

# ECGSIM tutorial

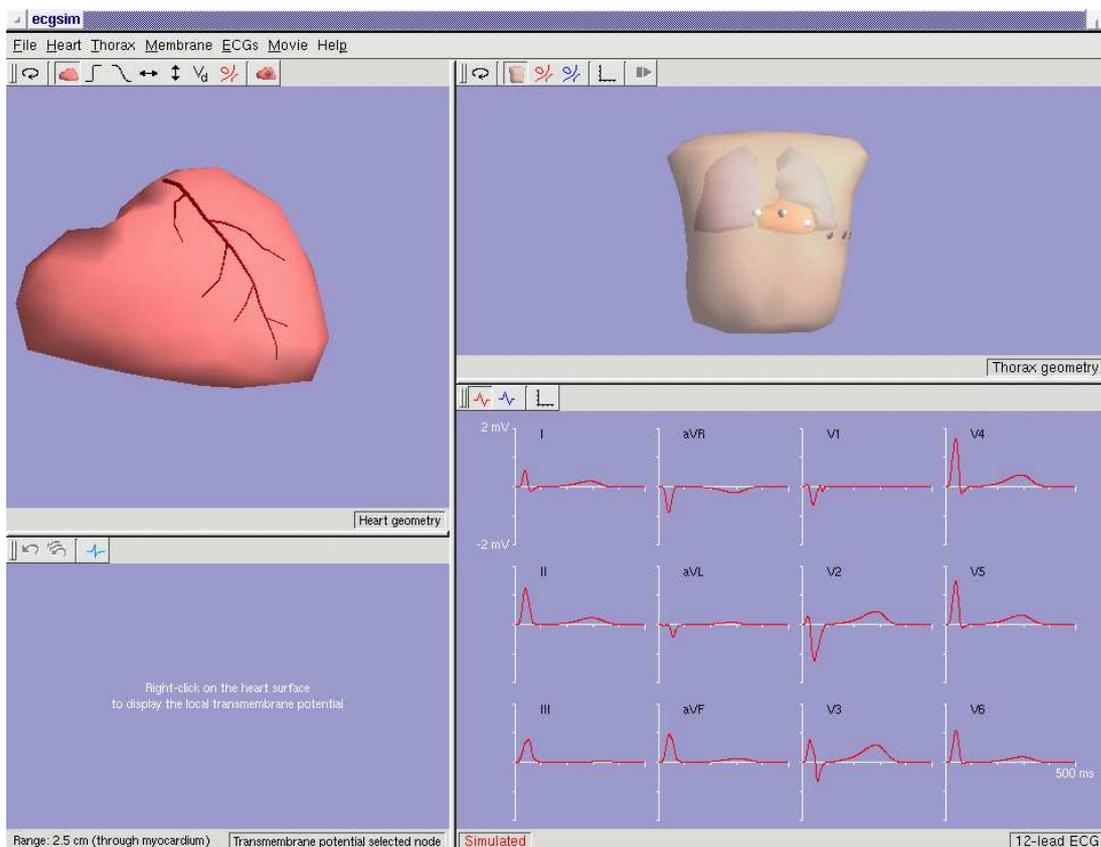
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## 1 Introduction

ECGSIM allows the user to view the effect on the ECG of changes in the electric activation of the heart. The purpose of this tutorial is to make the user familiar with the controls of ECGSIM. It is not a course in ECG interpretation. Neither does it explain the theoretical basis of ECGSIM (for that purpose, read the introduction of the ECGSIM manual — accessible from the help menu — and the references listed in the manual).

## 2 Layout of the main window

When ECGSIM is started, you see something like figure 1. The main window is divided into 4 panes: the heart pane (top-left), thorax pane (top-right), membrane pane (bottom left) and ECGs pane (bottom right). At the top of the window there is a menu bar, that gives access



Figur 1 The main window

the menu items that control the program. Each pane has its own tool bar with buttons that provide access to the most frequently used functions.

The relative sizes of the panes can be changed by grabbing the bars that separate the panes, and then move the mouse while holding down the mouse button (“dragging”).

