SIMULATING MYOELECTRIC SIGNALS WITH A FINITE-LENGTH MODEL OF MUSCLE

D MacIsaac, D Rogers, A Bhandarkar

Institute of Biomedical Engineering, University of New Brunswick, Fredericton, Canada

ABSTRACT

A myoelectric simulation tool is proposed here based on a finite-length model of muscle. The utility of this tool is demonstrated through a simple study of the influence of end-effects on conduction velocity estimation.

INTRODUCTION

Simulating the generation of myoelectric signals allows us to predict the influence of factors on the signal. A myoelectric simulation tool, developed for use in Matlab (Version 6.0 or higher), is proposed here based on a finite-length model of muscle.

The model was originally proposed by Gonzalez-Cueto and Parker [1]. It is based on the convolution of a source and a tissue filter to generate a single fiber action potential (SFAP) measured at the skin surface. A bi-directional propagating double layer differential source is utilized as suggested by Plonsey [2]. The filtering function, based on the work by Dimitriv and Dimitrova [3], takes into consideration the field distribution properties and conduction velocity of the source, the depth of the fibre, the location of the innervation point of the fibre, and the location of the left and right terminations of the fibre with respect to electrode location. Mathematical equations for the source and filter can be found in the Appendix.

In the model, surface motor unit action potentials (MUAPs) are generated by summing multiple SFAPs. Since the same fibers are always stimulated in a given motor unit, an MUAP train is formed by convolving an MUAP with a time-series of impulses representing the innervation process of that motor unit. An independent Gaussian distribution is used to model the interpulse interval (IPI) of the time-series. To generate a segment of myoelectric signal (MES), many independently generated MUAP trains are summed.

In this work, a software package called Myosim was developed to simulate myoelectric signals based on the model. Then, to demonstrate functionality, the tool was used to conduct an investigation on the influence of end-effects on conduction velocity (CV) estimation.

METHOD

Myosim

A screen shot of Myosim is presented in Fig. 1:

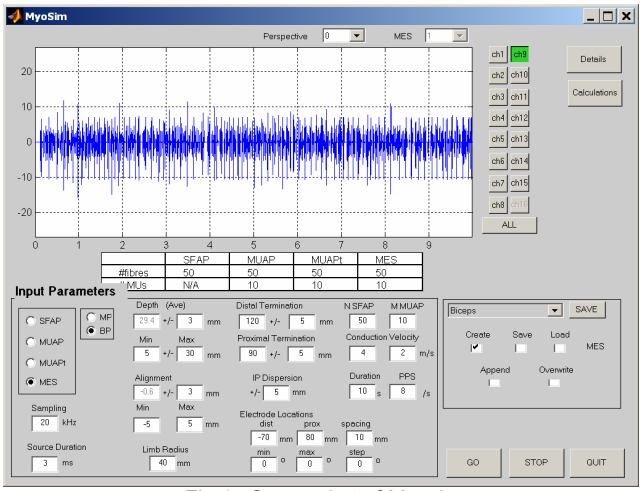

Fig 1: Screenshot of Myosim

The front-end graphical user interface (GUI) has been designed so that users can easily set parameters as described in Table 1 to generate and display SFAP, MUAP, MUAP trains or MES in either monopolar or bipolar mode, at up to 16 electrode locations. The 16 channel linear electrode array can also be placed at multiple locations around the diameter of the limb so that different perspectives can be simulated at the same time.

For single fibre simulations, users set fibre-specific parameter values. For multiple fibre, single motor unit simulations, users set motor-unit-specific parameter values and dispersion limits which randomly disperse fibre values according to the limits. For multiple motor unit simulations, ranges for motor unit values are set along with fibre dispersion limits and Myosim randomly disperses both fibres and motor units across these dispersions/ranges. All dispersions are randomly generated according to a uniform distribution.

