A MODEL OF THE MEDIAN SENSORY NERVE COMPOUND ACTION POTENTIAL LEADING TO A METHOD FOR NERVE FIBRE DIAMETER DISTRIBUTION DETERMINATION.

Tomás Ward*

1 INTRODUCTION

Nerve conduction studies (*NCS*) are one of the basic tools of the electrodiagnostic clinician and are performed in order to evaluate the integrity of peripheral nerve function . Using such techniques diagnosis of various diseases and disorders of nerve are possible. During *NCS* a peripheral nerve is stimulated using an electrical pulse of sufficient intensity to recruit as many nerve fibres as possible. This elicits a volley of action potentials (*APs*) in the individual nerve fibres which is then recorded at a distal point usually using surface electrodes. Usually only two components of the recorded response (called the compound action potential or *CAP*), the distal amplitude and the distal/peak latency are routinely recorded though the proximal latency is also used to construct an average measure of conduction velocity (*CV*). In this study a model of the sensory *CAP* of the median nerve as measured using bipolar electrodes is proposed and using this model an additional measure is extracted from the *CAP*. This measure represents the distribution of conduction velocities within the nerve trunk and from this a measure of nerve fibre diameter distribution can be ascertained.

2 GENERAL INFORMATION

The median nerve is derived through the spinal nerve roots C6-T1 and travels the whole length of the arm along through the carpal tunnel at the wrist to the palm of the hand. The median nerve innervates both the pronator teres muscle in the forearm and the abductor pollicis brevis muscle (often abbreviated to APB, it is this muscle that is responsible for thumb abduction). In humans the median nerve is made up from around 6500 nerve fibres of which over three quarters are sensory with external diameters ranging from 6-12μm as found by dissection [1]. The relationship between the external fibre diameters and conduction velocity has been found to be a linear one in which *CV* increases with fibre diameter. this relationship is often expressed thus

$$\text{conduction velocity } (m/s) = k.\text{fibre diameter}(\mu m) \quad (1)$$

where $k \cong 6$ [2].

There are currently several methods for decomposing the *CAP* into its constituent nerve fibres according to diameter such as the techniques by Tu *et al.*[3], Pollak *et al.*[4] and Hirose *et al.*[5] yet none of these methods have gained widespread acceptance as each method suffers from its own particular shortcomings e.g. Tu's method takes no account of the bipolar configuration of recording electrodes used in such measurements and its influence on the *CAP* morphology.

---

*Department of Electronic and Electrical Engineering, National University of Ireland, Dublin, Belfield, Dublin 4, Ireland. tomas.ward@ucd.ie.

3 THEORY

This model assumes a monophasic form for the extracellularly recorded *AP* (measured using a monopolar system)and that the conduction velocity is related to the nerve fibre diameter by

$$v = k_{cv}\phi \qquad (2),$$

where ϕ denotes the nerve fibre diameter, and t_1, the time between the onset of the stimulus and the onset of the *AP* at the recording site is defined as

$$t_1 = \frac{d_1}{v} = \frac{d_1}{k_{cv}\phi} \qquad (3),$$

where d_1 is the distance between the point of stimulation and the leading electrode.
The time between the two phases of the AP recorded with bipolar electrodes can similarly be represented as

$$t_2 = \frac{d_2}{v} = \frac{d_2}{k_{cv}\phi} \qquad (4),$$

where d_2 is the distance between the two recording electrodes.
A first order approximation to the biphasic waveform encountered is to use a single cycle of a sinusoidal function with period equal to t_2, *viz.*

$$h(t) = A_{\phi}.\sin(\pi \frac{k_{cv}\phi}{d_2} t) \qquad \text{for } t_1<t<(t_1+2t_2)$$

$$h(t) = 0 \qquad \text{otherwise} \qquad (5)$$

where $t=0$ is the onset of the stimulating pulse and A_{ϕ} can be a diameter dependent amplitude term. This waveform $h(t)$ is illustrated in Fig.1.

