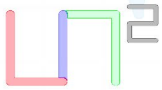
ECGDT: ECG Diagnosis Tool

User guide



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ECGDT: ECG Diagnosis Tool

This tool, named ECGDT, has been made available to the scientific community, free of charge, in GitHub[1].

Functions

The final objective of the present system is to obtain candidate diagnoses from the information obtained through the processing of the ECG. To simplify the user experience when using the system, a set of differentiated functionalities that should be present in the interface was identified. In this way, the functional requirements of the user interface are the following:

- Load an ECG record within the system, allowing the user to select an ASCII or WFDB file, search for the file within their computer, or specify a calibration factor for the signal.

- Export the values of an ECG record to an ASCII file, being able to establish a file name and path.

- Graphically represent the signal on the screen, either dynamically or by delimiting specific segments, being able to alternate the channel and the interval to be displayed at any time.

- Perform the detection of single-channel beats on all available channels within the record.

- Export to an ASCII file the positions of the detected beats within all channels.

- Represent the beats detected graphically by screen on the signal, also continuously or by segments of the signal.

- Perform multi-channel or global beat detection.

- Represent the multi-channel beats detected graphically by screen over the signal, also continuously or by segments of the signal. Besides, options for comparison between mono and multi-channel detection are also available.

1 https://milegroup.github.io/RECGDT

- Create custom basal beats, specifying the channel, the beat number, the number of beats to use before and after, and ms of signal before and after the position of the R wave to be bounded.

- Delineate waves within a beat, a process that, automatically and transparently to the user, must generate the corresponding basal beat.

- Perform the diagnosis based on the information recovered in the previous sections.

Configure environment

To use ECGDT, an R / RStudio environment must be mounted in a computer (for individual use) or in a centralized server (for remote use by several final users). To do that, R and RStudio should be installed, with the required package dependencies (i.e. the Shiny package). Once the basic software is installed and configured, the next step is the download of the contents of the GitHub repository (the RECGDT folder contains all the needed files and directories for the RECGDT RStudio Project, explained in the README.md file). After that, these contents should be put in a folder in the server, accesible by R / RStudio. The project should be executed through RStudio, and kept running in the server, in order to have its functionalities available via the Shiny interface. With the default configuration, Shiny launches in a localhost address, granting access to the apps in the computer where the environment is established. For the remote users to access the app within their computers, the shiny-server configuration must be modified, and the resultant URL must be provided to final users.

User interface & user guide

The interface is organized in two different areas: the menu area, on the left side of the window, through which the user can navigate over the different options, and the work area, occupying the central part of the interface, and which manages the content through tabs.

When the connection with the server was established, the start screen in Fig. 1 is shown. In the menu of this screen, the loading options of a new ECG record file are shown (*Load ECG*), and the tool settings option (*Settings*). The menu is reduced to guide the user in the utilization of the tool. So that, at all times only accessible options will be displayed. In some steps, auxiliary functions are also offered, such as the different signal representation options.

Once the system has all the necessary information to be able to process all its actions correctly, the complete menu shows, as in Fig. 2. The different options will be analyzed in more detail in the following sections of this guide.

Fig. 1: Welcome screen in ECGDT.

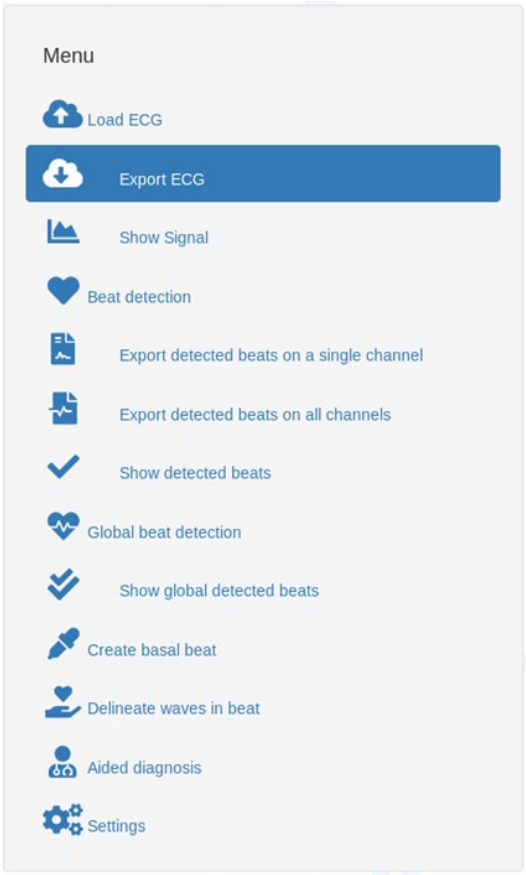

Fig. 2: The complete menu of ECGDT.

Record load

By default, the loading screen is located in the tab of the work area that allows loading files in the ASCII format (*Load ECG*), being able to alternate to WFDB format in the corresponding upper tab. The screen shows the instructions to follow in each case (in English), along with the new options that will appear in the menu area once a valid file has been uploaded, and loaded into the system. In this case, the user could export the ECG record to an ASCII file (*Export ECG* submenu), represent the signal of a specific channel on screen (*Show signal* submenu), or also obtain the positions of the beats present within the different channels of the record, through the single-channel detection process (*Beat detection* submenu).

To avoid execution errors, the load button on the system is disabled until a file is selected from the local computer and the file is uploaded to the server. Similarly, the upload button for a new file (*Upload another file*) is disabled until a file is already loaded in the system.

To start the process of uploading to the server, the user must first select *Load ECG* in the menu area, then click inside the work area in the *Browse...* button, and in the file browser window that opens, locate the file of the desired record in the local computer and select it. After this action, a progress bar shows the process of uploading the file to the server, whose duration will depend on the size of the file and the speed of the Internet connection. Once the copy of the local file is generated on the server, the progress bar indicates this through the *Upload complete* tag (Fig. 3).

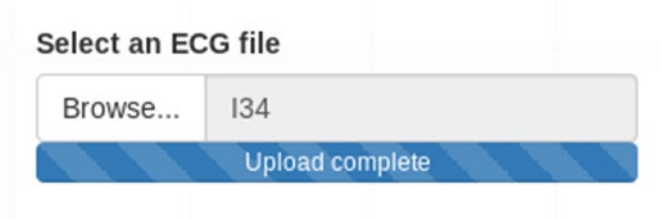

Fig. 3: Progress indicator when uploading to the server.

In the case of ASCII type files, the user can also specify a calibration factor to recalibrate the signal values (in the *Specify a calibration factor* box) or leave the voltage values for the samples as they are in the file, by keeping the value 1 established by default in this entry. In the case of WFDB files, the user must indicate the type of file to work with, selecting in the *Select a WFDB file type* drop-down list between the values 16 and 212. By clicking on the *Load ECG* file button, the contents of the record are dumped into a new variable of type *ECGData* within the system. In the lower right corner of the work area, a progress indicator is shown (Fig. 4). Once the loading process has been completed, the indicator disappears, and the label *File [record_id] successfully loaded* will appear at the bottom of the screen. From there, the label *You are currently working with record [record_id]* will be displayed at the top of the different screens of the interface. Also, the *Upload another file* button will be activated (and the *Load*

ECG file button will be deactivated) so that at any time the user can restore the contents of the system and upload a new file.

Fig. 4: Loading progress indicator.

The new submenus that appear in the menu area once the record is loaded, allow exporting it to an ASCII file inside the local computer, displaying the entire signal on screen or a specific segment, and detecting the beats at single-channel level. Each of these actions can be carried out in the corresponding submenu of the aforementioned ones, which are shown in Fig. 5.

If at any time, during the work with the current record, the user wants to discard it and start the process with a new record, such operation implies to return to this submenu and to click on the *Upload another file* button. The system deletes all the contents used for the record that was loaded, re-conceals menus and options not available in the loading step, restarts the statistics and the values entered through the interface in the different submenus, and eliminates the possible graphs generated during the processing of the previous record. Afterward, the user has to select the *Browse...* option again and to follow the steps previously used.

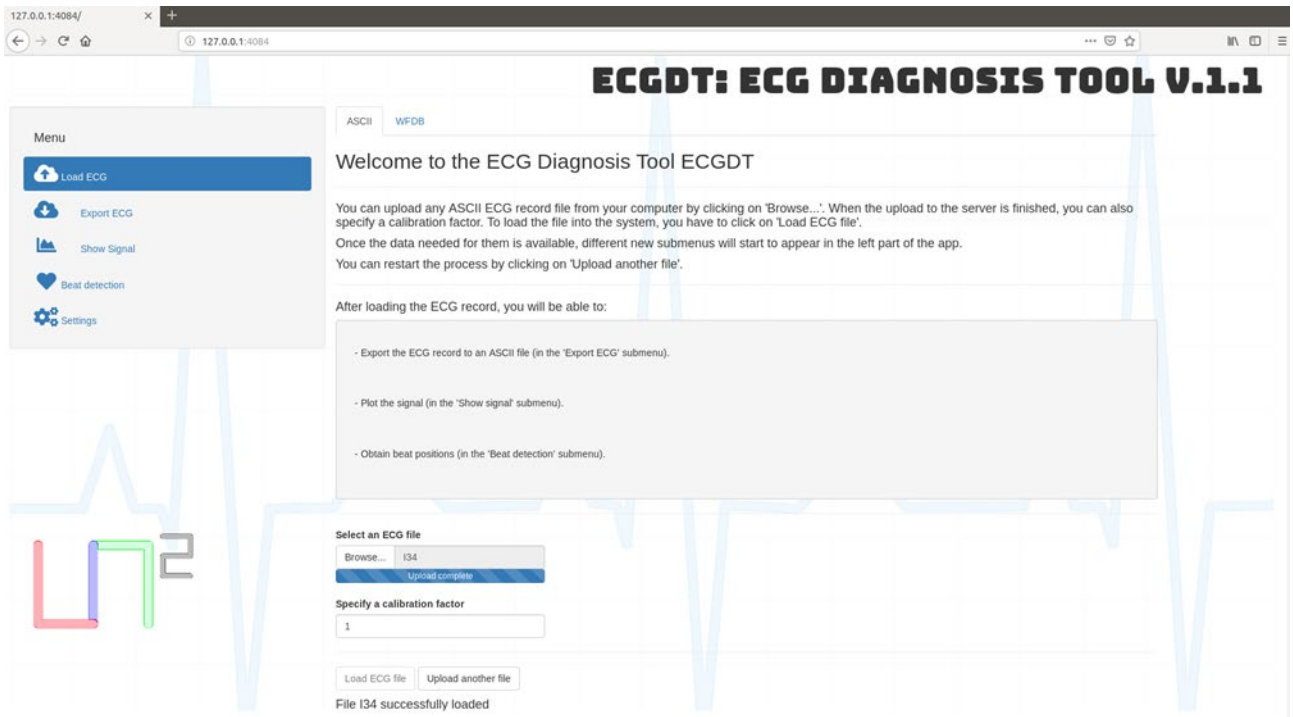

Fig. 5: Appearance of new options within the menu.

