BME 6460
ECG Simulation Lab

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1 Purpose and Background

1.1 Purpose

The goal of this computational lab is to develop a basic understanding of the relationships between cardiac electrical activity and ECG signals on the body surface. We will apply the software ECGSim developed by Prof. Adriaan van Oosterom, Prof. Thom Oostendorp and Dr. Peter van Dam to simulate, visualize and analyze cardiac conduction and ECGs. Each of the specific tasks below aims at familiarizing you with the measurement and simulation of ECGs as well as with effects of variations in cardiac electrical activity on ECGs. We will focus on variations that arise in heart disease and experimental studies.

1.2 Background

Most of the background on electrical conduction and stimulation of tissue as well as ECG simulation, including the physiology and physics background, is covered in the notes from our previous BE6460 lectures. In addition, the books written by Plonsey&Barr "Bioelectricity–A Quantitative Approach" and Malmivuo&Plonsey "Bioelectromagnetism" provide background information on ECG measurements, which is required for understanding the exercises.

Several programs allow simulation and visualizations of the ECG. We chose ECGSim as one example for software to provide you with at least a brief exposure. The software is described in detail at http://www.ecgsim.org.

2 Lab Procedure

2.1 Lab Preparation

1. Read over the manual available at http://www.ecgsim.org
2. Download and install ECGSim v3.0.0 on your computer.
3. Download and read the following article: http://www.ncbi.nlm.nih.gov/pubmed/14729788

2.2 Lab Day Setup

1. Come prepared with a laptop with ECGSim v3.0.0
2. Familiarize yourself with the ECGSim software. Go through the tutorials.
3. Explore ECGSim. Once familiar with the operation of the program, run simulations with the software and visualize the results.
4. Carry out the specific exercises in Section 2.3 below.

2.2 Capturing images

You need to use a screen capture utility to grab images. After capturing, the screen shot is copied to the clipboard and can be pasted into any paint or image processing program and saved in a variety of image formats.

2.3 Lab Exercises

Work through the simulations of the following assignments:

2.3.1 Modeling of Electrical Conduction in the Heart

Objective: Gain insights into electrical conduction and associated electrical fields in the heart.
Assignment:

1. Use the normal_male case file (default). Describe the visualized temporal sequence of electrical activation at the heart surface. Use figures to illustrate different phases in the activation sequence. Where are early and late sites of activation? What is their time difference? Provide an explanation for the activation sequence based on your knowledge of cardiac anatomy and electrical conduction.
2. Describe the temporal sequence of electrical deactivation at the heart surface. Use figures to illustrate different phases in the deactivation sequence. Where are early and late sites of deactivation? Identify differences between the simulated patterns of activation and deactivation. Speculate about their causes.
3. Investigate the distribution of extracellular potentials on the heart surface. What is the range of voltages during a cardiac cycle? Specify the time point at which the largest gradients of the electrical field occur at the epicardial surface. What is the cause for large gradients at this time?

2.3.2 Modeling of ECGs

Objective: Investigate the relationship between the electrical activity of the heart and the ECG.
Assignment:

1. Explain the measurements underlying a clinical 12-lead ECG. Where are electrodes placed on a patient? Compare to the electrode placement in ECGSim. How is each lead (Einthoven, augmented and chest leads) determined from the measured voltages? What is the voltage range (minima and maxima) and what are the typical features in ECGs simulated by ECGSim using the normal_male case file? Hint: This case file considers only the ventricles.
2. Study effects of alterations of action potential duration on the ECG. Vary the action potential duration in the left ventricular free wall by +/-25 % and +/-50%. What are the effects of the varied action potential on the Einthoven I lead? Explain the effects based on the simulated sequence of electrical fields on the heart surface.
3. Investigate effects of left bundle branch block on the ECG. Hint: Left bundle branch block leads to delayed activation of the left ventricle. Assume that the maximal additional delay occurs in the left ventricular free wall and is increased by 100 ms. Visualize the activation times, in particular in the left and right ventricular endocardium, to investigate if your modeling of delayed activation is appropriate. What are the effects of bundle branch block on the Einthoven I lead? Based on this investigation, which ECG feature would you use to detect left bundle branch block?

3 Lab Report

Introduction (30 pts): Begin the report with an introduction to the ECG and its importance for clinical diagnosis of cardiac diseases. Introduce computational simulation of ECGs and explain how these simulations can help to understand relationships between the cardiac electrical activity and ECGs. Introduce ECGSim and its major building blocks. (Length: ~1.5 page)

Methods (10 pts): In the Methods section, describe briefly in a paragraph for each exercise, what you did to use the program and produce the figures in the results section. Include any relevant settings you had, but do not go into detail of things like how you acquired the images. Always keep in mind, the directions should be detailed enough to allow the instructors or someone with the background of your classmates to replicate your experiments. Find the correct balance between specific and general instruction and try not to replicate either the lab description (this document) or the material in the tutorials for the programs. (Length: ~1 page)

Results (30 pts): In the Results sections, for each exercise, address the questions in the description above. Make sure to use both images and text to describe all your results. The emphasis is on quantitative description, but also find ways to qualitatively describe the results where possible. (Length: ~1 pages without figures and tables)

Discussion and Conclusion (30 pts): What do you conclude from the computational approach to investigate relationships between cardiac electrical activity and ECGs? What are the advantages of simulation over experiments? What are the limitations of the software? (Length: ~1.5 pages)

Please work independently on the lab report. Submit lab reports in PDF format via canvas at the specified deadline. Write the lab report as if you would write a paper for submission to a scientific journal. Follow standards for scientific writing and citation of literature, for instance

http://tbme.embs.org/wp-content/uploads/sites/45/2017/10/TBME_template_September-2017.pdf
(use single column format)