Parameter	Default Value
sampling frequency	20 Khz
source duration	3 ms
average depth of MUAP	10 mm
range of average depth of MUAP*	[5, 30] mm
fibre depth dispersion*	+/- 3 mm
average off-set of MUAP (from center)	0 mm
range of off-set of MUAP (from center)*	[5, 30] mm
fibre off-set dispersion*	+/- 5 mm
limb radius	40 mm
distal fibre termination	120 mm
distal fibre termination dispersion*	+/- 5 mm
proximal fibre termination	90 mm
proximal fibre termination dispersion*	+/- 5 mm
innervation point dispersion*	+/- 5 mm
number of fibres	1
number of motor units	1
signal duration	1 s
firing rate	8 pps
distal electrode location	70 mm
proximal electrode loaction	80 mm
electrode spacing	10 mm
electrode array perspectives	[0°, 180°]
conduction velocity	4 m/s
conduction velocity dispersion	2 m/s

* limits for randomly generated parameters

Table 1: User-defined Input Parameters

Users have access to two sub-views from the main GUI. By selecting 'Details', users activate a sub-view which allows them to view each MUAP created and its associated SFAPs. This sub-view is designed so that users can navigate through the SFAPs and MUAPs easily with 'previous' and 'next' buttons as depicted in Fig 2. Also included in this subview is a dynamic parameter listing which updates as different SFAPs and/or MUAPs are selected.

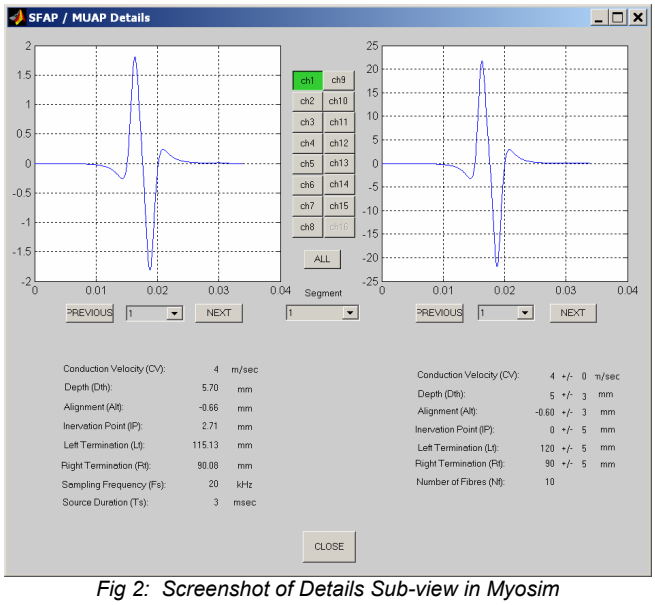

Fig 2: Screenshot of Details Sub-view in Myosim

The second sub-view is activated when users select 'Calculations'. This view allows users to set parameters for calculating mean frequency and CV based on the simulated MES records as depicted in Fig. 3. For mean frequency, segment length, epoch length and % overlap are user-defined and a Welshe's averaging algorithm is used to calculate a power spectrum for each segment. Then, a mean frequency value is calculated from each spectrum. For CV, segment length and % correlation length are user-defined and the shift in the cross-correlation between adjacent channels is used to determine the propagation time between channels. CV is then calculated by dividing the electrode distance by this time.

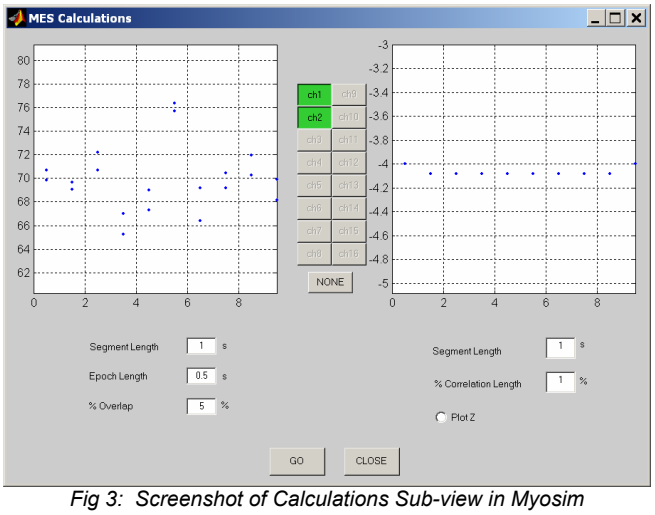

Fig 3: Screenshot of Calculations Sub-view in Myosim

All of the signals generated in Myosim can be saved and retrieved along with their parameter settings. The files are tagged so that associated SFAPS, MUAPs, MUAP trains and MES are easily identified. The default input parameters have been set to model the brachial biceps, but different configurations can also be named and saved.