### 3 ECGs pane

Let’s first take a look at the ECGs pane. The status bar at the bottom of the pane shows what is displayed in the pane, which is now the 12 lead simulated ECG. Later this manual we will explain what the simulated ECG is. For now, we’ll turn to the reference ECG. This is the ECG that was measured for a healthy subject.

In order to view the reference ECG, move your mouse to the tool bar on top of the ECGs pane. If you let the mouse rest on one of the buttons of the tool bar, a short text that describes the function of that button appears. Click the red  button. The simulated ECG then disappears. Click the blue  button to display the reference ECG.

As you can see, the vertical scale of the display runs from -2 mV to 2 mV, and the horizontal scale from 0 ms to 500 ms. To change the scale, click on the  button. A dialog window will appear, through which you can change the scale. Click OK to confirm the changes, or Cancel to revert them.

### 4 Thorax pane

In the thorax pane a thorax model is displayed. This is the thorax of the same subject whose measured ECGs are displayed in the ECGs pane. The model was constructed on the basis of MR images. The metallic knobs at the front of the thorax indicate the positions of the standard ECG leads  $V_1$  to  $V_6$ .

By dragging the mouse you can rotate the thorax. Click the  button to restore the standard frontal view.

In the ECGs pane the electric potentials measured at the standard leads are displayed. For the subject in question, the ECG was measured not only at the standard leads, but at 64 electrodes distributed over the front and back of the thorax. You can view the measured potentials on the thorax as a so called Body Surface Map (BSM) by clicking the blue  button. The bar at the right shows the color scale; blue for negative potentials, red for positive and green for zero. Isopotential lines are also displayed.

A vertical bar in the ECGs pane indicates the time instant for which the potentials are displayed in the thorax pane. This time value is also displayed in the thorax pane’s status bar. You can move through time by pressing the arrow left and right keys on the keyboard (small steps) or the arrow up and down keys (large steps). You can also click or drag the mouse in the ECGs pane to change the time instant for which the potentials are displayed.

If you click the  button, the BSM is displayed as a movie. You can change the speed and time interval of the movie by clicking on the `Movie` item of the menu bar at the top of the main window, and subsequently choosing `properties`, which brings up the movie `properties` dialog window.

Click again on the  button to stop the movie, and on the geometry button () to display the thorax geometry.

## 5 Heart and membrane panels

In the heart panel the ventricles are displayed (the atria are not included). To aid orientation, the Left Arteria Decendens (LAD), which runs along the boundary of the left and right ventricle at the front of the heart, is also displayed.

Use the mouse to rotate the heart, in order to look into the ventricles. What you see is actually the surface of the ventricular myocardium (heart muscle). The valves through which the blood enters and leaves the heart (that are all located at the top) are not displayed.

Move to the `Heart` menu in the menu bar, and select `Display options`. Check the `Show grid` box in order to display the triangulated mesh that represents the myocardial surface. Click `OK` to close the dialog box. Right-click on the heart surface (if you have a single buttoned mouse, you can use `Ctrl-click` as an alternative). This selects the nearest node on the heart surface, as indicated by a black dot. A region around the selected node turns dark; for now, press the  button to turn this effect off. Also, turn the grid off again.

When a node at the heart is selected, the membrane panel displays the *transmembrane potential* (the voltage over the cell membrane) for the heart cells at that node as a function of time. In rest, the transmembrane potential is  $-90$  mV. When the cell is activated (*depolarized*), the transmembrane potential rises sharply to  $10$  mV. Subsequently, during the repolarization phase, it gradually returns to  $-90$  mV. The depolarization time and repolarization time (defined as the timing of the steepest downward slope of the transmembrane potential) are indicated at the bottom of the plot, as well as the action potential duration (the difference between depolarization time and repolarization time).

Move to the heart pane, and select different nodes at the heart surface. Note that the depolarization and repolarization times differ between nodes. The depolarization of the cell membrane of a myocardial muscle fiber initiates the contraction of the fiber. Hence the sequence of depolarization corresponds to the sequence of contraction of the myocardium.

