PV Loop Analysis with LabScribe

Introduction

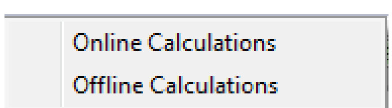
Ventricular pressure-volume loops are used to study many quantitative aspects of cardiac contractility. A single pressure-volume loop is a two-dimensional representation of the relationship of ventricular pressure to volume over time. The **PV Loops Advanced Analysis Module** integrates the variables and measurements necessary for the recording, analysis, and interpretation of ventricular pressure-volume loops. The **PV Loops Advanced Analysis Module** performs both baseline and occlusion analyses.

The **PV Loops Advanced Analysis Module** requires a separate license. The first time you select **PV Loops**, you will be asked for a username and a serial number. Contact iWorx Systems for more information.

This document includes a step by step tutorial for using most of the features of the **PV Loops Advanced Analysis Module** as well as a more detailed **Reference** section that covers the material in the tutorial, and adds additional context and detail. To use the step by step guide, you will need a recording with ventricular pressure and volume (or conductance) channels. This can be from any mammalian species. In order to use the online analysis part of the module, you will need to be recording these parameters as you proceed through the tutorial. This file can then be saved and used in the offline analysis tutorial.

PV Loop Analysis: Step by Step

The **PV Loops Advanced Analysis Module** is accessed through the **PV Loops** submenu of the *LabScribe* **Advanced** menu. Both real-time **Online Calculations** and more sophisticated **Offline Calculations** are possible.



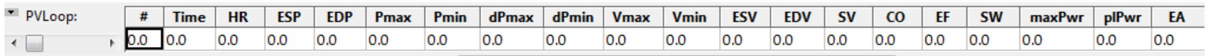
PV Loops submenu

PV Loop Online Calculations

It is possible to generate PV Loop calculations and graphs in real time.

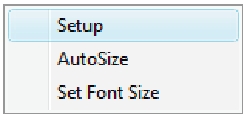
To use the Online Calculations:

1) Prepare the animal and configure the hardware and software to record ventricular pressure and volume measurements on two *LabScribe* channels. The volume measurement may be a conductance measurement or a calibrated or uncalibrated volume.
2) Record a sample and ascertain that the pressure and volume channels are recording data at the scale you desire. Stop recording while you configure the online analysis.
3) Choose **Online Calculations** from the **PV Loops** submenu to display the online **PV Loop Toolbar** above **Channel 1**.



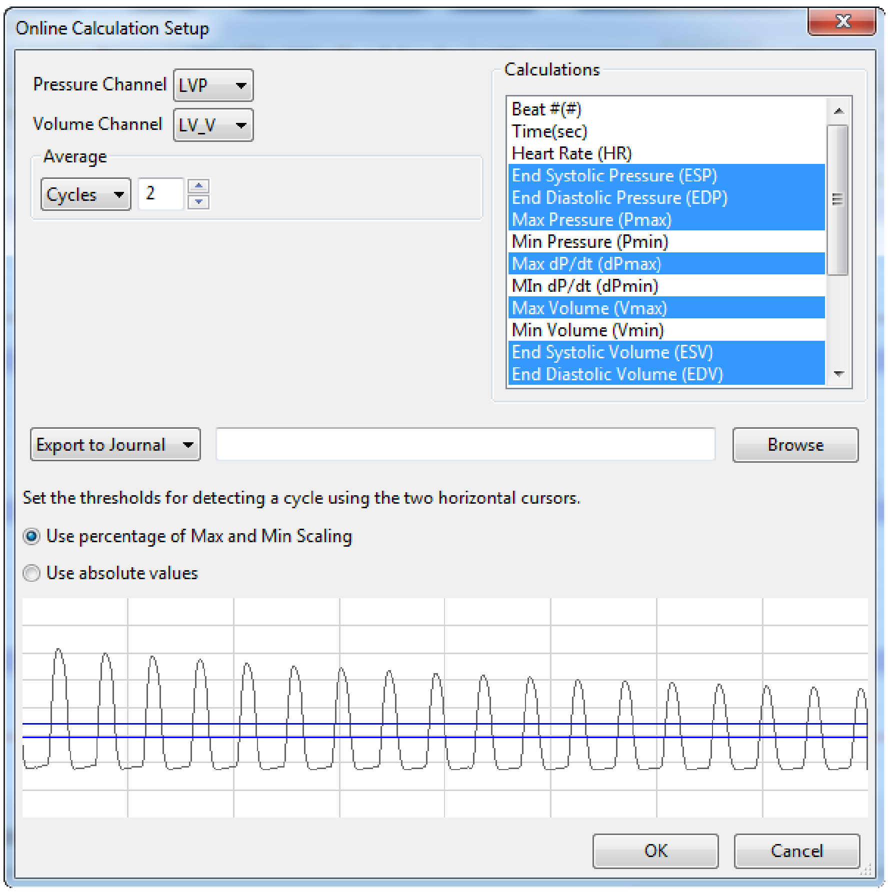
Online PV Loops Toolbar.

4) Click on the down arrow on the left side of the **PV Loop Toolbar** to display a menu with three choices: **Setup**, **AutoSize**, and **Set Font Size**.



PV Loop Online Setup menu.

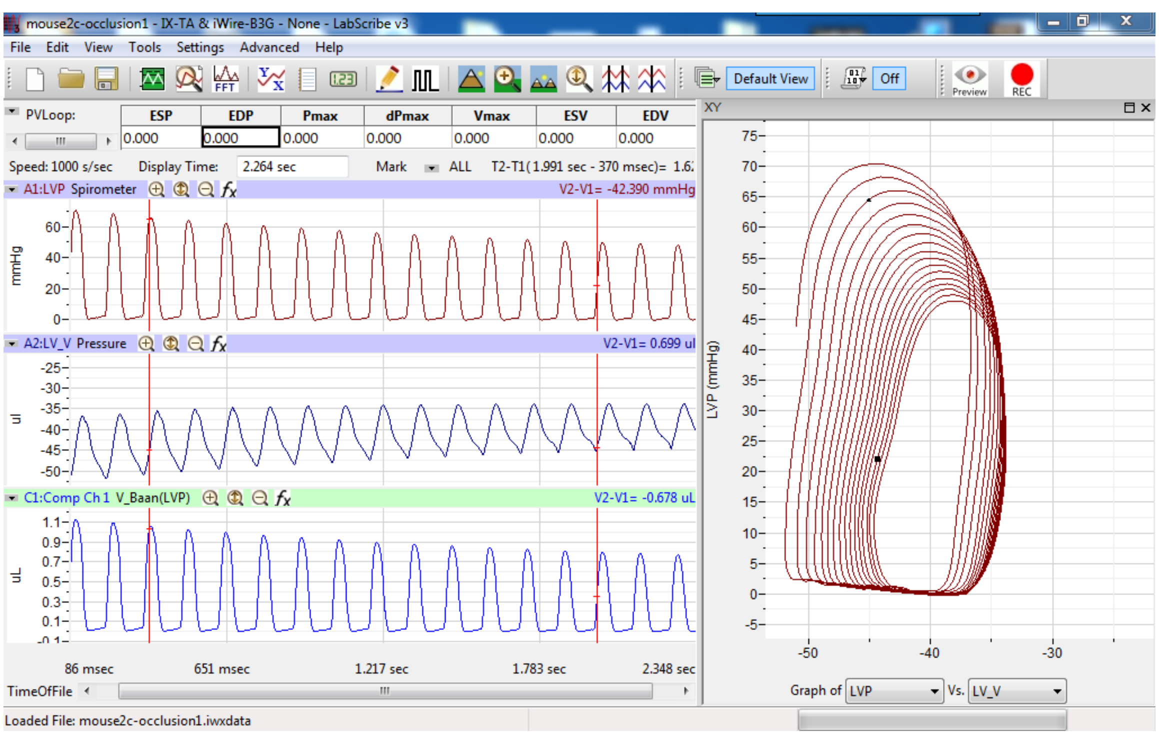
5) Choose **Setup** to open the **Online Calculation Setup** dialog.



Online Calculation Setup dialog.

6) From the **Pressure Channel** and **Volume Channel** menus, choose the ventricular pressure and volume channels from your recording.
7) Once you select the **Pressure Channel**, a sample of the recording will be displayed at the bottom of the dialog. Set the thresholds for cycle detection by adjusting the Max and Min blue horizontal lines so that all cycles pass through both lines.
8) As you record data, cycles will be detected as either a percentage of the amplitude of the cycles based on where you placed the Max and Min lines, or as the absolute values of their set location. Choose which you prefer from the two choices above the sample recording.

9) From the **Calculations** menu, control-click on those variables you would like to record in the data boxes of the **PV Loop Toolbar**. To remove a variable after you have selected it, control-click on that variable. Definitions of all variables can be found in the **PV Loops Analysis: Reference** section.
10) In order to compensate for variation from cycle to cycle, it is possible for *LabScribe* to average a user selected number of sequential cycles. Enter this number in the **Cycles to Average** text box. Start with a low number and adjust upward as necessary. Alternatively, **Time to Average** may be entered instead.
11) Click the **Export to File** menu item to send the data recorded in the **PV Loop Toolbar** as a .csv file to a location chosen in the dialog that opens. The other alternatives send the data to the *LabScribe* Journal (**Export to Journa**l) or do not export the data at all (**No Export**).
12) Click **OK** to close the dialog.
13) Return to the **PV Loop Toolbar** menu (accessed by clicking the arrow) and choose **AutoSize**. The size of the data boxes and the titles will be adjusted to the number of variables you have chosen.
14) From the **PV Loop Toolbar** menu, choose **Set Font Size**. The font size of the data box values can be chosen from the dialog that opens.
15) Resume recording. The pressure and volume channels, and any computed channels, will be displayed on the left side of the **Main Window**, the changing variables will be displayed in the data boxes of the **PV Loop Toolbar.**
16) A real-time pressure-volume XY graph of the screen data can be displayed by clicking on the **XY Graph** icon in the **Toolbar**. The position in the **XY Graph** of the two vertical cursors in the recording are indicated by two moving markers. To change the proportion of the screen devoted to the graph, move the mouse cursor over the left border of the graph until you see a double-headed arrow. Click and drag to change the size of the graph.



The online PV Loop display, with the XY Graph option activated.

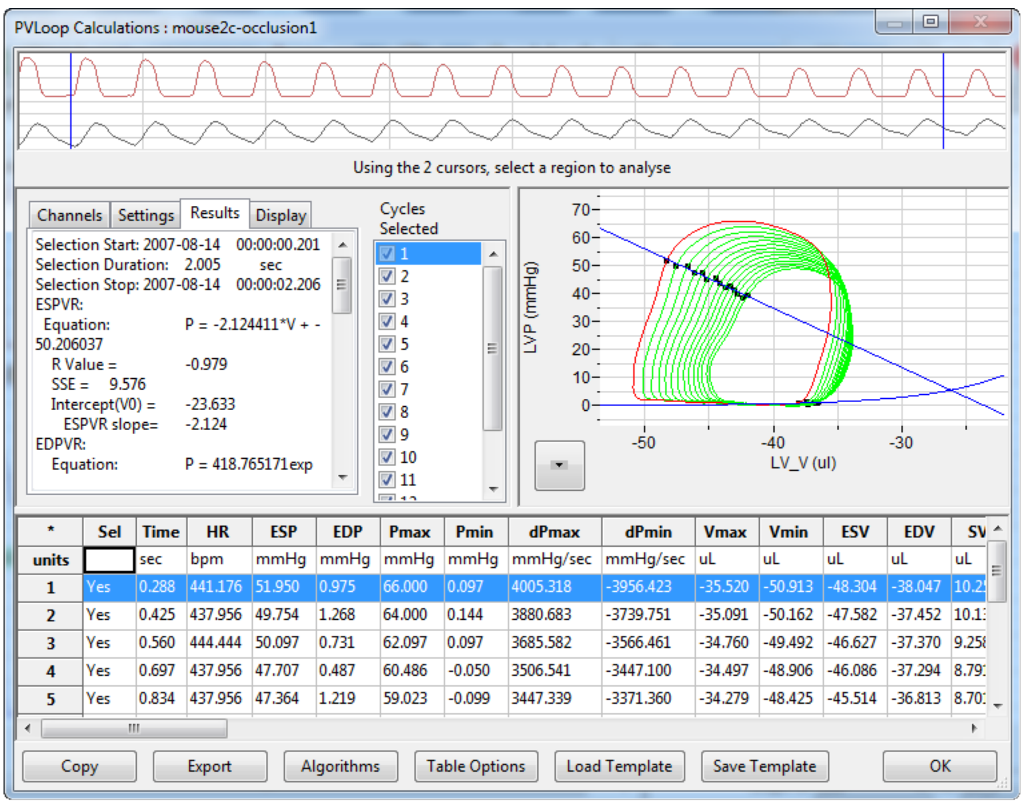
17) Save the recording for offline analysis.

PV Loop Offline Calculations:

The offline PV Loop Calculations dialog allows sophisticated offline analysis of previously recorded ventricular pressure-volume data.

To perform offline **PV Loop** analysis**:**

1) Open the recording from the online analysis or another file with previously recorded ventricular pressure and volume data.
2) Choose **Offline Calculations** from the **PV Loops** submenu to open the offline **PV Loop Calculations** dialog. The panels of this dialog can be resized by moving the mouse cursor over the boundaries until a double-headed arrow appears, and dragging the boundaries to resize the panels.

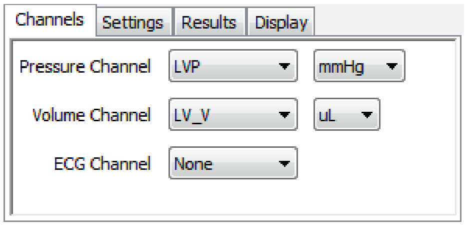


Offline PV Loop Calculations dialog.