Once the file has been correctly loaded into the system, new possibilities are offered to the user.

Record export

Using the *Export ECG* submenu, an ASCII file can be generated with a header that includes relevant information of the record, such as its id, channels or sampling frequency (as long as it is available). The header is followed by as many columns as channels the record presents. In these columns, each row contains the sample value for each channel. The file will be created and saved on the user's computer, specifying the name of the resulting file in the *Specify a file name* box, and the path to save it in the local computer, in the *Specify a file path* box. To do this, the user simply has to click on the *Export ECG* button, as shown in Fig. 6.

The process of generation of ASCII files used by ECGDT considerably reduces the size of the file, comparing with other tools. Therefore, if a file was originally loaded also in ASCII format, it is possible that their sizes differ, even containing the same information.

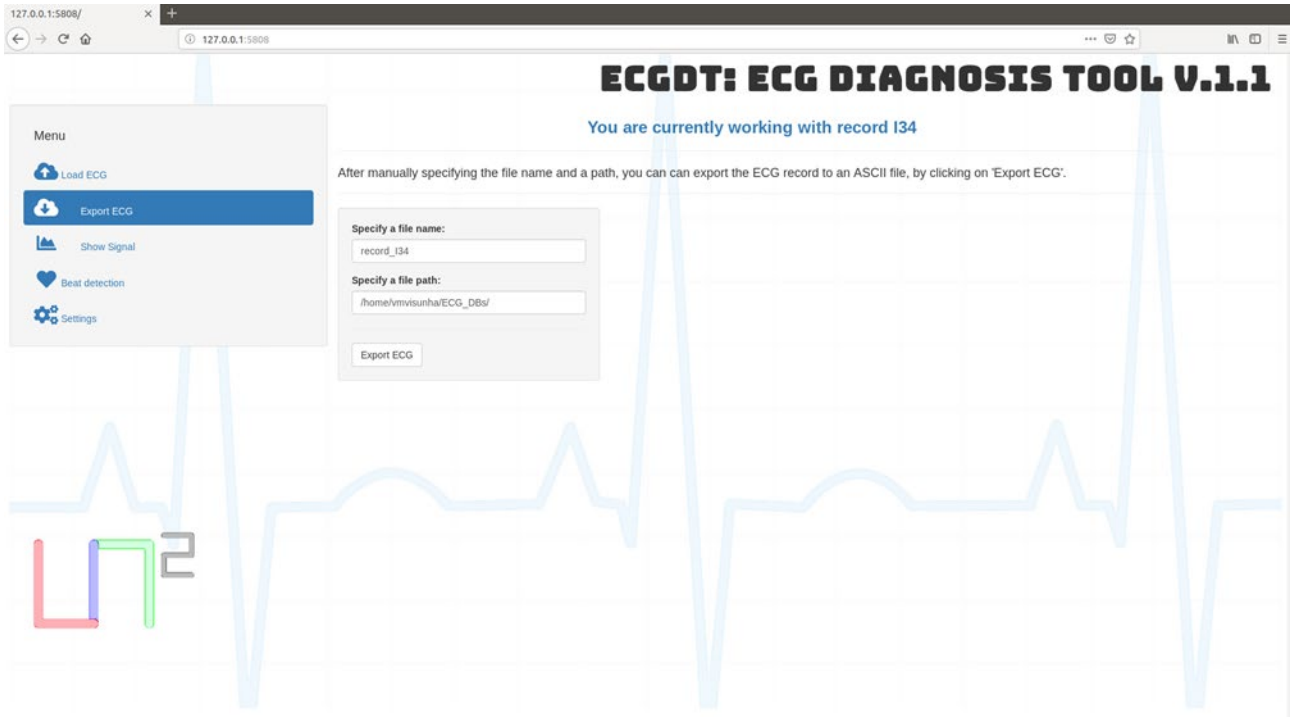

Fig. 6: Export to a local ASCII file process.

Signal graphic representation

The next submenu of new appearance is the one that offers the possibility of representing the ECG signal on the screen (*Show Signal*). Accessing this option, the user finds two possibilities, selectable in the tabs at the top of the work area. The first one, which is the default option, allows to continuously represent the signal of a channel. The second one shows a specific signal segment in a static way.

The continuous option, in the *Show all the signal* tab, allows the user to specify a channel of the record, and start displaying its signal dynamically, with a refresh of 5,000 samples every 1.5

seconds. The user can select the channel to display using the *Select a channel from the ECG* drop-down list, taking into account the equivalence between the channel number within the record (from 1 to a maximum of 12), with the corresponding derivation. For standard records of 12 channels, the system shows the equivalences between number and channel identifier.

Once the channel is established, only the button to start the representation (*Show*) is enabled. Below it are the << *Previous, Next* >> and *Stop* buttons. Once the signal is showing continuously, the *Show* button is disabled, and the *Stop* button is enabled to allow pausing the representation at any time. If the user clicks on it, it will re-enable the *Show* button (which would resume from the current point) and also the << *Previous* and *Next* >> buttons, which will allow, with the paused representation, to advance or rewind along the signal in intervals of 5,000 samples. << *Previous* is deactivated automatically when reaching the beginning of the signal, while *Next* >> is deactivated automatically when reaching the end of the signal. With the representation in progress, once the last sample of the signal is reached, the system automatically resumes the representation from the beginning. Both with the paused and running representation, the user can modify the channel at any time, to compare the signal in the different derivations. In Fig. 7 the process of continuous representation of the signal is appreciated. The graph will indicate in the upper part the record identifier and the channel identifier, as they appear in the information of the record, retrieved by the system. The vertical axis corresponds to the values in mV of the samples of the signal, while the horizontal axis corresponds to the sample numbers within the signal of the channel in question. The signal is represented by a continuous red line, while in those cases in which the signal alternates between positive and negative values, a gray line will be shown for the value 0.

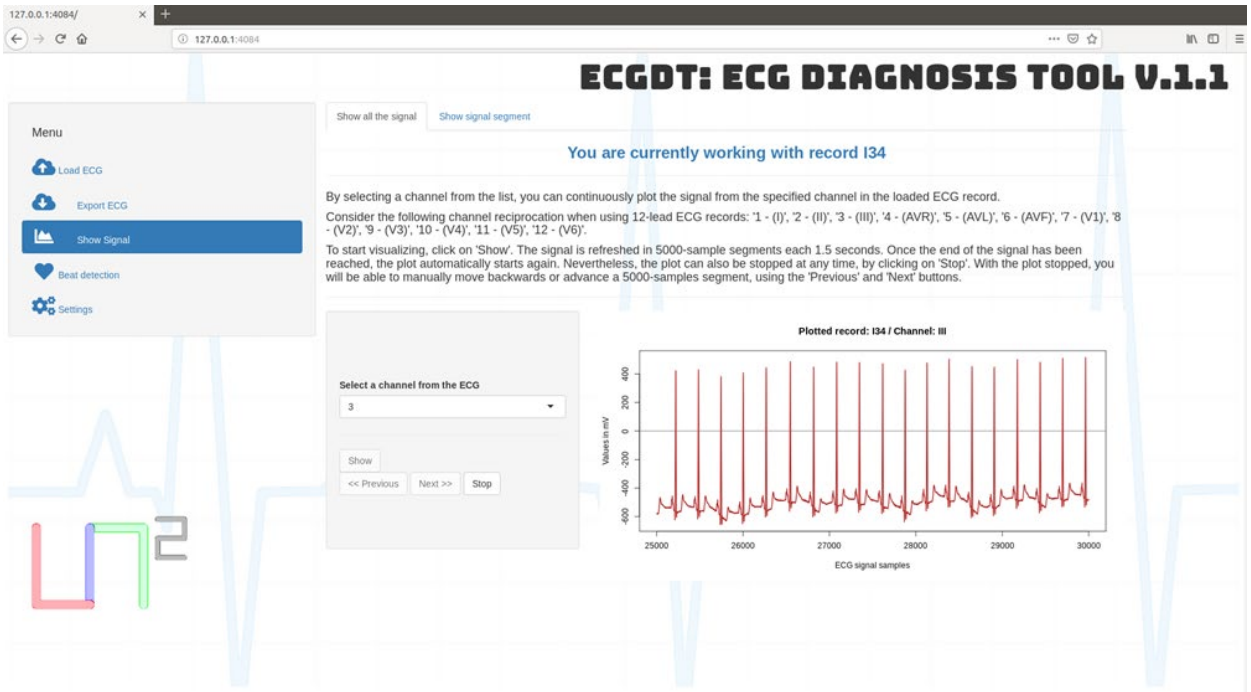

Fig. 7: Continuous representation of the signal for channel III.

The option to represent a specific segment is located in the *Show signal segment* upper tab. The user can specify the channel in the drop-down list, in the same way as in the previous screen, and indicate the numbers of the start sample (in the *From sample* box) and end sample (in the *To sample* box) of the segment to be displayed. The values have to differ in more than 10 samples but in less than 10,000. In case the value of the upper limit is below the start sample, the system automatically represents the interval by exchanging the limits. Once the parameters have been specified, the system displays the graph corresponding to the channel and segment established by the user, after clicking on the *Show* button. The user can also toggle between channels by simply selecting a different one in the list, to be able to compare the same signal fragment in different derivations. The result of this process is shown in Fig. 8.