You can display a map of the depolarization times at the heart surface by clicking the  button in the heart tool bar. Early depolarization times are indicated in red, and late ones in blue. Note that the earliest activation is at the left ventricular septum, and the latest in the outflow area of the right ventricle. The buttons  and  show maps of the repolarization times and action potential duration, respectively.

## 6 Simulated ECG

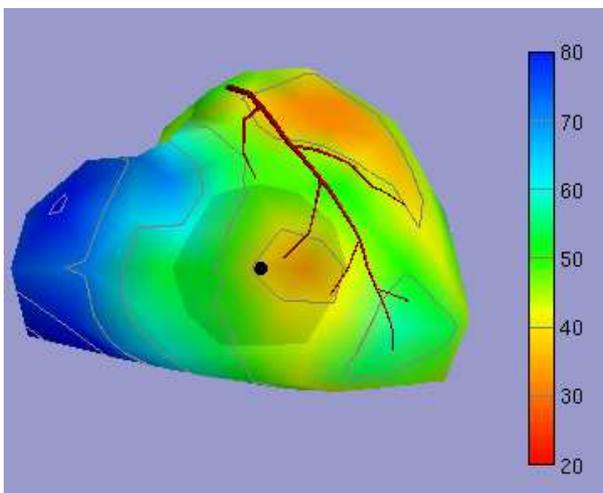
Now we come to the main feature of ECGSIM. Use the  button in the heart tool bar to reset to frontal view, display the depolarization times ( button), and select a node at the front of the heart (figure 2). Click the  button to display the range of the selection as a darker area on the heart surface.

The left knob of the horizontal slider in the membrane pane indicates the depolarization time of the selected node. Drag the knob with your mouse. You will see that the depolarization time of the selected node is changed to the value where you set the knob. Also, the depolarization times within in the range of the selection change with an amount that is zero at the rim of the range and maximum at the center (the selected node).

Click the  button. The original depolarization times are now restored. Click the red  button in the ECGs pane. The ECG that is now displayed in red is the ECG that ECGSIM computes from the transmembrane potentials at the heart, as defined by the current values of the depolarization times and repolarization times. Note that there is a near perfect match between the simulated and the reference (measured) ECGs.

Again modify the depolarization time of the selected node in the membrane pane. If you watch the ECGs pane, you will see that the simulated ECGs changes immediately. When the user changes the parameters that describe the transmembrane potentials, ECGSIM recomputes the simulated ECG.

You can now play around with the effect of changes in the depolarization and repolarization times in different regions of the heart. For instance, you will see that for some regions changes have a much larger effect than for other regions. Consequently, the standard 12-lead ECG is much more sensitive to some regions of the heart than to others. The  button undoes the most recent changes. Click that button repeatedly to move back in time. The  button undoes all changes.



**Figure 2** Selection of a node on the heart surface.

You can modify the size of the range around the selected node by clicking the central mouse button (or Alt-left-click if you don't have a central mouse button). The range will extend to the position where you click. There are 2 different ways in which ECGSIM determines which nodes are within the selection range. In the first method, the shortest distance *through the myocardium* between a node and the selected node is computed, and if this distance is smaller than a certain value, the node is within the range (this is the default method). In the second method the shortest distance *along the surface of the myocardium* is computed. You can choose the one you want to use in the dialog window that is activated by choosing Range from the Membrane menu. Select a node at the front of the heart as in figure 2. Watch the difference in the area that is selected for these 2 methods, especially inside the ventricles. In the next section we will see the purpose of having these 2 methods.