3) Familiarize yourself with the offline **PV Loop Calculations** dialog, illustrated above.
   - Across the top of the dialog, in the channel display area, are samples from the pressure and volume channels of the recording.
   - The tabbed configuration dialogs are on the left below the recordings.
   - An XY graph window on the right displays the **PV Loops Graph**, or one of a selection of other XY graphs illustrating pressure-volume relationships.
   - Between the configuration dialogs and the XY graph window is the **Cycles Selected** list, an editable list of the cycles that can be displayed and analyzed.
   - The **Data Table** is located across the lower part of the dialog.

To configure the **Channels:**

1) Click on the **Channels** tab, opening the **Channels** configuration dialog.



PV Loops Channels configuration dialog.

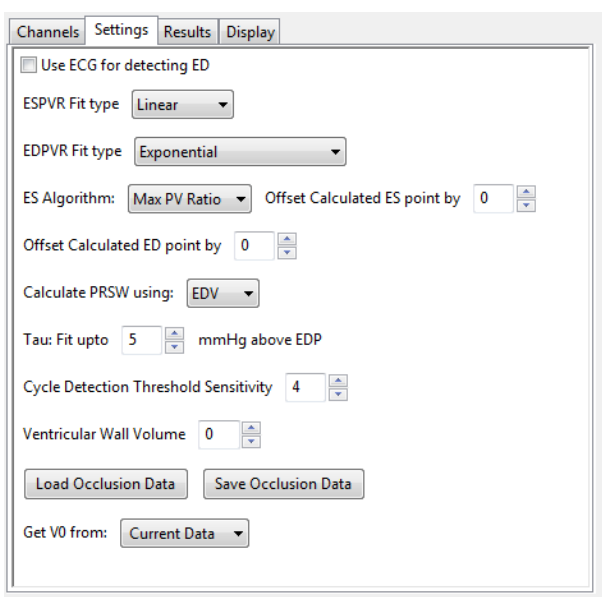
2) From the **Pressure Channel** menu, choose the channel with the ventricular pressure recording. Choose the pressure unit from the menu to the right.
3) From the **Volume Channel** menu, choose the channel with the ventricular volume recording. Choose the volume unit from the menu to the right.
4) Optionally, choose an ECG channel if there is one on the recording.

Once the pressure and volume channels are selected, the recordings of those channels will be displayed in the channel display area at the top of the dialog and the **PV Loops Graph** will be displayed in the XY graph window.

5) Select an area of the recording to be analyzed by moving the two vertical cursors in the channel display area to designate the section to be analyzed. Only those cycles will now be displayed in the **PV Loops Graph**, and the cycles will be listed by number in the **Cycles Selected** list to the left of the graph.

To configure the **Settings:**

1) Click on the **Settings** tab, opening the **PV Loops Settings** configuration dialog.



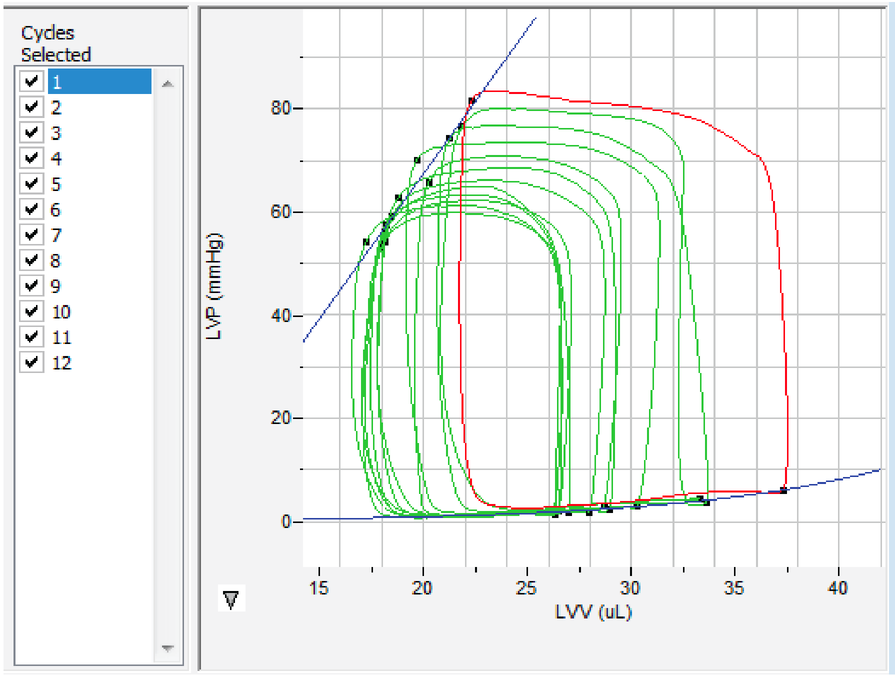
PV Loops Settings configuration dialog.

Starting at the top of the PV Loops Settings configuration dialog:

2) Check whether you wish to use an **ECG** recording for the detection of end-diastole (**ED**).
3) Choose **Linear** from the **ESPVR Fit type** menu. A linear fit is the default choice for the End Systolic Pressure-Volume Relationship (**ESPVR**) data, although an **Exponential** fit is an alternate choice.
4) Choose **Exponential** or **Exponential with Constant** from the **EDPVR Fit Type** menu.
5) Choose **Max PV Ratio** from the **ES Algorithm** menu. The maximum pressure-volume ratio (**Max PV Ratio**) will be used to compute end-systole (**ES**) in each cycle, and is the default value. Maximum pressure (**Max P**), and minimum or maximum derivatives of the pressure (**Min dP** or **Max dP**) are alternate choices.
6) End-systole will be offset from the selected value in Step 5 by a value selected in the **Offset Calculated ES point by** menu. This can be changed as desired.
7) Enter 0 into the **Offset Calculated ED point by** menu. This value can be changed as desired.
8) Specify end diastolic volume (**EDV**) as the value that should be used to calculate the preload recruitable stroke work, **PRSW**, a measure of contractility. The alternate choice is the maximum volume (**Vmax**).
9) Enter the number of mmHg above end diastolic pressure (**EDP**) that should be designated as the uppermost point to be used to create the best fit line from which **Tau** (the time constant of blood pressure decrease during diastole) is computed.
10) Enter 4 as the number of cycles that should be used to determine the **Cycle Detection Threshold Sensitivity**. By default, a threshold sensitivity of 4 is used to detect cycles. If each cycle is not being detected properly, the sensitivity can be adjusted.
11) The **Ventricular Wall Volume** can be compensated for by entering a value in the text box.
12) How to load and save occlusion data is described below.

To display and analyze the **PV Loops Graph:**

1) Familiarize yourself with the **PV Loops Graph**, which will be displayed in the XY graph area for all the cycles in the selection and is illustrated below.
   - By default, the highlighted cycle in the **Cycles Selected** window is shown in red, while all other selected cycles are displayed in green.
   - Cycles can be deselected (or selected) by clicking on the check box to the left of the cycle number in the **Cycles Selected** list to the left of the graph. The UP and DOWN arrows on the computer keyboard can be used to move quickly through the individual cycles.
   - The specific parameters shown in the graph are chosen from the **Display** configuration dialog.



The PV Loops Graph.

2) Click the arrow to the lower left of the XY graph window to open a menu with options for the displayed XY graph.

XY graph window menu.

3) Click **Copy Graph** to copy the current XY graph to the clipboard. It can then be pasted into the **Journal** or an external application.
4) Click **View PV Loops** to display the **PV Loops Graph** of the checked cycles in the **Cycles Selected** list to the left of the XY graph window.

A number of PV Loop relationships can be graphed from the items in this menu:

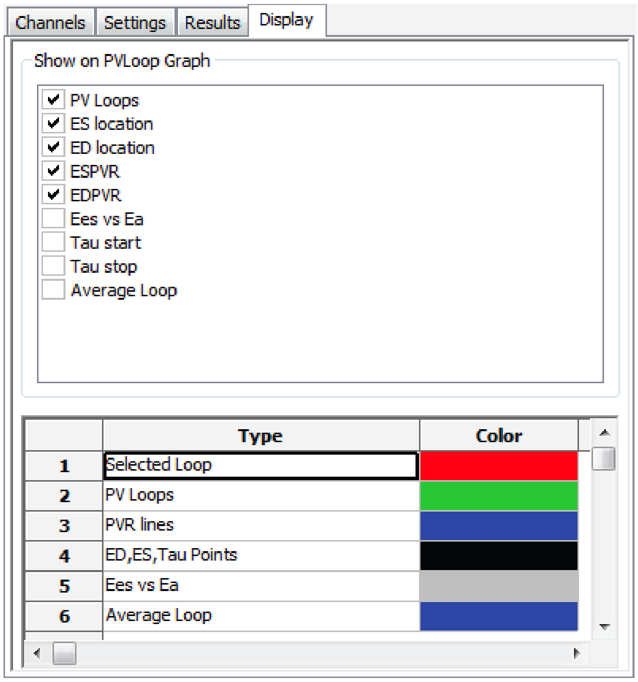
5) Click **View PRSW** to display the preload recruitable stroke work (**PRSW**) line, as defined in the **Settings**. By default, **PRSW**, a measure of contractility, is calculated by plotting stroke work (**SW**) on the Y-axis and end diastolic volume (**EDV**) on the X-axis. Maximum volume (**Vmax**) can be used as an alternative to **EDV** if desired.
6) Click **View Max dP vs. EDV** to display the XY graph of maximum dP/dt (**Max dP**) vs. end-diastolic volume (**EDV**).
7) Click **View PVA vs. EDV** to display the XY graph of the pressure-volume area (**PVA**) vs. end-diastolic volume (**EDV**).
8) Click **View PVA vs. ESP** to display the XY graph of the pressure-volume area (**PVA**) vs. end-systolic pressure (**ESP**).
9) Click **View E(t) vs. Time** to display time-varying elastance (**E(t)**) vs. **Time**.

Several display options are also available:

10) Click **Export Avg. Loop data** to export the data from the graphed average loop as a tab (*.txt) or comma (*.csv) separated text file.
11) Click **Export PV Loop data** to export the data from all the graphed loops as a tab (*.txt) or comma (*.csv) separated text file.
12) Click **View Markers** to display a graph of time (X-axis) vs. pressure and volume (Y-axis) with markers positioned at end-diastole (**ED**), maximum dP/dt (**Max dP**), end-diastole (**ES**), and minimum dP/dt (**Min dP**). The specific cycle displayed is determined by the position of the left cursor in the data recording at the top of the dialog.
13) Click **Export E(t) vs. Time data** to export the time-varying elastance (**E(t)**) vs. **Time** data as a tab (*.txt) or comma (*.csv) separated text file.
14) Click **Set X-axis Scale** or **Set Y-axis scale** to set the X-axis and Y-axis scales manually.
15) Click **AutoScale X-axis** or **AutoScale Y-axis** to optimize the display scale of the X-axis or Y-axis of the current XY graph.

To Configure the **Display:**

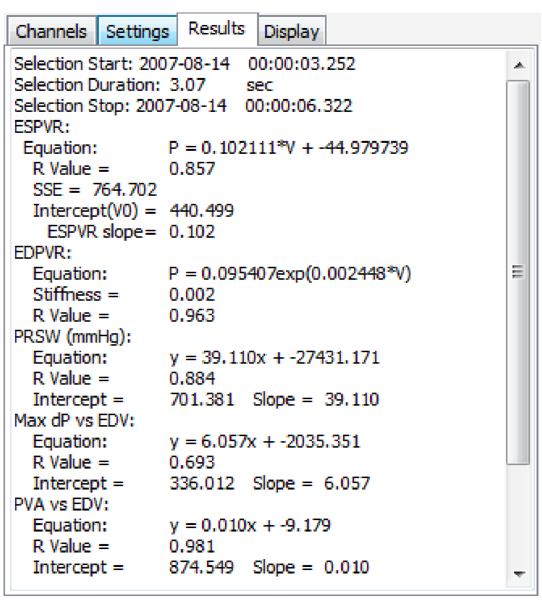
1) Click on the **Display** tab to open the **PV Loops Display** configuration dialog.
2) In the top panel of the **Display** dialog, choose the parameters you would like displayed on the **PV Loops Graph**. Observe the **PV Loops Graph** to see the addition or subtraction of the parameters as they are clicked and unclicked.
3) In the bottom panel of the **Display** dialog, choose the color that you would like each listed parameter to appear in the **PV Loops Graph**.



PV Loops Display configuration dialog.

To Configure the **Results:**

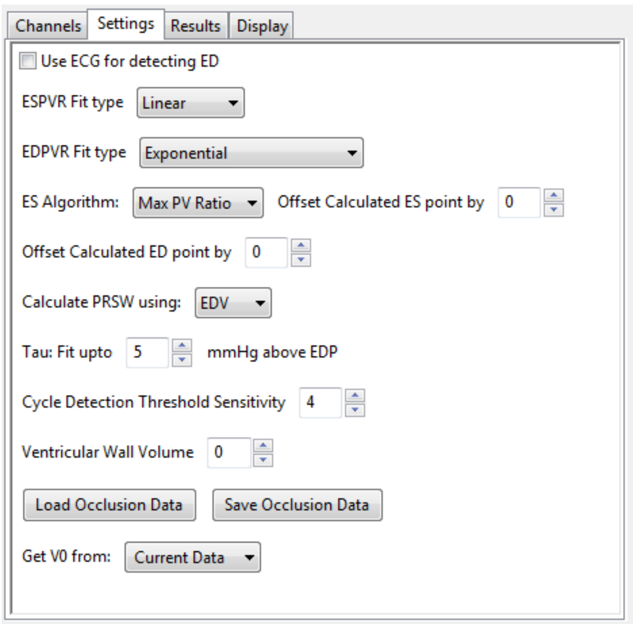
1) Returning to the tabs across the top of the configuration dialogs, click on the **Results** tab to open the **PV Loops Results** configuration dialog. Here the mathematical equations defining the end systolic pressure-volume relationship (**ESPVR**), the end diastolic pressure-volume relationship (**EDPVR**), the preload recruitable stroke work (**PRSW**), maximum dPdT (**Max dP**) vs. end diastolic volume (**EDV**), pressure-volume area (**PVA**) vs. **EDV**, and **PVA** vs. end systolic volume (**ESP**) and the time-varying elastance (**Emax or E(t)**) are displayed, based on the data from the currently displayed **PV Loops Graph**. Additional text can be entered into this dialog.



