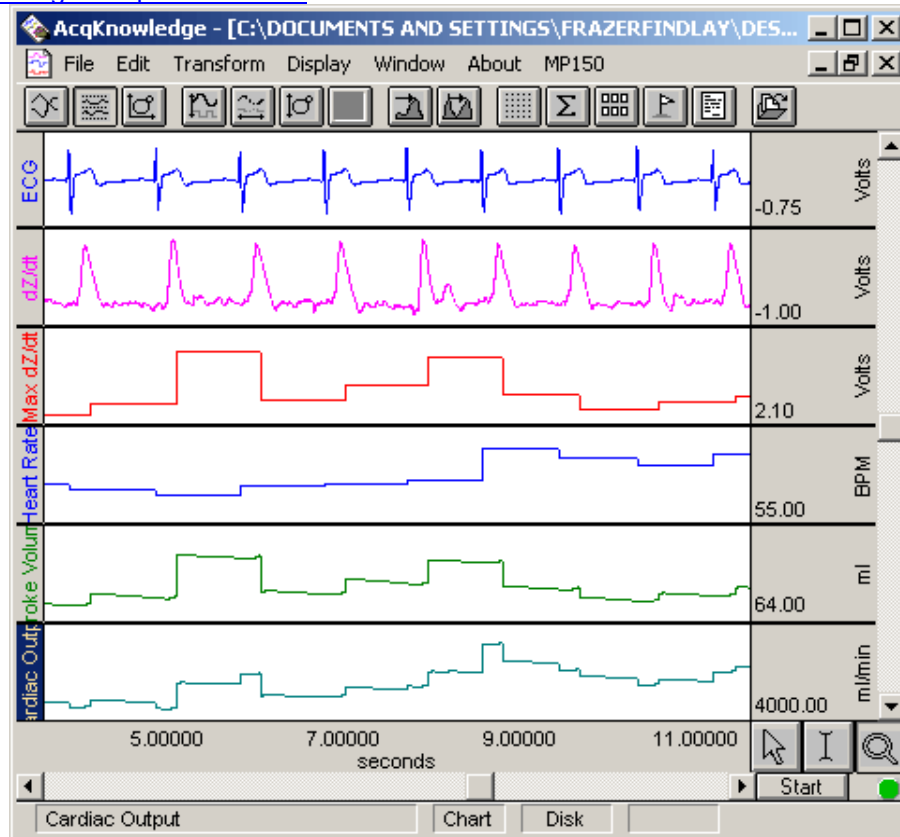


Application Note AS-199 Impedance Cardiography and Pre-ejection Period

This Application Note guides you through the analysis process only, based on the following signals: ECG, Z_0 and $dZ(t)/dt$ (equivalent to dZ/dt). It is not intended to assist in the acquisition process. [See Application Note # AH196 for further information about recording bioimpedance data.](#)



Compiled by **Ryan A. Brown** and **Jason A. DeCaro**; Laboratory for Comparative Human Biology (LCHB), Department of Anthropology, Emory University: <http://www.emory.edu/COLLEGE/ANTHROPOLOGY/CHB>

Copyright © 2002, Emory University. All rights reserved, except that this document may be freely posted and distributed, so long as no modifications are made and the authors and LCHB are credited appropriately.