Using Myosim to investigate the Influence of End-effects on Conduction Velocity Estimation

To demonstrate the functionality of Myosim, a simulation was conducted to investigate the influence of end-effects on CV estimation. End-effects are the effects that action potential origination and extinction have on the resulting signal. They are also known as non-propogating components because they are seen at the same time at every channel, regardless of channel location. Fig. 4 depicts the non-propagating nature of these effects. Since they are non-propogating, it is hypothesized that they manifest in cross-correlation estimations by biasing the peak towards zero, consequentially biasing CV estimates high.

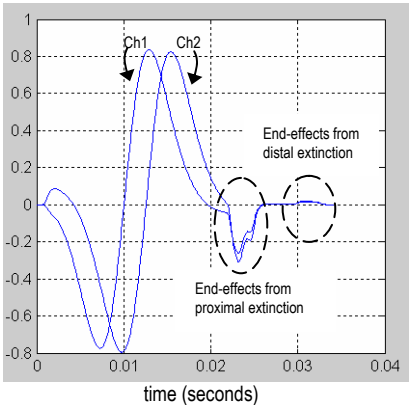

Fig 4: MUAP (100 fibres) at 2 Channels

To verify this hypothesis, a 10 second record of MES made up of 20 motor unit action potentials with a firing rate of 16 pps was simulated. Each motor unit was made from 100 fibres. Electrodes were placed along the length of a muscle which extended from -100 mm to + 80 mm with respect to the center of its innervation zone. Electrode spacing was set to 10 mm. The average depth of motor units was randomly distributed between 25-30 mm, a range known from previous studies to generate end-effects of significant size. Fibre depth dispersion about average depths was set to +/- 5 mm as was the dispersion of fiber terminations and innervation points. Motor unit alignment was set to 0 with no dispersion. Each fibre CV was set to 4.0 m/s. CV estimations were made from 2 second contiguous segments of the signals at each channel location.

RESULTS

Fig. 5 depicts one of the MUAPs generated to make up the MES as seen at electrode locations Ch1 = 10 mm, Ch3 = 30 mm, Ch5 = 50 mm, and Ch7 = 70 mm from the average distal termination of the motor unit. Fig. 6 depicts the same MUAP as seen at electrode locations Ch15 = 10mm, Ch13 = 30 mm, and Ch11 = 50 mm, from the average proximal termination of the motor unit. The average depth of the motor unit depicted was 27.5 mm. As the distance between the channel location and motor unit terminations decrease, there is a noticeable increase in end-effects.

Fig. 7 depicts the CV estimates across five 2 second segments of the simulated MES (20 motor units, 100 fibres/unit). Multiple points at each segment represent estimations based upon adjacent channels. Estimates about Ch8, Ch9 and Ch10 have been omitted because those channels traverse the innervation zone rendering the estimates meaningless. As the distance between the channel location and motor unit terminations decrease, there is a noticeable positive bias in the magnitude of the estimates.

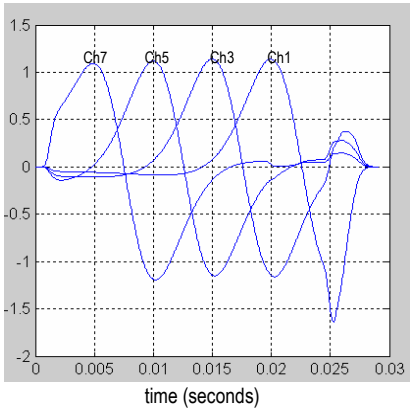

Fig 5: MUAP (100 fibres) at four electrode locations distal to the innervation zone

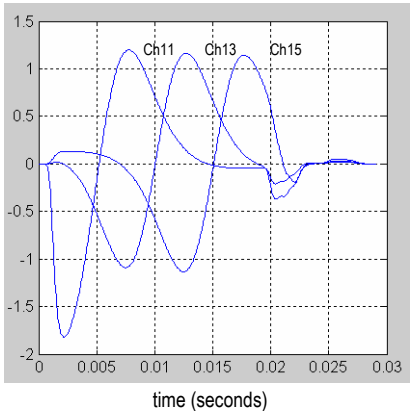

Fig 6: MUAP (100 fibres) at three electrode locations proximal to the innervation zone