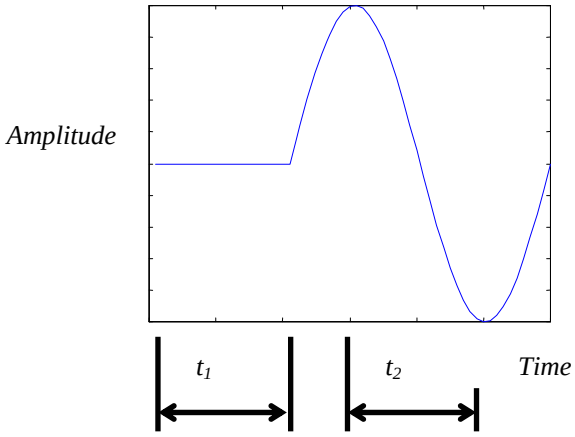


Fig. 1: *Idealised biphasic action potential*

The shape of the *CAP* then for a given fibre diameter distribution $p(\phi)$ varies with recording distance from the stimulating electrodes as

$$y(t) = \int_{\phi=\phi_{\min}}^{\phi=\infty} p(\phi)h(t,\phi,d_1,d_2)d\phi \qquad (6)$$

which is discretized as:

$$y(t_i) = \sum_{j=1}^{N} p(\phi^j)\left\{h^j(t_i,d_1,d_2)\right\} \qquad i = 1,2,....M, \quad j = 1,2,....N. \qquad (7)$$

where equation (7) is based on a volume conductor model.
This can be written as

$$\boldsymbol{y}=\boldsymbol{S}\boldsymbol{p} \qquad (8)$$

where

$$S(i,j) = A_{\phi}.\sin(\pi \frac{k_{cv}\phi_j}{d_2} t_i) \quad \text{for } t_1 < t_i < (t_1^j + 2t_2^j) \quad (9)$$

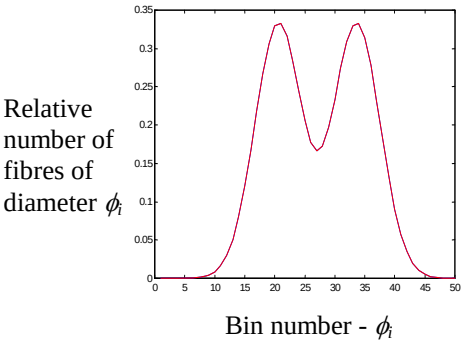
$$S(i,j) = 0 \quad \text{otherwise}$$

Using equation (8) *CAP* responses can be generated for arbitrary choice of *s*. Fig. 6(a) shows a bimodal distribution for ***s*** (containing fifty bins i.e. *N=50*)based on the double gaussian distribution below.

$$s(\phi) = \frac{1}{\sigma_1\sqrt{2\pi}}\left[e^{-\frac{1}{2}\left(\frac{\phi-\mu_1}{\sigma_1}\right)^2}\right] + \frac{1}{\sigma_2\sqrt{2\pi}}\left[e^{-\frac{1}{2}\left(\frac{\phi-\mu_2}{\sigma_2}\right)^2}\right] \quad (9)$$

The vector *s* is in effect a histogram, the elements of which are numbers relating the number of fibres of a particular diameter to the total number of fibres . Fig. 2(b) shows the response generated using equation (8).

Reconstruction of ***p*** given ***y*** and a form for ***S*** involves minimizing the euclidean length of ***Sp-y,*** and this is achieved using the method of nonnegative least squares (NNLS) [6] which is a least squares method which utilises the additional constraint that all the elements ***p*** must be positive. Using this numerical method and the simulated *CAP* from Fig. 2(b) the orginal vector ***p*** can be reconstructed perfectly . Of course with noisey data perfect reconstruction is not possible although averaging techniques appear to eliminate most of the error.



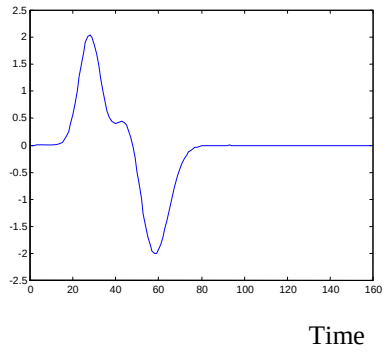
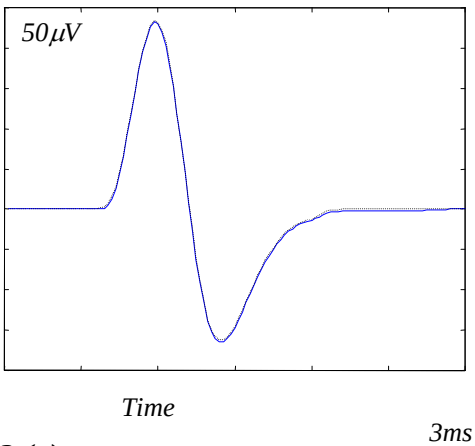


Fig. 2 (a) : *Distribution of fibre diameters for CAP generation* ***(b) :*** *Modeled CAP output baed on (a).*

4 EXPERIMENT

A median nerve palmar sensory study was used to test the method developed. The response shown in Fig. 3(a) (dashed line) exhibits normal features and had a latency of about 2*ms*. For more detail on the procedure involved in obtaining the response see [7]. The response was lowpass filtered before being processed by the NNLS method. The figures used for electrode placements were d_1=6cm and d_2=2.5cm.