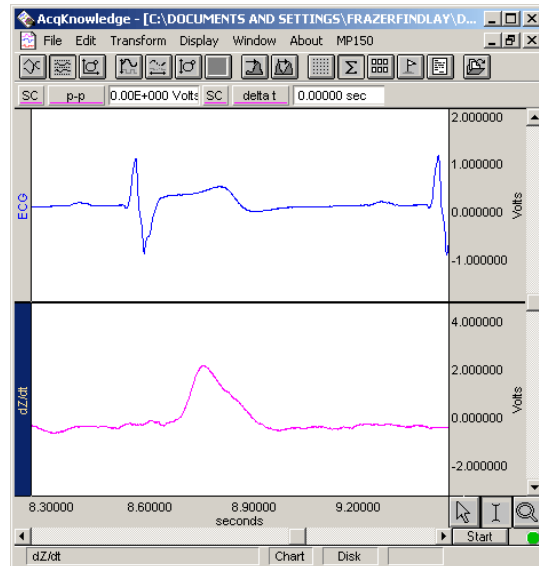
Part I. Abstract

A common variable in recent psychophysiology research, pre-ejection period (PEP) measures the latency between the onset of electromechanical systole, and the onset of left-ventricular ejection. Interest in PEP springs largely from studies suggesting it is most heavily influenced by sympathetic innervation of the heart. Particularly in combination with more heavily parasympathetically-mediated markers of cardiovascular activity (e.g., RSA/"vagal tone"), PEP can be used to partition components of autonomic activation in a study of cardiovascular reactivity. PEP is noninvasively measured for any given beat as the time between the Q-point in an electrocardiogram (ECG) signal and the B-point in the derived impedance signal, $dZ(t)/dt$.

The following procedures for deriving PEP measurements from impedance and ECG data are most directly applicable to AcqKnowledge for PC, v.3.7.1. This is the platform on which they were developed and tested. However, with minimal revision, it should be possible to apply these procedures in other versions of AcqKnowledge, including versions of AcqKnowledge for Mac.

Part II. Pre-ejection Period using AcqKnowledge, Beat-to-Beat Technique

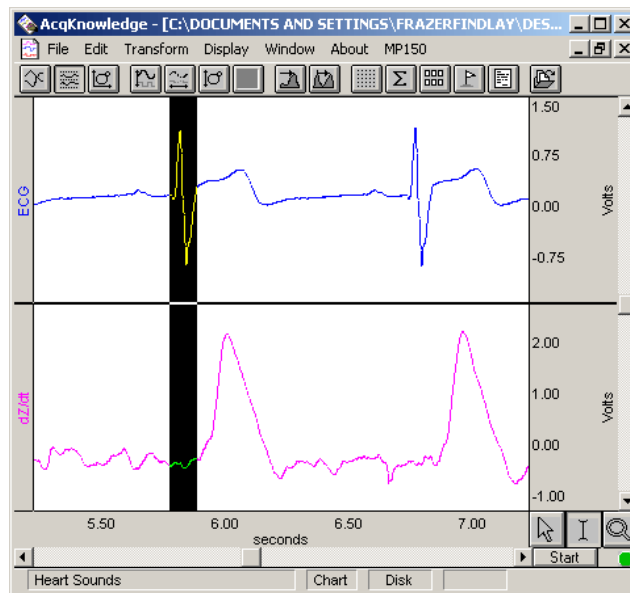
1. Isolate the ECG and dZ(t)/dt waveforms. Do this by clicking on the channel numbers for the other waveforms on the left upper side of the screen (e.g., raw impedance, skin conductance) one at a time, selecting Edit, and then Remove waveform from the pull-down menu at the top. Alternately, it is possible to hide the unneeded waveforms without removing them, by holding down Ctrl and clicking on the channel number.
2. Select Display and then Autoscale waveforms. Left-click on the X-axis (seconds), and set the Time box appropriately: for rapid PEP analysis, 1 second per division is appropriate, although precision is compromised. A high degree of precision is yielded by 0.3 seconds/division.
3. Rescale the Y-axes (Volts) for the dZ(t)/dt and ECG waveforms. Generally, as seconds/division are decreased (step 2), it is helpful to decrease volts/division on the Y-axes. A large portion of the ECG and dZ(t)/dt waveforms can be left off the screen in order to make the B-point on the dZ(t)/dt and the Q-point on the ECG more clearly distinguishable (see below).



4. Once X- and Y-axes have been properly scaled, move to the beginning of the recording (0 seconds), using the scroll bar at the bottom of the screen. Set one calculation channel to delta t, and all other channels to none. Now, click on the I-Beam button on the lower right corner of the AcqKnowledge screen. Finally, select Display, then Show, and then Journal. Also under Display, choose Preferences, and then Journal. Make sure none of the boxes are checked. You are now ready to calculate and record pre-ejection period (PEP) for each individual cardiac cycle.
5. Using the mouse, place the I-Beam directly on top of the point of onset of the Q-wave in the ECG signal. The Q-wave point of onset is the end of the small plateau that directly precedes the small negative peak, which in turn precedes the R-wave (see below).



