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PROPOGATION OF ACTION POTENTIAL FOR HANSEN'S DISEASE AFFECTED NERVE MODEL USING FITZHUGH NAGUMO LIKE EXCITATION

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ABSTRACT

This paper deals with the modeling of a Hansen's disease (HD) affected nerve using FEM based simulation tool. There exists an exponential delay in the propagation of action potential for a diseased nerve as compared to a healthy one. To include this exponential delay, the FitzHugh Nagumo equation has been modified and modeled using COMSOL Multiphysics 4.0a. Time domain and frequency domain analyses help in a better diagnosis of the disease. The simulation results are promising and the systematic exposition discussed in this paper will be useful for the diagnosis of Hansen's disease

Keywords: *Hansen's disease, action potential, FitzHugh Nagumo excitation, COMSOL Multiphysics 4.0a*

1. INTRODUCTION:

The peripheral neuropathy symptomatic of Hansen's disease (HD) may be linked to the obstruction of signals by a damaged nerve connecting the neurons in the brain and muscular fibres innervated by it. HD can lead to the development of serious complications due to peripheral neuropathy. Numbness and tingling can occur in the hands, arms, feet and legs. *Myobacterium leprae* attacks the nerve endings and destroys the body's ability to feel pain and injury [1]. These injuries become infected and result in tissue loss which interrupts the vast communication network transmission from the brain and spinal cord. As peripheral nerves are always involved in HD and ulnar nerve being the coolest region in the arm it plays host of the *M. leprae* [2]. Thus the nerve trunks in the arm get affected and part of the hand becomes numb and small muscles become paralysed, leading to clawing of fingers. It happens due to the disturbance in the activity of voltage gated potassium and sodium ions leading to the delay in the propagation of action potential across the arm [3].

Figure 1: Propagation Of Ions Across The Membrane

Sodium and potassium ions being electrogenic contribute to the maintenance of the membrane potential in the nerve, thereby influencing the excitability by an influx of Na^+, followed by an exflux of K^+ as shown in figure 1. For a healthy nerve, the electrical stimulation and opening of Na^+ channels cause activation within seconds allowing the transport system to maintain a lower intracellular Na^+ whereas for a HD nerve, there occurs a delay in activation resulting in a decreased affinity for intracellular Na^+ [4]. These Na^+ and K^+ mechanism play an important role in the detection of HD nerve and can be applied to any spiking neuron model in the conduction based FitzHugh Nagumo formation. In order to trap the electrical activity generated by the human body, knowledge of electrophysiology along with the advanced electronic tools are call for [10]. To interpret the result, the computer paradigm chosen is COMSOL Multiphysics.

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2. DESIGN OF FITZHUGH NAGUMO SYSTEM

FitzHugh (1961) derived a set of differential equations from Hodgkin Huxley (HH) model, followed by Nagumo, Arimoto and Yoshizawa (1962) who developed a similar expression from HH equation [5]. The conclusion drawn from both the studies was that the essentials of the excitable process in HH equation could be distilled into a simpler model and named as FitzHugh Nagumo (FHN) model [6]. Their argument was based on the fact that the time scales for m, n and h in HH equation were not all of the same order; the four variables of HH can be simplified into a two variable (V, W) model as given in the following equations [4].

$$\frac{dV}{dt} = V(\alpha - V)(V - 1) - W + I \quad (2.1)$$

$$\frac{dW}{dt} = \varepsilon(V - \gamma W) \quad (2.2)$$

Where ε denotes excitability, γ is the parameter responsible for the change in the resting state and dynamics of the model, I is the parameter affecting the external stimulus which has to be greater than the threshold value.

The above equation is used for the modelling of a healthy neuron and the recovery variable W has an exponential distribution delay with mean 1/εγ, whereas a disease affected ulnar nerve model responds very slowly to an external stimuli, or it can also be said that their sensory velocity is slightly delayed and the duration of action potential is high. Therefore to make the FHN model compatible with the disease affected nerve, it should also show more delay. Thus the W variable in equation 2.2 is modified into W and W1as shown in equation 2.3 and 2.4 with a mean time delay of 2/εγ and the equation now has three variables [4].

$$\frac{dW1}{dt} = \varepsilon(V - \delta W1) \quad (2.3)$$

$$\frac{dW}{dt} = \varepsilon(\delta W1 - \delta W) \quad (2.4)$$

Power spectral density can be obtained from the modified FHN model as shown in equation 2.5-2.7 and it will be useful in differentiating the disease from a healthy nerve in terms of zero crossing and power intensity [7, 8].

$$\varepsilon\frac{dV}{dt} = V(V - \alpha)(1 - V) - W + \eta(t) \quad (2.5)$$

$$\frac{dW}{dt} = V - dW - (\beta + r\sin\beta t) \quad (2.6)$$

$$\frac{d\eta}{dt} = -\lambda\eta + \lambda\xi(t) \quad (2.7)$$

Where η = noise, $\xi(t) = 0$,
$\xi(t)\xi(s) = 2D\delta(t - s)$, η (t) = D(λ)
denotes noise intensity, correction time($t_{c)}$ = 0.01,

3. METHODOLOGY

Modelling of a surface EMG has proved to be a valuable tool in the interpretation and diagnosis of a disease affected nerve model. COMSOL Multiphysics considers the timing of the spikes and the amplitude of potential for the time domain interpretation of the signal. To simulate the nerve model, it was necessary to define its geometry, boundary conditions and the domain settings [9].