PV Loops Results configuration dialog.

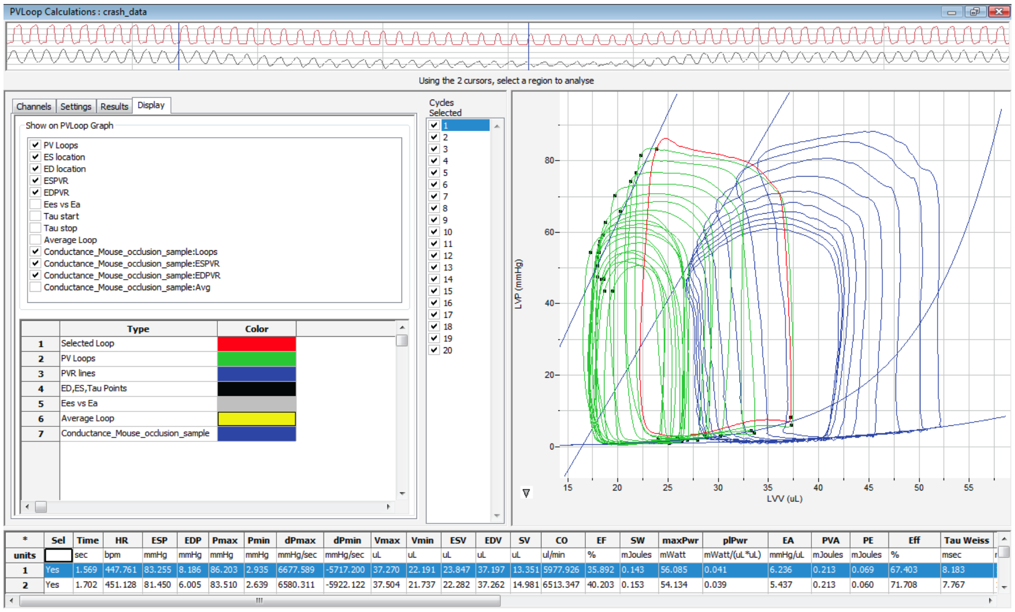
Save or Load Occlusion Data

Use the **Save Occlusion Data** and **Load Occlusion Data** buttons to save the data from the section of the trace where occlusion occurs or to load a previously saved occlusion. This allows the user to perform an occlusion and make direct comparisons to an occlusion under different conditions or from another subject. These options are accessed from the **PV Loops Settings** configuration dialog.



The PV Loops Settings configuration dialog.

1) To save occlusion data, choose **Save Occlusion Data** to open a dialog where you can specify the computer location to save the occlusion data as an iWorx occlusion data file (*.iwxocc).
2) To load previously saved occlusion data, choose **Load Occlusion Data** to open a dialog where you can choose a previously saved occlusion data settings file.
3) Once a previously saved occlusion data file is loaded, the tabbed **PV Loops Display** configuration dialog will add parameters from the loaded occlusion file that can be added to the current **PV Loops Graph**. From the **Display** dialog, choose the specific parameters to be displayed from the checklist, and select the display color of these parameters. An example is shown below.
4) Choose to **Get V0** (the zero-pressure end systolic volume) **from** from the **Current Data** or a previously saved occlusion data file.



Offline PV Loop Calculations dialog with an occlusion comparison.

To Use the **Data Table:**

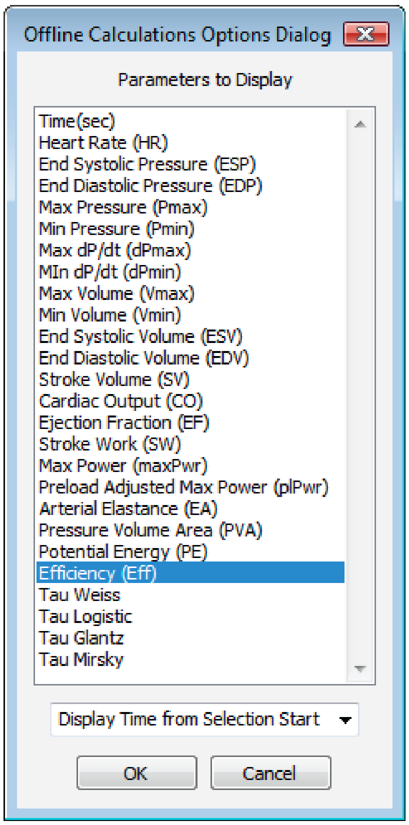
*	Sel	Time	HR	ESP	EDP	Pmax	Pmin	dPmax	dPmin	Vmax	Vmin	ESV	EDV	SV	CO	EF	SW	maxPwr	plPwr	EA
units		sec	bpm	mmHg	mmHg	mmHg	mmHg	mmHg/sec	mmHg/sec	uL	uL	uL	uL	uL	ul/min	%	mJoules	mWatt	mWatt/(uL*uL)	mmHg/uL
1	Yes	2.086	441.176	70.169	2.975	73.467	1.535	5806.989	-5881.777	31.337	19.153	19.673	30.230	10.556	4657.279	34.921	0.108	42.612	0.047	6.647
2	Yes	2.218	454.545	65.860	3.177	70.815	1.252	5521.278	-5802.478	29.510	19.552	20.256	28.663	8.407	3602.915	29.330	0.085	39.379	0.048	7.834
3	Yes	2.349	458.015	62.710	2.464	68.553	1.225	5293.833	-5401.578	29.234	17.767	18.753	28.913	10.160	5347.105	35.138	0.095	35.486	0.042	6.173
4	Yes	2.481	454.545	59.196	1.831	66.183	1.050	5035.133	-5219.100	28.718	17.802	18.494	27.942	9.448	4137.767	33.813	0.086	32.081	0.041	6.266
5	Yes	2.614	451.128	56.275	1.885	65.053	0.983	4946.811	-5139.844	27.066	17.017	18.156	26.945	8.789	3935.239	32.617	0.075	31.205	0.043	6.403
6	Yes	2.746	454.545	57.487	2.221	63.356	0.754	4709.045	-4879.511	26.639	17.443	18.184	26.197	8.013	3785.811	30.589	0.070	28.000	0.041	7.174
7	Yes	2.879	451.128	54.228	2.101	62.333	0.835	4622.289	-4816.667	27.105	17.174	18.106	26.384	8.278	3678.934	31.374	0.073	26.739	0.038	6.551
8	Yes	3.011	454.545	54.282	1.992	61.350	0.647	4432.289	-4562.433	26.667	16.542	17.251	26.455	9.204	4090.755	34.792	0.074	25.433	0.036	5.898
9	Yes	3.142	458.015	53.071	1.548	59.829	0.727	4252.755	-4421.811	26.590	17.065	17.962	26.332	8.370	3862.892	31.785	0.069	23.352	0.034	6.341
10	Yes	3.274	454.545	50.620	1.966	58.806	0.619	4139.034	-4379.900	26.206	17.109	17.939	26.039	8.100	3600.045	31.107	0.062	22.179	0.033	6.249
11																				
12	#		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
13	Mean		453.219	58.390	2.216	64.975	0.963	4875.946	-5050.510	27.907	17.662	18.478	27.410	8.932	4069.874	32.547	0.080	30.647	0.040	6.554
14	SD		4.567	5.848	0.489	4.558	0.287	520.454	508.255	1.608	0.919	0.840	1.370	0.840	521.027	1.929	0.013	6.477	0.005	0.534
15	Max		458.015	70.169	3.177	73.467	1.535	5806.989	-4379.900	31.337	19.552	20.256	30.230	10.556	5347.105	35.138	0.108	42.612	0.048	7.834
17	Min		441.176	50.620	1.548	58.806	0.619	4139.034	-5881.777	26.206	16.542	17.251	26.039	8.013	3600.045	29.330	0.062	22.179	0.033	5.898

PV Loops Data Table.

1) Familiarize yourself with the **Data Table**.
   - The **Data Table** spans the lower part of the **PV Loops Calculations** dialog and displays the calculated values for each of the cycles checked in the **Cycles Selected** list.
   - The top line indicates the **units** for each of the chosen parameters.
   - The bottom few rows show the sample size, the mean, the standard deviation, minimum and maximum values, and the range of each of the chosen parameters averaged over all the selected cycles.
2) Click the asterisk at the upper left of the **Data Table** to display two options: **Autosize** and **Copy Selection**. **Autosize** will optimize the size of the **Data Table** boxes, and **Copy Selection** copies any selected **Data Table** cells to the clipboard.

There are six buttons beneath the **Data Table**: **Copy**, **Export**, **Algorithms**, **Table Options**, **Load Template**, and **Save Template**.

3) Click **Copy** to copy all the calculated data in the **Data Table** to the clipboard.
4) Click the **Export** button to export the data as a tab (*.txt) or comma (*.csv) separated text file. The currently displayed XY graph can be exported as a Portable Network Graphics (*.png) or JPEG (*.jpg) image.
5) Click **Algorithms** to display the mathematical definitions of the parameters included in the **Data Table**.
6) Click **Table Options** to open the **Offline Calculations Options Dialog**, which lists the functions from which the **Data Table** parameters can be chosen. All functions are described in the **PV Loops Analysis: Reference** section.



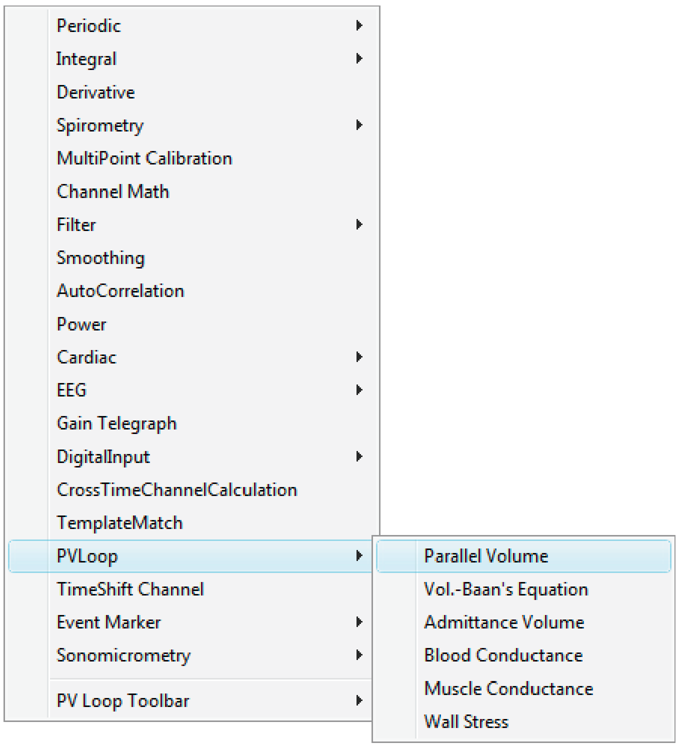
Complete list of Data Table parameters.

7) Click **Load Template** or **Save Template** to display a dialog allowing you to name and save a specific configuration for future use or to load a previously saved template.
8) Click **OK** to close the analysis.

Volume Calibration

Most sensors will need calibration of some type for ventricular volume measurements. While uncalibrated volumes or even raw conductance measurements will show contractility changes relatively well, calibration is necessary to obtain absolute volumes. For a more complete theoretical background, see the **PV Loops Analysis: Reference** section.

LabScribe offers a variety of algorithms for volume calibration, all accessed from the **PV Loop** submenu of the **add function** menu for the **Main Window** channel with the raw data.

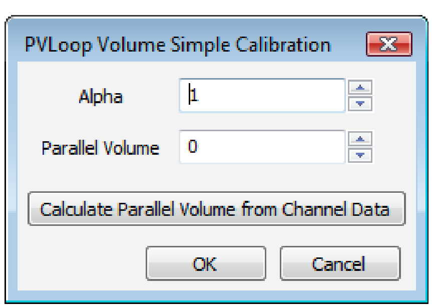


PV Loop Calibration options.

Conductance Volume

LabScribe offers two means of performing volume calibration based on the change in conductance due to the injection of a saline bolus. To use the **Parallel Volume** function to determine the parallel volume, it is necessary to use a calibrated total volume channel (one which includes the parallel volume). To use the **Vol.-Baan's Equation** function, it is possible to use a raw conductance channel. The resulting function channels will be volume calibrated and corrected for parallel conductance.