- After locating the Q-wave, hold the left mouse button down and "stretch" the I-Beam to the B-point of the $dZ(t)/dt$ wave (the point of inflection directly before the large amplitude jump in the wave, or the point of maximum rate change). This represents the point of opening of the aorta. The B-point is often preceded by a high velocity but low amplitude increase in voltage. After this increase, there will often be a small dip or plateau. The B-point occurs after this dip or plateau (see below).



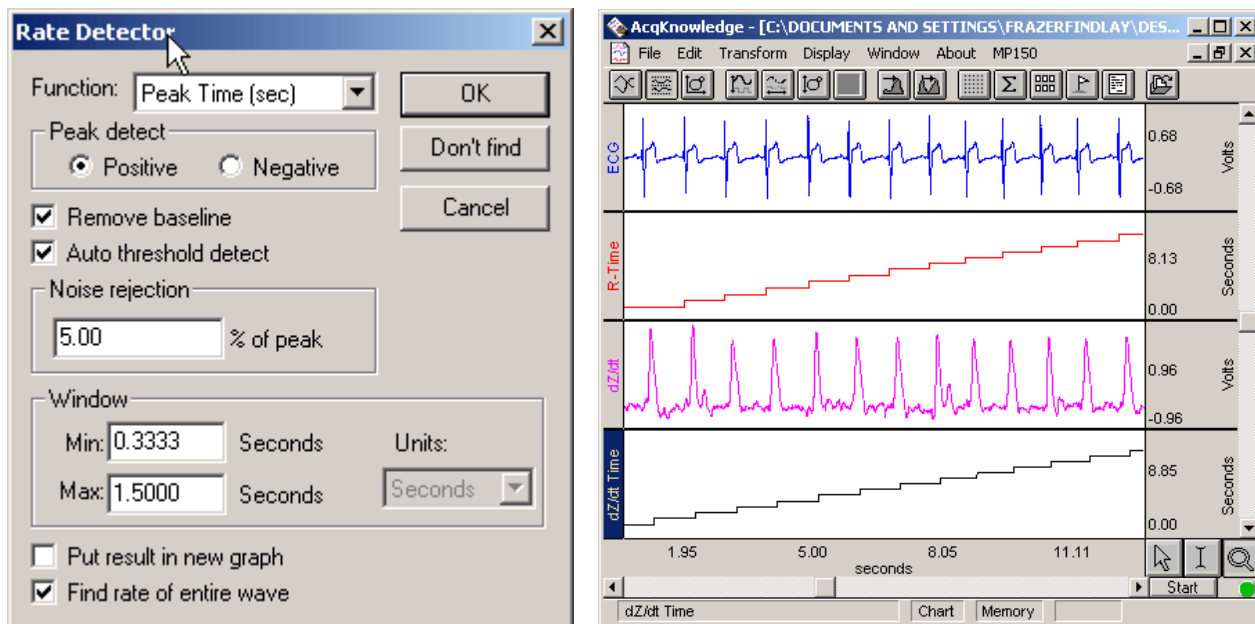
- With this section highlighted, use the mouse to select Edit, then Journal, then Paste measurement. [You can also perform this function by pressing Ctrl-M.] This will automatically paste the first pre-ejection period (PEP) into an *AcqKnowledge* text file, which you will see at the bottom of your screen. PEP measurements should be in the range of .13-.23 seconds. Note that, as a control against bias, it may be desirable to hide the journal and the measurements once you verify that they are working correctly. Hide the journal by selecting Display, then Show, and then unselecting Journal. Hide measurements by unselecting Measurements in the same menu.
- Repeat steps 5-7 for the remaining portion of the recording. When you are finished with the entire waveform (may take up to 15 minutes), cut and paste the resulting string of individual PEP measurements into Excel or other data management/statistical software.
- At this point, you must choose between two alternative approaches to interpreting this beat-to-beat PEP data. The most common approach described in the literature is to obtain an average PEP value for the entire block of data, and consider variability only between blocks. Another approach, less frequently used but with interesting prospects, is to examine variability over the course of a single block or task. Preliminary research at LCHB suggests that beat-to-beat PEP may be responsive within each block or task to psychosocial challenges in a manner reminiscent of skin conductance. However, these results are highly preliminary, and as yet unconfirmed, and beat-to-beat PEP remains an intriguing possibility rather than a thoroughly fleshed-out procedure. The authors encourage readers to consider including this measure in future studies, so that the utility of the measure as a gauge of sympathetic activity can be evaluated in comparison to more traditional measures like averaged PEP or skin conductance response.