A diseased nerve with the surrounding neuronal environment is assumed to be a cylinder and was simulated in a three dimensional environment by choosing an electrostatic medium with the user defined relative permittivity of 80 and spatial charge density of 0 [6]. Table I shows the global parameters of a healthy and diseased nerve. The Physics is taken as the Partial differential equation (PDE) general form which solves the FHN equations.

Table I: Parameters Related To FHN

Parameters	Value for HD nerve	Value for healthy	Description
A	0.139	0.1	Excitation threshold
Λ	.027	1	Parameter
B	0.75	0.75	Parameter
E	0.008	0.01	Excitability
V_0	1	1	Elevated potential (V)
nu0	0.025	.025	Elevated relaxation value (V)
Δ	0.011	0.011	Parameter
D	1	1	Off axis shift distance (m)
I	4.65	0	Stimulus

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All boundaries of the neuron in the PDE are governed by Neumann Boundary condition and a FEM based analysis is done to approximate PDE by meshing the model.

4. RESULT AND DISCUSSION

After the completion of post processing in COMSOL Multiphysics, the result has been obtained by keeping the value of ε = 0008, a constant and varying the γ and I of the FHN equation. Fig. 2(a) and (b) have been plotted using equation 2.1 & 2.2 and equation 2.5 & 2.6 to study the difference between the firing of a healthy and diseased nerve.

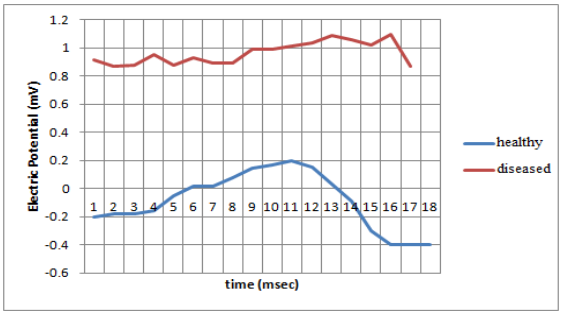

Figure 2 (A) Y = 0.027; I = 4.42

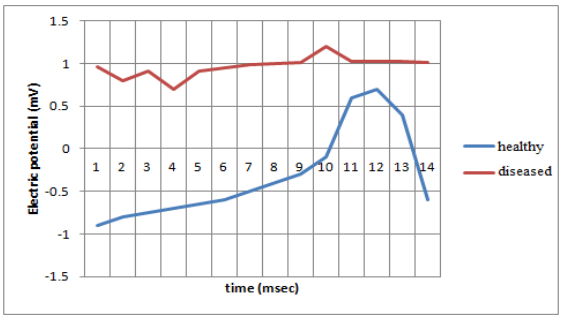

Figure 2 (B) Y = 0.04, I = 2.54

Power spectral density gives a clear cut difference between a healthy and diseased nerve. By plotting equation (2.5 - 2.7), power spectral density is obtained in frequency domain as shown in fig. 2c.

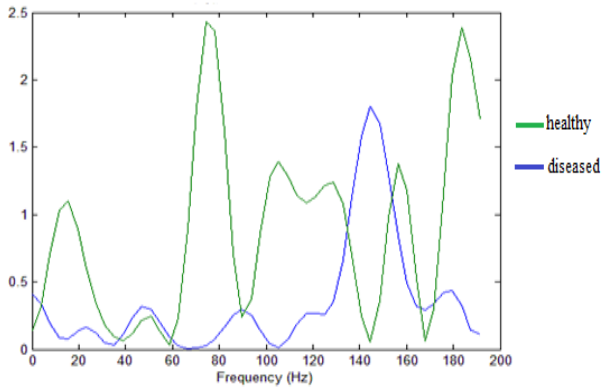

Figure 2 (C) Power Spectral Densities

The detection of neuromuscular diseases can be done by varying the parameters of the FHN [11]. The duration of action potential is within the normal range for a healthy nerve while it gets delayed for the diseased. In the diseased, some of the motor units are inactive and do not respond to the stimulus. This causes the fluctuations which can be viewed as a zig - zag pattern in the fig 2(a & b). The amplitude of voltage of the diseased nerve fiber was also raised, denoting the thickening of the sheath [13].

It can be seen from the figure 2c that the diseased crosses the X axis at about 200 Hz. In all the healthy cases, the power amplitude is high whereas with the diseased, it is low. In some cases, the diseased have low power throughout the spectrum while in some it is observed only in the higher frequency region. Thus it can be inferred that the disease affects both sections of the spectrum, while its impact is more pronounced in the higher frequency segment of the spectrum [12].

5. CONCLUSION

This paper reports the first effort in HD - modelling a diseased ulnar nerve in COMSOL Multiphysics. It clearly differentiates a healthy from the diseased. This approach can be extended for other HD affected nerves like median nerve in the arm and common peroneal nerve in the leg. The methodology if perfected can be used for the early detection of disease before other symptoms set in.

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