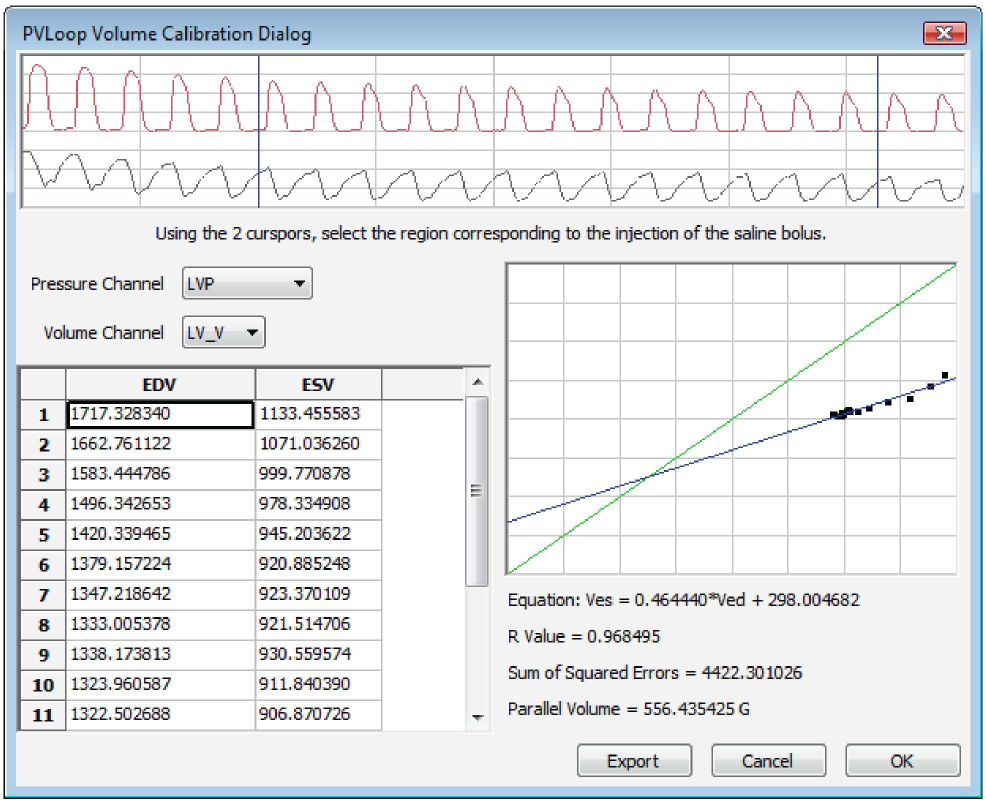
To use the Parallel Volume function:



PV Loop Volume Simple Calibration dialog.

1) Click on **add function** on the **Main WIndow** volume channel.
2) In the dialog that opens, select **PV Loops**, and then **Parallel Volume** from the submenu.

3) Enter the **Alpha** slope correction value, and click on **Calculate Parallel Volume from Channel Data**, opening the **PV Loop Volume Calibration** dialog.
4) In the **PV Loop Volume Calibration** dialog, choose the **Pressure** and calibrated **Volume** channel.
5) Using the cursors in the **Pressure** and **Volume** trace window at the top of the dialog, select the region corresponding to the saline bolus injection.

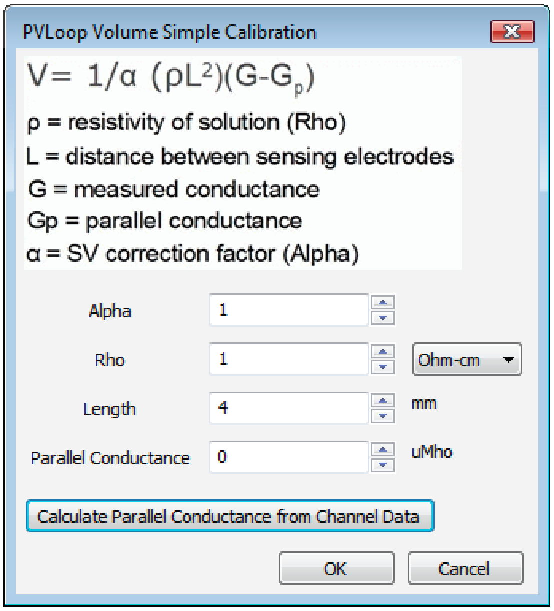


PV Loops Volume Calibration dialog: Parallel Volume from calibrated total volume channel.

6) In the end diastolic volume (**EDV**) vs. end systolic volume (**ESV**) XY graph, the line created by the shifting conductance values caused by the saline bolus will cross the identity line at the parallel volume. The equation of the data line, its goodness of fit, and the parallel volume are displayed below the XY graph window. Click **OK**.
7) The parallel volume will now be displayed in the **PV Loop Volume Simple Calibration** dialog. Click **OK** and a calibrated volume channel is added to the recording.

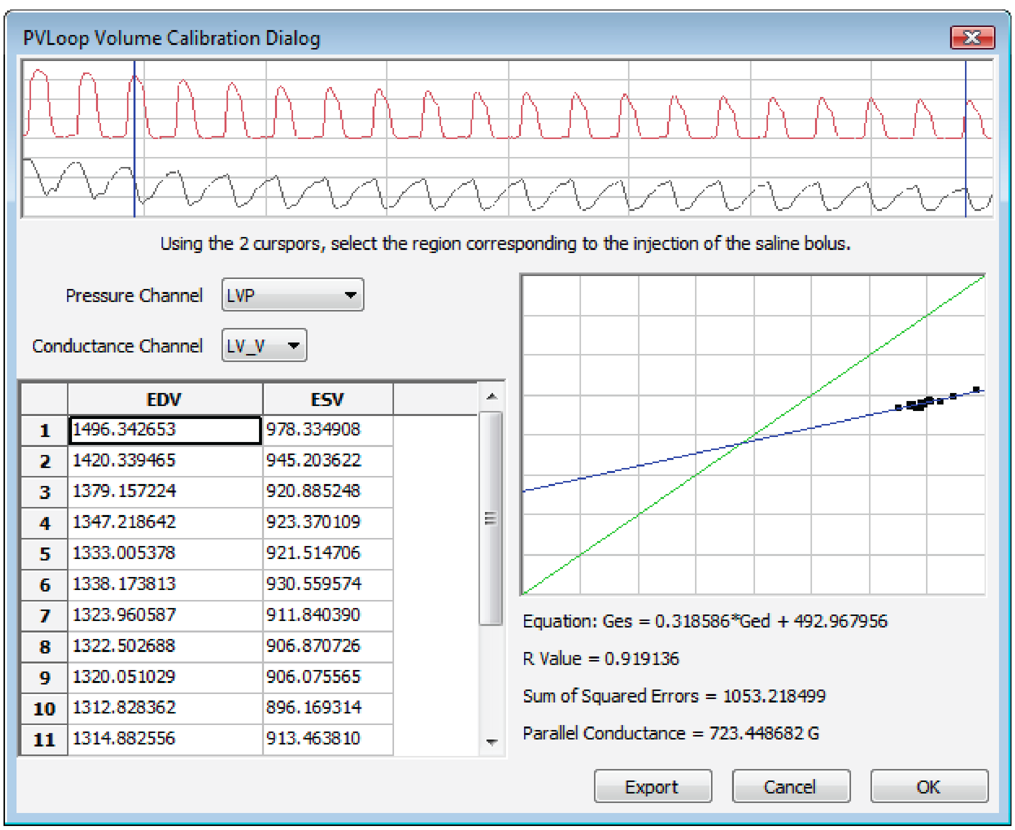
Baan's Equation: To use the Baan's Equation function:

1) Click on **add function** on a conductance (**Volume**) channel.
2) In the dialog that opens, select **PV Loops**, and then **Vol.-Baan’s Equation** from the submenu, opening the **Baan’s Equation** version of the **PV Loop Volume Simple Calibration** dialog.
3) Enter the **Alpha** slope correction factor, the resistivity of the blood (**Rho**), and the inter-electrode distance (**Length**).



PV Loop Simple Volume Calibration dialog: Baan's Equation.

4) Click on **Calculate Parallel Conductance from Channel Data**, opening the **PV Loop Volume Calibration Dialog**.



PV Loops Volume Calibration dialog: Parallel Conductance for Baan's Equation.

5) Choose the **Pressure** and conductance (**Volume**) channel.

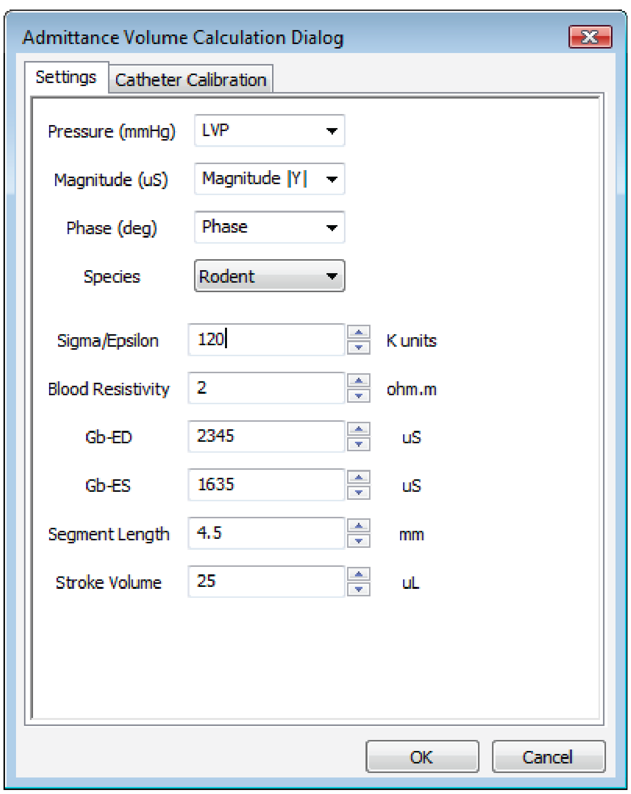
6) Using the cursors in the **Pressure** and **Volume** trace window at the top of the dialog, select the region corresponding to the saline bolus injection.
7) In the end diastolic volume (**EDV**) vs. end systolic volume (**ESV**) XY graph, the line created by the shifting conductance values caused by the saline bolus will cross the identity line at the parallel conductance. The equation of the data line, its goodness of fit, and the parallel conductance are displayed below the XY graph window. Click **OK**.
8) The parallel conductance will now be displayed in the **PVLoop Volume Simple Calibration** dialog. Click **OK** and a corrected volume channel is added to the recording.

Admittance Volume

Admittance sensors do not require the calculation of parallel volume or conductance. If you are using the *ADVantage* system, you will have entered the appropriate constants into the *ADVantage* interface, or used the *ADVantage* default values, and the calibrated volume, based on Wei's Equation, will be shown as a raw data channel in *LabScribe*. It may be necessary to recalculate this calibrated volume based on updated information that may cause a change in the constants. The **PV Loops Advanced Analysis Module** can compute the calibrated volume based on these updated constants and display the revised volume as a computed channel.

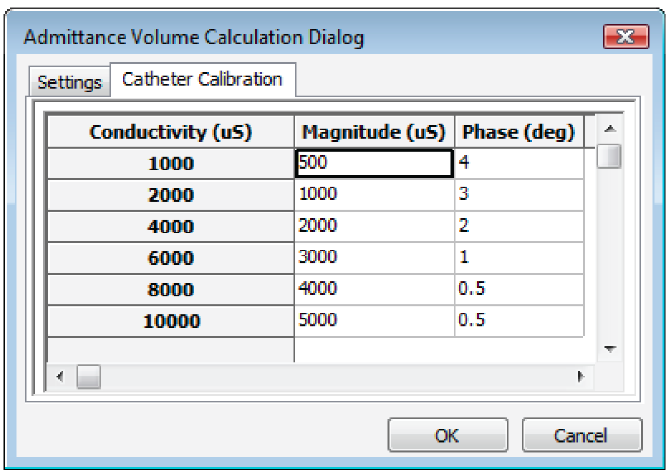
To calibrate ventricular volume based on revised constants:

1) To add a channel showing the ventricular volume based on new constants, from the **PV Loops** submenu, choose **Admittance Volume**, displaying the **Admittance Volume Calculation** dialog.



PV Loops Admittance Volume Calculation dialog.

2) In the dialog, enter the **Pressure**, **Magnitude**, and **Phase** channels, the appropriate species, and any revised constants: the **Sigma/Epsilon** ratio, the **Blood Resistivity**, the blood conductance (**Gb**) values at end-diastole (**ED)** and end-systole (**ES**), the **Segment Length** between the sensing electrodes, and the **Stroke Volume**. Click **OK** to add a calibrated volume channel based on the entered constants.
3) It is also possible to calibrate the catheter as part of this procedure. In the **PV Loops Admittance Volume Calculation** dialog, click on the **Catheter Calibration** tab.
   - The correct **Magnitude** and **Phase** are calculated as the catheter is placed in each standard saline (as indicated by its **Conductivity**), and these are incorporated into the admittance volume calibration.



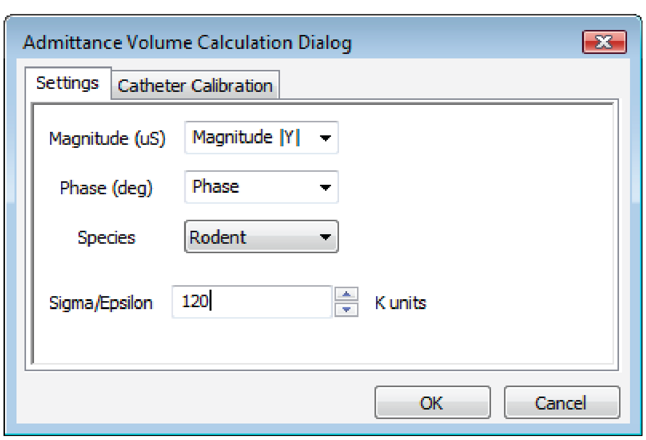
PV Loops Admittance Volume Calculation dialog: Catheter Calibration.

Muscle and Blood Conductance Calibration

Muscle and blood conductance can also be calibrated and determined based on revised constants.

To calibrate muscle and/or blood conductance:

1) Click on **add function** on a **Main Window** volume channel.
2) From the **PV Loops** submenu, choose **Muscle** or **Blood Conductance**, displaying the **Admittance Volume Calculation** dialog for **Muscle** or **Blood Conductance**.



Muscle or Blood Conductance dialog.

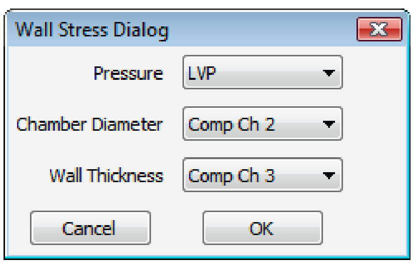
3) Choose the **Magnitude** and **Phase** channels and the appropriate species.
4) Enter a known or default **Sigma/Epsilon** value.
5) Click the **Catheter Conductance** tab and select corrected **Magnitude** and **Phase** values.
6) Click **OK**. A **Muscle** or **Blood Conductance** channel will be added with calibrated muscle or blood conductance values.