Part III. Pre-ejection Period using *AcqKnowledge*, Ensemble Averaging

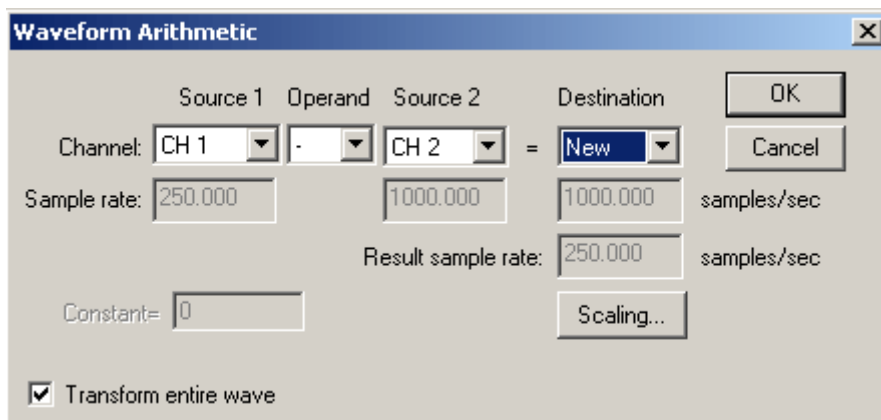
A common analytic technique with impedance data is to average raw $dZ(t)/dt$ and ECG data for a given period of time (e.g., one minute) prior to measuring PEP. While this technique lacks the flexibility to examine changes over the course of a single block of data, it has the advantage of averaging out noise in a poor quality signal, and can be quicker and easier than manual beat-to-beat PEP coding depending on the quality of the data.

Off-line averaging or ensemble averaging is based on peak detection, and is described in more detail in another *AcqKnowledge* application note (see the application note #AS177 for ECG Analysis using the off-line Averaging Mode at <http://www.biopac.com/AppNotes/app177ecganal2/onlineecgavg.html>). The principal difference between the general procedure for off-line averaging and the technique required for a valid measure of PEP is that not only must the two waveforms ($dZ(t)/dt$ and ECG) individually be averaged, their average relative position with respect to each other must be preserved. The example below presumes a 1-minute data block. However, this procedure is applicable in any case where the $dZ(t)/dt$ and ECG data are contained within a single block, regardless of length.

