DCV of the motor nerve fibres taking part in the F-responses will be confirmed. The simple inverse relationship between them then will allow an easy visualisation of this DCV, contributing to a new technique for physiological understanding and neural diagnosis.

More specifically, a relative DCV of such motor nerve fibres may be obtained by calculating velocities corresponding to each of the F-latencies obtained and grouping them into a number of suitable bins in terms of velocity. However, an approximate DCV may be visualised through a mirror image of the obtained DFL about the vertical axis, which may provide a quick diagnostic procedure, although it may not represent an accurate DCV.

To validate the above findings, another experiment was performed. Carpal tunnel syndrome (CTS) is a well-understood disorder in which the median nerve is compressed at the wrist, causing a conduction delay through all the nerve fibres [5 (p. 501)]. The entrapment is expected to affect all the nerve fibres equally due to pressure transmission in a fluid, and it has also been demonstrated well through a shift in the M-response towards longer latencies (delays) without any significant change in its shape, unless other abnormalities are involved. This also results in a delay of the shortest F-latency. In many subjects CTS occurs only in one hand while the other hand has normal conduction. So the new multiple F-latency technique was used to obtain DFLs from both hands of such patients, particularly those who demonstrated similar shapes of M-responses from the two hands except for the delay. This disorder is expected to shift the DCV towards lower velocities in the affected side without significant change in the relative distribution pattern. If DFL is related to DCV as suggested, then DFL will shift to longer latencies without significant change in shape as well, and the lateral time shift would be almost the same as the difference between the latencies of the M-responses. If DFL was unrelated to DCV, there would not be any such correlation between the DFLs from the two hands. Therefore, the above test may provide a validation technique for the proposed relationship between DFL and DCV.

3 Results

Respective DFLs were obtained and plotted for all the 20 median nerves of 10 subjects. Typical DFLs from two subjects are shown in Fig. 3 arranged in three columns. The graphs in the first two columns show the even and odd distributions respectively as described above, and the third column shows the total distribution. The respective numbers of

occurrences of F-responses (n) for each are also indicated in the figures. The vertical scales of the plots in the first two columns have been doubled to compare the patterns with that of the third column on the same visual scale. As can be seen the patterns obtained for the corresponding odd and even data sets agree very well visually, and they also agree with the corresponding total distribution. The correlation coefficients obtained from the 20 pairs of data sets (odd and even occurrences) are given in Table 1. These varied between 0.46 and 0.99 with a mean of 0.81 and an unbiased standard deviation of 0.15. Except for four with values of 0.46, 0.53, 0.62 and 0.68, all others were greater than 0.75. The above result appears to support the contention that DFL is a physiologically significant parameter and thereby confirm the proposed hypothesis that DFL is simply related to DCV of motor nerve fibres contributing to F-responses, which is discussed further in the next section.

There appear significant differences between the DFLs of the two subjects shown in Fig. 3. Subject RH was normal, having no neurological complaints while subject MM reported having been diagnosed with cervical spondylosis. In fact, four subjects out of the 10 studied reported diagnosed cervical spondylosis, and for all of them double or even triple peaks were observed in DFL. Some subjects demonstrated a rather broad plateau with slight indication of dual peaks, although they did not complain of any neurological problem. These results open up further scope for investigation.

For the validation experiment using patients with CTS in one hand only, Fig. 4 shows M-responses obtained from both the left and right median nerves for one such subject (AR). The response from the right hand shows a prolonged latency indicating entrapment, i.e., CTS. The responses appear similar except for latencies (3.7 and 7.9 ms, respectively, with a difference of 4.2 ms) and amplitudes. DFLs obtained from both the median nerves of this subject are shown in Fig. 5a. The respective number of F-responses obtained for each is also indicated in the figure. The DFLs appear similar in shape except for the lateral shift in time delay of about 4 ms for right hand, the same as the shift in the M-latencies. Figure 5b shows DFLs from another subject having CTS in one side only with a M-latency difference of 1.7 ms. The DFLs also demonstrate a delay shift of about 2 ms and a similar pattern supporting the above hypothesis. These results seem to validate the hypothesis proposed in

Table 1 Correlation coefficient (r) between odd and even occurrences

Subject identifier	Age	Right Median		Left Median	
	yrs	n	r	n	r
1. MF	25	12	0.75	15	0.97
2. JA	32	17	0.93	15	0.77
3. MM	29	15	0.68	20	0.95
4. OS	25	15	0.90	15	0.89
5. SI	23	15	0.86	12	0.81
6. SN	45	16	0.85	16	0.62
7. AS	40	15	0.88	15	0.53
8. UB	28	15	0.46	15	0.75
9. MR	26	15	0.91	15	0.80
10. RH	43	14	0.97	14	0.99
Summary					
Mean Age, yrs	31.6				
St Dev _{n-1} Age, yrs	8.11				
Mean Corr. Coeff.	0.81				
St Dev _{n-1} Corr. Coeff.	0.15				