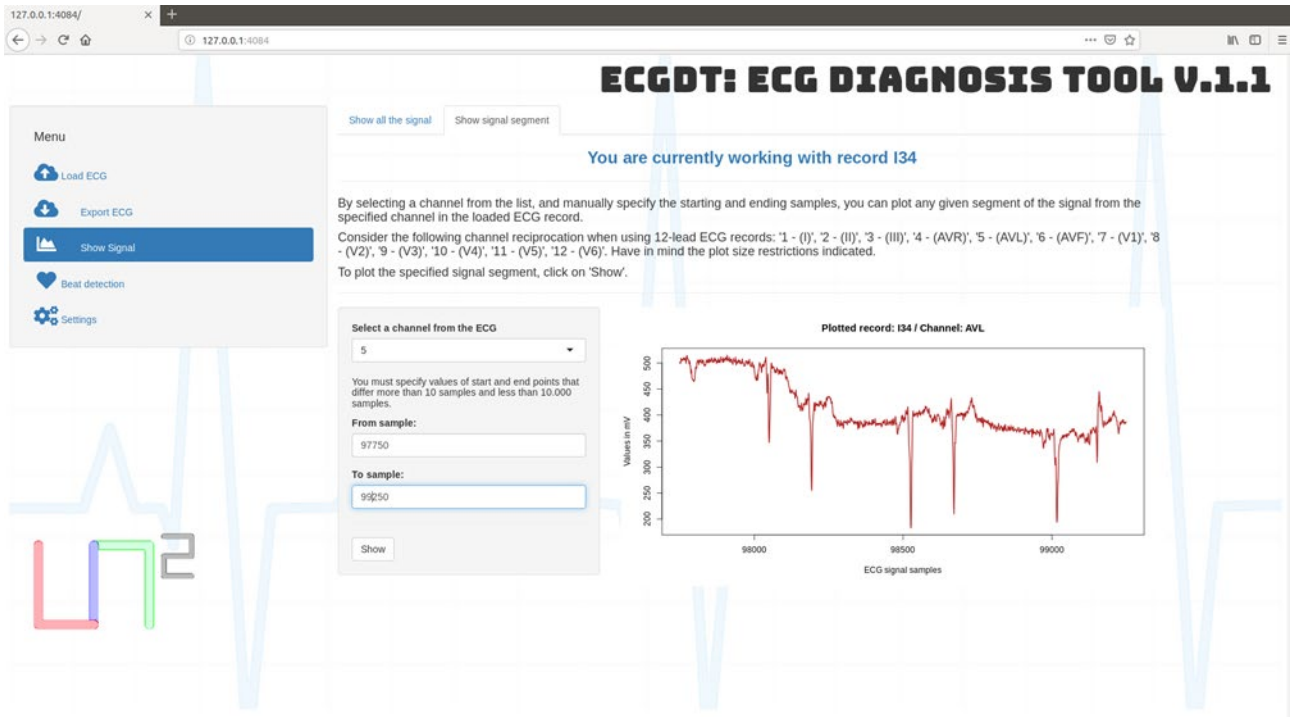

Fig. 8: Representation of a segment of the signal.
In this case, it is the segment 97,750 – 99,250 inside the signal of the channel AVL.

Single-channel detection

The submenu for single-channel beats detection (*Beat detection*) allows to automatically advance through the channels of the record one by one, and identify the beats present in each one of them. To do this, the user only has to select the *Detect beats* button. Once the progress message in the lower right corner disappears, and the *Beats successfully detected on all channels* label appears, the positions of the beats are recorded, to be used by the submenus that are discovered in the menu area at the end of this process (Fig. 9). These are new options to export the beats detected in a specific channel (submenu *Export detected beats on a single channel*), those detected in all the channels of the record (*Export detected beats on all*

channels), show the detected beats over the signal (in *Show detected beats*) and the possibility of using these positions to obtain multi-channel detection (in *Global beat detection*).

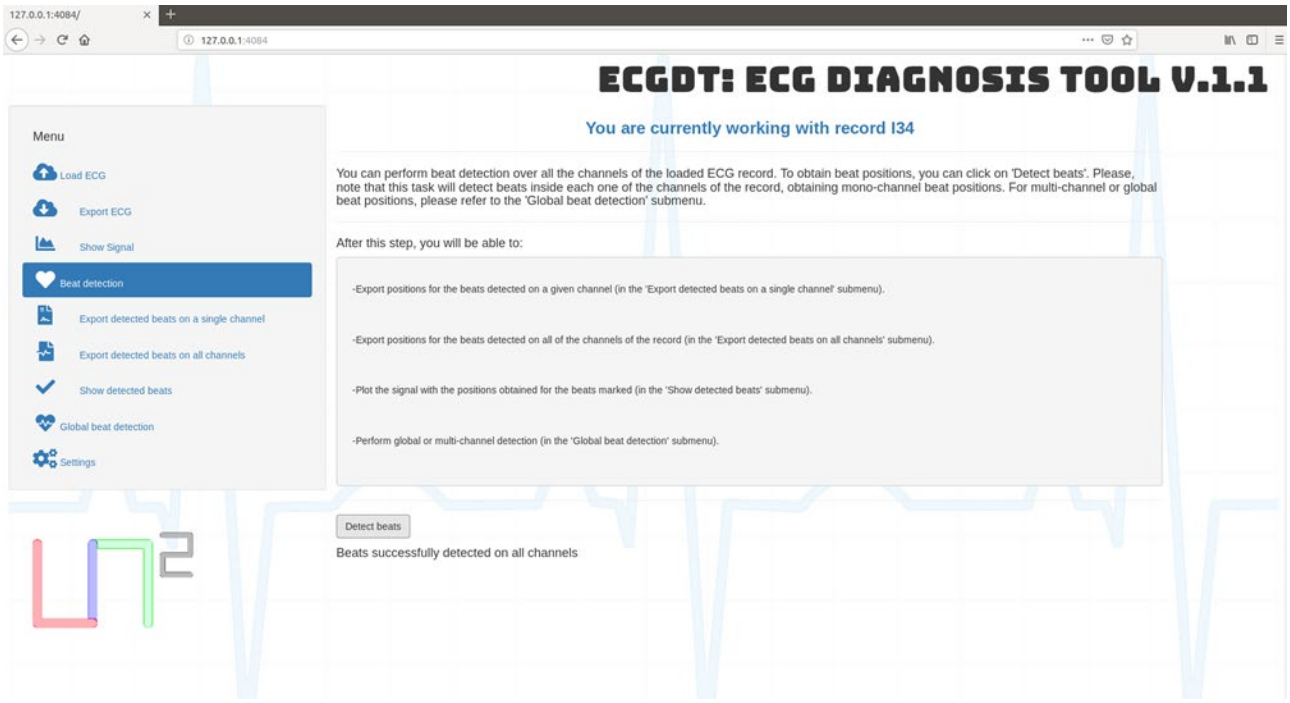

Fig. 9: Single-channel beat detection process.

Export of single-channel detection positions

The export of beats positions is accomplished similarly for one channel or all. Likewise, these are simple processes if the task of exporting the record has been followed previously. In the first case (submenu *Export detected beats on a single channel*), the user has to specify a name for the resulting file, in the box *Specify a file name*, the path where to save it in the local computer, in the box *Specify a file path*, and select within *Select a channel from the ECG*, the number of the channel from which the beats positions will be exported. After that, it requires to press the button *Export detected beats*, as shown in Fig. 10. In the case of all channels (*Export detected beats on all channels*), the only thing that differs is the fact that there is no need to specify a channel number In this case, for the name of the files a root will be specified, and the system will automatically add the termination _X to it, where X is the number of the channel which beats positions will be exported to the current file. The system will generate a file for each of the channels of the record, storing in each file the positions of the beats detected in the corresponding channel.

In this section, the export of the positions resulting from the single-channel detection process, positions for the beats detected within each channel individually, has been explained. For the multi-channel detection positions (the more precise ones obtained through the combination of

the single-channel positions of all the channels of the record), the corresponding multi-channel detection must be executed before, through the corresponding option *Global beat detection* of the menu, which will be explained later.

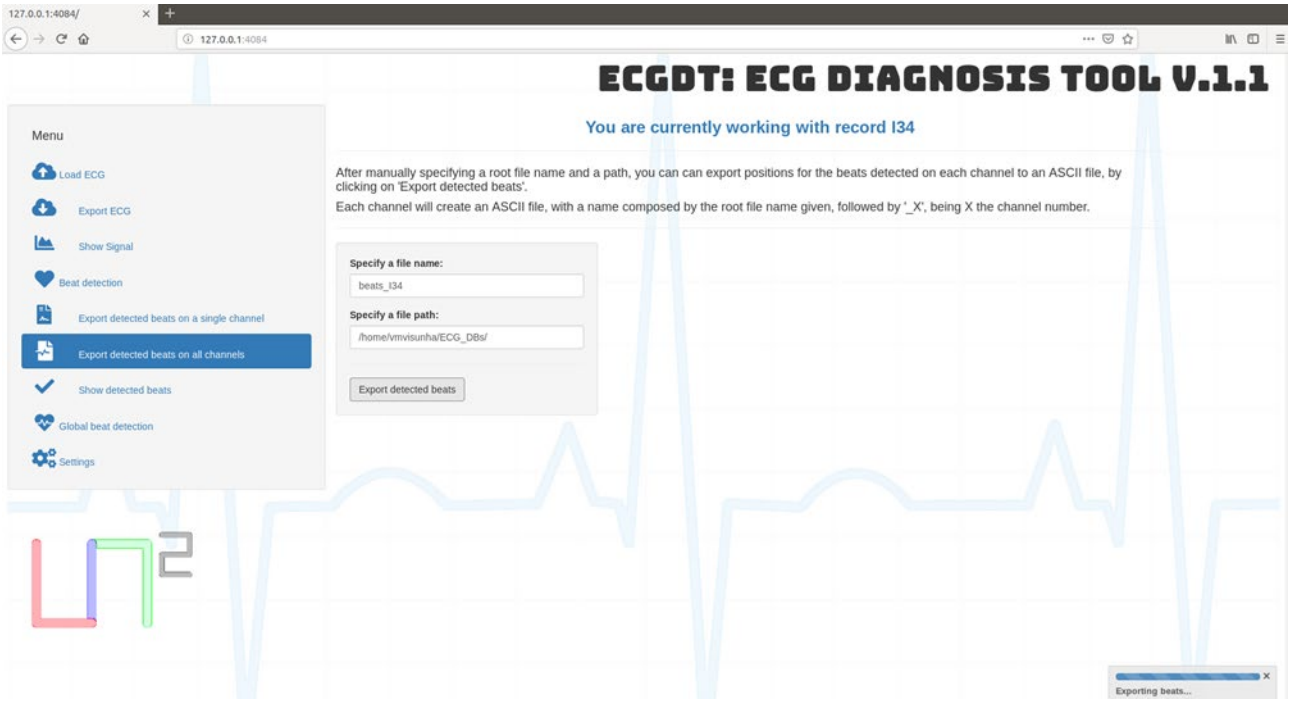

Fig. 10: Single-channel detection positions export.
Beats positions obtained inside channel AVL are exported.