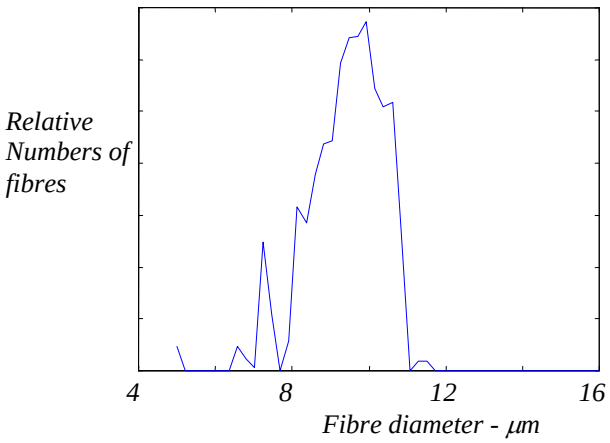


Fig. 3 (a) : *Actual median nerve response with model output* ***(b) :*** *Derived nerve fibre distribution*

The results from the optimisation procedure are shown in Fig. 3(b) and exhibit a unimodal appearance which is expected given the biphasic morphology of the measured *CAP*. The solid line in Fig. 3(a) shows the reconstructed *CAP* as then produced by equation (8) based on the distribution of Fig. 3(b).

5 DISCUSSION

The results appear to show a healthy distribution of nerve fibres in the range 6-12μm. this attends to agree well with standard dissection data for this range. Of course it is impossible to test how accurate this result actually is without conducting a biopsy of the actual nerve and counting the actual fibres according to external diameter but by repeating the experiment over multiple trials and averaging the resultant distributions one can derive quite an accurate measure of the nerve fibre diameter distribution. It is worth noting that the method can also be optimised in terms of d_1 and d_2 simply by searching for a minimum in the d_1-d_2 error surface in the neighbourhood of the measured values for these parameters.

6 CONCLUSION

The non-invasive estimation of fibre distribution in nerve trunks is of great importance in neurological studies but as yet there is no satisfactory method for making such estimations. Most methods suffer difficulties due to noise contaminated data, poorly positioned electrodes and inaccurate recording of conduction lengths. It is hoped that the approach being put forward here which can overcome some of these difficulties may prove to be applicable in routine clinical nerve conduction studies.

Acknowledgement

I would like to thank Barbara Crout of the American Society of Electroneurodiagnostic Technologists who has kindly provided numerous NCS datasets for this work.

References

[1] Buchthal, F. and Rosenfalck, A. (1966), Number and diameter of myelinated fibres in human sensory nerves. *Brain Research,* vol. 3 , no. 1 , pp. 85-94

[2] Hursh, J. B. (1939), Conduction velocity and diameter of nerve fibres. *Amer. J. Physiol.*, vol. 80, pp. 522-547.

[3] Tu, Y. X., Wernsdörfer, A., Honda, S. and Tomita, Y. (1997). Estimation of conduction velocity distribution by regularized-least-squares method. *IEEE Trans. BME,* vol. 44, ,no. 11.

[4] Pollak, V. A., and Wan, Q. X. (1997). The Z-transform of the compound action potential. *IEEE Eng. Med. Biol.,* vol. 16, no. 3, pp. 80-86.

[5] Hirose, G., Tsuchilani, Y. and Huang, J. (1986). A new method for the estimation of nerve conduction velocity distribution in the frequency domain. *Electroenceph. and Clin. Neurophys.*, vol. 63, pp. 192-202.

[6] Lawson, C. L. and Hanson, R. J. (1974). *Solving least squares problems.* Prentice-Hall inc., N. J.

[7] Crout, B. O. and Flicek, C.W. (1997). *Nerve conduction studies from A to Z.* The American Society of Electroneurodiagnostic Technologists.