Fig. 4 M-responses from both median nerves for a subject (AR) with unilateral carpal tunnel syndrome (CTS). CTS is evident in the right hand

Fig. 5 Comparison of distribution of F-latency (DFL) from both median nerves of two subjects [AR (a) and BM(b)] with unilateral carpal tunnel syndrome (CTS). CTS is on the right, for both, and DFLs also show the shift of the whole pattern in latency

this paper that DFL is a direct reflection of the DCV of motor nerves that contribute to F-responses.

According to the method described in the previous section, suggested relative and approximate DCVs for motor nerves that participate in F-responses were obtained as the mirror images of DFLs (total, third column) for subjects RH and MM (from Fig. 3), and are shown in Fig. 6.

4 Discussion

The mean value of the correlation coefficients (0.81 ± 0.15) of DFLs between the odd and even data sets, which essentially form independent pairs of data samples for all the 20 median nerves, indicates a high degree of correlation. Even a cursory glance at the plots in Fig. 3 supports this finding. However, the slightly lower values in four sets ($r=0.46, 0.53, 0.62, 0.68$) may be attributed to experimental inadequacies, or there may be some other physiological causes yet to be determined. Subsequent experiments where DFLs were obtained at separate sittings also demonstrated such high degree of correlation. The overall high correlation appears to support a corollary of the proposed hypothesis that DFL obtained from multiple F-responses cannot be a mere chance occurrence; DFL is a valid physiological parameter describing a characteristics of a nerve trunk.

Following the arguments in the Methods section above, since the DFLs have reproduced very well for independent data samples from each nerve, the conceptual relationship

Fig. 6 Relative distribution of conduction velocity (DCV) of motor nerves obtained as mirror images of distribution of F-latency (DFL) for the median nerves of subjects RH and MM from Fig. 1

between DFL and DCV of motor nerves, which is the main hypothesis of this present work, appears to hold good. Furthermore, the observation of expected patterns of DFL for patients with unilateral CTS supports the proposition. It can be seen from the M-responses in Fig. 4 that the right hand has CTS with a delay shift of 4.2 ms with respect to the unaffected left side. Looking at the corresponding DFLs in Fig. 5a, the shortest non-zero latency group means are 25 and 29 ms from the left and right hands, respectively, differing by 4 ms, which agrees very well with the delays of the M-responses mentioned above. This is somewhat expected based on previous studies of CTS. However, that the two DFLs are almost similar in shape, having only a lateral time shift, is new information providing details of the delay profile of nerve fibres, and which seems to support the hypothesis presented in the present paper that DFL is the direct outcome of DCV. An M-response can only give information about the delay shift of the fastest fibres, but the pattern of DFL gives information on the slower nerve fibres as well, which are not obtainable directly from the M-response. The DFLs from another CTS patient shown in Fig. 5b also support the same conclusion.

Here we have shown examples where DFLs have similar patterns on the two sides for the CTS patients, but there were cases with slightly different shapes for the affected side, which, we suggest, may reveal non-uniform nerve degeneration due to prolonged entrapment or due to other neurological disorders. Therefore, DFL and DCV (of motor nerves participating in F-responses) are related to each other in an inverse manner, and their general pattern should be almost mirror images of each other. Strictly speaking there would be some skewing when one goes from the one to the other, and, to be more specific, F-wave conduction velocity [5 (p. 341)] values may be obtained from the corresponding raw F-latency values, and a DCV may be obtained directly as mentioned before. However, for diagnostic purposes, the above mirror image of DFL to represent DCV of motor nerve fibres taking part in F-responses may be acceptable.