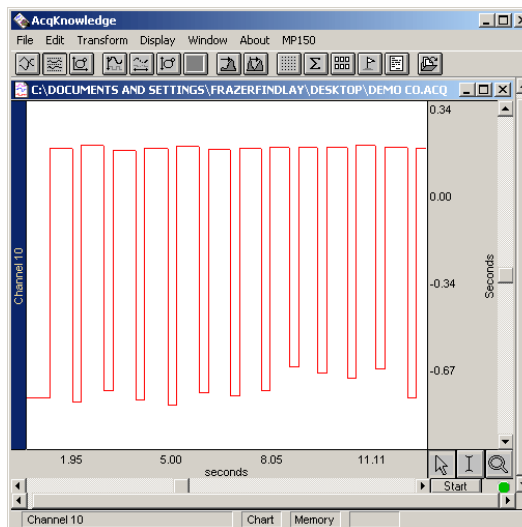
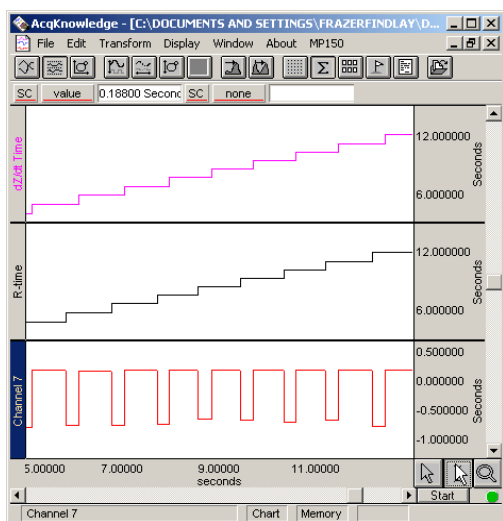
1. Isolate the ECG and dZ(t)/dt waveforms. Do this by clicking on the channel numbers for the other waveforms on the left upper side of the screen (e.g., raw impedance, skin conductance) one at a time, selecting Edit, and then Remove waveform from the pull-down menu at the top. Alternately, it is possible to hide the unneeded waveforms without removing them, by holding down Ctrl and clicking on the channel number.
2. Make sure the dZ(t)/dt channel is selected by left-clicking on the waveform. Now, select Transform and then Find rate. A box entitled Rate detector will appear. Set the Function box to Peak time. Peak detect should be set to Positive. Remove baseline, and Auto threshold detect should both be checked. Press OK. A stepped waveform will appear (see below, dZ(t)/dt stepped waveform).



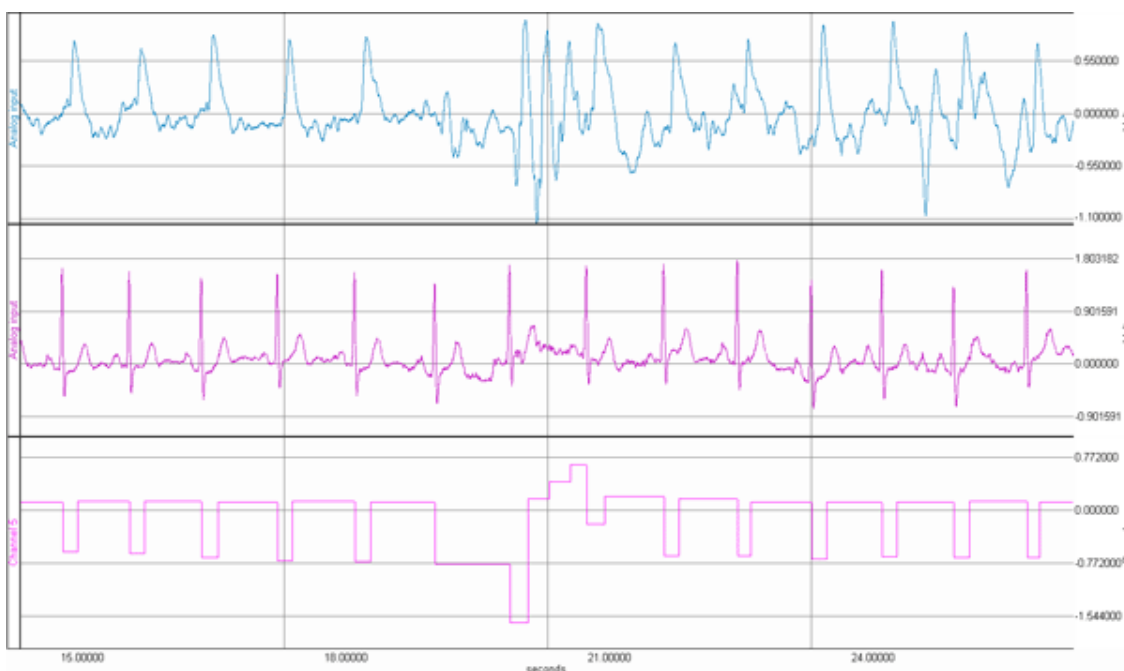
3. Repeat step 2 for the ECG data. A second stepped waveform will appear (see above, R-Time stepped waveform).
4. You are now ready to calculate the average distance between ECG and impedance positive peaks. To do this, select Transform and then Waveform math. Set Source 1 to the dZ(t)/dt peak time series (the dZ(t)/dt stepped waveform). Set Operand to -. Set Source 2 to the ECG peak time series. Set Destination to New. Make sure Transform entire wave is checked. Press OK.