Single-channel detection representation

Another option that appears with the positions of single-channel beats detected is that of representing the marks of the beats over the real signal. For this purpose, the *Show detected beats* submenu has a structure quite similar to that present in the *Show Signal* submenu. Again, two upper tabs are present in the work area. The first of them is used to continuously represent the signal of a channel, while marking by vertical green lines the positions of the R waves, used as fiducial points for the position of the beats. The second tab allows, once again, to show a specific signal segment statically, also indicating the positions of the beats through the same vertical green lines.

The continuous representation functionality is found within the *Show beats detected on all the signal* tab. Specifying the channel of the record through the *Select a channel from the ECG* list, the signal starts to be displayed dynamically, with a refresh of 5,000 samples every 1.5 seconds, once the *Show detected beats* button is clicked. As in the option to display the signal, under this button there are three others, *<< Previous, Next >>* and *Stop*. Once the signal is showing continuously, the *Show* button is disabled, and the *Stop* button is enabled to be able to pause the representation. In the pause mode, the *Show* button is reactivated (to resume the representation from the point where it is paused) and also the *<< Previous* and *Next >>* buttons, to, in the pause mode, advance or rewind at intervals of 5,000 samples. Again, *<< Previous* is disabled when the user reaches the beginning of the signal, and *Next >>* does the same when the user reaches the end of it. When the representation is in progress and reaches the end of the signal, it returns to the initial sample. The user can also alternate between different channels at any time, to compare the result of the detection in the different derivations. In this graph, the vertical axis corresponds to the axis of values in mV of the samples of the signal, and the horizontal axis to the sample numbers within the signal of the specified channel. The signal is represented again by the same continuous red line, with a gray line for the value 0, if the signal oscillates between positive and negative values. The positions marked for the beats present in the displayed interval are represented by vertical green lines.

To show a specific segment, the user has to access the upper tab *Show beats detected on a segment of the signal*. After that, indicate the channel number, start sample and end sample, just as it was done in the representation of signal segments. Then, click on the button *Show detected beats*, so that the system represents the desired segment. Once again, the user can modify the channel for a representation that is already on screen, just by selecting a different one in the list.

The legends of the graphs of these two functions adapt dynamically according to the channel number. Due to its particularities (depending on the position of the derivation on the skin of the patient, and how the electrical signal of the heart reaches it), the morphology of the signal in some channels tends mainly towards the top of the baseline, and in others towards the lower part of this line.

The results of the representation of single-channel beats, in continuous and in segment, are shown in Fig. 11 and 12.

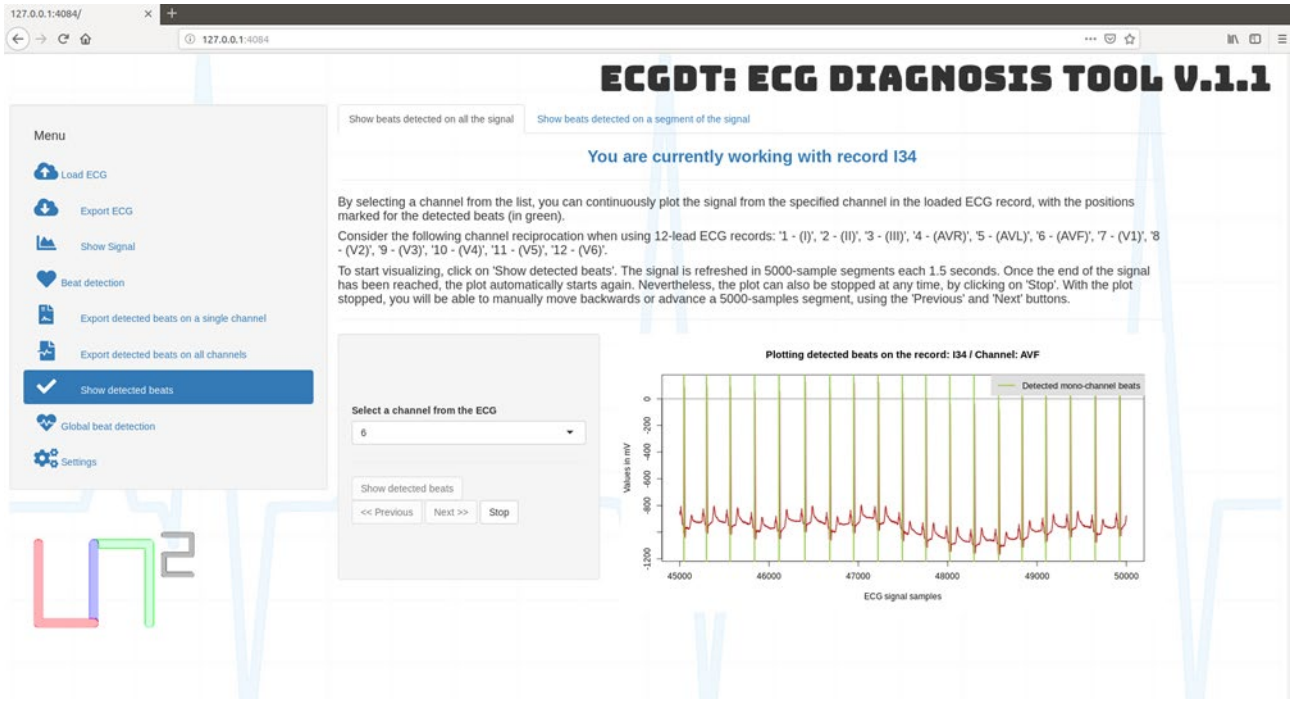

Fig. 11: Continuous representation of beats detected in channel AVF.

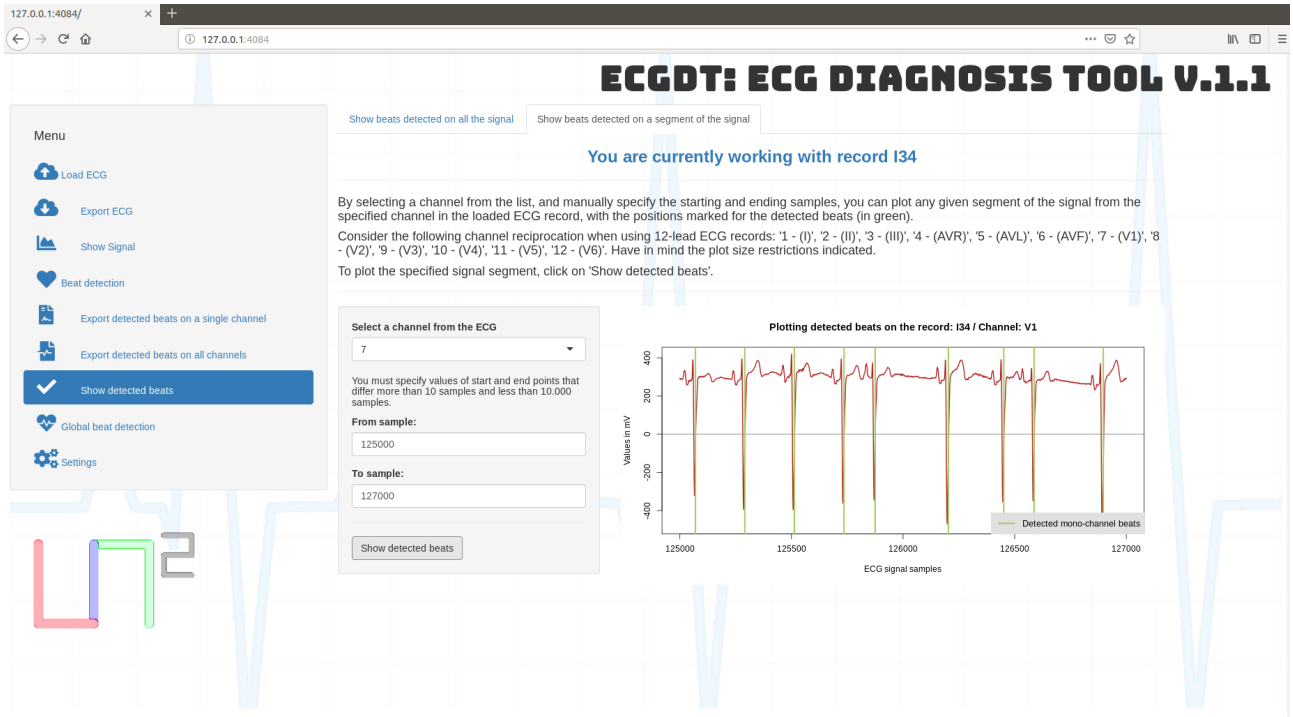

Fig. 12: Representation of beats detected inside a given segment.
Single-channel beats, detected in the segment 125,000 – 127,000 within the signal of channel V1 are shown.

Multi-channel detection

Using the *Global beat detection* submenu, the user can obtain the positions of the multi-channel detection for the beats present in the record. As previously, it is necessary to have the single-channel detection positions in each of the channels of the record. Because of that, this submenu is hidden until the previous process is finished. To obtain the multi-channel or global detection positions, simply access through this option from the menu area, and select the option *Obtain global beat positions*. When the progress bar disappears in the lower right corner, and the message *Global beats successfully detected* is displayed, the system has the multi-channel beat detection positions for the current record. This process can be seen in Fig. 13.