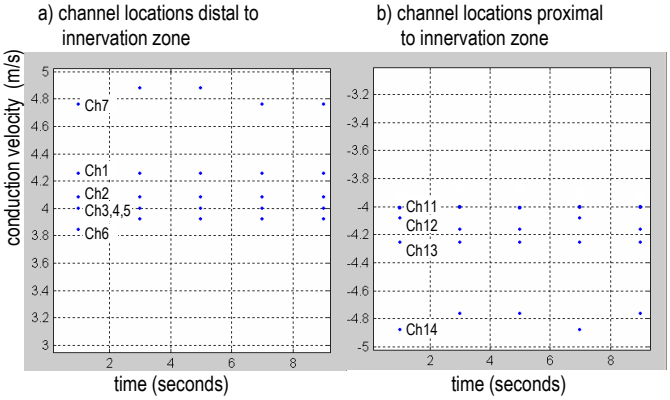

Fig 7: CV Estimations across MES segments (2 seconds)

DISCUSSION

According to results of this simulation, electrodes must be optimally placed in order to get precise estimates of CV. If electrodes are within the innervation zone, the shift in the cross-correlation between adjacent measurements does not represent the time taken for the signal to propagate from one channel to the next and CV estimates are meaningless. This effect tapers as electrodes straddle fewer fibre innervation points towards the ends of the innervation zone. According to Fig 7, this occurs around Ch7 on the distal end and before Ch11 on the proximal end.

Moreover, on either side of the innervation zone, as indicated in Fig. 7, the magnitude of CV estimates increases as the distance between the electrodes and the fibre terminations decreases. This confirms the hypothesis. That is, as the electrodes get closer to fibre terminations, end-effects become more pronounced, as indicated in Fig. 5 and Fig. 6, and have more of an influence on CV estimation.

The magnitude of CV estimates made outside the innervation zone in this simulation ranged from 3.86 m/s to 4.88 m/s depending upon the channel location. The sign of the estimate simply represents the propagation direction of the signal (+ towards the proximal termination, - towards the distal termination). The root mean squared error of these estimates was 0.31 m/s, given that a known CV of 4.0 m/s was set for all fibres. This error estimate should be interpreted cautiously however, since previous studies have indicated that variability in CV across fibres attenuates end-effects and thus acts to mitigate their influence on CV estimates.

CONCLUSIONS

The results of this work indicate that Myosim is a useful tool for investigating factors that may influence myoelectric signals and parameter estimation. This tool has many applications in both research and teaching.

APPENDIX

The source $s(t)$ is represented by [1]:

$$s(t) = \sum_{i=1}^{3} k_i \cdot \left[c_i \cdot (t/2 - m_i)\right] \cdot e^{c_i \left[t/2 - m_i\right]} \qquad (1)$$

where k_i, c_i and m_i have been empirically determined to be:

	k_i	m_i	c_i
$i = 1$	51	0.54	-64.00
$i = 2$	72	0.66	-28.41
$i = 3$	18	0.86	-11.09

Table 2: Model Values for Source

The tissue filter, $h_{L+R}(t)$ is represented by [1]:

$$h_{L+R}(t) = h_L(t) + h_R(t) \qquad (2)$$

where

$$h_L(t) = \begin{cases} 0, & t > 0 \\ h\left(t + d/v\right) & 0 \le t \le t_L \\ 0, & t > t_L \end{cases} \qquad (2a)$$

$$h_R(t) = \begin{cases} 0, & t > 0 \\ h\left(t - d/v\right) & 0 \le t \le t_R \\ 0, & t > t_R \end{cases} \qquad (2b)$$

and

$$h(t) = \frac{t}{\left[\left[r/v\right]^2 + t^2\right]^{3/2}} \qquad (2c)$$

where d represents the distance along the axis between the innervation point and the recording electrodes, r represents the depth of the fibre, v represents the conduction velocity of the source, t_L represents the time taken for the source to propagate to the left termination of the fibre and t_R represents the time taken for the source to propagate to the right termination of the fibre.

REFERENCES

1. JA Gonzalez-Cueto, PA Parker, “Deconvolution estimation of motor unit conduction velocity distribution,” IEEE Transactions on Biomedical Engineering, 49(9), pp 955-962, 2002.
2. R Plonsey, “The active fiber in a volume conductor,” IEEE Transactions on Biomedical Engineering, BME-12(2), pp. 371-381, 1974.
3. GV Dimitriv, NA Dimitrova, “Fundamentals of power spectral of extracellular potentials produced by a skeletal muscle fibre of finite length,” Medical Engineering & Physics, 20(8), pp. 580-587, 1998.