## 7 Some exercises

### *Acute myocardial infarction*

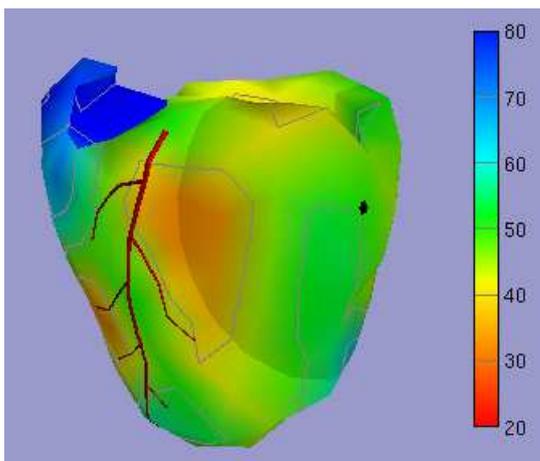
In the case of acute myocardial infarction, the infarcted region of the heart becomes ischemic. As a result, the amplitude of the action potential in that region decreases (more precise: the transmembrane potential in the resting phase becomes less negative). To simulate the effect on the ECG of acute infarction, select a node at the heart, at the position indicated in figure 2. Choose the size of the range as in that figure. Use the vertical slider in the membrane pane to decrease the action potential amplitude. In the simulated ECG you will see that the signal does not return to the baseline between the depolarization phase (QRS-complex) and the repolarization phase (T-wave). This effect is called ST suppression or elevation, and is typical of acute infarction. If the selection range is small, the effect is only visible in the electrodes close to the infarction. As the size of the range is increased, the effect becomes visible in other leads as well.

If the infarction is transmural, the tissue both at the outside (epicardium) and inside (endocardium) is affected. If it is not transmural, only one side is affected. To simulate transmural infarction, choose Range from the Membrane menu, and select distance computation through the myocardium, otherwise select computation along the myocardium.

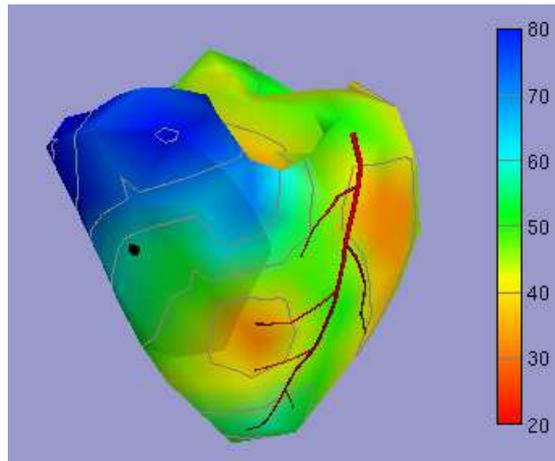
### *Bundle branch block*

If a bundle of the Purkinje system is blocked, the depolarization of the region of the heart that is served by this bundle is delayed. To simulate a left bundle branch block, select a node and range approximately as in figure 3. Set the depolarization time of the selected node to about 180 ms. You will see all typical effect of a left bundle branch block: elongation of the QRS-complex, and more negativity (or less positivity) in  $V_2$  to  $V_5$ .

### *Hypertrophy*



**Figure 3** Node selection for a left bundle branch block.



**Figure 4** Node selection for a right ventricular hypertrophy.

In the case of right ventricular hypertrophy, the thickness of the right ventricular wall is increased. As a result, it takes longer for the depolarization wave front to spread from the endocardium to the epicardium. Hence, the depolarization times at the endocardium are normal, and those at the epicardium are late.

To simulate right ventricular hypertrophy, choose a node and range as in figure 4. Choose distance computation along the surface, to make sure only the epicardium is selected. Delay the depolarization of the selected node. The late part of the QRS-complexes in  $V_1$  to  $V_2$  will become positive, which is commonly observed in the case of right ventricular hypertrophy.

## 8 Moving on

ECGSIM has far more possibilities than explained in this tutorial, but you should be able to explore these for yourself. A good idea would be to study the manual, which is displayed if you choose Manual from the Help menu. If, while a dialog is displayed, you wonder what some of the controls are for, you can (only in the Windows version) select the button with the question mark at the top-right of the dialog window. The mouse cursor will change into a question mark. If you now click on a control, a short text explaining its purpose will appear.

We hope you will enjoy using ECGSIM .