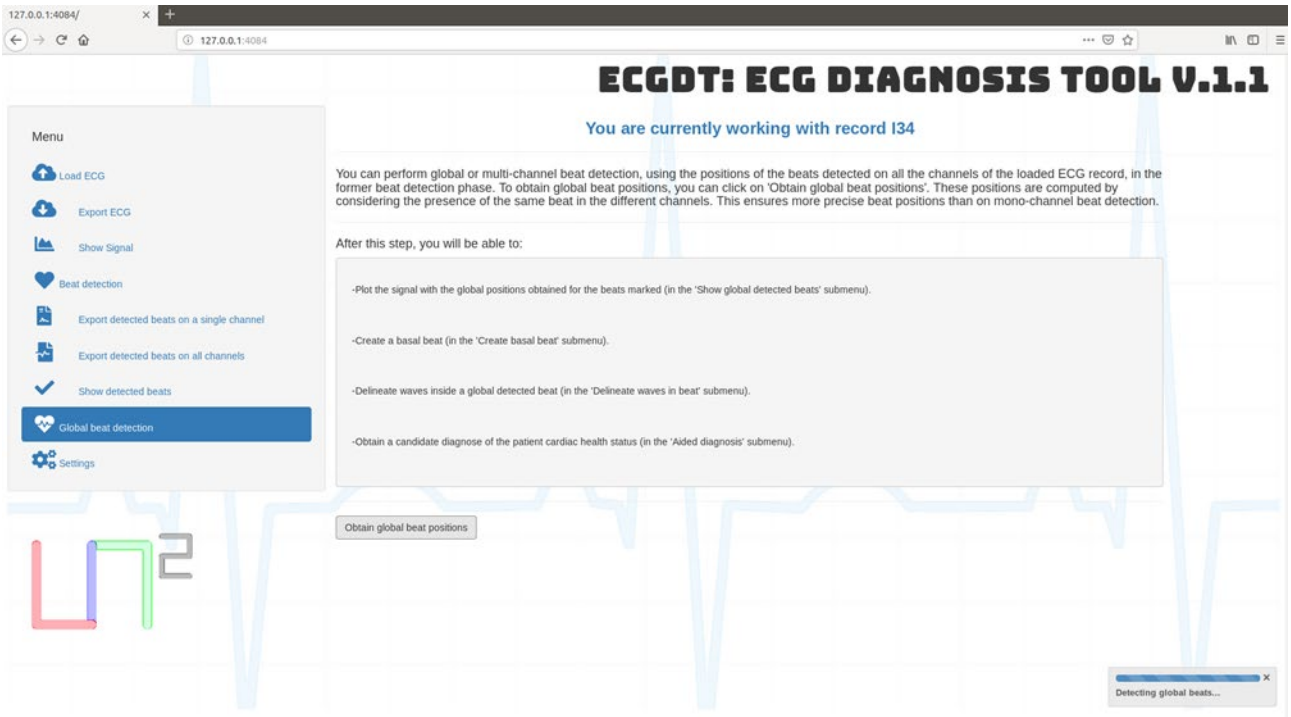

Fig. 13: Multi-channel beat detection process (global beats).

After this step, new submenus are unlocked. Now, the user can execute the representation of global or multi-channel beats on the signal (through the *Show global detected beats* submenu), create the basal beat for a specified beat (through the *Create basal beat* submenu), delineate the waves of a beat (in *Delineate waves in beat*), or execute a diagnostic process with the information obtained so far (within *Aided diagnosis*).

Multi-channel detection representation

With the option *Show global detected beats*, the signal can be represented dynamically or statically. This is done by processes practically identical to the previous ones, to visualize in this

case the positions resulting from the multi-channel detection. This time, there are presented in the upper area of the work section, in addition to the tabs *Show global beats detected on all the signal* (for continuous representation) and *Show global beats detected on a segment of the signal* (for the representation of a punctual segment), two new tabs that allow making similar representations, but comparing the positions of single-channel detection versus multi-channel detection positions. These two new options are found in the *Compare global and individual beats detected on all the signal* and *Compare global and individual beats detected on a segment of the signal* tabs. The process is similar to the previous ones: the button *Show global detected beats* shows the global beats employing abscissas of discontinuous blue color on the signal of continuous and static representations, in the corresponding tabs (Fig. 14 and 16). The button *Show global & individual detected beats*, shows the global beats using abscissas of discontinuous blue color, and the single-channel beats employing abscissas of continuous green color (Fig. 15 and 17).

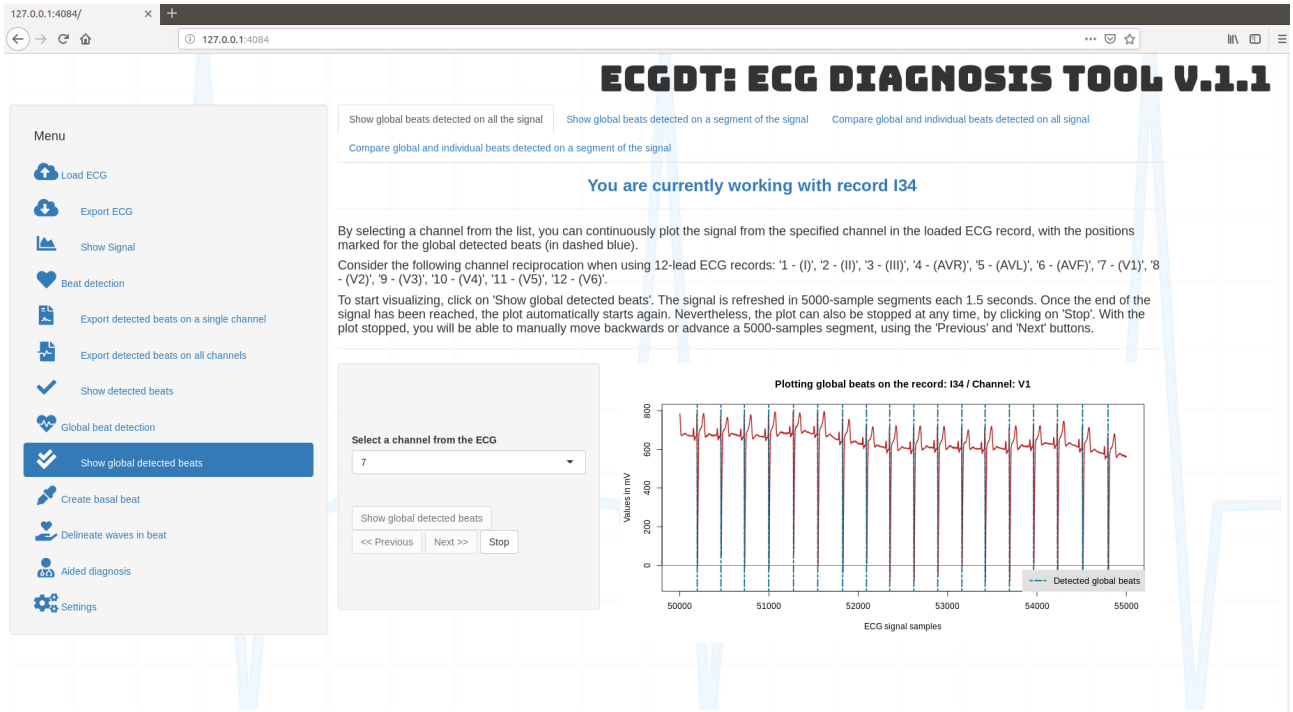

Fig. 14: Continuous representation of global beats in channel V1.

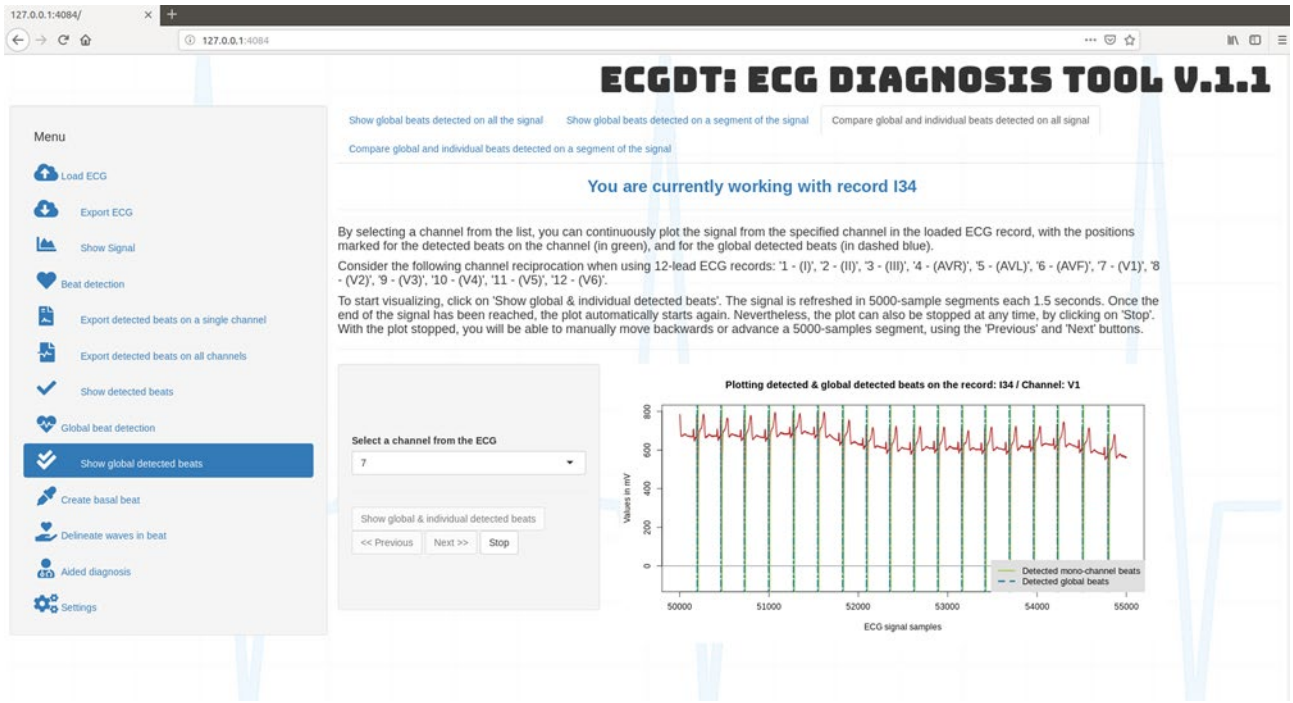

Fig. 15: Single-channel vs. Global beats comparison in channel V1.

