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Muscle-Electrode Interface Simulation

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Abstract: The aim of this article is to analyze the electric interaction between bipolar configuration for electromyography (EMG) electrodes and muscle emulator (phantom). A comparison of three different electrodes superficially connected to the phantom will be presented. EMG signal acquisition on direct contact with the muscle presents many issues, since the electrodes must be biocompatible so as to be implantable. Choosing the right electrode is a very important part of the process, since it will eliminate further problems.
COMSOL Multiphysics allows modeling electrodes shapes, contact surfaces and their properties. AC/DC module helps us to simulate the electrical behavior between the metallic and biological material. The electrode has 30 mm2 area and 3 mm thick. The three forms to be compared are: flat, convex and point type. The electrodes have gold and polymer electric properties. Two different configurations for electrode connection will be presented: common mode and differential mode. The excitation signal is set within the EMG signal features, in frequencies from 20 Hz to 200 Hz, and amplitudes from 5 mV to 50 mV.
We determine the amplitude relationship of the sampled signal from the electrode with the excitation signal through the phantom. A comparison of the different geometric shapes and materials for implantable EMG electrodes will allow us to conclude which parameters have the best performance.

Keywords: Electrode, phantom, polymer, EMG.

Introduction

A bioelectric signal acquisition system, today, represents an essential stage for prosthetic robotic systems [1] or prosthetic monitoring systems [2].
Development of robotic prosthetics for upper limb needs bioelectric signals‟ acquisition systems, mainly from muscles and nerves. For this part, several kinds of electrodes are used including surface electrodes and implantable ones.
Such electrodes take into account parameters such as: length, width, deepness and shape according to their dimensions. [3]. All of the above are variables considered in the present study in which different shapes of implantable electrodes are shown in direct contact with a muscle emulator (*Phantom)*.

Muscle Emulator or *Phantom*

In order to simulate real scenarios, it is necessary to use materials that mimic the electrical behaviour of tissues, these materials are called *phantoms.*
A muscle emulator that has impedance, acoustic and electrical characteristics similar to a real muscle is used [4].
To produce a phantom with electrical characteristics, polymers with electrical conductivities similar to living tissues are used. The electrical parameters used are those of a 3 layered polymer made up of poli (3, 3 ethylene dioxiriophene) and poli (N-methyl pyrrol) where the conductivity is determined by:

$$\sigma = 0.08\,\frac{S}{m} \qquad [5].$$

Electrodes

To simulate the contact, a 2 layer-electrode configuration was used: a gold layer and a polycristal silica layer (**Figure 1**) [4].

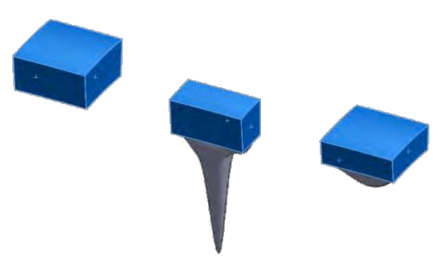

Figure 1 Electrodes: Flat, pin & Semi-Spherical

Use of COMSOL Multiphysics

By using COMSOL Multiphysics®, 3 different electrodes (**Figure 2**) in contact with a muscle emulator were compared. The emulator had 2 electrical regions: the source of the signal (Amplitude from 5 mV to 50 mV, and frequency from 20 Hz to 200 Hz), and a ground or reference terminal.
Two electrical configurations were used for the electrical interaction simulation: common and differential mode (Fig. 2).

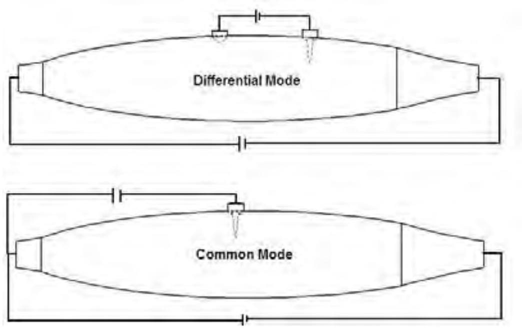

Figure 2 Differential Mode (Upper) & Common Mode (Lower)