Wall Stress

It is possible to use stress-volume loops (instead of pressure-volume loops) to evaluate certain cardiomyopathies. To compute a **Wall Stress** channel, it is necessary to know the ventricular chamber diameter and the wall thickness. These channels, plus the pressure channel, can be used to calculate a **Wall Stress** channel that can be used to create and analyze wall stress-volume loops.

To calculate **Wall Stress**:

1) Choose **Wall Stress** from the **PV Loops** submenu, accessed by clicking **add function** on the volume channel.



PV Loops Wall Stress dialog.

2) In this dialog, choose the channels with the **Pressure**, **Chamber DIameter**, and **Wall Thickness** variables, and click **OK**. A computed **Wall Stress** channel will be added. This channel can be used instead of a pressure channel to compute and analyze stress-volume relationships.

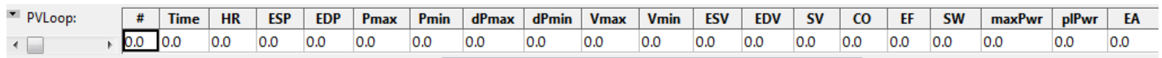
PV Loops Analysis: Reference

When **PV Loops** is chosen from the **Advanced** menu, a submenu opens, displaying two choices: **Online Calculations** and **Offline Calculations**.

Online Calculations:

LabScribe displays ventricular pressure and ventricular volume data in real time as individual waveforms as well as on a **PV Loops** XY graph. Beat-to-beat summary data from left ventricular pressure (**LVP**) and left ventricular volume (**LVV**) signals are displayed in real time and can be saved, during acquisition, to the online **Journal**. The summary data contained in the **Journal** can be saved, copied into a spreadsheet, or exported to an external application for further analysis.

While recording data, it is possible to measure certain beat-by-beat parameters using **Online Calculations**. Choosing **Online Calculations** from the **PV Loops** submenu displays the **PV Loop Toolbar** above the uppermost channel.



The Online PV Loops Toolbar.

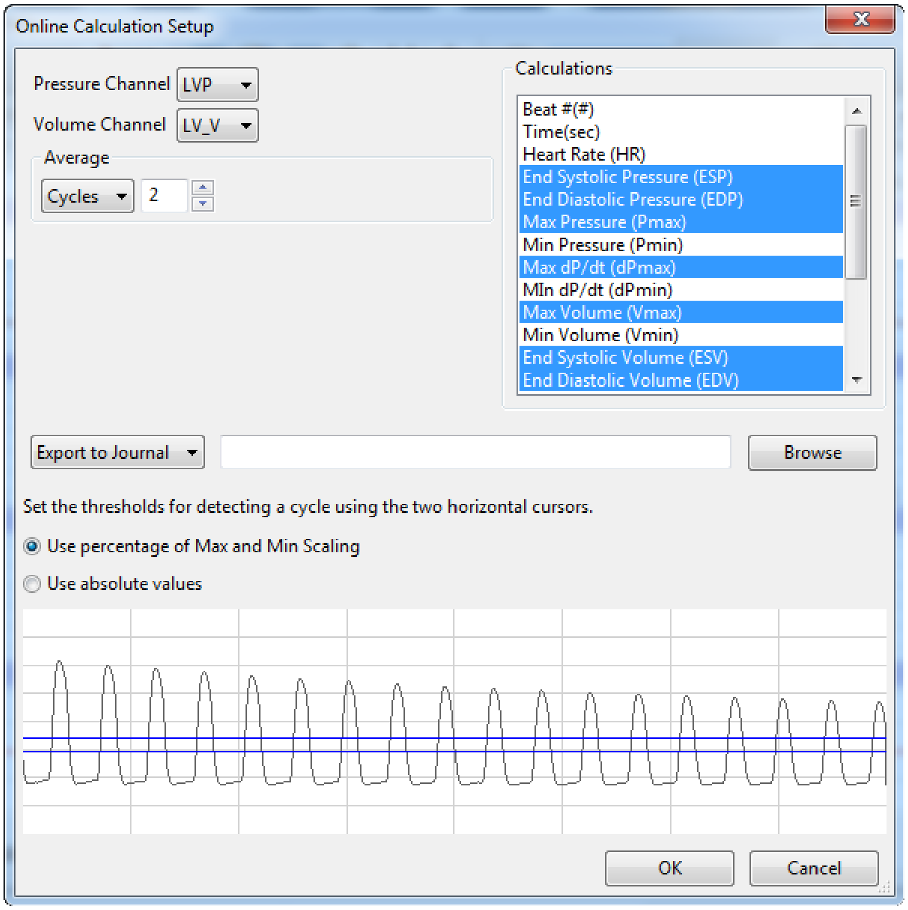
Online PV Loop calculations include:

- Sequential beat number (**#**): The sequential number of the particular cycle in the selection.
- Heart rate (**HR**): The heart rate during the cycle.
- End systolic pressure (**ESP**): The ventricular pressure at the end of systole.
- End diastolic pressure (**EDP**): The ventricular pressure at the end of diastole.
- Maximum pressure (**Pmax**): The maximum pressure generated during the cycle.
- Minimum pressure (**Pmin**): The minimum pressure generated during the cycle.
- Maximum dP/dt (**dPmax**): The maximum dP/dt during the cycle.
- Minimum dP/dt (**dPmin**): The minimum dP/dt during the cycle.
- Maximum volume (**Vmax**): The maximum ventricular volume during the cycle.
- Minimum volume (**Vmin**): The minimum ventricular volume during the cycle.
- End systolic volume (**ESV**): The ventricular volume at the end of systole.
- End diastolic volume (**EDV**): The ventricular volume at the end of diastole.
- Stroke volume (**SV**): The stroke volume based on the parameters of the cycle.
- Cardiac output (**CO**): The cardiac output based on the parameters of the cycle.
- Ejection fraction (**EF**): The ejection fraction based on the parameters of the cycle.
- Stroke work (**SW**): The stroke work based on the parameters of the cycle.
- Maximum Power (**maxPwr**): For each point in the cycle, power is calculated current value of the pressure multiplied by the current value of the smoothed derivative. **MaxPwr** is the maximum of the power averaged over the selected cycles.
- Preload Adjusted Max Power (**plPwr**): **maxPwr**/(**EDV** * **EDV**).
- Arterial Elastance (**EA**): **ESP** / **SV**.

Clicking on the down arrow on the left side of the PV Loop Toolbar will display a menu with three choices:

- **Setup**: Opens the **Online Calculation Setup** dialog.
- **AutoSize**: Adjusts the size of the **PV Loop Toolbar** title and data boxes.
- **Set Font Size**: Changes the size of the font in the **PV Loop Toolbar** data boxes.

The criteria for setting up the **PV Loops** online calculations are entered into the **Online Calculation Setup** dialog.



The Online Calculation Setup dialog.

In this dialog, the **Pressure** and the **Volume** channels, the calculations to be performed online, and whether these calculations should be exported to the **Journal**, are specified.

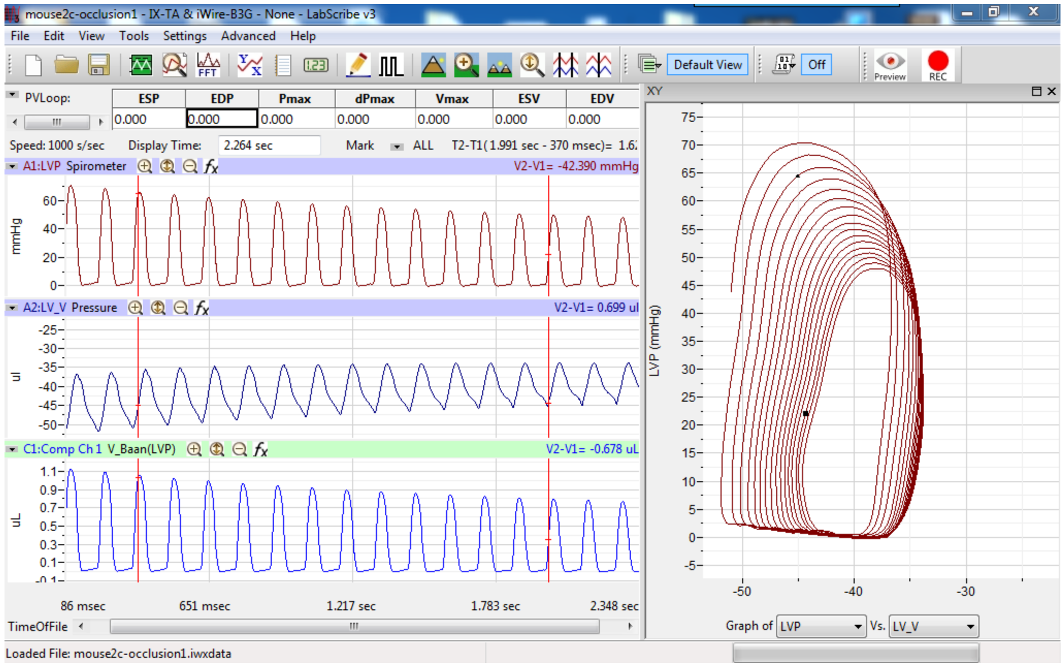
The **Volume** channel may be a recording from a conductance catheter, or a recording in which ventricular volume has been determined in some other way, for example, from **Sonomicrometry** measurements.

When the **Pressure** channel is selected, its graph will appear at the bottom of the dialog. The two horizontal threshold lines should be placed so that they are between each cycle's maximum and minimum. *LabScribe* uses the positive threshold crossing from below the lower threshold to above the upper threshold to determine the cycle.

In order to compensate for variation from cycle to cycle, it is possible for *LabScribe* to average a user-selected number of sequential cycles. This number should be entered in the **Cycles to Average** text box. Alternatively, data can be averaged over a specified **Time**.

Once the dialog is completed, and **OK** is clicked, the dialog will close and the selected calculations will be displayed in the data boxes of the **PV Loops** toolbar as data are recorded.

It is possible to generate a pressure-volume graph in real time by clicking on the **XY Graph** icon in the **Toolbar** and specifying the pressure and volume channels. The position in the loop of the left and right cursors are indicated by moving markers in the graph.



The online PV Loops dialog, with XY Graph activated.

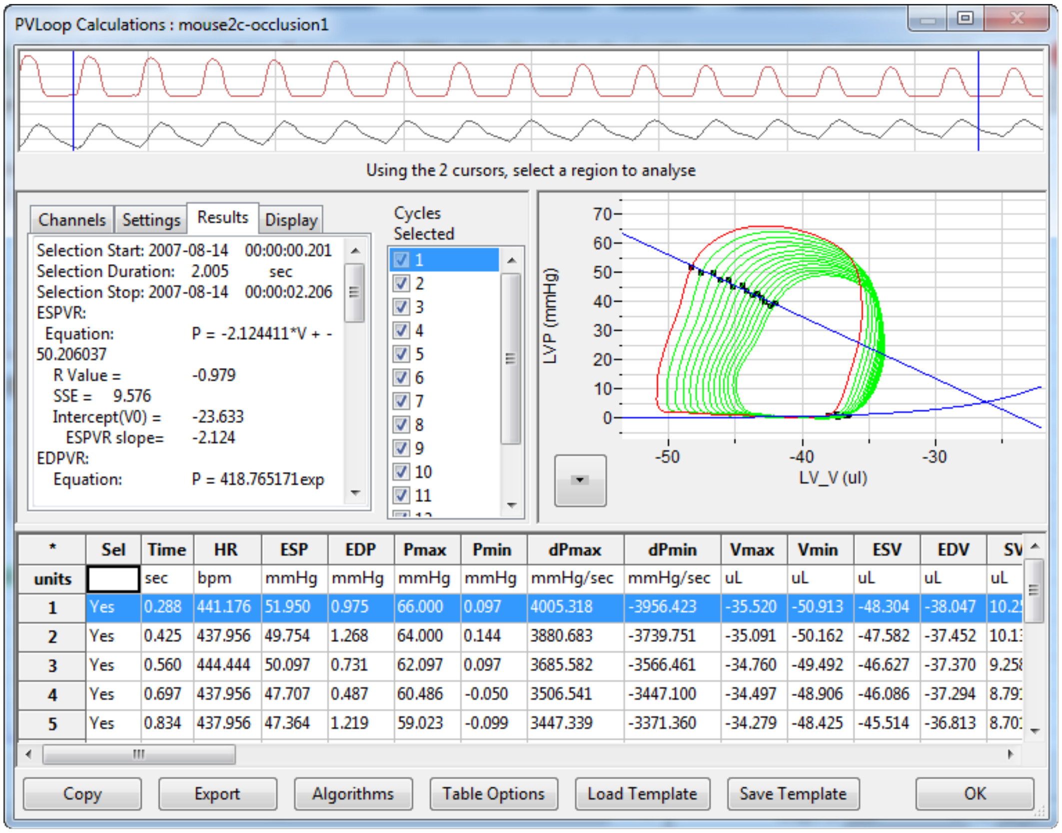
Offline Calculations

Offline, using previously recorded pressure and volume channels, *LabScribe* can calculate virtually every PV Loop derived parameter of cardiac function. XY graphs displaying relationships among the parameters can also be displayed. All calculations can be exported or copied to Excel or other spreadsheets for further analysis. The graphs can all be copied as images to include in presentations or manuscripts.

The Offline PV Loop Calculations Dialog: Choosing **Offline Calculations** from the **PV Loops** submenu opens the offline **PV Loop Calculations** dialog. The panels of this dialog can be resized by moving the mouse cursor over the boundaries until a double-headed arrow appears, and dragging the boundaries to resize the panels.