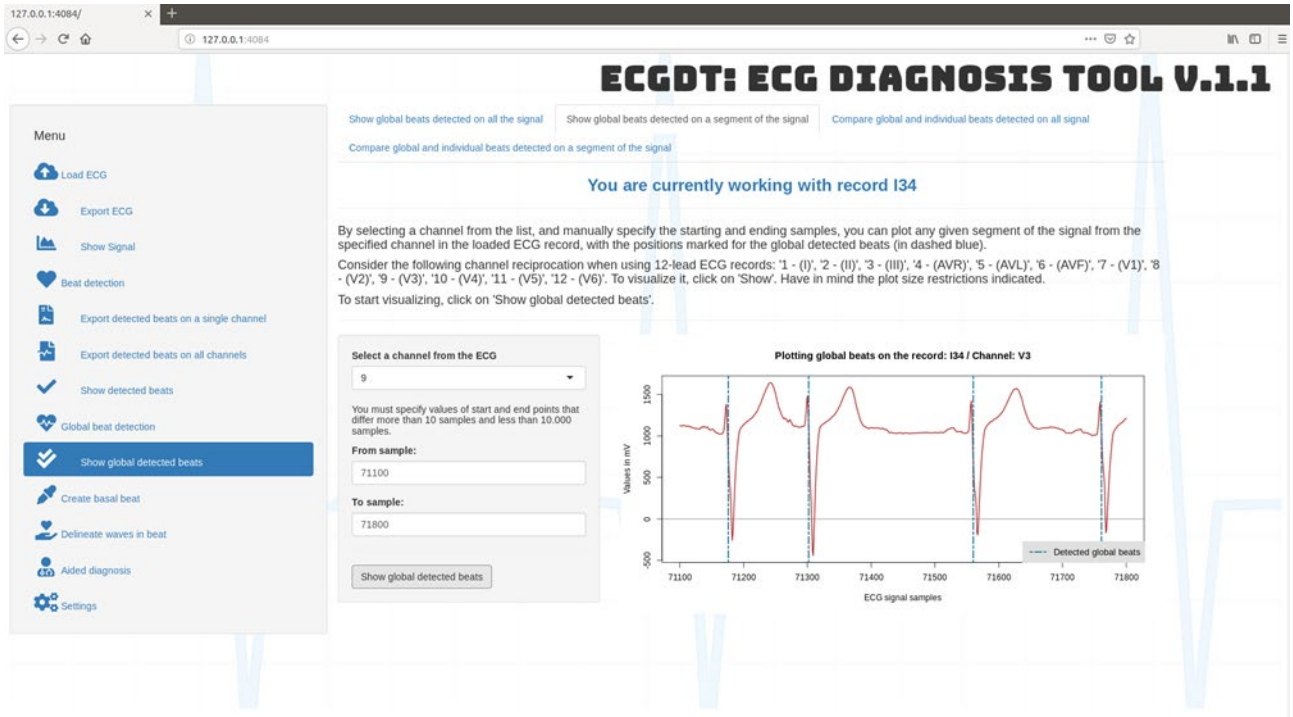

Fig. 16: Global beats representation within a given segment and channel.
In this case, beats identified in the segment 71,100 – 71,800 of channel V3 are shown.

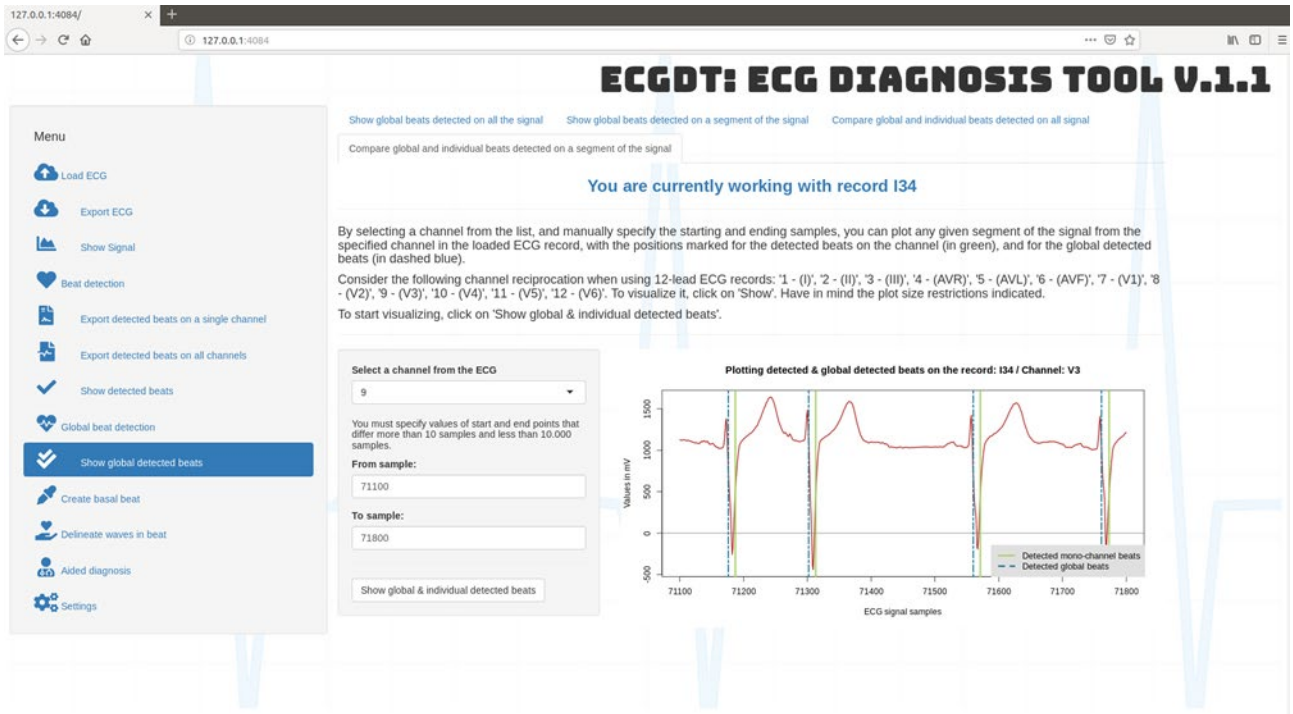

Fig. 17: Single-channel vs. Global beats comparison within a given segment and channel. The comparison over the same segment (71,100 – 71,800 of channel V3) is shown.

Basal beat creation

The *Create basal beat* submenu gives the user the possibility to create the basal beat for a given beat, superimposing the resulting basal beat to the original signal fragment. To be able to generate a basal beat, the user has to specify the channel, the beat number within the global beats, the signal intervals to be recovered before and after the beat position, and the number of beats before and after that will be used to average the values of the signal for each of the samples that compose it. The channel is selected through the *Select a channel from the ECG* drop-down list. The rest of the values can be specified manually, modifying the default contents of the boxes *Base beat* (base beat number within the global beats list, default 6), *ms to use before the QRS location* (fragment of signal, measured in milliseconds, to be taken before the beat position, by default 200), *ms to use after the QRS location* (signal fragment, measured in milliseconds, to be taken after the beat position, default 500) and *Beats used before and after the selected beat* (beats before and after to be used in the process, by default 5). Once the *Compute* button is clicked, the result is shown in a graph on the right side of the screen, contrasting the original signal (in red) with the generated basal beat (in gray). This process is shown in Fig. 18.

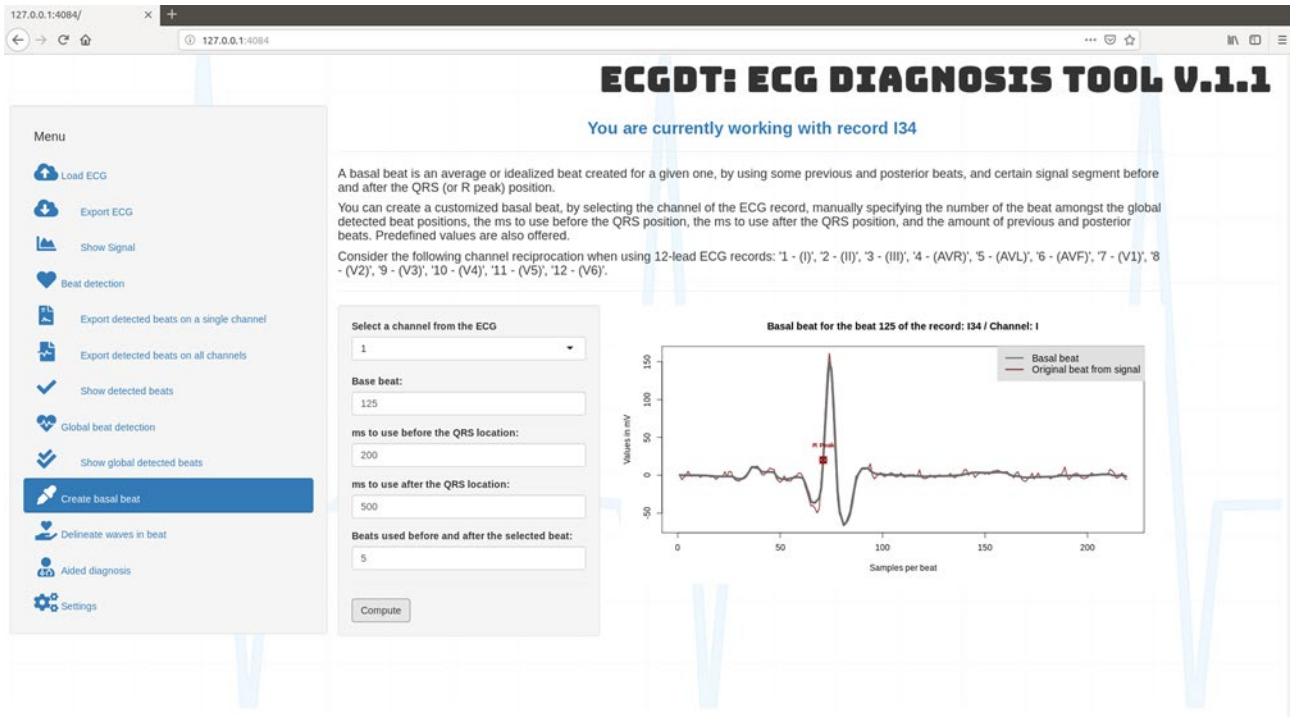

Fig. 18: Basal beat creation process.

Wave delineation

The wave delineation function (*Delineate waves in beat*) identifies the different waves that shape the beat. Although this task is carried out on the basal beat, it is a completely independent process from the previous submenu. That is, at the time of delineation, the system automatically generates the basal beat it needs to be able to properly perform the delineation. For this reason, it is not necessary to obtain it previously through the submenu of the creation of the basal beat to be able to work in this section. The user must indicate the channel number in the *Select a channel from the ECG* drop-down list, and the beat number in the *Base beat* entry. For the rest of the necessary parameters in the creation of the basal beat, the system uses the optimal default parameters for the wave delineation process. The user can start the delineation tasks using the *Delineate beat* button. After the delineation process, a graph with the basal beat in gray is shown, and the different waves and peaks appear highlighted over it. The P wave is represented with the segment of the basal beat along which it extends highlighted in green, and also in green, a mark for the position of the P peak. In the case of the QRS complex, its extension is highlighted in red over the basal beat, and the positions of the Q peak, R peak and S peak are indicated in red. Finally, the T wave is represented in the same way in blue, with a blue mark on the basal beat, which indicates the position for the T peak established by the system. Fig. 19 illustrates the delineation of waves on beat 125 inside channel I.