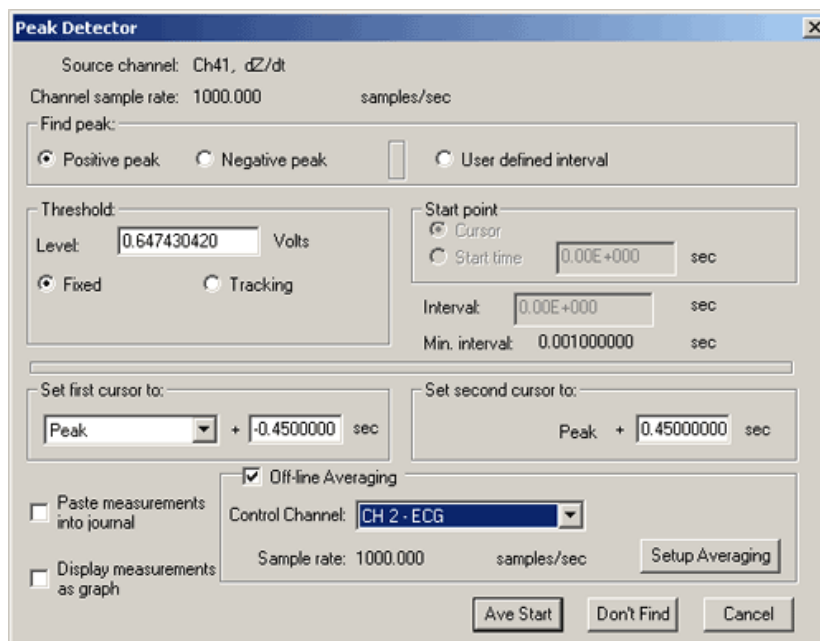
5. A highly patterned city skyline waveform will appear (Ch7 below). Each wide peak of this waveform represents the difference between one pair of ECG and dZ(t)/dt positive peaks. Set the first measurement to value and all the remaining measurements to none. Now select Display and then Show and then Journal. Make sure the new waveform is selected by left-clicking on the waveform. Step the I-Beam through the new waveform. Stop at each positive peak and press Ctrl-M. This will copy and past the relevant time measurement into the journal field.