Simulation

Implantable electrodes are needed mainly to obtain the minimum signal attenuation possible, as well as the minimum interfering signals from neighboring tissues or external contact noise signals [6].
Mostly, microneedle electrodes in matrix or linear arrays are used [7], inserted in the tissue; however, there are surface electrodes that only touch the muscle, needing no insertion into the muscle fibers. Yet, the latter present an electrical problem: since they are not attached, they tend to move and cause capacitive effects with the surrounding tissue, which translates in noise signals.
Electrode behaviour resulted very similar to the rest of the simulated electrodes.
For each electrode, there were no variations in the current density distribution in terms of frequency variation. These may be because the characteristic impedance curves for each polymer were not considered.
The 3 electrodes have the same pattern of current density flux, which tends to travel on the electrode itself, since it is a leak point nearer than the muscle reference point, along the flux trajectory. Fig. 3.

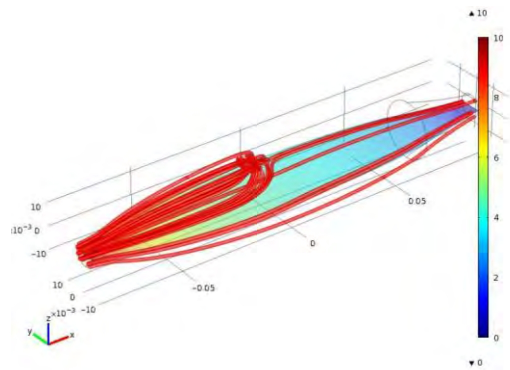

Figure 3a. Common Mode Density Current Flux & Biopotential.

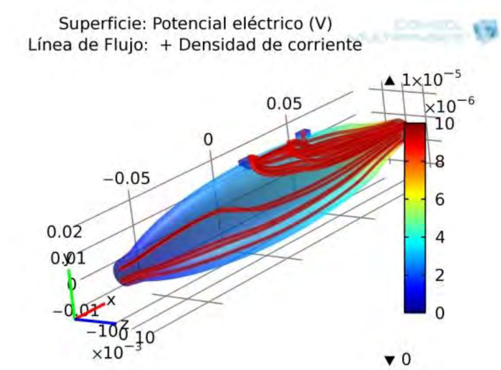

Figure 3b. Differential Mode Density Current Flux & Biopotential

There is a difference among the flux patterns in terms of the electrodes" shape differences: although the pin electrode penetrates the phantom deeper, the surface spherical electrode is the one with the most flux towards its surface.
It is also considered that the closeness of an electrode to the origin point of the bioelectric signal will translate into a larger intensity of the acquired signal. Therefore, the nearer the acquisition electrode is placed to the nerve, the larger the intensity of the acquired signal will be.

Results

Six different models were obtained, they cover 3 in common mode and 3 in differential mode. For common mode models the same curves for flux of current density were obtained, in which every electrode was in contact with the muscle. In differential mode, two electrodes are placed apart, so a differential signal will be obtained from the two of them. The curves for flux of current density are very different, since they tend to go from the potential line towards both electrodes, and in between them.

Discussion

The results show a very similar behavior between the electrodes and in the hold proposed frequencies for 20 to 200 Hz. This homogeneity in the results is attributed to a lack of the impedance parameter for the muscle phantom as a polymer, which will have a non-lineal function as any biological system.
The trend of the flux of current density to be intense towards the electrodes comes from the fact that they are closer to the biopotential source; the closest it is, the higher the intensity.
In differential mode we have a similar behavior as if a biopotential source is closely placed to the electrode; although the high flux density is also attributed to a way of amplification of the signal between both electrodes.

Conclusions

By using COMSOL Multiphysics we obtain 3 hypotheses which there are important in the selection and application of implantable electrodes from the electrical point of view: Invariant electrical behavior by changing contact surfaces, increase of signal intensity obtained from the nearby regions of biopotential and using differential mode electrodes increases the intensity of the signal and noise abatement.

The use of electrodes with different geometries on their surfaces is not the main feature to take to the implantable electrodes from the electrical point of view, because the three different shapes simulated show the same behavior.
However, the use of tip electrodes is mainly used for fixing to the tissue.
Electrode placement represents an important factor in the intensity of the desired signal, if you want to have a better signal, the electrode should be placed as close as possible to the biopotential source, in this case the nerve.
On the other hand, the use of electrode placed nearby to another electrode provides a stronger signal and noise-free from the surrounding tissues, this is the both signals have the same source, although there are also includes a density current flow to keep the same potential level.

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