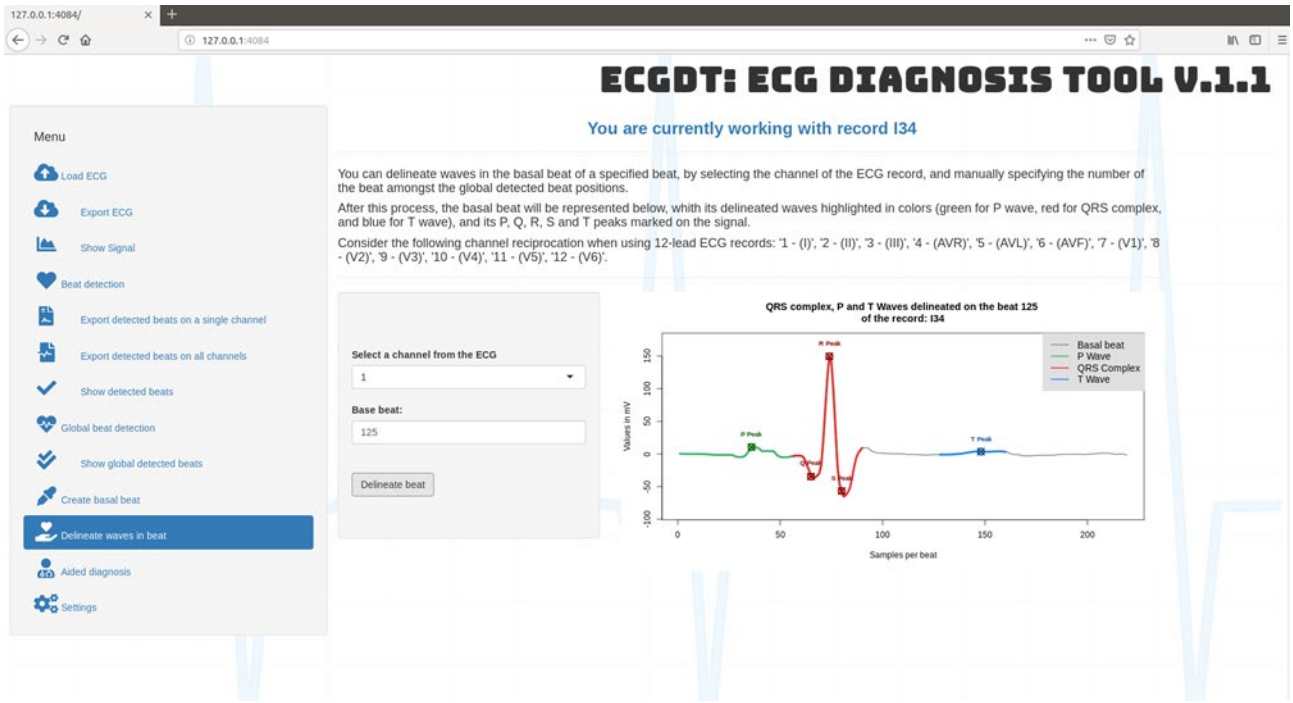

Fig. 19: Wave delineation process for a given beat.

Diagnosis

The aided diagnosis of the current record can be achieved through the *Aided diagnosis* submenu. The system will perform this procedure independently of the delineation section. Once the user clicks the button *Obtain a candidate diagnose for this patient*, the system automatically generates the 5 basal beats needed in each of the available channels, delineates them, and applies the classifier on the results obtained for the variables in each one of them. Finally, it returns the scores obtained for the 6 diseases (bradycardia, ischemia, myocardial infarction, tachycardia, ventricular hypertrophy and Wolff-Parkinson-White syndrome), expressed between 0.00 and 1.00. Thus, the higher the score, the greater the probability of the presence of the corresponding disease in the record. Those scores from 0.20-0.25 onwards must be taken into consideration, and the final decision must always be taken by the clinical professional. An example of this process can be seen in Fig. 20.

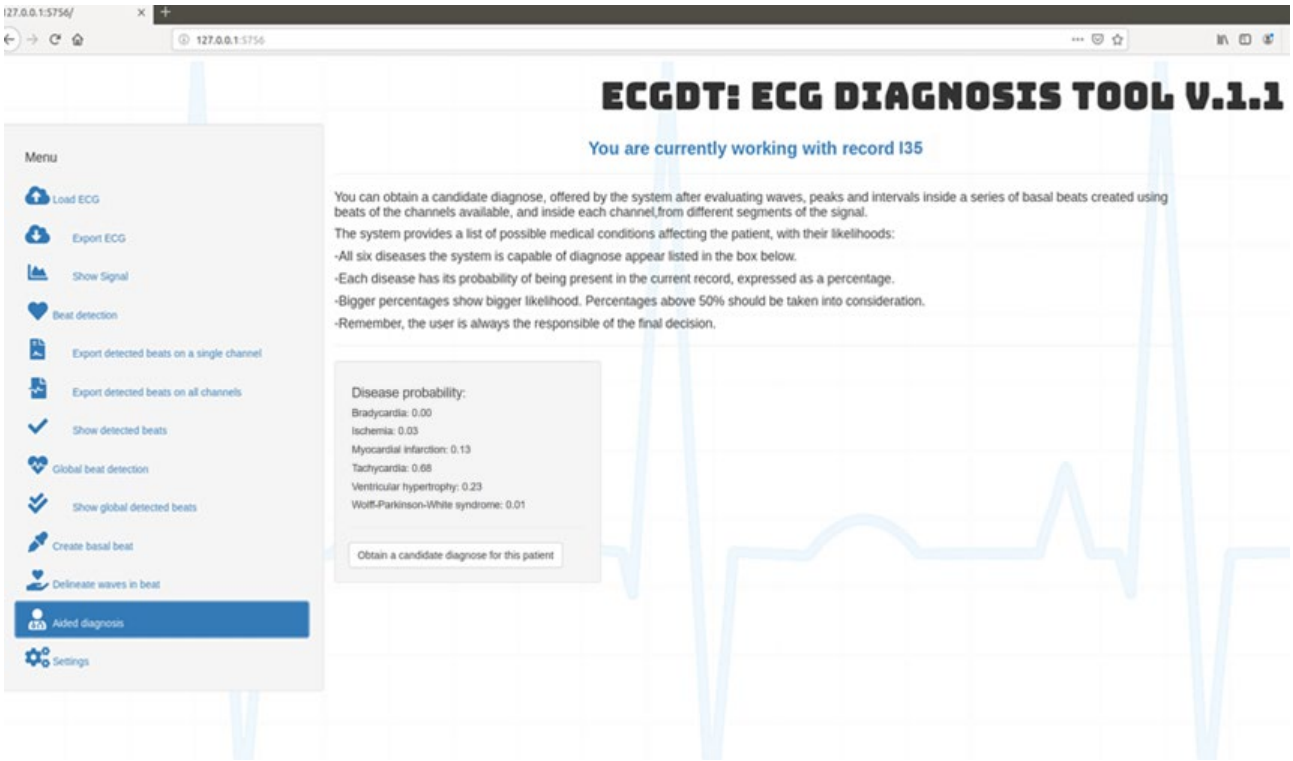

Fig. 20: Example of a candidate diagnosis for an ECG record.

Settings

The last section of the ECGDT menu is the Settings option (*Settings* submenu). Unlike other submenus presented previously, this is available at all times, regardless of the contents of the system. However, some of the options will see their presentation altered, depending on the information available. Its general view is the one shown in Fig. 21.

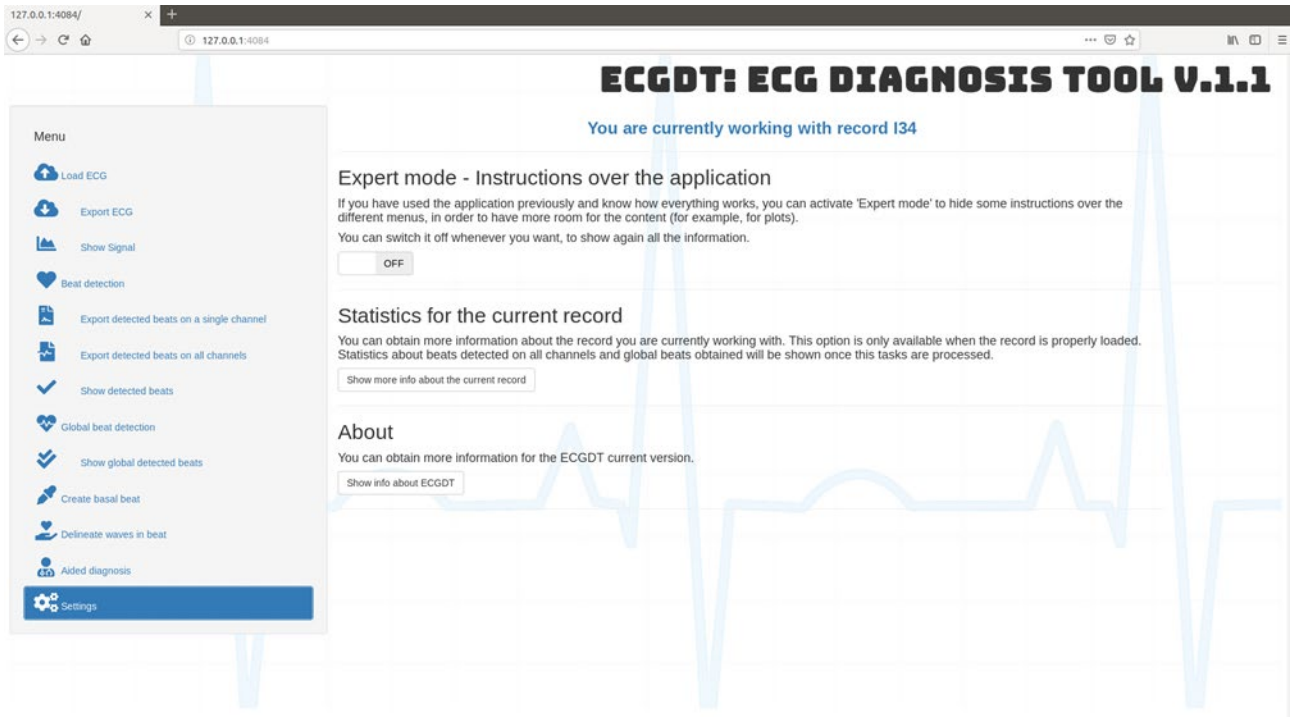

Fig. 21: Settings submenu in ECGDT.