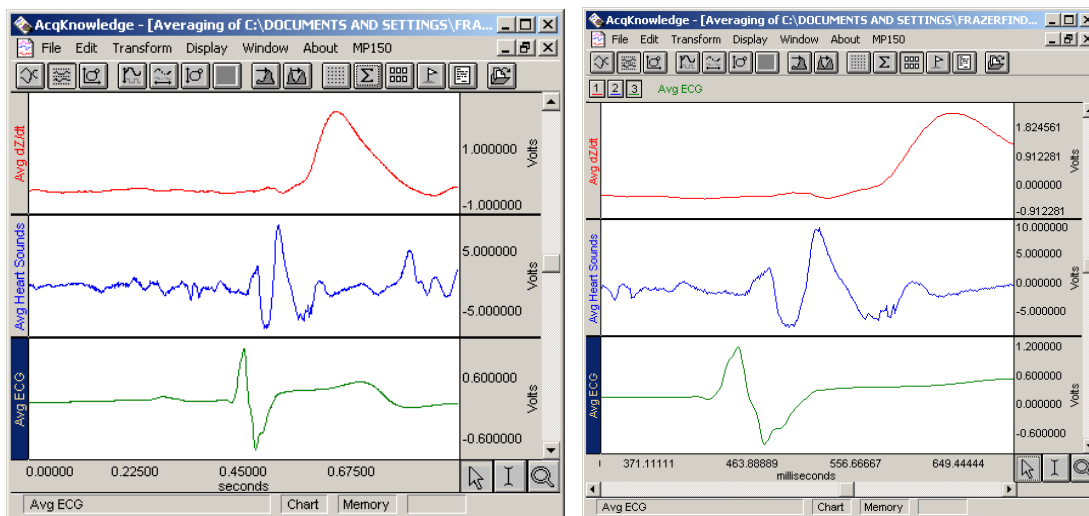
6. NOTE: If sections of the $dZ(t)/dt$ and/or ECG waveform exhibit noisy interpeak spikes or slow-wave oscillations precluding continuous peak detection, it is possible to clean the waveform through the waveform editing procedure. The resulting peak time series will not be completely accurate. However, the generated interval time series will render exclusion of inaccurate intervals quite easily (see below). This process is aided by keeping the ECG and $dZ(t)/dt$ waveforms on the screen, and by checking measurements for wide unexpected variance (i.e., beyond ± 0.03 seconds from the last measurement).



7. When you are finished, copy and paste this series into Excel or other data management software. Obtain the mean of this series, and make a note of it. You are now ready to obtain ensemble averages of the ECG and $dZ(t)/dt$ waveforms.
8. Select a base time window to either side of the $dZ(t)/dt$ waveform that encompasses $\frac{1}{2}$ of the distance to the next positive peak. This does not have to be an exact measurement. Usually, 0.45 seconds is adequate. You may use the I-Beam (and a measurement set to delta T) in order to find an adequate time window.
9. Make sure the $dZ(t)/dt$ channel is selected. Now select Transform and then Find peak. A window marked Peak detector will appear. In the bottom right corner, check the Off-line averaging box. Set first cursor to should be set to Peak + -0.45 seconds [or any other time window selected, see above]. Set second cursor to should be set to Peak + 0.45 seconds [or other time window]. Note that the first number is negative and the second number is positive. Check the Fixed Threshold box and enter a Level suitable to detect each R-wave. Select the ECG signal for the Control channel. Now press the box marked Ave Start.



10. The ensemble averaged $dZ(t)/dt$ wave will appear. You are now ready to obtain the ensemble averaged ECG wave. To return to the raw data screen, use the Window menu to choose the appropriate Display window. Now, make sure the ECG waveform is selected. Now, select Transform and then Find peak from the pull-down menu.
11. To obtain the ensemble-averaged ECG waveform, use the same time values as in step 8, and follow the procedure in step 9 with the following exceptions. (1) Make sure that the voltage threshold for ECG positive peak detection is in the box marked Threshold. Select a voltage threshold suitable for each R-wave to cross. (2) Set first cursor to should be set to -0.45 [or other value] + the value obtained in step 6. Set second cursor should be set to 0.45 [or other value] + the value obtained in step 6. This will result in a slightly attenuated time window, and will create the desired offset for PEP estimation.
12. You will now see the ensemble-averaged ECG waveform. Choose Edit and then Select all from the pull-down menu. Now press Ctrl-C to copy this waveform. Using the Window tool from the pull-down menu, return to the ensemble-averaged $dZ(t)/dt$ waveform. Now choose Edit and then Insert waveform. The two waveforms will now appear stacked on top of each other (see below).
13. **Optional.** The heart sounds signal is very useful for identifying the B-point of the $dZ(t)/dt$ signal. To average the Heart Sounds, you have to repeat steps 8 and 9. The following screen shot displays the results of the averaged $dZ(t)/dt$ signal (red), ECG signal (green) and also the averaged heart sounds.



14. You are now ready to estimate PEP. Adjust the X- and Y-axes for maximum precision (see above right), and use the I-Beam to obtain delta T from one of the measurements for the distance between Q-wave onset and the B-point of the $dZ(t)/dt$ waveform. This represents PEP.