The sections of the offline PV Loops Calculations dialog, each of which is described in more detail below:

- The raw pressure and volume channels are displayed across the top of the dialog in the channel display area.
- Tabbed configuration dialogs are on the left of the center part of the dialog.
- The XY graph window, in which the **PV Loops Graph** and pressure-volume relationships can be graphed, is on the right.
- Between the configuration dialogs and the graph area is the **Cycles Selected** list, in which the graphed cycles can be selected by checking the boxes to the left of each cycle number.
- The **Data Table** with each cycle's parameters extends across the lower part of the dialog.



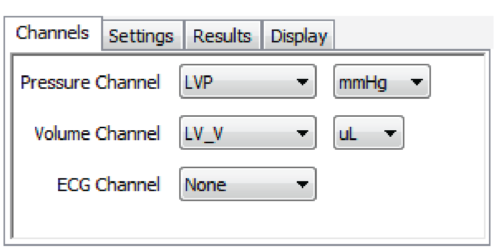
The offline PV Loop Calculations dialog.

The Channel Display Area: In the channel display area, the two vertical blue lines can be adjusted to designate a section of the recording for analysis.

The Configuration Dialogs

There are four tabbed dialogs used to configure the analysis: Channels, Settings, Results, and Display.

The Channels Configuration Dialog

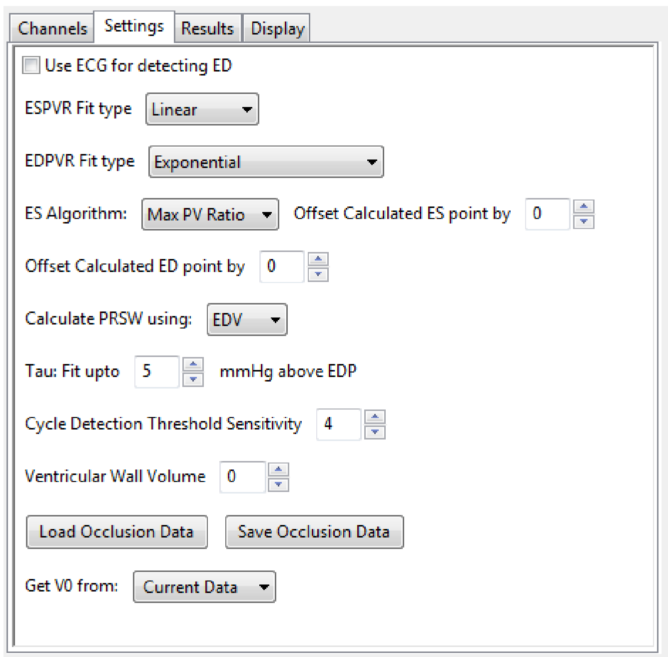


PV Loops Channels configuration dialog.

- The **Pressure Channel** and the **Volume Channel**, as well as the appropriate units, are chosen from the first two menus. Optionally, an **ECG** channel can also be chosen.
- The region of interest is defined by adjusting the two cursors in the channel display area at the top of the **PV Loop Calculations** dialog.

- Once the **Pressure** and **Volume** channels are designated, the **PV Loops Graph** will be displayed in the XY graph area for all the cycles in the selection between the cursors. The highlighted cycle in the **Cycles Selected** window is shown in red, while all other selected cycles are displayed in green. This makes it easy to identify individual cycles for inclusion or exclusion from the analysis. Cycles can be deselected (or selected) by clicking on the check box to the left of the cycle number. The UP and DOWN arrows on the computer keyboard can be used to move quickly through the individual cycles.

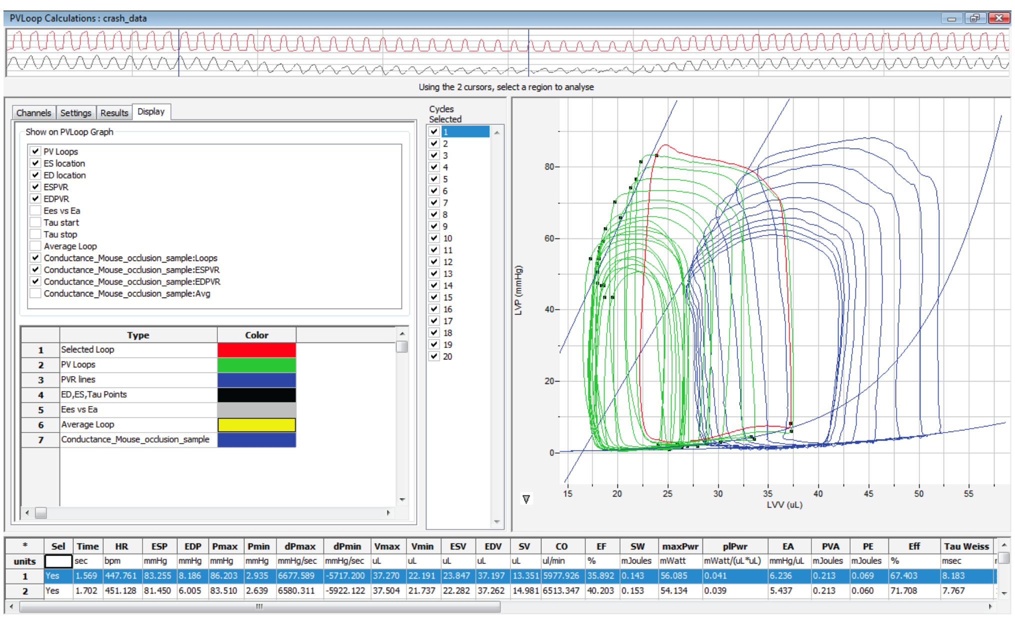
The Settings Configuration Dialog



PV Loops Settings dialog.

- Optionally, an **ECG** recording may be used for the detection of end-diastole (**ED**).
- A linear fit is the default choice for the end-systolic pressure-volume relationship (**ESPVR**) data, although an **Exponential** fit is an alternate choice.
- An **Exponential** or **Exponential with Constant** fit can be chosen from the **EDPVR Fit Type** menu.
- **Max PV Ratio** will be used to compute end-systole (**ES**) in each cycle, and is the default value. **Max P**, **Min dP**, and **Max dP** are alternate choices.
- The **Offset Calculated ES point by** menu indicates how far to offset **ES** from the calculated value. This can be changed as desired.
- The **Offset Calculated ED point by** menu indicates how far to offset **ED** from the calculated value. This value can be changed as desired.
- **EDV** or **Vmax** can be chosen to calculate the preload recruitable stroke work, **PRSW**.
- The number of mmHg above end diastolic pressure (**EDP**) that should be designated as the uppermost point that should be used to create the best fit line from which **Tau** (the time constant of blood pressure decrease during diastole) is computed should be entered in the **Tau fit** box.

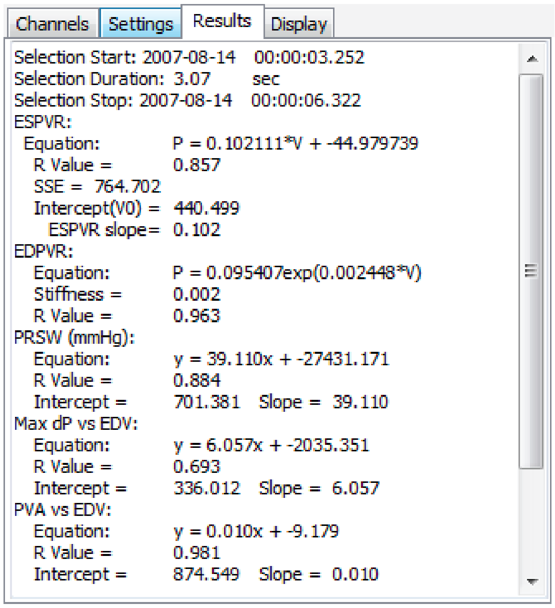
- The number of cycles that should be used to determine the **Cycle Detection Threshold Sensitivity** can be indicated. By default, a threshold sensitivity of 4 is used to detect cycles. If each cycle is not being detected properly, the sensitivity can be adjusted.
- The **Ventricular Wall Volume** can be compensated for by entering a value in the text box.
- The **Save Occlusion Data** and **Load Occlusion Data** buttons save the data from the section of the trace where occlusion occurs or load a previously saved occlusion. This allows the user to perform an occlusion and make direct comparisons to an occlusion under different conditions or from another subject. These options are accessed from the **PV Loops Settings** configuration dialog.
  - Choosing **Save Occlusion Data** opens a dialog where the user can specify the computer location to save the occlusion data as an iWorx occlusion data file (*.iwxocc).
  - Choosing **Load Occlusion Data** opens a dialog where the user can choose a previously saved occlusion data settings file.
  - Once a previously saved occlusion data file is loaded, the tabbed **Display** configuration dialog will add items from the loaded occlusion file that can be added to the current **PV Loops Graph**. From the **Display** dialog, the specific parameters to be displayed are chosen from the checklist, and the display color of these parameters is chosen. An example is shown below.



Offline PV Loop Calculations dialog with an occlusion comparison.

- The user can choose to **Get V0** (the zero-pressure end systolic volume) **from** from the **Current Data** or a previously saved occlusion data file.

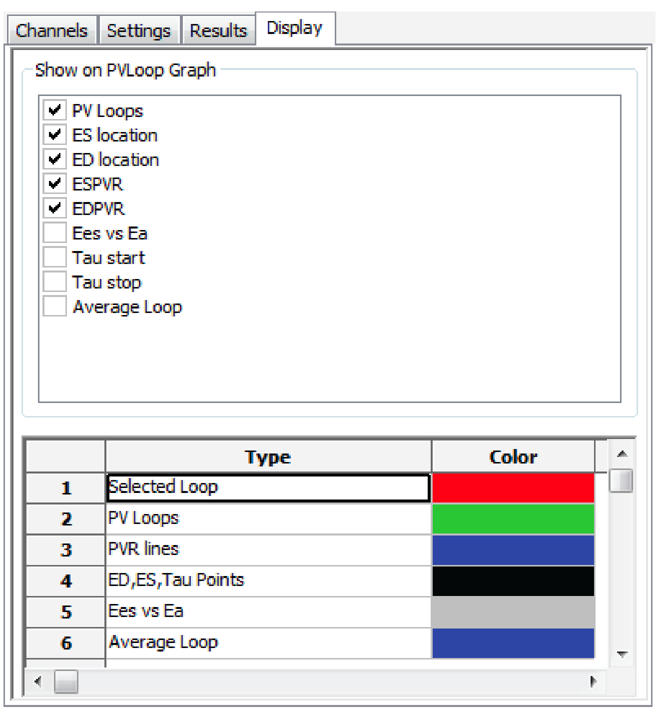
The Results Configuration Dialog



PV Loops Results configuration dialog.

- The mathematical equations defining **ESPVR**, **EDPVR**, **PRSW**, **Max dP** vs. **EDV**, **PVA** vs. **EDV**, and **PVA** vs. **ESP** and **Emax (E(t))** are displayed, based on the data from the currently displayed **PV Loops Graph**.
- Additional text can be entered into this dialog.

The Display Configuration Dialog



PV Loops Display configuration dialog.

- The specific parameters shown in the graph are chosen from the top part of the **Display** configuration dialog.
- The colors of those parameters in the **PV Loops Graph** are chosen in the lower part of the **Display** configuration dialog.

The XY Graph Window

'The arrow to the lower left of the XY graph window can be clicked to open a menu with options for the displayed XY graph.

XY graph window menu.

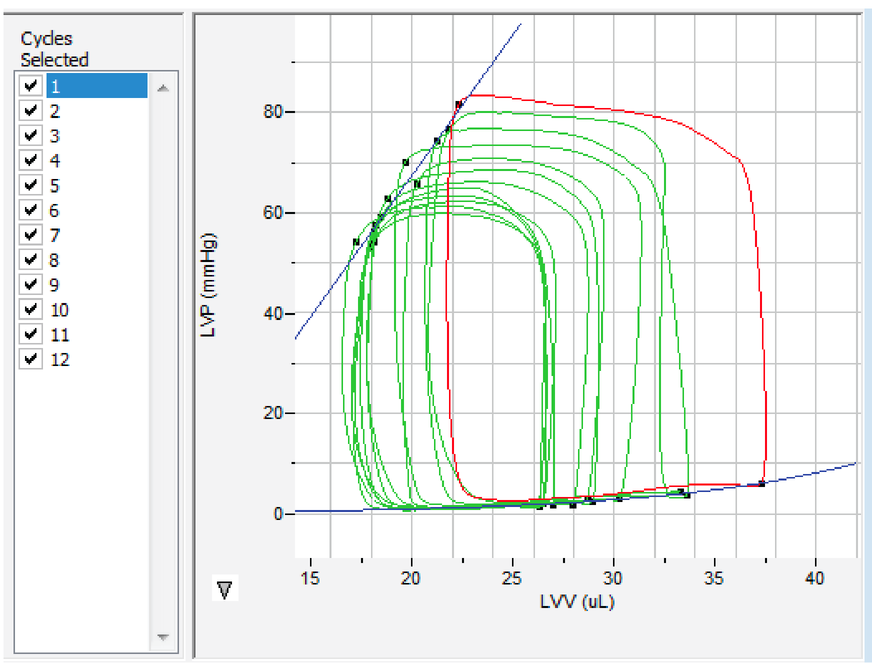
- **Copy Graph**: Copies the current XY graph to the clipboard. It can then be pasted into the **Journal** or an external application.
- **View PV Loops**: Displays the **PV Loops Graph** of the checked cycles in the **Cycles Selected** list to the left of the XY graph window.
- **View PRSW**: Displays the preload recruitable stroke work (**PRSW**) line, as defined in the **Settings**. By default, **PRSW** is calculated by plotting **SW** on the Y-axis and **EDV** on the X-axis. **Vmax** can be used as an alternative to **EDV** if desired.
- **View Max dp vs. EDV**: Displays the XY graph of maximum dP/dt (**Max dP**) vs. end diastolic volume (**EDV**).
- **View PVA vs. EDV**: Displays the XY graph of the pressure-volume area (**PVA**) vs. end diastolic volume (**EDV**).
- **View PVA vs. ESP**: Displays the XY graph of the pressure-volume area (**PVA**) vs. end systolic pressure (**ESP**).
- **View E(t) vs. Time**: Displays time-varying elastance (**E(t)**) vs. **Time**.
- **Export Avg. Loop data**: Exports the data from the graphed average loop as a tab (*.txt) or comma (*.csv) separated text file.
- **Export PV Loop data**: Exports the data from the all the graphed loops as a tab (*.txt) or comma (*.csv) separated text file.