In this section, the user can reduce the contents of the interface, alternating by using a switch between the expert mode and the normal mode. For a user using ECGDT for the first time, it is recommended to keep expert mode disabled (default value each time the system is accessed). Once the user becomes familiar with the contents and possibilities present in each screen, the expert mode can be activated, putting the switch of *Expert Mode - Instructions over the application* to ON. This mode will hide some of the texts and explanatory messages of the interface, to reduce the space occupied by them. Thus, it offers a more simple presentation, in which the contents have a greater role and appear more in view. If for any reason the user wants to go back to the instructions in more detail, normal mode can be returned by deactivating expert mode again, turning the switch to OFF.

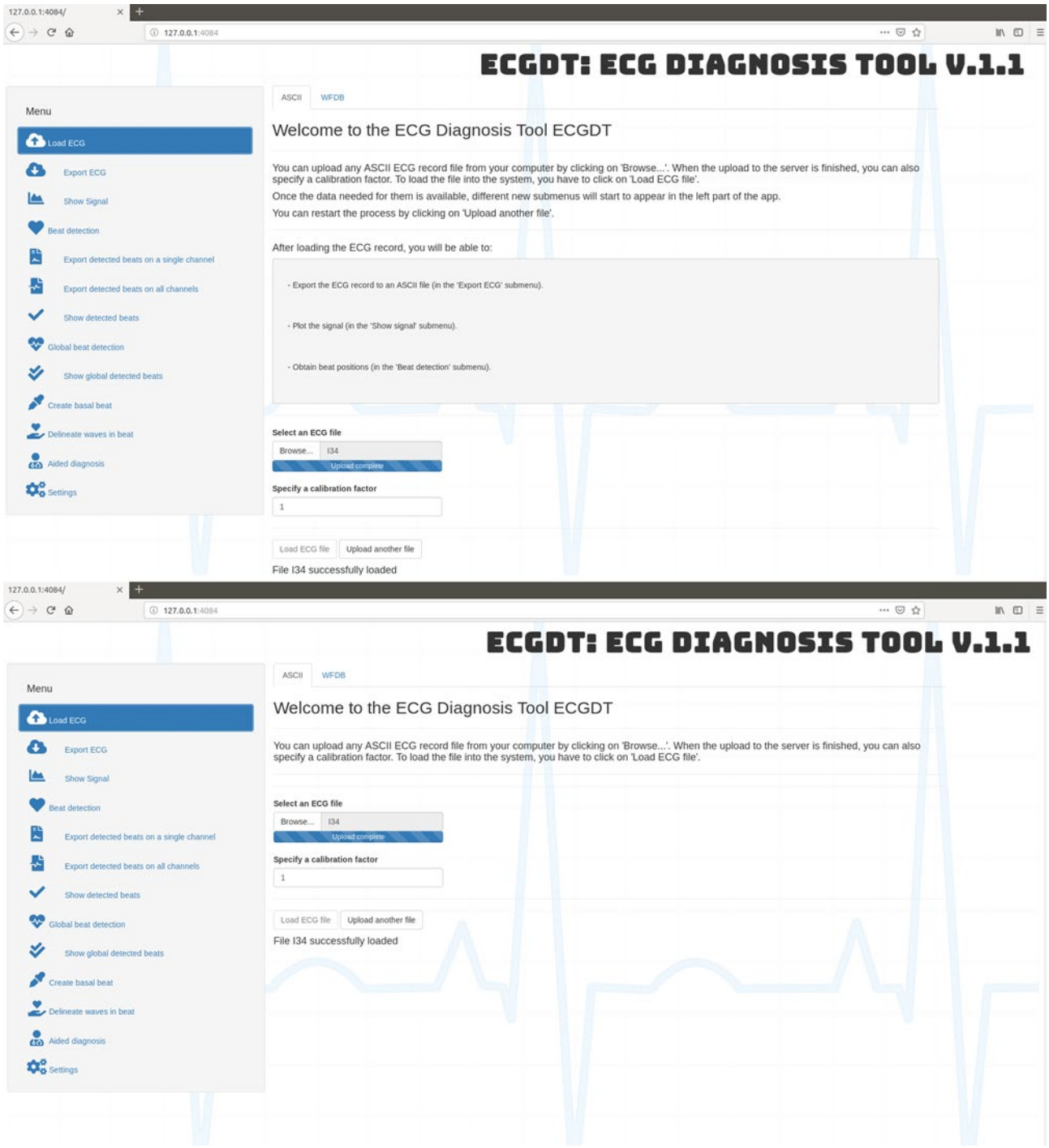

Fig. 22: Comparison between Normal mode vs. Expert mode.
It is shown the load screen, in Normal mode (above), and in Expert mode (below).

Modifying the value of this switch implies changes in the contents of the rest of the screens of the system. Fig. 22 shows an example of how this action affects the screen corresponding to the load submenu of an ECG record. In this case, some of the initial instructions of the system are hidden from the user, as well as the list of options that will become available once the record is properly loaded. Depending on each particular section, the amount of content to be hidden will be greater or less, in order to always make available the most essential instructions.

The next option in the settings submenu generates a dialog box that contains relevant information about the current values of the system variables. This option is initially disabled; Once the user successfully loads a record, the option is enabled in the *Statistics for the current record* section, through the *Show more info about the current record* button. Basic data about it can be consulted (as long as the system has been able to recover it from the file header). The data that is summarized within this option is the record identifier (in *Record ID*), the sampling frequency of the signal (in *Sampling frequency*), the number of samples present in the signal (in *Number of samples per channel*), the number of channels available in the record (in *Number of channels*), the identifiers of the available channels (in *Channels available*, the first identifier in the list being the one corresponding to channel number 1, the second one to channel number 2, and so on), the number of beats detected in each of the channels (in *Number of beats detected on each channel*, single-channel detection) and the number of global beats detected in the channels of the record (in *Number of global beats detected*). These last two data will be displayed once the corresponding detection action has been previously executed. Before that, a message will be displayed in the section concerned, *Beats not available yet. To obtain this statistic, detect beats before in the 'Beat detection' menu*, for the case in which the single-channel detection process has not yet been performed, and *Global beats not available yet. To obtain this statistic, detect global beats before in the 'Global beat detection' menu*, for those situations in which the statistics are consulted before having executed the global or multi-channel detection process. An example of system statistics (in which values are shown for all sections), is what is shown in Fig. 23. To discard this dialog box and return to the settings screen, just click on the *Dismiss* button, located in the lower right corner, returning the focus to the settings submenu screen.

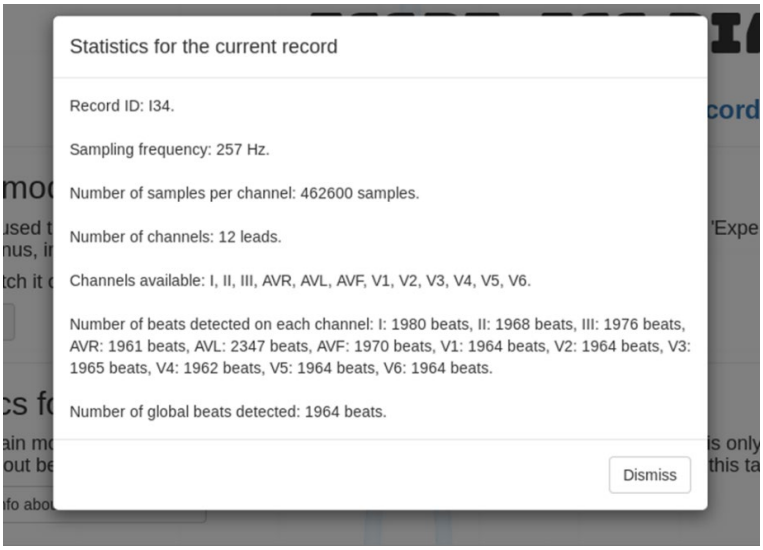

Fig. 23: System statistics for the current record.

Similarly, on this screen, the user can get more information about the tool and its current version, through an about dialog box. This information can be obtained in the *About* section, by

clicking on the *Show info about ECGDT* button. The resulting dialog box is shown in Fig. 24, and as in the previous case, it can be closed by pressing the *Dismiss* button, located in the lower corner of it. This action returns the focus to the screen of the settings submenu.

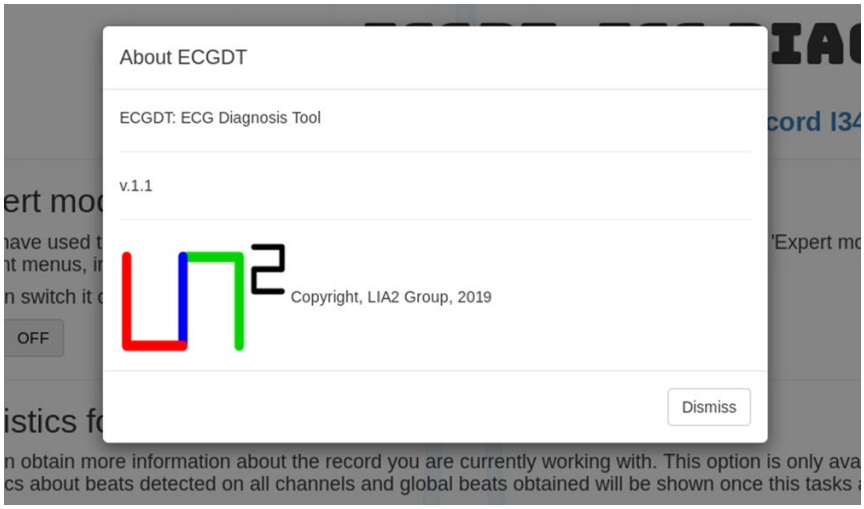

Fig. 24: Information available inside the *About* option.