In the absence of an alternative reliable and accurate method of measuring DCVs it is difficult to compare the results of the present work for their accuracy. However, earlier work using collision techniques [1–3] and diameter distribution obtained from nerve biopsies [5 (p. 64)] would suggest a feature common to the DCVs of all healthy motor nerves measured using surface electrical stimulation: these will have a single peak falling off in both directions. The above inference in terms of diameter distributions needs some explanation. The conduction velocity is known to be directly proportional to the diameter of a nerve fibre for the same type of nerve fibre, and diameter measurements of myelinated nerve fibres in a nerve trunk had shown a bimodal distribution. The two peaks representing A-alpha and A-delta nerve fibres have peak velocities of about 60 m/s and 20 m/s respectively. Of these, only A-alpha group is present in the motor (efferent) nerves [5 (p. 62–64)]. Therefore, for normal subjects, only the A-alpha fibres with a single peak in the DCV would be involved in any motor conduction study. DFL, being a mirror image of DCV as suggested, would therefore have a single peaked pattern for normal healthy nerves as well. Under this criterion the DFL in the top row of Fig. 3 (subject RH) is expected to represent a normal condition; the subject also did not report any symptoms of neurological disorder. The same pattern was also observed for the unaffected sides of the two CTS subjects in Fig. 4 and also for many subsequent studies on normal subjects. Therefore, it seems reasonable to accept DFL as an approximate mirror image of DCV of motor nerve fibres participating in F-responses.

On the other hand the double peak of DFL for subject MM in Fig. 3 raises a question. As mentioned before, the patient had reported having been diagnosed with cervical spondylosis (CS) and that four subjects out of the 10 studied in this experiment reported having been diagnosed with CS, and DFLs from all of them demonstrated double or even triple peaks. This is very interesting and needs further study to understand the origin of these extra peaks

and their relationship to CS. If this can be established on a firm ground, DCV obtained from DFL, or the DFL itself may become an important parameter for the diagnosis of CS. Again, as has been mentioned in the Results section above, some subjects demonstrated a broad DFL with a tendency of showing two peaks. If the above relationship between CS and double peak of DFL bears out, then these patterns may indicate early stages of CS, which are possibly still subclinical. Conventional neurophysiological techniques have so far not produced any method to give a positive diagnosis of CS except for excluding other peripheral nerve disorders. Using a train of 200 stimuli, Peioglou-Harmoussi et al. [23] studied the frequency of occurrence of F-responses from ulnar nerves, frequency of identical responses and F-wave shapes to relate these to CS. None of these led to any clear-cut method to identify CS, as the distinctions were not well marked; however, there appears to be a correspondence with one of their observations with our observation of DFL. They found that the F-wave appeared complex visually compared to those from controls. In our findings, DFL is a simple distribution with a single peak for normal subjects; therefore the backfiring nerve cells have less dispersion in latency among them, contributing to simple F-waves on combination of the individual motor unit responses. On the other hand, in case of CS, DFL has more dispersion with double peaks, meaning that latencies from back firing nerves may have wider separation among them, leading to more complex patterns on combination.

Since DCV is affected differently by different disorders, DFL may possibly show these disorders quite early, making a sensitive neuro-diagnostic tool. Even if the DCV obtained through the present method cannot be taken as correct, for argument's sake, the DFL itself may form a new parameter for diagnosis. Maximum and minimum velocity values obtained from DCV based on collision techniques mentioned before were used to identify diagnostic parameters for certain neurological disorders [22], but the use of the whole patterns of DCV or of DFL are something novel, and are expected to provide a far improved visualisation for diagnosis.

The present method of obtaining relative DCV is a direct experimental one and is therefore free from analytical errors. This method may be applied to any of the peripheral nerves of the limbs, upper or lower, that are usually studied for NCV determination and for which an F-response can be obtained. The present method can be readily implemented using a standard EMG equipment through manual recording of the F-latencies. However, specialised computer-based equipment with automatic evaluation of DFL or DCV, as has been performed in our laboratory recently, will make the measurement simpler and suitable for routine measurement in clinics or hospitals.

Here, we have presented a new physiological parameter describing a neural system, in the form of the frequency distribution of F-latencies, or DFL, hitherto unknown, and which can be obtained through multiple stimulation of a motor nerve, a simple procedure. The work has shown that DFL has a physiological basis; it is not a chance occurrence. As DFL owes its origin to DCV of motor nerve fibres conceptually, it is very likely that the relative and approximate DCV of motor nerves obtained directly as a mirror image of DFL is valid for nerve fibres participating in F-responses. This may help in visualising neuropathies of different kinds in terms of velocity or latency values, even under subclinical conditions. The simplicity of this measurement may open up a whole new avenue in neural investigation and diagnosis.

Acknowledgement The authors acknowledge the support provided by Bangladesh Institute for Biomedical Engineering and Appropriate Technology (BiBEAT), a non-Government and non-profit research organisation, in allowing the use of facilities at an EMG clinic run by them, at no cost. The authors would also like to acknowledge the help of the 10 subjects who volunteered for the measurements without asking for any payment.

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