- **View Markers**: Displays a graph of time (X-axis) vs. pressure and volume (Y-axis) with markers positioned at **ED**, **Max dP**, **ES**, and **Min dP**. The specific cycle displayed is determined by the position of the left cursor in the data recording at the top of the dialog.
- **Export E(t) vs. Time**: Exports the **E(t)** vs. **Time data** as a tab (*.txt) or comma (*.csv) separated text file.
- **Set X-axis Scale** or **Set Y-axis Scale**: Allows the user to set the X-axis and Y-axis scales manually.
- **AutoScale X-axis** or **AutoScale Y-axis**: Optimizes the display scale of the X-axis or Y-axis of the current XY graph.

The PV Loops Graph

The **PV Loops Graph** will be displayed in the XY graph area for all the cycles in the selection and is illustrated below.

- By default, the highlighted cycle in the **Cycles Selected** window is shown in red, while all other selected cycles are displayed in green.
- Cycles can be deselected (or selected) by clicking on the check box to the left of the cycle number in the **Cycles Selected** list to the left of the graph. The UP and DOWN arrows on the computer keyboard can be used to move quickly through the individual cycles.
- The specific parameters shown in the graph are chosen from the **Display** configuration dialog.



The PV Loops Graph.

The Data Table

The **Data Table** displays the calculated values for each of the selected cycles.

*	Sel	Time	HR	ESP	EDP	Pmax	Pmin	dPmax	dPmin	Vmax	Vmin	ESV	EDV	SV	CO	EF	SW	maxPwr	plPwr	EA
units		sec	bpm	mmHg	mmHg	mmHg	mmHg	mmHg/sec	mmHg/sec	uL	uL	uL	uL	uL	ul/min	%	mJoules	mWatt	mWatt/(uL*uL)	mmHg/uL
1	Yes	2.086	441.176	70.169	2.975	73.467	1.535	5806.989	-5881.777	31.337	19.153	19.673	30.230	10.556	4657.279	34.921	0.108	42.612	0.047	6.647
2	Yes	2.218	454.545	65.860	3.177	70.815	1.252	5521.278	-5802.478	29.510	19.552	20.256	28.663	8.407	3602.915	29.330	0.085	39.379	0.048	7.834
3	Yes	2.349	458.015	62.710	2.464	68.553	1.225	5293.833	-5401.578	29.234	17.767	18.753	28.913	10.160	5347.105	35.138	0.095	35.486	0.042	6.173
4	Yes	2.481	454.545	59.196	1.831	66.183	1.050	5035.133	-5219.100	28.718	17.802	18.494	27.942	9.448	4137.767	33.813	0.086	32.081	0.041	6.266
5	Yes	2.614	451.128	56.275	1.885	65.053	0.983	4946.811	-5139.844	27.066	17.017	18.156	26.945	8.789	3935.239	32.617	0.075	31.205	0.043	6.403
6	Yes	2.746	454.545	57.487	2.221	63.356	0.754	4709.045	-4879.511	26.639	17.443	18.184	26.197	8.013	3785.811	30.589	0.070	28.000	0.041	7.174
7	Yes	2.879	451.128	54.228	2.101	62.333	0.835	4622.289	-4816.667	27.105	17.174	18.106	26.384	8.278	3678.934	31.374	0.073	26.739	0.038	6.551
8	Yes	3.011	454.545	54.282	1.992	61.350	0.647	4432.289	-4562.433	26.667	16.542	17.251	26.455	9.204	4090.755	34.792	0.074	25.433	0.036	5.898
9	Yes	3.142	458.015	53.071	1.548	59.829	0.727	4252.755	-4421.811	26.590	17.065	17.962	26.332	8.370	3862.892	31.785	0.069	23.352	0.034	6.341
10	Yes	3.274	454.545	50.620	1.966	58.806	0.619	4139.034	-4379.900	26.206	17.109	17.939	26.039	8.100	3600.045	31.107	0.062	22.179	0.033	6.249
11																				
12	#		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
13	Mean		453.219	58.390	2.216	64.975	0.963	4875.946	-5050.510	27.907	17.662	18.478	27.410	8.932	4069.874	32.547	0.080	30.647	0.040	6.554
14	SD		4.567	5.848	0.489	4.558	0.287	520.454	508.255	1.608	0.919	0.840	1.370	0.840	521.027	1.929	0.013	6.477	0.005	0.534
15	Max		458.015	70.169	3.177	73.467	1.535	5806.989	-4379.900	31.337	19.552	20.256	30.230	10.556	5347.105	35.138	0.108	42.612	0.048	7.834
17	Min		441.176	50.620	1.548	58.806	0.619	4139.034	-5881.777	26.206	16.542	17.251	26.039	8.013	3600.045	29.330	0.062	22.179	0.033	5.898

PV Loops Data Table.

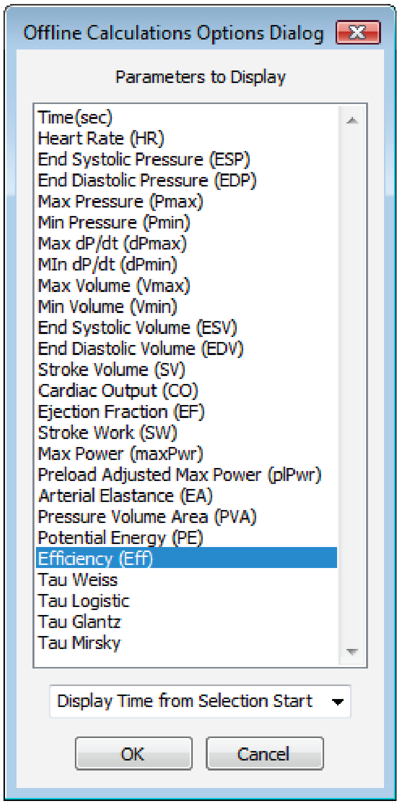
The top line indicates the **units** for each of the chosen parameters.

The bottom few rows show the sample size, the mean, the standard deviation, minimum and maximum values, and the range of each of the chosen parameters averaged over all the selected cycles.

Clicking the asterisk at the upper left of the **Data Table** to display two options: **Autosize** and **Copy Selection**. **Autosize** will optimize the size of the **Data Table** boxes. **Copy Selection** copies any selected **Data Table** cells to the clipboard.

There are six buttons beneath the Data Table: **Copy, Export, Algorithms, Table Options, Load Template,** and **Save Template.**

- **Copy:** Copies all the calculated data in the **Data Table** to the clipboard.
- **Export:** Exports the data as a tab (*.txt) or comma (*.csv) separated text file. The currently displayed XY graph can be exported as a Portable Network Graphics (*.png) or JPEG (*.jpg) image.
- Clicking **Algorithms** displays the mathematical definitions of the parameters included in the **Data Table**.
- **Table Options:** Opens the **Offline Calculations Options** dialog, which lists the functions from which the **Data Table** parameters can be chosen.



Complete list of Data Table parameters.

- **Load Template** or **Save Template:** Displays a dialog allowing you to name and save a specific configuration for future use or to load a previously saved template.

Offline Calculation Algorithms: The Offline PV Calculations displayed in the Data Table include:

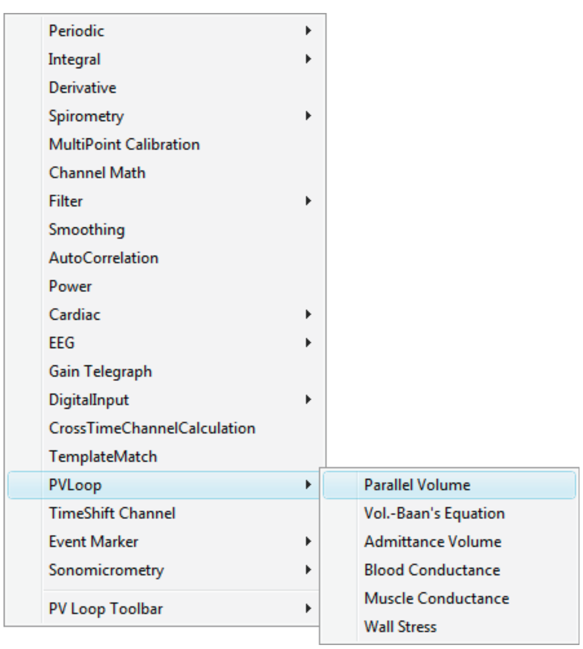
- Heart rate (**HR**): 60/average cycle period.
- End-systolic pressure (**ESP**): Ventricular pressure at end-systole.
- End-diastolic pressure (**EDP**): Ventricular pressure at end-diastole.
- Maximum pressure (**Pmax**): Average maximum value of pressure channel over selected cycles.
- Minimum pressure (**Pmin**): Average minimum value of pressure channel over selected cycles.
- Maximum dP/dt (**dPmax**): Average maximum value of smoothed derivative over selected cycles.
- Minimum dP/dt (**dPmin**): Average minimum value of smoothed derivative over selected cycles.
- Maximum volume (**Vmax**): Average maximum value of volume channel over selected cycles.
- Minimum volume (**Vmin**): Average minimum value of volume channel over selected cycles.
- End systolic volume (**ESV**): Average value of volume channel at end-systole over selected cycles.
- End diastolic volume (**EDV**): Average value of volume channel at end-diastole over selected cycles.
- Stroke volume (**SV**): **EDV – ESV.**
- Cardiac output (**CO**): **SV** * **HR**.
- Ejection fraction (**EF**): **100***(**SV** / **EDV**).
- Stroke work (**SW**): Area within the PV Loop averaged over selected cardiac cycles.

- Maximum power (**maxPwr**): For each point in the cycle, power is calculated current value of the pressure multiplied by the current value of the smoothed derivative. **MaxPwr** is the maximum of the power averaged over the selected cycles.
- Preload adjusted maximum power (**plPwr**): **maxPwr**/(**EDV** * **EDV**).
- Arterial elastance (**Ea**): **ESP** / **SV**.
- Pressure-volume area (**PVA**): **PE** + **SW**.
- Potential energy (**PE**): (**ESP** * (**ESV** - **V0**))/2 - (**EDP** * (**EDV** - **V0**))/4, where **V0** is the zero-pressure end systolic volume.
- Efficiency (**Eff**): **SW** / **PVA**.
- Isovolumic relaxation time constant (**Tau**): Can be calculated a number of ways:
  - **Weiss**: P(t) = A(-t/**Tau**).
  - **Logistic**: P(t)= A(-t/**Tau**) + B.
  - **Glantz**: Regression of dP/dt vs. Pressure.
  - **Mirsky**: Time (in ms) required for left ventricular pressure to fall to 1/2 of its value at **ESP**.
- End systolic pressure-volume relationship (**ESPVR**):
  - Linear fit: Slope of line created by **ES** points of PV Loops during an occlusion.
  - Quadratic fit: sqrt(b2 -4 * a * c) where **ESP** = (a * **ESV** * **ESV**) + (b * **ESV** + c).
- Time-varying elastance (**E(t)**): **ED** points for all the loops are aligned and the maximum slope is calculated.

Calibration of Volume Data

Most sensors will need calibration of some type for ventricular volume measurements. While uncalibrated volumes or even raw conductance measurements will show contractility changes relatively well, calibration is necessary to obtain absolute volumes.

LabScribe offers a variety of algorithms for volume calibration, all accessed from the **PV Loops** submenu of the **add function** menu for the channel with the raw data.



PV Loops Calibration options.

Conductance Volume

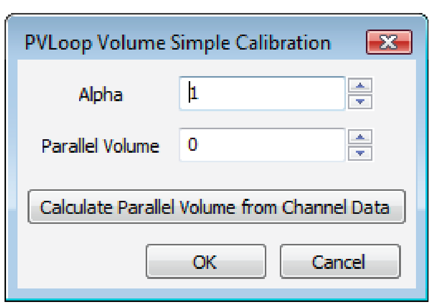
Conductance catheters output raw conductance measurements that need to be converted to volumes, and it is necessary to correct for the conductance contributions (parallel conductance) of surrounding heart structures. It is possible to get calibrated volumes from conductance measurements through the use of Baan's equation, which uses variables including the distance between the electrodes, the resistivity of blood, and the conductance measurements to calculate calibrated volumes. A slope factor **Alpha** is also necessary to adjust for the physical shape of a heart and the nature of the electric field itself.

In the most common method of adjusting for the parallel conductance, a bolus of hypertonic saline is injected into the blood before it reaches the ventricle and the change in conductance as it passes through the ventricle is measured and used to determine the parallel conductance (or volume), as the parallel conductance won't change while the blood conductance will change as a result of the saline passing through the ventricle.

LabScribe offers two means of performing volume calibration based on the injection of a saline bolus. To use the **Parallel Volume** function to determine the parallel volume, it is necessary to use a calibrated total volume channel (including the parallel volume). To use the **Vol.-Baan's Equation** function, it is possible to use a raw conductance channel. The resulting function channels will be volume calibrated and corrected for parallel conductance.

Selecting the **PV Loops** submenu from the **add functions** list opens a dialog in which **Parallel Volume** or **Vol.-Baan's Equation** can be chosen. To use the **Parallel Volume** function to determine the parallel volume, it is necessary to use a calibrated volume channel. To use the **Vol.-Baan's Equation** function, it is possible to use a raw conductance channel. The resulting function channels will be volume calibrated and corrected for parallel conductance.

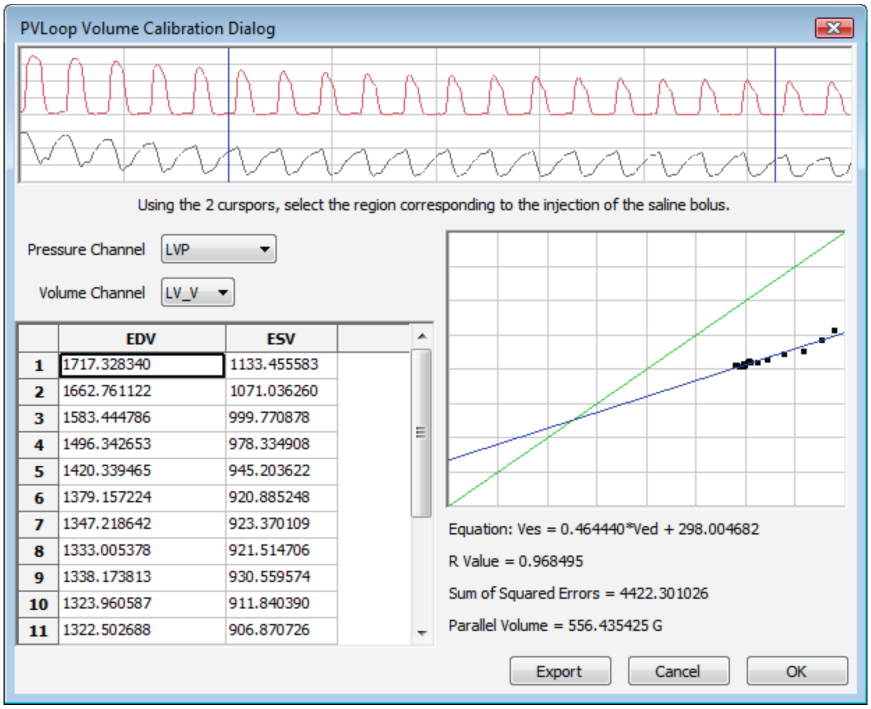
Using the **Parallel Volume** function:



PV Loop Volume Simple Calibration dialog.

- Clicking on **add function** on the volume channel displays a menu from which **PV Loops**, and then **Parallel Volume,** can be chosen. The **PV Loop Volume SImple Calibration** dialog will open.
- The **Alpha** slope correction value should be entered before clicking on **Calculate Parallel Volume from Channel Data**, which opens the **PV Loop Volume Calibration** dialog.

In the **PV Loop Volume Calibration Dialog**, the **Pressure** and calibrated **Volume** channel are chosen from the appropriate menus. The cursors in the **Pressure** and **Volume** trace window at the top of the dialog should be adjusted to select the region corresponding to the saline bolus injection.

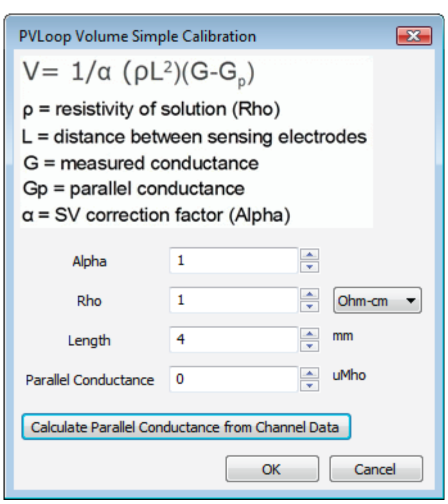


PV Loops Volume Calibration dialog: Parallel Volume from calibrated total volume channel.

In the **EDV** vs. **ESV** XY graph, the line created by the shifting conductance values caused by the saline bolus will cross the identity line at the parallel volume. The equation of the data line, its goodness of fit, and the parallel volume are displayed below the XY graph window. Upon clicking **OK**, the parallel volume will now be displayed in the **PVLoop Volume Simple Calibration** dialog. Clicking **OK** in this dialog adds a corrected volume channel to the *LabScribe* **Main WIndow**.

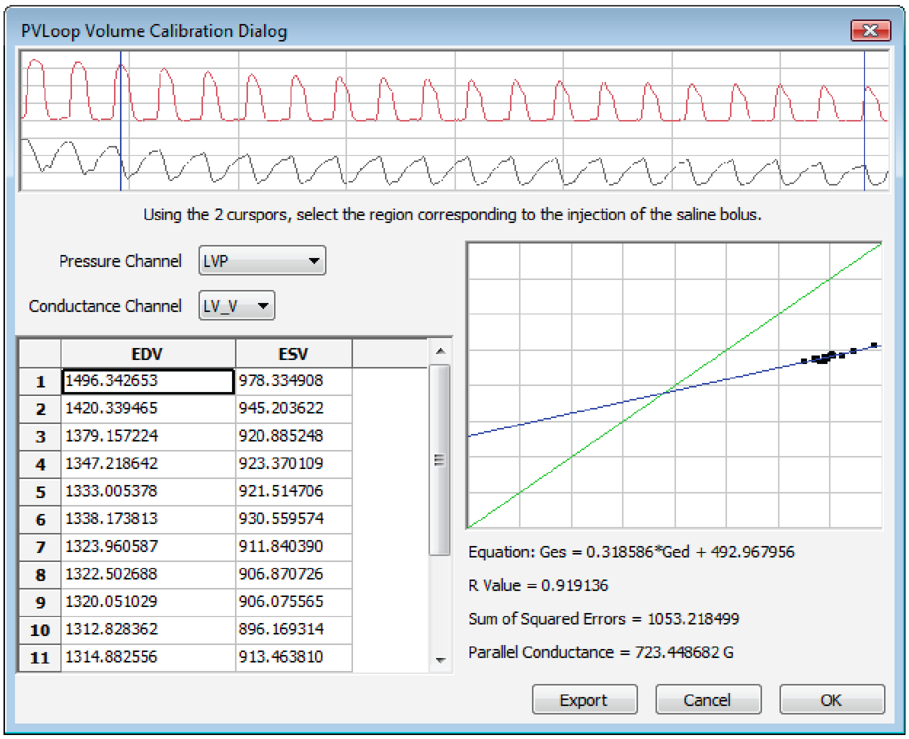
Using the **Baan's Equation** function:

- Clicking on **add function** on a conductance (**Volume**) channel displays a menu from which **PV Loops**, and then **Vol.-Baan's Equation** should be chosen. The Baan's Equation version of the **PVLoop Volume Simple Calibration** dialog will open.



PVLoop Volume Simple Calibration dialog: Baan's Equation.

- In this dialog, the **Alpha** slope correction factor, the resistivity of the blood (**Rho**) and the inter-electrode distance (**Length**) should be entered.
- Clicking on **Calculate Parallel Conductance from Channel Data** will display the **PV Loop Volume Calibration** dialog.



PV Loops Volume Calibration dialog: Parallel Conductance for Baan's Equation

The appropriate **Pressure** and conductance (**Volume**) channels should be entered. Using the cursors in the **Pressure** and **Volume** trace window at the top of the dialog, the region corresponding to the saline bolus injection should be selected.

In the **EDV** vs. **ESV** XY graph, the line created by the shifting conductance values caused by the saline bolus will cross the identity line at the parallel conductance. The equation of the data line, its goodness of fit, and the parallel conductance are displayed below the XY graph window.

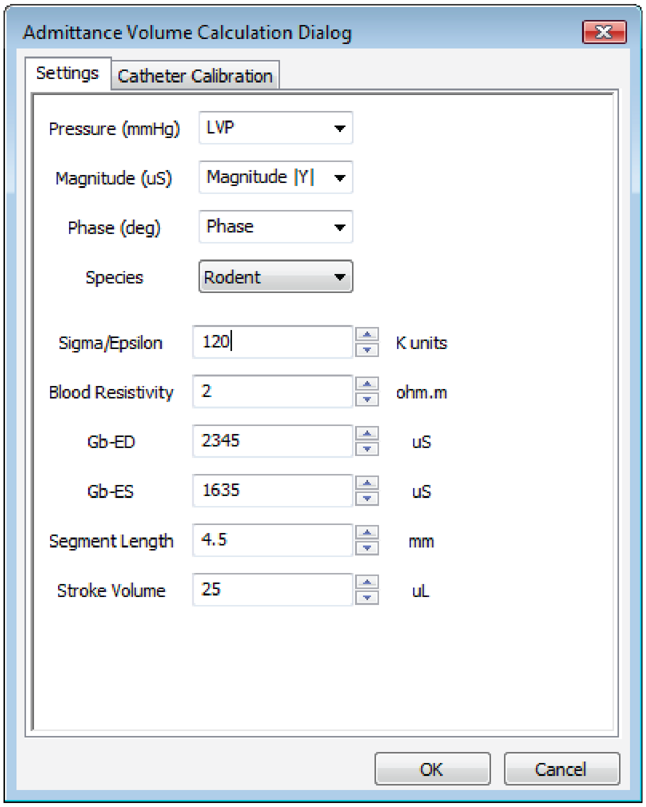
Upon clicking **OK**, the parallel conductance will now be displayed in the **PVLoop Volume Simple Calibration** dialog. Clicking **OK** in this dialog adds a calibrated volume channel to the *LabScribe* **Main WIndow**.

Admittance Volume

Admittance sensors do not require the calculation of parallel volume or conductance. If the ADVantage system is being used, the user will have entered the appropriate constants into the ADVantage interface, or used the ADVantage default values, and the calibrated volume, based on Wei's Equation, will be shown as a raw data channel in *LabScribe*, along with **Magnitude** and **Phase** channels. It may be necessary to recalculate this calibrated volume based on updated information that may cause a change in the constants. The **PVLoops** functions can compute the calibrated volume based on these updated constants and display the volume as a computed channel.

Calibration of the ventricular volume based on revised constants:

Choosing **Admittance Volume**, from the **PV Loops** submenu of the **add function** menu associated with the raw volume channel, displays the **Admittance Volume Calculation** dialog.



PV Loops Admittance Volume Calculation dialog.

- In this dialog, the **Pressure**, **Magnitude** and **Phase** channels, the appropriate species, the **Sigma/ Epsilon** ratio, the **Blood Resistivity**, the **GB** values at **ED** and **ES**, the **Segment Length** between the sensing electrodes, and the **Stroke Volume**, should be entered in the appropriate data boxes. Clicking **OK** adds a calibrated volume channel based on the entered constants.

It is also possible to calibrate the catheter as part of this procedure. In the **PV Loops Admittance Volume Calculation** dialog, click on the **Catheter Calibration** tab.

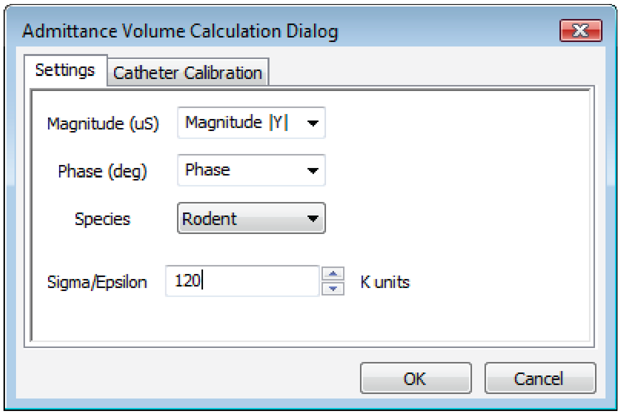
- The correct **Magnitude** and **Phase** are calculated as the catheter is placed in each standard saline (as indicated by its **Conductivity**), and these are incorporated into the admittance volume calibration.

Muscle and Blood Conductance Calibration

Muscle and blood conductance can also be calibrated and determined based on revised constants.

Calibration of muscle and/or blood conductance:

- From the **PV Loops** submenu of the **add function** menu of the volume channel, **Muscle** or **Blood Conductance** should be selected, displaying the **Admittance Volume Calculation** dialog for **Muscle** or **Blood Conductance**.



Muscle or Blood Conductance dialog.

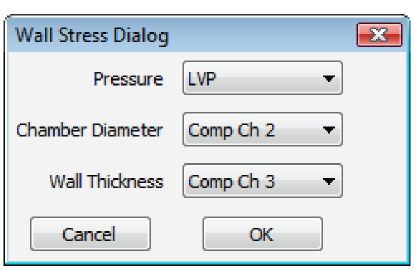
- In this dialog, the **Magnitude** and **Phase** channels, the appropriate species, and a measured or default **Sigma/Epsilon** value should be entered.
- Clicking the **Catheter Conductance** tab and selecting the corrected **Magnitude** and **Phase** values, and then **OK**, will add a **Muscle** or **Blood Conductance** computed channel with the recalibrated muscle or blood conductance values.

Wall Stress

It is possible to use stress-volume loops (instead of pressure-volume loops) to evaluate certain cardiomyopathies. To compute a **Wall Stress** channel, it is necessary to know the ventricular chamber diameter and the wall thickness. The chamber diameter and the wall thickness can be calculated via ultrasound. The ultrasound system will calculate these values and output them as text values which can be imported into *LabScribe* as individual channels. These channels, plus the pressure channel, can be used to calculate a **Wall Stress** channel that can be used to create and analyze wall stress-volume loops.

To calculate **Wall Stress**:

- Choosing **Wall Stress** from the **PV Loops** submenu, accessed by clicking **add function** on the volume channel, opens the **Wall Stress** dialog.



PV Loops Wall Stress dialog.

- The **Pressure**, **Chamber Diameter**, and **Wall Thickness** channels are chosen from the three menus. Upon clicking **OK**, a computed **Wall Stress** channel will be added to the display. This channel can be used instead of a pressure channel to compute and analyze stress-volume relationships.